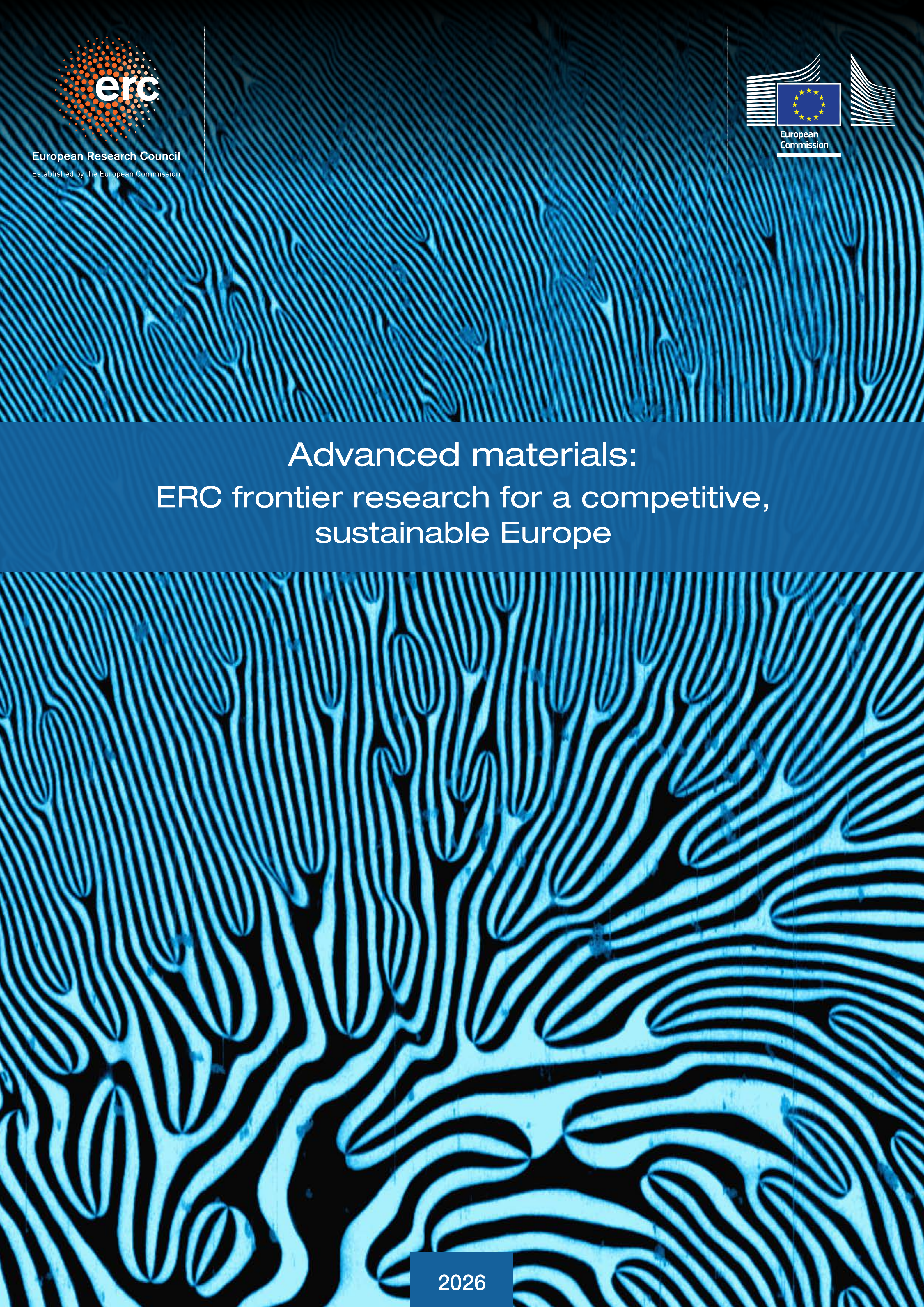

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Advanced materials:
ERC frontier research for a competitive, sustainable Europe

2026

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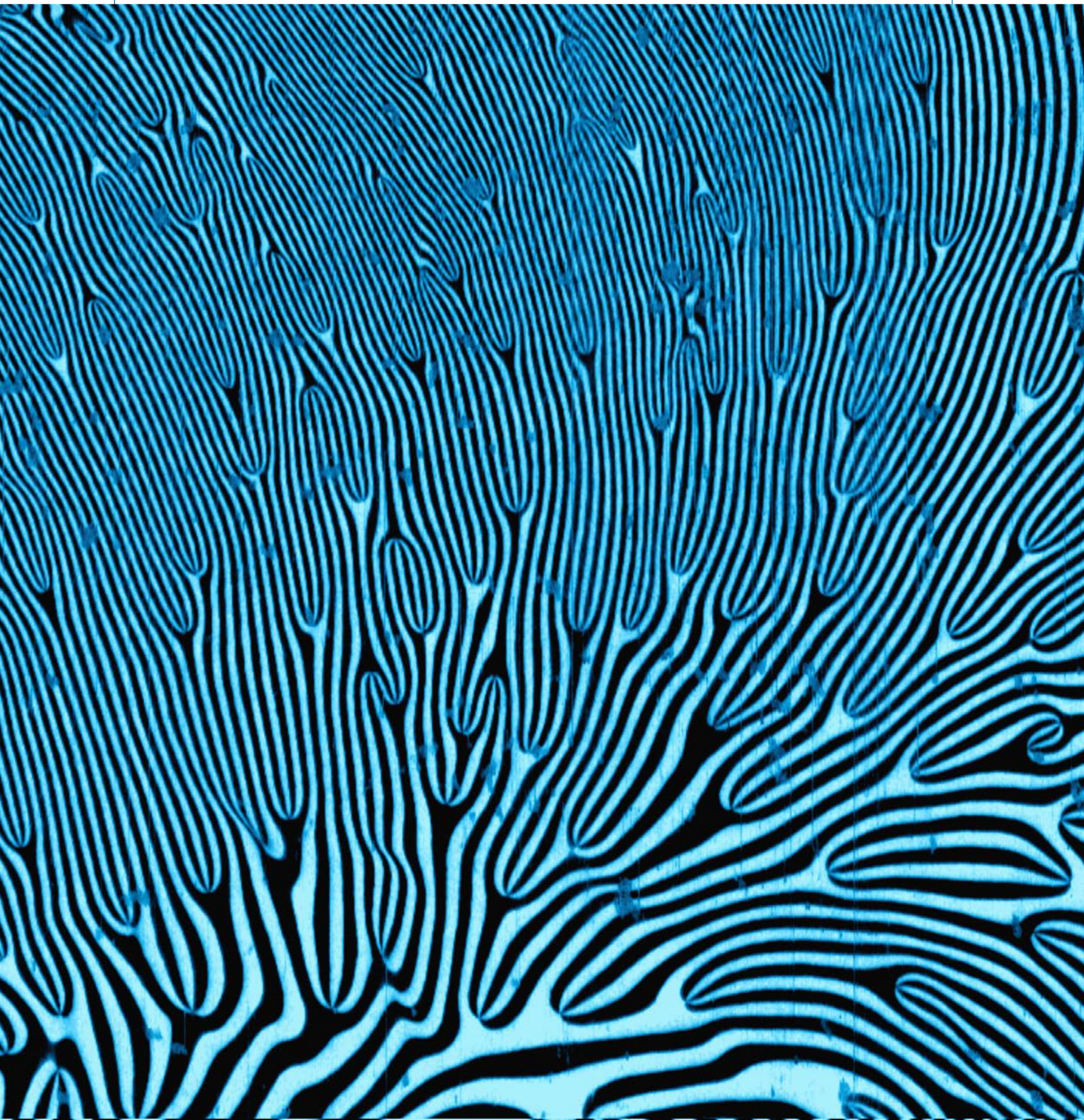

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Foreword

From the Stone Age through the Bronze and Iron Ages to today's Silicon Age, every major advance in human civilisation has been enabled by a breakthrough in materials. Each of these transitions was rooted not only in technological ingenuity, but in fundamental advances in knowledge. Bronze production, for example, depended on the discovery of high-temperature, low-oxygen smelting processes to extract metals from mineral ores, as well as on the controlled alloying of copper and tin to achieve superior mechanical properties — a remarkable achievement in early physical metallurgy. Likewise, the silicon transistors at the heart of modern microelectronics, which underpin contemporary society, would have been inconceivable without the discovery of the electron, a transformative milestone in sub-atomic physics.

Today, addressing many of the most pressing global challenges requires fundamental research across the full breadth of materials science and engineering. Climate change and environmental degradation will only be mitigated through new materials that enable clean, affordable energy generation and the capture, storage and utilisation of greenhouse gases. New paradigms in information technology — essential for reducing energy consumption — will rely on novel quantum materials with exotic topological, magnetic or electronic properties. Housing security and sustainable mobility, in turn, demand lighter, stronger and more durable structural materials. And innovations in biomaterials engineering, such as development of responsive implants and 3D bioprinting of biocompatible components, are revolutionising health care and enhancing life quality for people with disabilities. Crucially, these new advanced materials must be based on earth-abundant and readily available elements, both to support a more equitable global distribution of wealth and to reduce dependence on raw materials sourced from conflict-affected regions. They must also be designed with their full life cycle in mind, ensuring long-term environmental and societal sustainability.

This report maps ERC-funded frontier research in advanced materials across the societal domains where it can have the greatest impact, while remaining firmly anchored in fundamental science. It brings together a quantitative overview of the ERC advanced materials portfolio with a structured analysis of the scientific landscape, spanning disciplines, material classes, functionalities and emerging research approaches such as artificial intelligence. On this basis, the report examines how materials research underpins progress in health, energy, advanced electronics, mobility and construction, illustrating pathways from discovery to application through selected examples. Throughout, cross-cutting priorities — including sustainability, life cycle thinking, strategic autonomy and the use of earth-abundant materials — are highlighted, before concluding with an assessment of the mechanisms and conditions required to translate scientific excellence into long-term societal and economic value.

While this report is structured around the solutions that frontier research in advanced materials can offer to today's societal challenges, it is essential to emphasise the enduring importance of research with no immediate or obvious application. When scientific enquiry is constrained to areas where applications can already be anticipated, discovery itself becomes limited to what can already be imagined. Truly transformative breakthroughs — the kind that redefine technological landscapes and alter the course of history — rarely emerge from incremental improvements to existing materials or devices, or from efforts focused solely on predefined technological goals. Instead, they arise from unconventional ideas pursued by individual researchers or small teams, driven by curiosity and a willingness to explore the unknown.

These pioneers do not simply follow established trajectories; they change direction entirely, opening paths that were previously unthinkable. The European Research Council is proud to foster an environment that nurtures this spirit of intellectual adventure — one that supports not only applied research with immediate societal benefits, but also unrestricted, curiosity-driven frontier research that can be valued for its intrinsic beauty and whose technological impact may only become apparent in future generations. The fundamental research undertaken today will provide the conceptual and material foundations needed to confront the societal challenges of tomorrow — and may ultimately lead to the discovery of the material that defines the next chapter of human civilisation.

Nicola Spaldin
ERC Vice-President

Executive Summary

Advanced materials are foundational to Europe's capacity to deliver the green and digital transitions, strengthen industrial competitiveness and safeguard strategic autonomy. They enable innovation across critical value chains—from energy and electronics to health, mobility, and construction — and are central to achieving the EU's long-term economic, technological and sustainability objectives.

This report presents a comprehensive mapping of **frontier research in advanced materials, funded by the European Research Council (ERC)**, highlighting its pivotal role in advancing scientific excellence while laying the foundations for future technological leadership and industrial transformation.

Between 2014 and 2023, the ERC funded **1 503 advanced materials-related projects**, representing a total investment of **€2.37 billion** and involving **1 397 researchers** across **29 countries**. These projects account for approximately **13% of all ERC grants** and **12% of total ERC expenditure per year**, underlining the strategic weight of advanced materials within the ERC portfolio. Germany (€462 million), the United Kingdom (€257 million), France (€224 million), Spain (€219 million) and the Netherlands (€207million) are the largest recipients in absolute terms. In several Member States, advanced materials represent ≥15% of total ERC funding, signalling a strong national specialisation in this area.

ERC-funded advanced materials research **demonstrates world-leading scientific performance.** Publications linked to these projects are cited **3.2 times more than the global disciplinary average**, with nearly **90% appearing in top-quartile journals**. This reflects both the scientific excellence and the high international visibility of ERC-supported research across materials science, physics, chemistry, engineering and the life sciences.

The portfolio is highly **multidisciplinary** and closely aligned with European strategic priorities. Strong research activity is observed in compound semiconductors, polymers, nanomaterials, perovskites, quantum materials and bio-integrated materials, supporting innovation pathways across key sectors. Project distribution is concentrated in **health (36.5%)**, **advanced electronics (36.5%)** and **energy (19%)**, with additional contributions to mobility and construction. Breakthroughs highlighted in this report include hydrogels for chronic pain management, nanorobotics for precision oncology, ultra-bright perovskite light-emitting diodes, neuromorphic computing based on engineered oxides, and bio-integrated sensing and energy-harvesting systems.

Beyond scientific excellence, the ERC advanced materials portfolio shows notable **innovation and translation potential**. **Ninety-four projects** have reported generating **patents**, **16 European Innovation Council (EIC) Transition grants** have been awarded to ERC grantees and at least **52 spin-off companies have been established as an outcome of the ERC grants**, illustrating progress from curiosity-driven discovery toward lab-to-fab pathways.

Interviews with ERC-funded researchers highlight that:

- Strong technology transfer support, particularly in intellectual property management and early commercial assessment, acts as a critical enabler.
- Flexible, investigator-led ERC funding - especially Proof of Concept grants - supports early-stage innovation and facilitates the recruitment of entrepreneurial research talent.
- Early engagement with industry partners helps align research with application pathways.

However:

- Complex intellectual property and equity arrangements at institutional level can delay spin-off creation.
- Limited access to private investment, especially for capital-intensive deep-tech ventures, slows scale-up.
- Balancing innovation activities with academic responsibilities remains challenging, constraining innovation momentum.

Overall, ERC-funded frontier research in advanced materials provides a **robust scientific and technological foundation** for Europe's leadership in areas central to EU policy priorities, including the European Green Deal, the Artificial Intelligence and Chips Acts, energy security, health innovation, and resilience in critical materials. Sustained investment in curiosity-driven research, complemented by strengthened support for technology transfer and innovation financing, will be essential to accelerate lab-to-market translation and to maintain Europe's competitive advantage in this strategically vital field.

Introduction

Advanced materials are at the heart of Europe's ambitions for economic and technological advancement, playing a crucial role in driving green and digital transitions, enhancing industrial competitiveness, and securing strategic autonomy. As essential components across key sectors such as energy, mobility, construction, electronics, and health, advanced materials bolster sustainable growth and resilience within a rapidly shifting global landscape.

The European Union (EU) has identified advanced materials as critical enablers for achieving competitiveness and **facilitating the dual green and digital transitions.**

In the 2024 Communication on Advanced Materials for Industrial Leadership, advanced materials are highlighted as pivotal to innovation and industrial policy[i]. The document outlines a strategic framework comprising five pillars: research excellence, faster lab-to-fab transitions, investment, production and uptake, and governance. This comprehensive approach is designed to accelerate innovation and enhance Europe's independence on the global stage.

Advanced materials are integral to various EU strategies and initiatives, such as the **EU Competitiveness** compass[ii] and the **Strategic Technologies for Europe Platform**[iii], both of which highlight the necessity of reducing strategic dependencies on critical raw materials and strengthening Europe's industrial foundation through innovation. Furthermore, the **Commission Recommendation on Critical Technology Areas for the EU's Economic Security**[iv] underscores the importance of these materials in promoting EU's strategic autonomy globally.

The Scientific Advice Mechanism's Scoping Paper on Advanced Materials (2024)[v] emphasises the importance of designing materials for safety and sustainability and highlights their potential to substitute or reduce the use of critical raw materials, aligning with the broader EU goals of competitiveness, sustainability and autonomy. The paper highlights the central role of these materials to enhance the EU's circular economy and the EU's commitment to building secure, sustainable and resilient material value chains.

Nevertheless, as Europe continues to advance in the implementation of these objectives, it faces challenges such as the need for swifter laboratory-to-factory transitions and secured investments for scaling-up production and uptake. The upcoming Advanced Materials Act is expected to bolster the above-described strategic framework and provide a solid foundation to address these challenges effectively[vi].

The European Research Council (ERC) supports investigator-driven frontier research across all scientific domains, enabling scientific excellence and intellectual freedom that generate breakthrough knowledge for Europe's future technological leadership. ERC-funded research has delivered key advances in nanostructures, lightweight composites, multifunctional and bio-inspired materials, and recyclable materials for sustainable production, while Proof of Concept (PoC) grants help bridge early-stage discoveries towards industrial uptake and impact.

This report provides an in-depth analysis of ERC-funded research in advanced materials. It examines funding trends, disciplinary and geographic patterns, and the contribution of ERC projects to innovation ecosystems and industrial applications.

I. The advanced materials portfolio in numbers

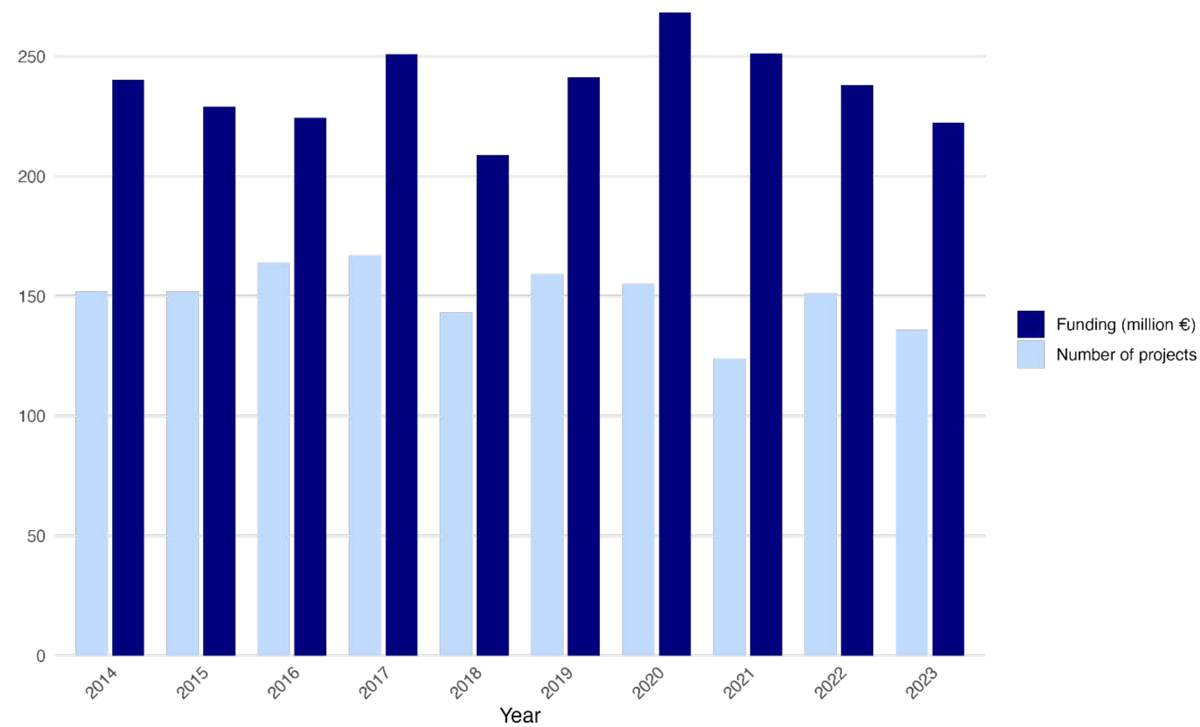
The ERC portfolio on advanced materials encompasses a wide range of high-impact and versatile research. The portfolio analysed in this report includes all projects identified as relevant to advanced materials that were funded under the Horizon 2020 and Horizon Europe programmes (between 2014 and 2023)[vii].

A total of **1 503 projects** were identified, representing a total **investment of €2.37 billion**. These projects span all ERC funding schemes — Starting (StG), Consolidator (CoG), Advanced (AdG), Synergy (SyG), and Proof of Concept grants (PoC)

The portfolio includes a substantial number of PoC projects, highlighting both the critical importance of translating scientific breakthroughs into practical applications in materials science and the strong interest of principal investigators (PIs) in unlocking the innovation potential of their research. This aligns with the findings of a recent ERC analysis, which showed that 17% of all PoC projects focused on advanced materials, making it the second largest thematic area after health biotechnology[viii].

Advanced materials research has received a consistent portion of ERC funding over the years (Figure 1). For the period considered, the average annual number of advanced materials projects is 150, and total funding averages €237 million per year. This represents approximately 13% of the grants awarded and 12% of the overall ERC expenditure year-by-year for the whole period.

Figure 1: ERC advanced materials projects funded between 2014 and 2023 by call year



Funding for advanced materials research varies geographically in both project counts and total allocations (Figure 2), partly reflecting differences in project types, including PoC grants. The proportion of ERC funding dedicated to advanced materials also differs across countries, in some cases exceeding 15% of the total allocation (Figure 3).

Figure 2: ERC advanced materials projects by country of host institution

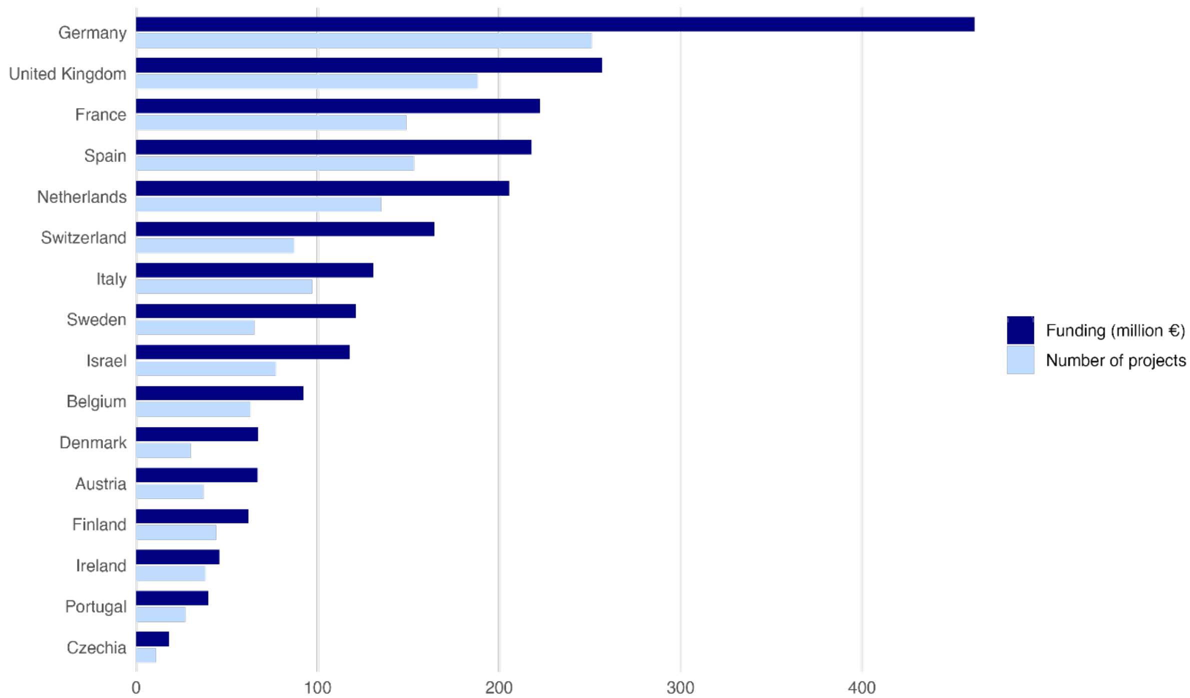
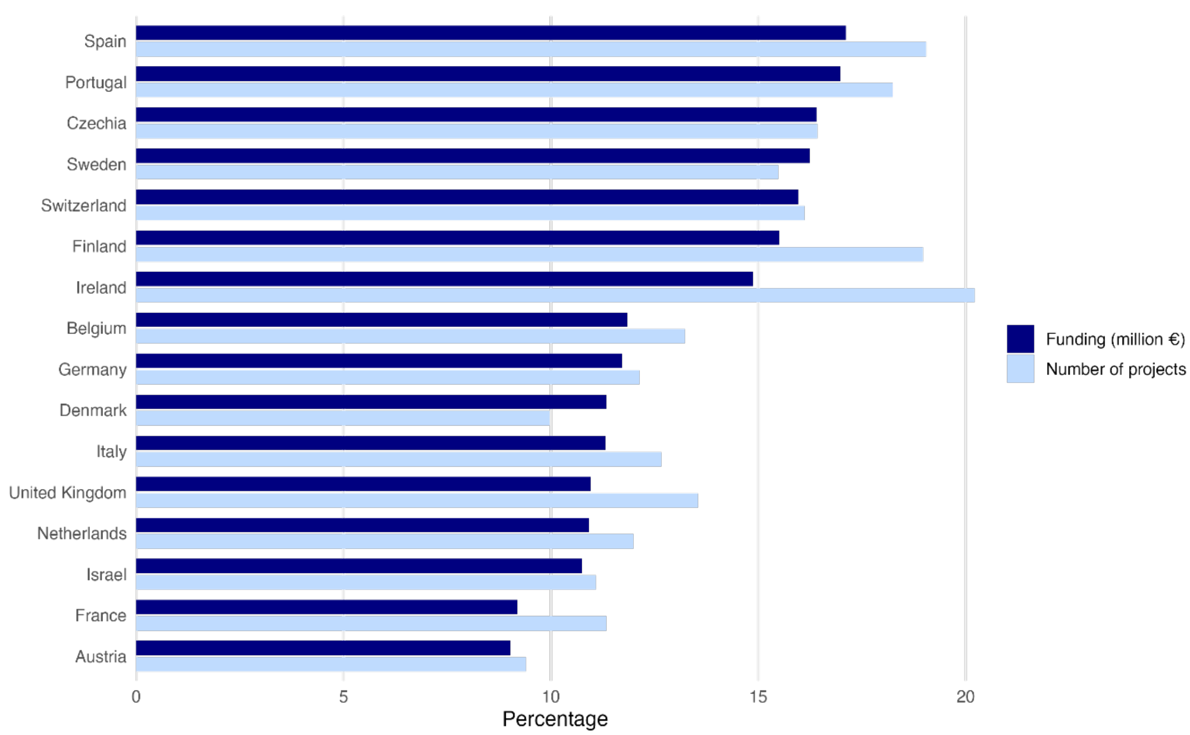
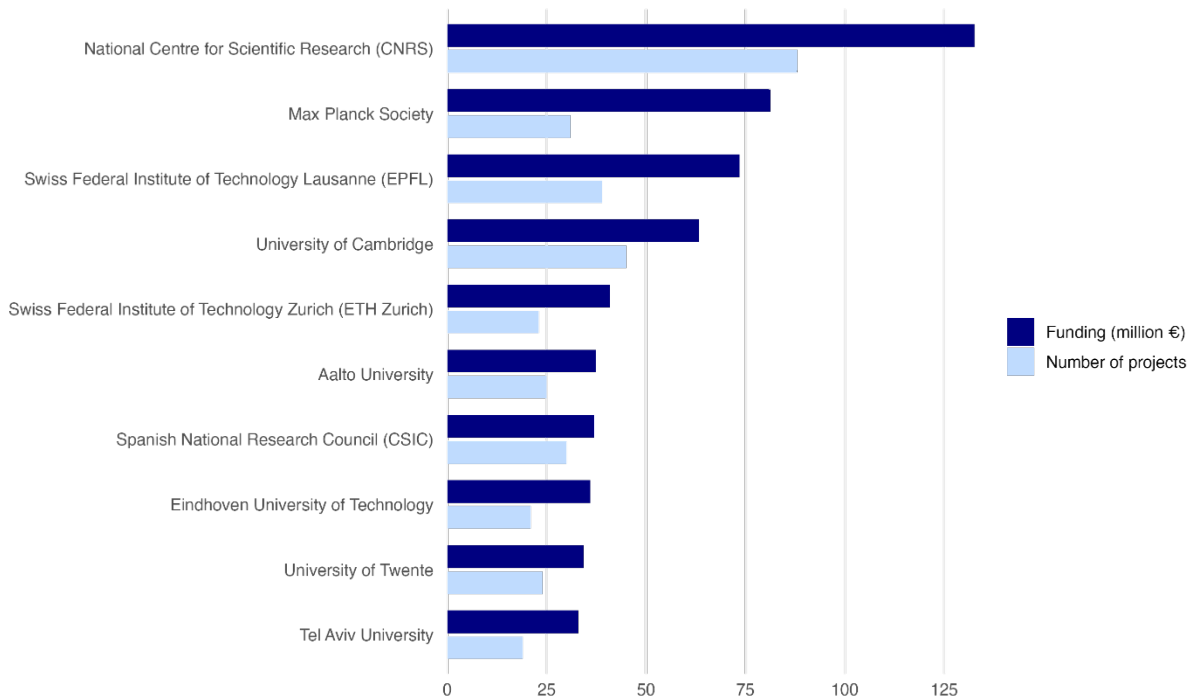


Figure 3: Percentage of ERC advanced materials projects relative to all funded projects by country



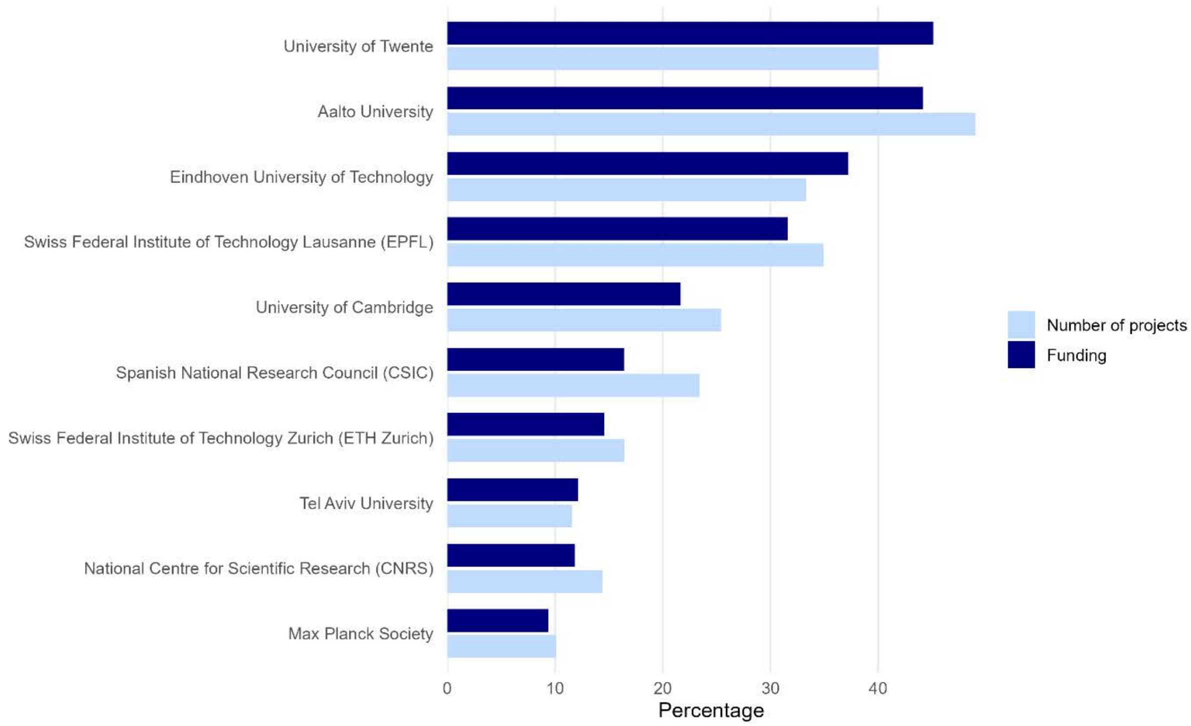
Looking at Host Institutions (HIs), the National Centre for Science Research (CNRS) in France is the largest beneficiary of ERC grants in advanced materials research both in terms of funding and number of projects. The top six are completed by the University of Cambridge, Max Planck Society, the Swiss Federal Institute of Technology Lausanne (EPFL) and Aalto University in Finland. (Figure 4)

Figure 4: ERC advanced materials projects by host institution (total funding and number of projects)



Advanced materials-related research represents 10% - 35% of the overall portfolio of ERC grants (by number of projects) for the top four host institutions. It is particularly prominent in the case of the EPFL (35%) and Cambridge University (25%) and less so in the case of CNRS (14%) and the Max Planck Society (10%). Similar percentages apply when looking at the share of total funding received through ERC grants (Figure 5). Besides the top beneficiaries, advanced materials research plays a prominent role in the ERC grant portfolios of several host institutions such as the University of Twente (45%), Aalto University (44%) and the Eindhoven University of Technology (37%).

Figure 5: ERC advanced materials projects as a share (%) of total ERC projects (by number and funding), by host institution



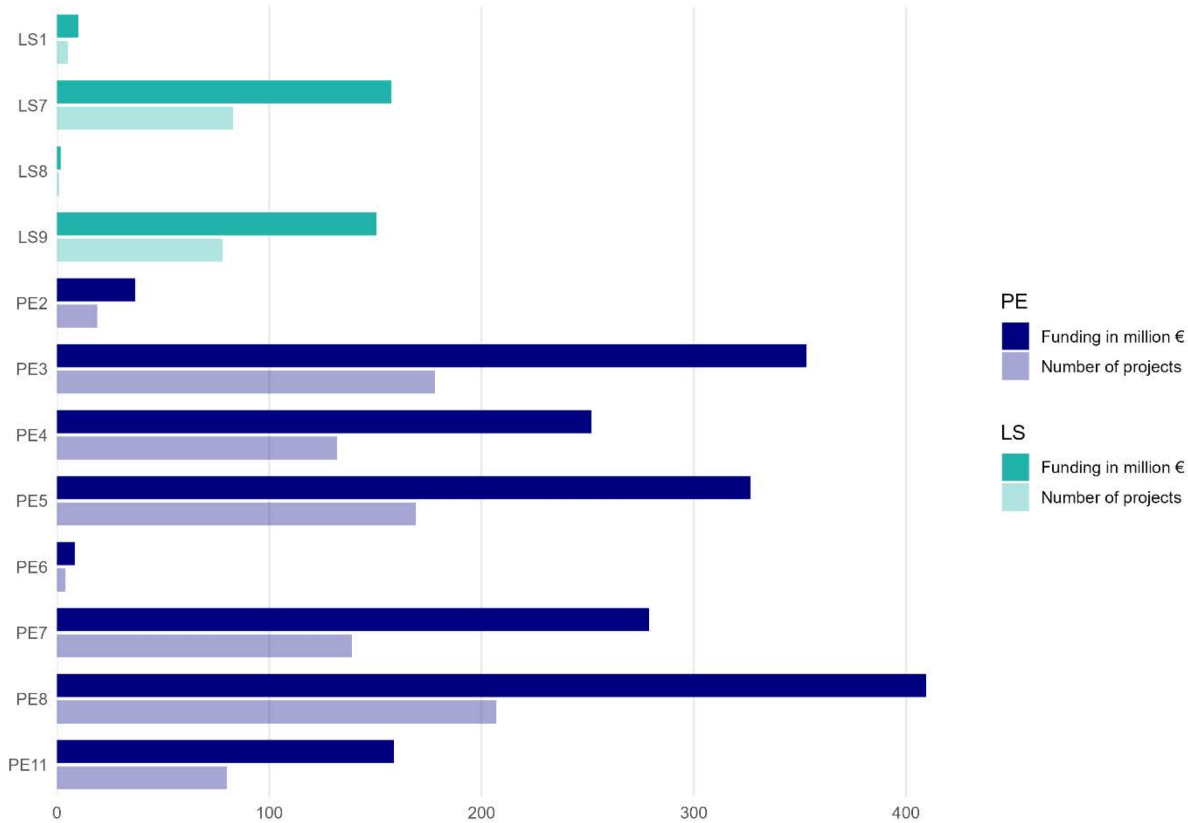
II. Mapping the scientific landscape

a. Scientific domains and disciplines

The portfolio extends across two of the ERC's main scientific domains: the Life Sciences and Physical Sciences and Engineering — the latter being dominant in terms of number of projects and funding.

As shown in Figure 6, the analysis of funding distribution by ERC evaluation panel[ix] shows that PE8 (Products and Processes Engineering) accounts for the largest share of funding, followed by PE3 (Condensed Matter Physics), PE5 (Synthetic Chemistry and Materials), PE7 (Systems and Communication Engineering), PE4 (Physical and Analytical Chemical Sciences) and PE11 (Materials Engineering) which was created from PE8 in 2021 as proposals submitted in this area grew. Overall, more than 40% of the allocation across these Physical Sciences and Engineering (PE) panels relates to advanced materials research. In the Life Sciences (LS), LS7 (Prevention, Diagnosis and Treatment of Human Diseases) and LS9 (Biotechnology and Biosystems Engineering) feature prominently within the LS panels (Figure 6).

Figure 6: ERC advanced materials projects by panel



b. Materials and functionalities

To provide a structured and comparable view of the scientific landscape, the analysis applied a three-layer taxonomy, visually presented in Figure 7, which illustrates a hierarchical framework progressing from fundamental material characteristics to policy relevance. The taxonomy of advanced materials design was established through literature review and refined through the in-house expertise of the scientific officers and the ERCEA Feedback to Policy team[x].

To better assess the portfolio's scope, each project was analysed using a multi-layer taxonomy as explained below[xi]:

- **Layer A** classifies projects by fundamental material type, based on composition and structure — essentially *what the material is*.
- **Layer B** focuses on the material's function and behaviour — *what the material does*.
- **Layer C** links projects to policy-relevant sectors, indicating *which policy domain the material primarily supports*.

Layer A, illustrated in Figure 8, categorises materials according to their chemistry and physical form, mapping research from foundational substances to complex, application-driven systems.

The taxonomy begins with the traditional structural families of materials science: **A1. Metals and Alloys, A2. Polymers and Soft Matter** and **A3. Ceramics, Glasses and Inorganic Solids**, which are defined by their chemical composition and bonding. These categories typically exhibit characteristic property profiles (e.g. strength and ductility in metals, elasticity and tuneability in polymers, thermal stability and corrosion resistance in ceramics), although the classification itself is based on structure rather than function, as is natural since this layer corresponds to Layer A in the taxonomy.

It then highlights strategically important and rapidly evolving classes: **A4. Carbon-based Materials**, including graphene, diamond and porous carbons used in catalysis, energy storage and filtration and **A5. Semiconductors and Dielectrics**, classified here based on their composition and bonding, while also recognised for their crucial role in electronic and photonic technologies. Further, **A6. Composites and Hybrid Materials** combine different material types to enhance performance, often guided by modelling and simulations (e.g. metal–organic frameworks (MOFs) and covalent organic frameworks (COFs), bio-inspired systems).

Finally, **A7. Dimensionally-defined Materials** covers materials, the properties of which are driven primarily by nanoscale geometry (e.g. quantum dots, nanowires, graphene, MXenes, metamaterials), enabling functionalities unattainable in conventional materials.

Figure 7: Hierarchical structure of the taxonomy applied in the present analysis

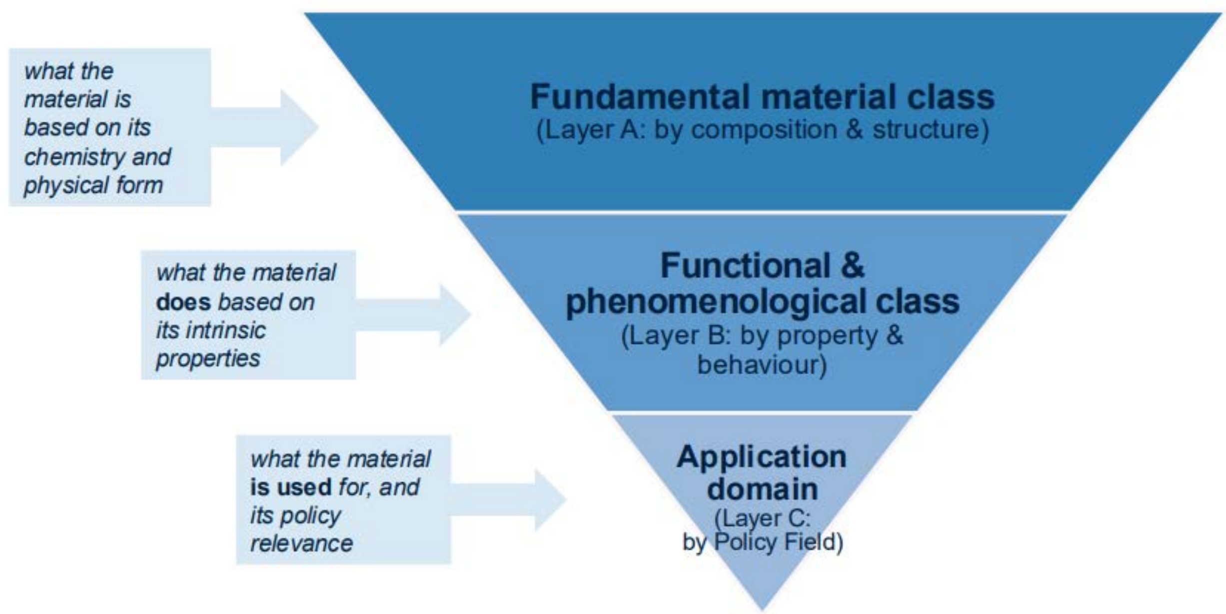


Figure 8: Layer A of the taxonomy – fundamental material class (composition and structure)

Metals and Alloys (A1)

- A1.1 Advanced structural alloys
- A1.2 High-Entropy Alloys (HEAs) & Multi-Principal Element Alloys (MPEAs)
- A1.3 Amorphous metals (metallic glasses)
- A1.4 Intermetallics
- A1.5 Nanostructured & Ultra-Fine Grained Metals

Polymers and Soft Matter (A2)

- A2.1 Synthetic structural & functional polymers
- A2.2 Biopolymers & bio-derived polymers
- A2.3 Supramolecular Assemblies & Dynamic Soft Matter
- A2.4 Elastomers, Foams, and Porous Polymers
- A2.5 Macromolecular Hybrids

Ceramics, Glasses, and Inorganic Solids (A3)

- A3.1 Oxide ceramics including classical oxides and perovskites
- A3.2 Non-oxide ceramics
- A3.3 Inorganic glasses & Amorphous Solids
- A3.4 Cements, Geopolymers, and Construction Binders
- A3.5 Inorganic Porous & Framework Solids

Carbon-Based Materials (A4)

- A4.1 Carbon Allotropes known for high conductivity and strength (e.g. graphene) extreme hardness (e.g. Diamond) as well as amorphous and porous carbon materials used in applications such as energy, storage, catalysis and filtration

Semiconductors and Dielectrics (A5)

- A5.1 Elemental Semiconductors
- A5.2 Compound Semiconductors
- A5.3 2D Semiconductors
- A5.4 Organic & Polymeric Semiconductors
- A5.5 Dielectrics & Insulators

Composites and Hybrid Materials (A6)

- A6.1 Polymer-Matrix Composites (PMC)
- A6.2 Metal-Matrix Composites (MMC)
- A6.3 Ceramic-Matrix Composites (CMC)
- A6.4 Organic-Inorganic Hybrids & Frameworks (MOFs, COFs, etc.)
- A6.5 Bio-inspired & Hierarchical Composites

Dimensionally-Defined Materials (A7)

- A7.1 0D (Quantum dots, nanoparticles, nanocrystals)
- A7.2 1D (Nanowires, nanorods, nanotubes)
- A7.3 2D (Graphene, TMDs, MXenes, nanosheets)
- A7.4 3D Architected & Metamaterials

Layer B complements Layer A by focusing not on *what materials are*, but on *what they do*—that is, their interaction with electricity, light, magnetism, chemical species, mechanical forces or biological systems. This functional lens is essential for understanding both the scientific drivers of materials research and its societal and industrial implications (Figure 9).

Classifying projects by function helps identify areas of high technological potential, policy relevance and emerging risks. It supports a more transparent regulatory environment, informs standards development (e.g. biocompatibility) and guides strategic investment in sectors central to Europe's digital, energy, health and sustainability ambitions.

Key functional categories include:

- **B1. Electromagnetic and Quantum Materials** — such as semiconductors, photonic crystals, spintronic systems and superconductors. These underpin advances in low-power electronics and quantum technologies, supporting strategic initiatives such as the EU Chips Act.
- **B2. Catalytic and Separation Materials** — enabling sustainable chemical reactions, carbon capture, hydrogen storage and water purification, directly contributing to the Green Deal objectives.
- **B3. Mechanical and Structural Materials** — advancing safer, lighter and more durable systems for aerospace, mobility and infrastructure, with architected metamaterials offering novel stress and wave control.
- **B4. Bio-functional and Soft Materials** — underpinning innovation in healthcare, biotechnology and soft robotics, including biocompatible implants, stimuli-responsive systems and advanced drug delivery platforms.

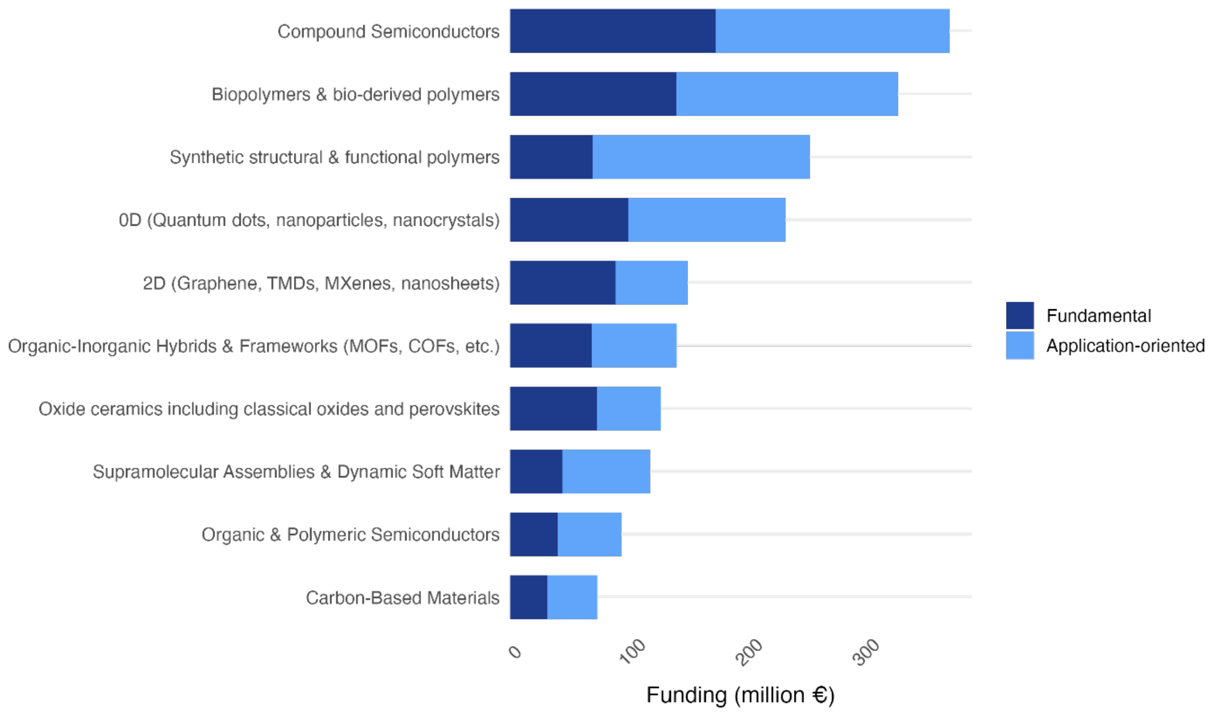
It is acknowledged that certain materials, such as graphene, naturally span multiple classes due to their structural and functional complexity. For example, graphene can be classified as a carbon-based material (A4), a zero-gap semiconductor depending on electronic properties (A5), and a dimensionally-defined material due to its two-dimensional (2D) structure (A7). While such overlaps are inevitable in any comprehensive materials taxonomy, this multi-layer framework allows these multifunctional materials to be represented accurately: Layer A captures structural perspectives, whereas Layer B highlights functionality and phenomenology (e.g. graphene's role in electronics, photonics, and quantum technologies).

Figure 9: Layer B of the taxonomy — functional and phenomenological class

Electromagnetic & Quantum Materials (B1)	Catalytic and Separation (chemo-functional) Materials (B2)	Mechanical and Structural Materials (B3)	Bio-Functional & Soft Materials (B4)
• B1.1. Electronic Materials • B1.2. Photonic & Plasmonic Materials • B1.3. Magnetic & Spintronic Materials • B1.4. Dielectric & Ferroic Materials • B1.5. Superconducting & Topological Materials	• B2.1. Catalytic Materials • B2.2. Separation & Sorption Materials • B2.3. Chemical Sensing Materials • B2.4. Electrochemical Storage Materials	• B3.1. High-Performance Structural Materials • B3.2. Surface & Tribological Materials • B3.3. Architected & Mechanical Metamaterials	• B4.1. Biocompatible & Bioactive Materials • B4.2. Stimuli-Responsive & Active Materials • B4.3. Drug Delivery & Theranostic Systems

The analysis of the project portfolio by **materials class** that was described in the Layer A of the taxonomy in Figure 8 shows a strong concentration of projects in compound semiconductors, biopolymers and bio-derived polymers, synthetic structural and functional polymers, as well as dimensionally-defined materials as shown in Figure 10. Figure 10 further details the distribution of projects by material class, distinguishing between fundamental and application-oriented projects.

Figure 10: ERC advanced materials projects by material class as described in layer A of the taxonomy



Compound semiconductors constitute a cornerstone of advanced materials research, underpinning innovations in quantum and optoelectronic devices, high-efficiency photovoltaics, power electronics, and sensing technologies. These advances support applications across multiple sectors, including electronics, energy, and healthcare.

Biopolymers and bio-derived polymers feature prominently across both the Physical Sciences & Engineering and Life Sciences domains, reflecting the inherently multidisciplinary nature of materials science and its strong cross-sectoral impact.

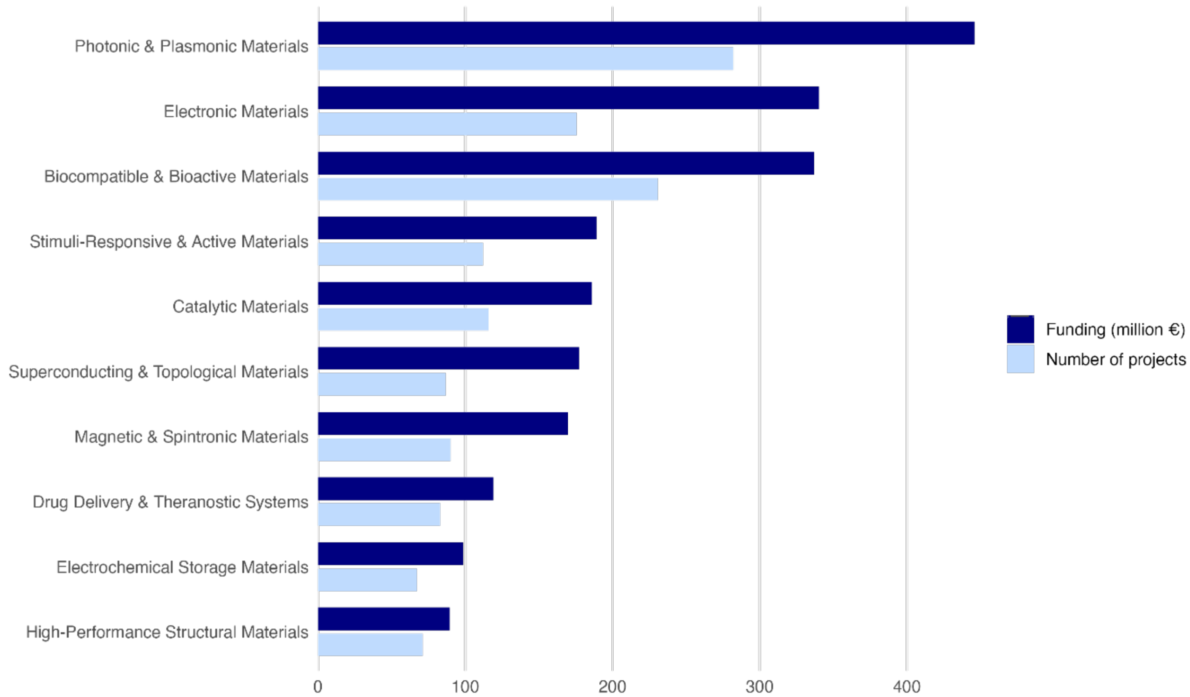
- In Physical Sciences & Engineering, research focuses on the development of renewable and biodegradable alternatives to petrochemical-based materials, addressing environmental sustainability and resource efficiency challenges.
- In the Life Sciences, this work drives advances in tissue engineering, wound healing, drug delivery systems, and stimuli-responsive medical technologies.

Quantum and optoelectronic research is driven by compound semiconductors, quantum dots, and 2D materials (e.g. graphene, transition-metal dichalcogenides, MXenes), enabling breakthroughs in computing, photovoltaics and sensing across sectors such as electronics, infrastructure, and healthcare.

The strong presence of **oxide ceramics** (notably oxide and halide perovskites), **metal–organic and covalent organic frameworks (MOFs** and **COFs)**, and **supramolecular soft matter** highlights active innovation in energy storage, catalysis, and molecular self-assembly - key enabling areas for decarbonisation and advanced manufacturing.

From a **materials functionality** perspective described in layer B of the taxonomy in Figure 9, the analysis highlights a convergence of fundamental physics, materials chemistry and the life sciences in driving transformative technological advancements (Figure 11):

Figure 11: ERC advanced materials projects by function of material



- The prevalence of research on photonic and plasmonic systems highlights the pivotal role of light–matter interaction in ERC-funded projects. This broad field spans nanophotonics, quantum communication, energy harvesting, and optical computing.
- Magnetic, spintronic, superconducting, and topological materials constitute a second cluster of frontier research, bridging condensed matter physics and information science. These areas are opening pathways toward low-power computing and the development of quantum technologies.
- The strong focus on biocompatible and bioactive materials reflects the ERC's active contribution to advances in bioengineering, regenerative medicine, and health-related technologies.

More detailed insights into these trends are provided in the sectoral analysis sections below (see Section IV).

c. Artificial intelligence in advanced materials research

Artificial intelligence (AI) is fundamentally changing advanced materials research by accelerating and enriching every stage of the traditional design–make–test–analyse cycle. Machine learning and deep learning models enable predictive, non-linear mapping between a material's composition, structure and function, thus transforming the exploration of an astronomically large materials space into a tractable, data-driven process.

To train these powerful models, researchers rely on extensive virtual databases created using methods such as Density Functional Theory (DFT), a quantum-mechanical method that computes the electronic structure of atoms, molecules and materials, providing first-principles insights into their chemical and physical properties. Efficiency is further enhanced by active-learning strategies, where AI iteratively selects only the most informative experiments or simulations, often integrated with robotic platforms.

Complementing these approaches is generative AI, a class of machine learning methods that learn underlying structure–property relationships and the chemical rules governing stability, synthesisability, and performance. Rather than merely predicting properties from known materials, generative models construct a compact virtual design space (latent space) from which they can propose entirely new candidates. This enables inverse design, in which the process begins with a targeted optical, electronic, catalytic, or mechanical functionality and identifies material compositions or structures that are most likely to achieve it.

Collectively, these methods shift materials discovery from a slow, trial-and-error process to a proactive, data-driven and scalable engineering discipline.

The following ERC-funded projects exemplify how AI is being integrated into advanced materials research.

The project SupraModel addresses the challenge of predicting structures in multicomponent peptide co-assembly, an emerging materials approach with promising applications ranging from drug delivery to peptide-based organic and bioelectronic semiconductor systems. The team of researchers led by Julija Zavadlav at the Technical University of Munich, Germany, develops a next-generation computational framework that leverages advanced AI including Graph Neural Networks (GNN), differentiable molecular simulation, and active-learning pipelines, to achieve fast and accurate predictions of multicomponent peptide co-assembly. The methodology includes leveraging GNNs for potential energy and structure–property predictions, and employing Differentiable Trajectory Reweighting (DiffTRe), a technique that efficiently incorporates real experimental measurements into deep neural network potentials to improve their accuracy. It also integrates active learning with uncertainty quantification, enabling the AI models to recognise where their knowledge is limited and selectively request only the most informative new data. By combining traditional molecular dynamics simulations with these advanced, yet increasingly accessible AI methods, the project aims to gain unprecedented molecular insight, discover novel materials, and establish clear, evidence-based design rules that can guide the future development of supramolecular materials.

Led by Blazej Grabowski at the University of Stuttgart, Germany, the project Materials 4.0 aims to overcome the long-standing limitations of current phase diagrams, which often depend on scarce experimental data and uncertain extrapolations, by building a new generation of highly accurate, first-principles thermodynamic databases. The project integrates finite-temperature *ab initio* simulations with advanced machine learning potentials, AI models trained on quantum-mechanical data that learn to predict interatomic forces with near-*ab initio* accuracy but at a fraction of the computational cost. These machine learning potentials make it possible to efficiently compute key thermodynamic and kinetic properties, such as Gibbs free energies, which indicate material stability, and migration barriers, which govern atomic movements across the full temperature range, including liquids and dynamically unstable solids that conventional methods struggle to simulate. Implemented within an open-source computational environment, this AI-enhanced framework will enable realistic, high-temperature phase diagram prediction for technologically relevant materials such as hydrides, lightweight alloys, superalloys, MAX phases, and high-entropy alloys, ultimately providing a robust, predictive foundation for the rational design of next-generation materials.

The project ADAM, led by Andrew Cooper (University of Liverpool, UK), Graeme Day (University of Southampton, UK) and Kerstin Thurow (University of Rostock, Germany), is developing an autonomous ‘closed-loop’ platform to accelerate the discovery of new functional materials for healthcare, energy, data storage and pollution control, where conventional trial-and-error approaches remain slow and resource-intensive. ADAM connects two complementary engines: a Computational Engine that combines crystal structure prediction (CSP), machine learning and evolutionary search to identify promising candidates, and an Experimental Engine that uses AI-enabled robotics to autonomously synthesise, crystallise, characterise and test materials, feeding results back to improve subsequent searches. As the project is ongoing, key achievements to date include crystal structure prediction at unprecedented scale (over 1 000 molecules) and an evolutionary search that uses predicted crystal properties to prioritise candidates. In parallel, the team has advanced autonomous synthesis and characterisation, including automated crystallisation and powder X-ray diffraction preparation, AI-assisted experiment monitoring, and robotic platforms such as ‘Robinhood’ and mobile robot chemists, alongside early foundations for a shared CSP database.

Led by José Hugo Garcia Aguilar at the Catalan Institute of Nanoscience and Nanotechnology in Spain, the ERC-funded project AI4SPIN aims to reduce the energy footprint of digital technologies by accelerating the development of ultra-low-power electronics. It targets spin–orbit torque (SOT) memories, which can operate faster while using far less power than conventional memory and seeks to optimise them using stacks of atom-thin 2D materials assembled into van der Waals heterostructures with tailored quantum properties. To explore the vast number of possible material combinations, AI4SPIN combines deep neural networks with quantum transport simulations to compute and rank SOT efficiencies, bringing together AUTOMATA (an automated assessment tool) and COMPASS (an evolutionary structure optimiser) in a feedback loop that continuously improves candidate designs. Beyond SOT memories, the resulting approach is designed to be adaptable to other electronic response functions, supporting broader progress toward energy-efficient technologies.

Led by Alejandro A. Franco at the University of Picardy Jules Verne in France, the ERC-funded project SMARTISTIC has developed and demonstrated a first prototype of smart, interactive augmented reality software to support decision-making in battery electrode formulation and manufacturing in laboratories and production lines. The software runs on tablets and augmented reality glasses (including HoloLens 2) and overlays interactive holograms onto real manufacturing equipment, powered by experimentally validated physical and machine-learning models from the earlier project ARTISTIC that aimed to predict how manufacturing parameters affect electrode properties and performance. Reported results include a secure working prototype demonstrated in a real battery manufacturing environment (the RS2E pilot line in Amiens, France), enabling users without programming skills to create real-time databases from ongoing experiments, launch analyses, and request predictions to guide process choices, alongside ergonomic improvements aimed at safe and effective use in manufacturing settings.

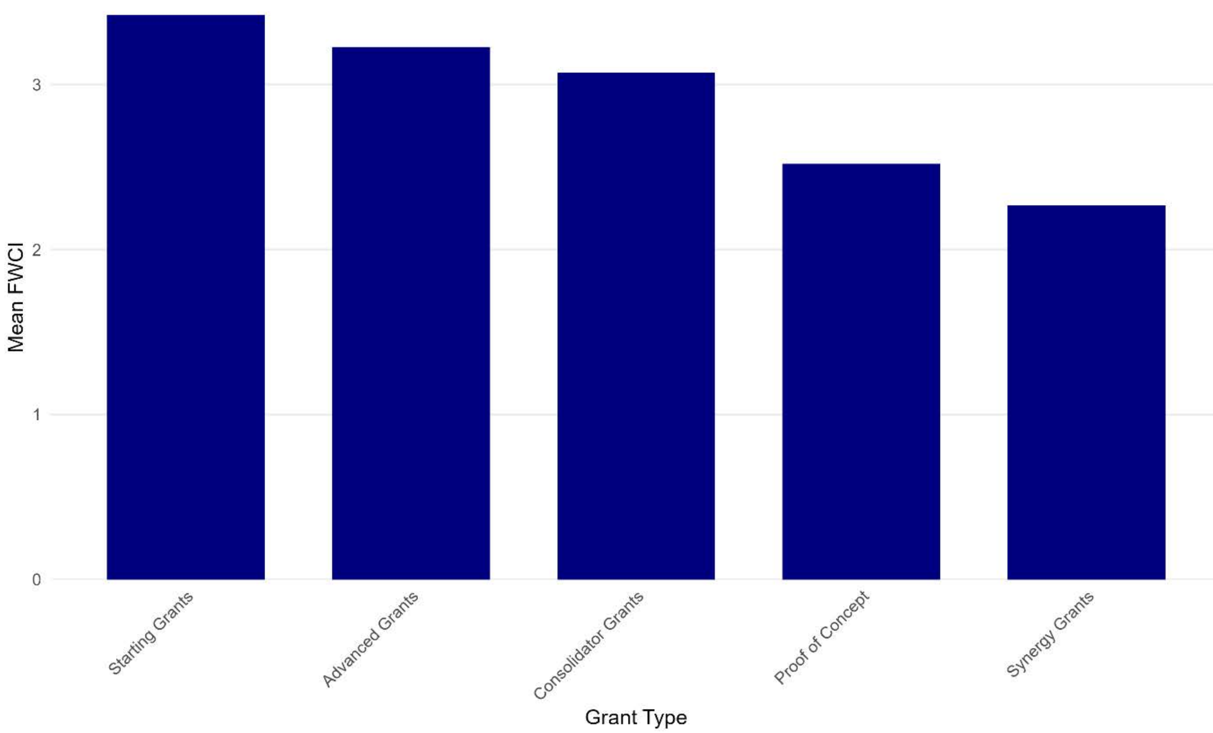
III. Scientific leadership and broader influence of the ERC advanced materials portfolio

a. Impact through citations in scientific publications

To assess scientific excellence, the Field-Weighted Citation Impact (FWCI) of publications linked to the funded projects was analysed, as defined by SciVal. The results reveal a strong performance: on average, these publications are cited 3.2 times more often than the global disciplinary baseline. Around 5% achieve citation levels more than ten times the field average, demonstrating exceptional visibility and influence. This trend is consistent across all scientific domains covered in this analysis.

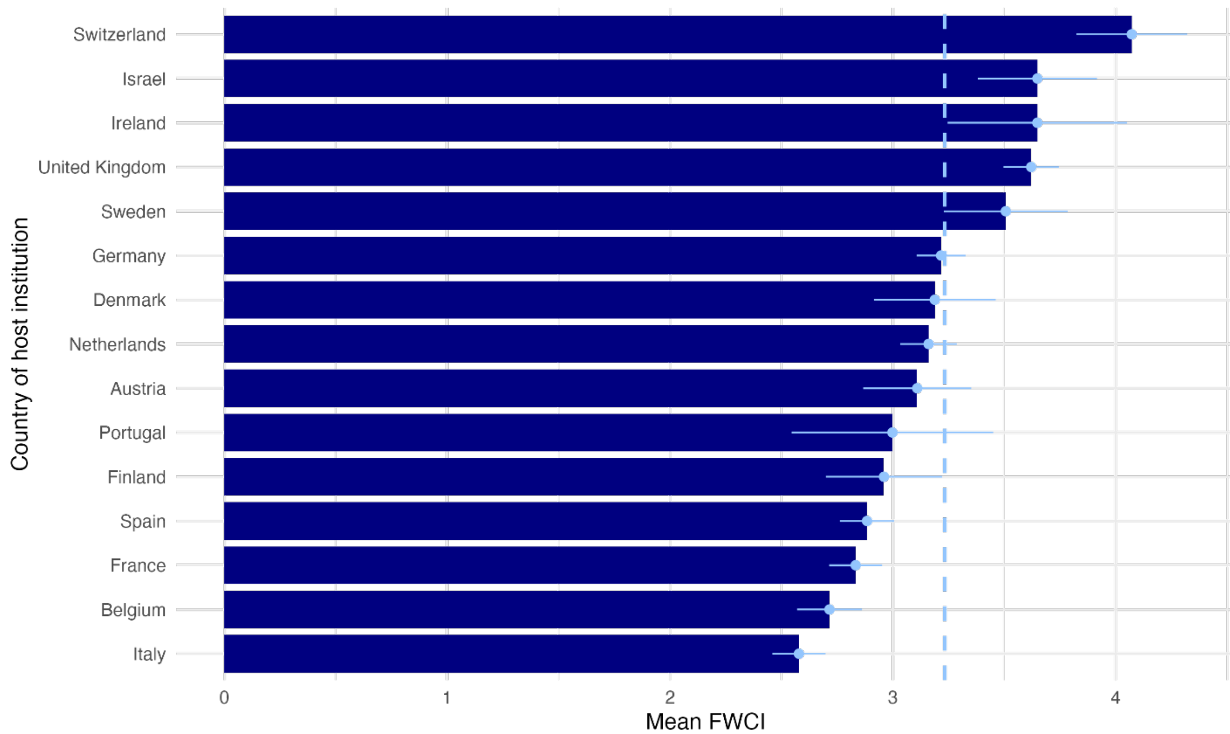
Impact is also broadly comparable across the ERC’s core schemes — Starting (StG), Consolidator (CoG), and Advanced (AdG) Grants — with StGs showing a slightly higher average FWCI. As expected, PoC projects show lower citation levels, reflecting their focus on innovation uptake rather than academic publication. Synergy Grants display the lowest average FWCI, likely due to the small sample size (*n = 229*), as only the 2018–2020 Horizon 2020 calls included this scheme. (Figure 12).

Figure 12: Mean field-weighted citation impact (FWCI) of project publications by grant type



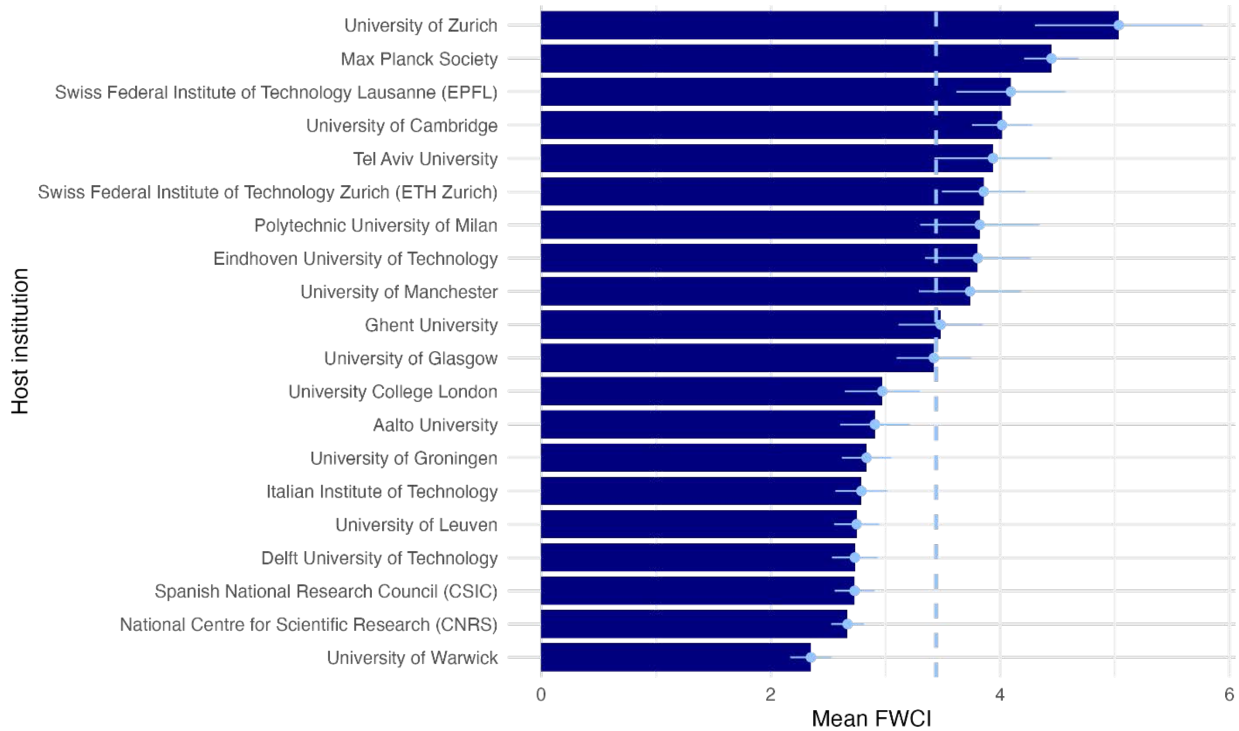
Among the countries with the highest research output in the advanced materials portfolio, notable differences in citation impact are observed. According to the Mean Field-Weighted Citation Impact (FWCI) bibliometric shown in Figure 13, institutions in Switzerland, Israel, Ireland, UK, Sweden and Germany display above-average FWCI levels.

Figure 13: Mean field-weighted citation impact (FWCI) for project publications by country of host institution (for countries with 200 or more identified publications). The dotted line indicates the overall mean; error bars show standard errors.



When disaggregated by the host institutions with the highest research output, the overall patterns remain largely consistent. Institutions located in countries with above-average citation impact tend to perform similarly well. These include the University of Zurich, the Swiss Federal Institute of Technology Lausanne (EPFL), the University of Cambridge, Tel Aviv University, the Swiss Federal Institute of Technology Zurich (ETH Zurich), the University of Manchester, and the University of Glasgow. At the same time, several institutions outperform their national averages. Notably, the Max Planck Society in Germany, the Polytechnic University of Milan in Italy, Eindhoven University of Technology in the Netherlands, and Ghent University in Belgium show an above-average citation impact (Figure 14).

Figure 14: Mean field-weighted citation impact (FWCI) for project publications by host institution (for host institutions with 150 or more publications). The dotted line indicates the overall mean; error bars show standard errors.

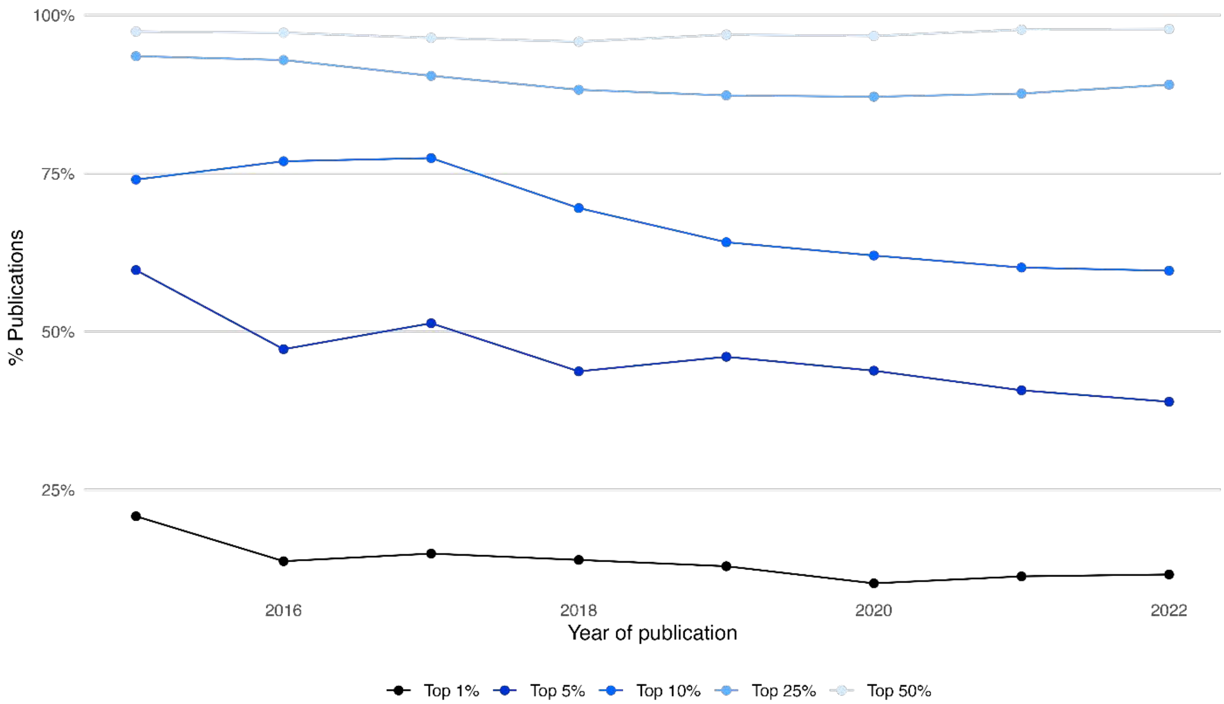


Publications in top journals

An additional indicator of scientific influence is the frequency with which research outputs appear in leading journals. These journals were identified according to their CiteScore ranking,[xii] which measures citation-to-publication ratios over the previous four years.

The analysis of the presence of publications linked to ERC-funded research in top-journals shows the consistently high prominence of ERC-funded research outputs[xiii]. Between 60% and 75% of the publications stemming from ERC-funded research has featured in top 10% journals, while nearly 90% of publications were placed in the top 25% journals (Figure 15).

Figure 15: Percentage of project publications in top journals by year of publication



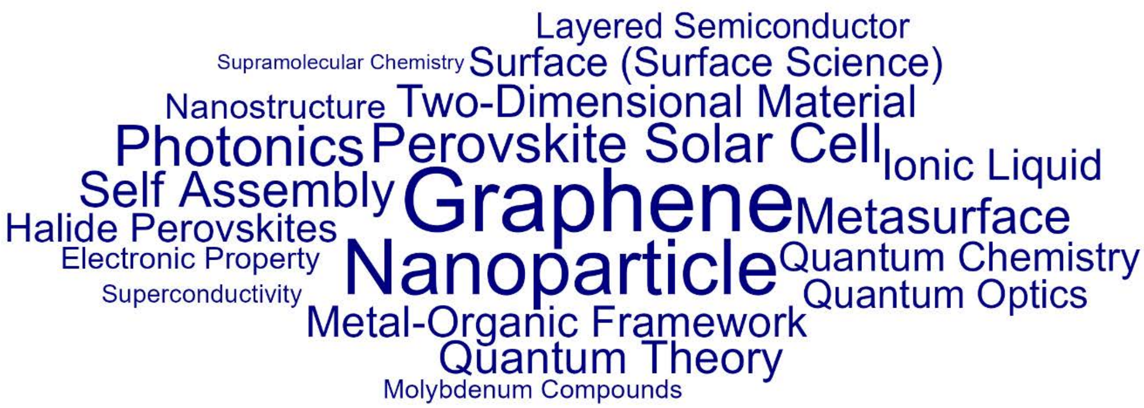
Key themes

ERC-funded research in advanced materials demonstrates both scientific breadth and excellence, covering well-established domains as well as rapidly emerging high-impact areas.

Bibliometric analysis of thematic terms confirms this diversity. The term mapping[xiv] highlights the most frequent topics across all publications (Figure 16) and those most prevalent in outputs published in the top 1% of journals (Figure 17).

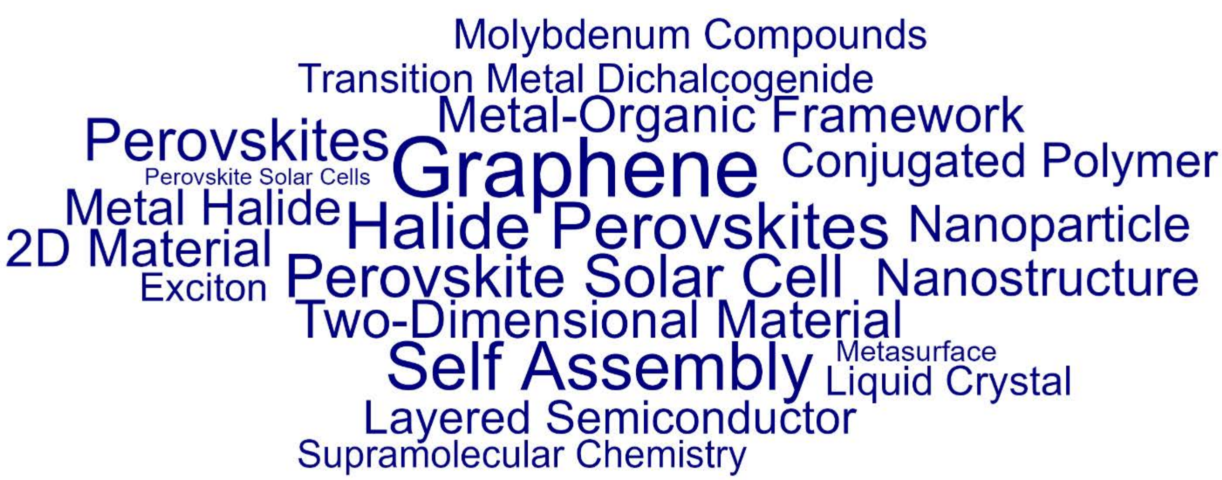
Across the full publication set, key themes include graphene, nanoparticles, halide perovskites, photonic materials, and perovskite solar cells (Figure 16). These materials are of strategic relevance due to their applications in next-generation energy systems and information technologies. For example, perovskite solar cells drive advances in high-efficiency photovoltaics, while graphene and nanoparticles underpin developments in nanoelectronics and sensing technologies.

Figure 16: Key themes in all project publications



Notably, when focusing on publications in the top 1% of journals, the relative prominence of certain topics shifts, for example, halide perovskite-based materials appear more frequently than before, indicating particularly high scientific visibility and impact for ERC-supported research in this area (Figure 17).

Figure 17: Key themes in project publications appearing in the top 1% of journals



b. Impact beyond science through citations in policy documents - examples

In addition to scientific impact, ERC-funded research has also informed policy. Publications from advanced materials projects in this portfolio have been referenced in policy documents prepared by governments, think tanks, and intergovernmental organisations.[xv] Although these citations offer only an indirect measure of potential policy influence, several projects and publications emerge as notable examples of that type of influence:

- Some projects contributed more than one publication to policy-oriented documents. A prominent example is the ERC project SMART-POM, led by Leroy Cronin at the University of Glasgow in the United Kingdom, which focuses on the use of AI- driven chemical robots to help discover and manufacture new molecules and materials. Research from this project featured in a report on 'Animated Materials' by the Royal Society, two separate EU and OECD reports on the role of AI in science, as well as a report by the Organisation for the Prohibition of Chemical Weapons (OPCW) Scientific Advisory Board. Another is the ERC project HybridSolarFuels, led by Csaba Janáky at the University of Szeged in Hungary. The project provided a pathway toward sustainable, low-carbon fuel production by advancing high-efficiency solar-driven CO_2-to-fuel technologies. Its research outputs were used in a report on solar fuels research and investment published by the European Commission's Directorate-General for Research and Innovation. Other policy bodies citing research from this project include the U.S. Department of Energy, and the Umwelt Bundesamt in Germany.

- In addition, authors of policy-oriented documents also drew on publications from multiple ERC projects, underlining the complementarities and added value of ERC-funded research in certain areas. For instance, the report 'Materialising the future', published by the Joint Research Centre and focusing on horizon scanning for emerging technologies and breakthrough innovations in the field of advanced material for energy, refers to several publications originating from ERC-funded research. Among the contributing projects is the ERC project SmartGraphene, led by Coskun Kocabas at the University of Manchester in the United Kingdom, which developed electrically tunable graphene surfaces that actively control light and heat across a broad electromagnetic spectrum for advanced technological applications. Another referenced project is the ERC project PARATOP, led by Titus Neupert at the University of Zurich in Switzerland, which reached new frontiers in numerically simulating quantum many-body systems using variational methods, crucial for future developments in electronics, like electronic chip architectures, sensors, or quantum computers. A third cited publication is associated with the ERC project MOOiRE, led by Alexandru Vlad at the University of Louvain in Belgium, which advanced new high-voltage, air-stable organic battery chemistries as sustainable alternatives to cobalt-based Li-ion systems.

IV. Sectorial landscape

The Policy Sector Domain layer (Layer C in Figure 7) classifies materials research according to the primary societal or industrial sectors it supports, bridging scientific innovation with policy priorities. The landscape was analysed according to the five policy sectors identified in the Scientific Advice Mechanism's Scoping Paper on Advanced Materials, enabling clearer alignment with EU strategic objectives. This approach highlights the real-world applications and policy relevance of advanced materials, helping decision-makers understand how research contributes to sectoral needs and societal challenges.

The taxonomy covers five sectors[xvi]:

- **Health** – materials for medical devices, implants and bio-functional systems
- **Energy** – materials for sustainable production, storage and conversion
- **Mobility** – transport and aerospace applications
- **Construction** – durable, high-performance and sustainable building materials
- **Advanced Electronics** – semiconductors, photonics and quantum materials

As shown in Figure 18, the distribution of projects across Layer C provides a clear view of the portfolio's strategic alignment with European and global priorities. Research activity is strongly concentrated in **Health (36.5%)**, **Advanced Electronics (36.5%)** and **Energy (19%)**, reflecting major societal and policy challenges.

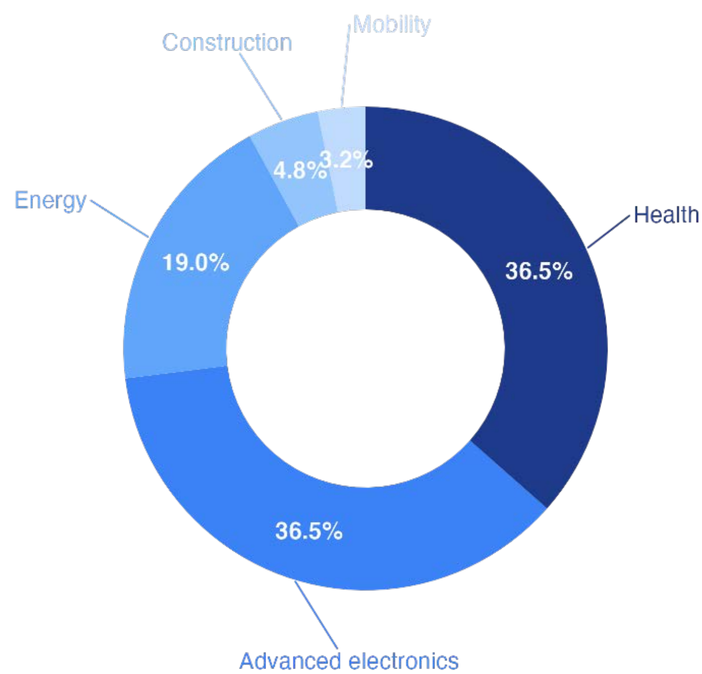


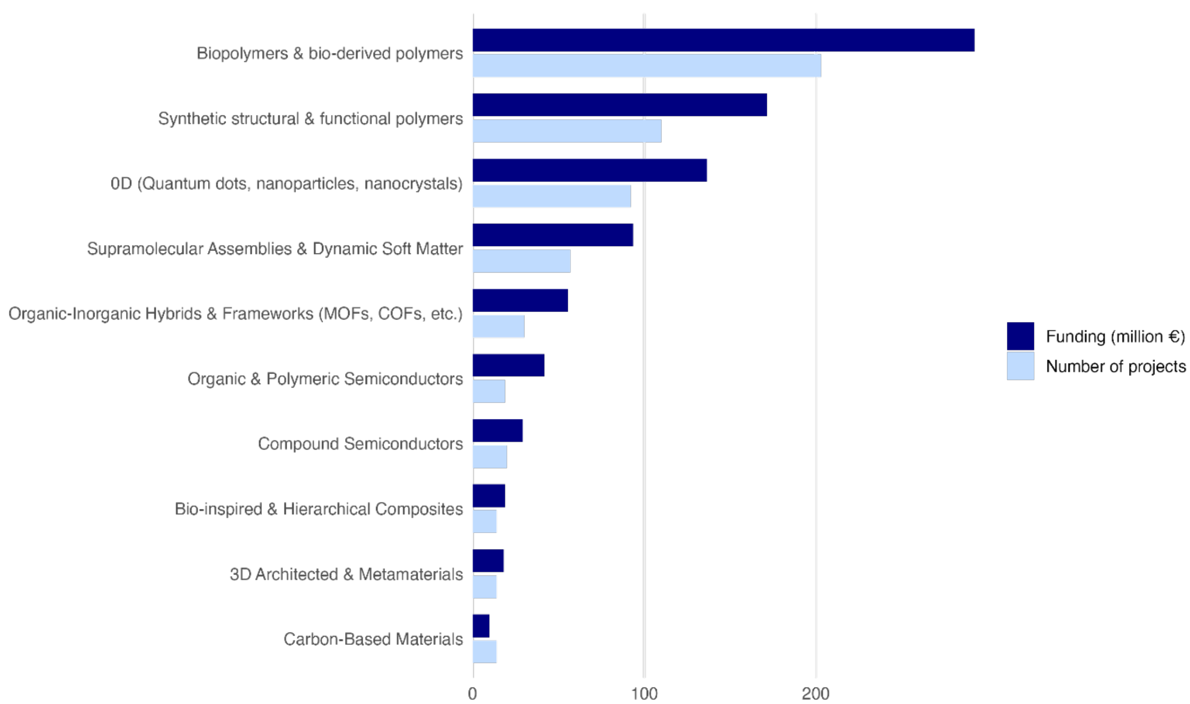
Figure 18: Percentage of ERC advanced materials projects by policy sector

V. Health

Advanced materials play a pivotal role in enabling the development of next-generation products that have the potential to transform healthcare — from novel medical devices and regenerative materials to breakthrough diagnostic tools and therapeutic solutions.

Within this dynamic domain, most of the ERC projects are highly interdisciplinary, drawing upon recent advances in areas such as chemistry, physics, biology and engineering, and addressing a wide range of applications and diseases (Figure 19).

Figure 19: ERC advanced materials projects in health by material class



The development of advanced materials is driving innovation in various fields, particularly in the areas of biomaterials, smart/responsive biomaterials, nanotechnology, and bioelectronics and energy harvesting.

Biomaterials and tissue engineering are advancing with the development of biocompatible materials, artificial cilia and hydrogels, biocompatible ceramics, among others. The convergence of nanotechnology and nanomedicine is yielding novel solutions for cancer research, targeted therapy and drug delivery. The development of diagnostic tools and biosensors is another area where novel advanced materials are making a significant impact. Energy harvesting and electronics are also being transformed by advanced materials, with flexible thermoelectric generators and piezoelectric materials, enabling the creation of wearable electronics and sensing devices.

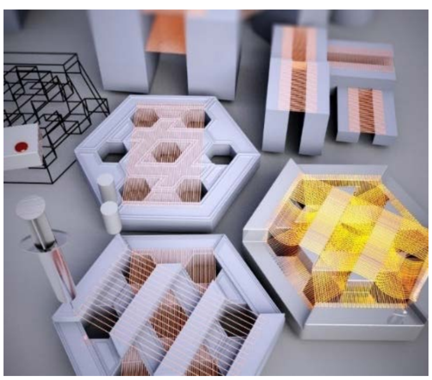
Advanced polymer-based (bio)materials

The most prominent functional class of polymer-based materials is Biocompatible & Bioactive Materials (around 28% of the portfolio). This area includes novel biomaterials (cell-based or cell-free), which can be introduced into body tissue as part of an implanted medical device or used to replace an organ or bodily function, among others. These biomaterials hold great potential to revolutionise the fields of tissue engineering and wound healing, as they can provide structural support and also be active in biological processes.

Stimuli-responsive & Active Materials (around 7% of the portfolio) and Drug Delivery & Theranostic Systems (around 5% of the portfolio) are the other main represented categories of polymer-derived materials. Both the magnitude and spectrum of applications observed in this large cluster reflect the importance of polymer-derived materials in the healthcare sector and their foundational importance for future medical care.

Within the prominent class of polymer-derived biomaterial, hydrogels stand out as a versatile class of bioactive and biocompatible materials for health applications. An example of how hydrogels are poised to revolutionise medical care is showcased in the project HydroLieve, led by Martin O'Halloran at the National University of Ireland Galway. The project focused on developing a long-lasting **hydrogel** for non-migrating relief of chronic pain, particularly targeting conditions such as trigeminal neuralgia[xvii]. Within HydroLieve, researchers designed a chemically modified hydrogel that interrupts the pain transmission cascade directly at the nerve level. In preclinical studies, the prototype hydrogel demonstrated a 40% reduction in pain sensation compared to controls, validating its analgesic efficacy. The project achieved key milestones, including the establishment of a team for a spin-off company. By eliminating the need for repeated drug administration and using a minimally invasive injection system, HydroLieve's polymeric hydrogel provides a drug-free and sustained mechanical solution to pain management, exemplifying how materials themselves can become therapeutic agents in the management of chronic neuropathic pain.

Complementing these therapeutic directions, the project BIOELE, led by Yanyan Huang, from the University of Cambridge in the UK, explored how polymers can serve as the structural and electronic foundation of bionic devices. The project pioneers a revolutionary 3D biofabrication platform that enables the production of high-performance, cell-compatible **biointerface fibres**. While the underlying multi-material 3D printing process is key to overcoming major limitations in merging materials with divergent mechanical and chemical properties, this project underscored the importance of polymers in the fabrication of compact, smart and customisable bioelectronic devices. BIOELE's functional fibres hold great potential to be used for diverse applications, from biomedical diagnostics and in vitro models to electronic textiles. The results of this frontier research have led to a patent filing process covering the fibre printing technology, proprietary inks and yarn production process. Moreover, the project highlighted the potential of 'fibre printing' as a technological leap beyond the state-of-the-art for the creation of new eco-friendly fibre formats that can redefine future bionic and biomedical device manufacturing.



Decorating functional nano-micro-fibres on 3D structures.

Dandelion seed head decorated with functional microfibres.

The project ARTSILK, led by Anna Rising at the Karolinska Institute in Sweden, tackled the urgent need for sustainable bio-based fibres with mechanical properties comparable to, or exceeding, those of petroleum-derived materials such as nylon and Kevlar. The project expanded the fundamental understanding of silk biogenesis. Building on their discoveries, Rising and her team advanced the design of engineered recombinant **silk proteins** and silk production methods, resulting not only in the development of novel environmentally friendly production processes but also in the development of artificial spider silk fibres with exceptional tensile strength, toughness and scalability. The project's success resulted in a patent application, an ERC PoC grant ArtSilkTex and industrial partnerships to advance commercialisation[xviii]. Furthermore, ARTSILK has led to an unexpected outcome: the researchers discovered that the recombinant silk proteins could also form self-sustaining hydrogels at body temperature (37 °C). These hydrogels retain their biological activity and can potentially be used to encapsulate living cells, enabling new approaches for cell immobilisation and tissue engineering.

Biomimetic artificial spider silk fibers

Next generation of smart/responsive (bio)materials

Within the main category of polymers and soft matter, a relevant number of projects focused their research on supramolecular assemblies. These relate to materials that can self-assemble and/or respond dynamically to external stimuli, but that differ from previous generations of responsive materials for their improved control over biomolecular processes. These 'smart' materials form the technological basis for responsive implants, adaptive prosthetics, real-time diagnostic tools and nano/micro robots, as exemplified by the project highlights below.

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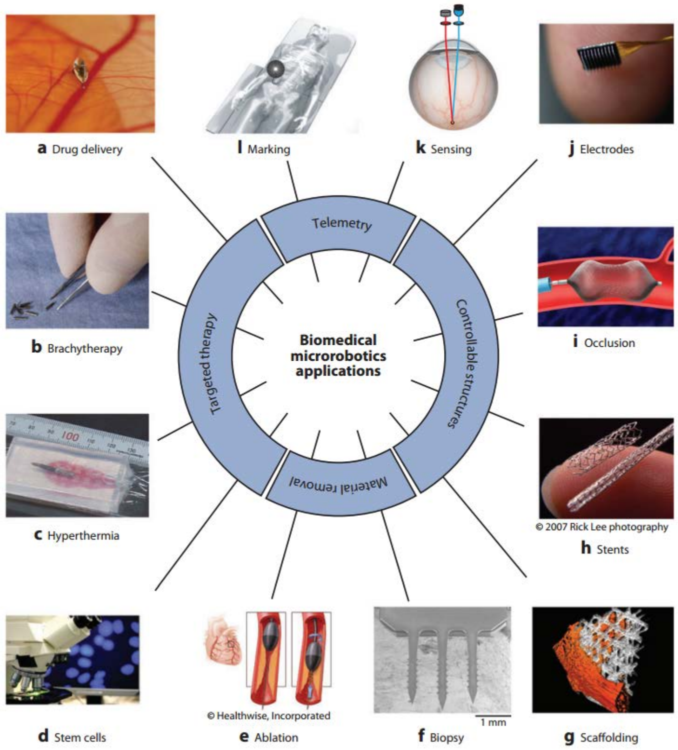
Led by Ebbe Sloth Andersen from Aarhus University in Denmark, the project RNA Origami pioneered a new class of nanostructures that fold like origami to control and programme biological functions inside living cells. By applying the principles of molecular self-assembly to RNA, the project demonstrated how rationally designed **RNA scaffolds** can organise proteins and small molecules with nanoscale precision. Beyond fundamental science, the project generated an advanced open-source software toolkit and a publicly available web server that enables researchers worldwide to design and express RNA origami nanostructures. Leveraging these advancements, the team has generated RNA origami scaffolds that were placed inside cells to control metabolic pathways, opening up new avenues for real-time cellular diagnostics. RNA Origami has also delivered a proof of concept for therapeutic RNA particles that modulate blood coagulation, illustrating the broader translational potential of this technology. RNA Origami demonstrates how RNA/DNA can be used as advanced materials for accelerating innovation in synthetic biology and RNA medicine, unlocking new routes in synthetic biology and RNA-based therapeutics.

The development of molecular machines, pioneered in 1999 by Ben Feringa from the University of Groningen in the Netherlands, and later recognised with the 2016 Nobel Prize in Chemistry, is widely regarded as a major scientific breakthrough. Feringa's work was supported by three ERC grants, which collectively contributed to the expansion of our understanding of the basic principles, rules and parameters that govern molecular motion at the nanoscale, through the design and control of light-driven unidirectional molecular motors. The project MOLECULAR MOTORS culminated in major advances in the materials field, such as the development of responsive photo-switchable gels, hybrid membrane protein channels with light-controlled transport and photo-and redox-active materials for information storage and electronics. The project MMDYNASYS further pushed the state of the art in several ways. It developed molecular motors that can work in water and affect biomolecules, as well as the first-ever catalytic rotary molecular motor. The project also showcased motor rotation in solid state (MOFs) and created new, fast-acting molecular motors powered by visible light. Notably, an artificial molecular muscle was developed to lift larger objects and a light-powered system that converts motion into chemical energy, paving the way for advanced nanomachines. His ERC PoC grant PHOTOPHARM extended this work into the emerging field of photopharmacology, exploiting the discoveries of light-powered molecular machines to develop smart pharmaceuticals precisely activated by light irradiation, including antibiotics and antitumour agents.

The project MolMacIP, led by David A Leigh at the University of Manchester in the UK, explored the frontiers of **synthetic molecular machinery**, seeking to bridge the gap between different generations of nanoscale switches and actuators. This visionary project aimed to create artificial molecular machines capable of performing complex tasks, such as mimicking aspects of robotic manipulation on a molecular scale. Through a series of groundbreaking advances, MolMacIP established new paradigms in this arena, exemplified by the successful design of a chemically fuelled molecular pump that functions autonomously against a concentration gradient, which can be used to drive molecular motion and directionality. The achievements of MolMacIP opened a pathway towards responsive nanoscale architectures with potential applications in targeted drug delivery, chemically powered sensing and autonomous therapeutic systems and materials.

Still in the area of nanorobotics, the project SOMBOT, led by Bradley James Nelson at ETH Zurich, advanced the frontier of biodegradable, shape-adaptive microrobots capable of navigation, sensing and actuation within biological environments. These soft, polymer-based devices are engineered to perform tasks such as targeted drug delivery, tissue repair and minimally invasive surgery. The material unlocking the promise of SOMBOT was a new **photoresist material (P2CK–GelMA)** enabling 3D printing of soft hydrogel microrobots with high precision and biocompatibility. Using template-assisted fabrication and biodegradable polymers, the team demonstrated fully functional microrobots integrated **with iron oxide nanoparticles for magnetic actuation and guidance.** These devices could deliver drugs efficiently or act as shape-memory stents, adapting to physiological conditions and degrading safely once their function was complete. At the systems level, SOMBOT developed advanced magnetic navigation technologies and novel



Potential medical applications of soft microrobots

catheter-based delivery platforms, allowing precise control and tracking of microrobots in vitro and ex vivo. The team also introduced continuum robotic tools for ophthalmic, gastrointestinal, and neurosurgical interventions, tested using medical imaging modalities such as optical coherence tomography and fluoroscopy. The project resulted in multiple patents, and a new generation of compact, high-performance electromagnetic navigation systems suitable for clinical integration[xix]. SOMBOT has set the foundation for intelligent soft microrobots that autonomously respond to their environment, enabling minimally invasive, high-precision therapies across multiple medical domains.

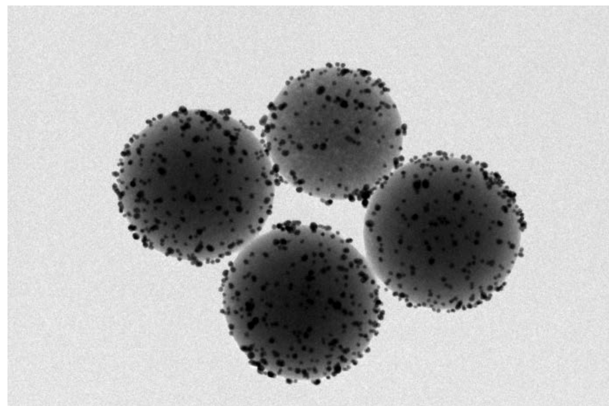
Nanoscale advanced materials

This area includes materials that can be used for precise biosensing, diagnostics, drug delivery, and advanced targeted therapies bolstered by nanorobotics, holding great promise to accelerate the next generation of biomedical tools. It should be noted that while the materials presented in this section can be metallic, polymeric or hybrid in nature, for the purpose of this report, projects in this cluster include nanoscale materials, the dimensions of which represent their main defining characteristic.

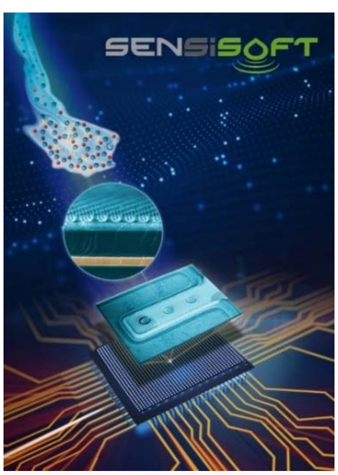
Leveraging the versatility of **nano metal-organic frameworks (MOFs)**, researchers from the University of Cambridge in the UK, led by David Fairen-Jimenez, have generated hybrid materials (MOFs within hydrogel matrices) to treat cancers, including pancreatic cancer, mesothelioma, glioblastoma, and breast cancer.

Recognised in the 2025 Nobel Prize in Chemistry, MOFs are revolutionary materials because of their ability to both store and transform substances within[xx]. The hybrid architecture developed by Fairen-Jimenez and his team merges the porosity and drug-loading capacity of MOFs with the biocompatibility and tuneable mechanics of hydrogels, producing systems capable of localised and sustained drug release. The unique features of this advanced material were demonstrated in the project MOHEDD. The project's translational success was underscored by the creation of Vector Bioscience Cambridge Ltd, a spin-off company that is advancing the developed nano-MOFs towards clinical application. Building on these ERC-funded discoveries, a winning consortium was established to secure a European Innovation Council (EIC) Transition Challenge grant in 2023, which aimed to support preclinical studies and regulatory preparation. MOHEDD exemplifies the transformative potential of hybrid materials in oncology and highlights Europe's growing commitment to accelerate the translation of complex materials into clinical products.

Another example of how hybrid nanomaterials are contributing to the advancement of precision medicine has been more recently showcased in the project i-NANOSWARMS, which introduced the intriguing concept of collective, cooperative nanorobotics. Led by Samuel Sánchez, from the Institute for Bioengineering of Catalonia, Spain, the project aimed to engineer intelligent, self-powered nanosystems capable of communicating and responding within complex biological environments. Through a combination of **enzyme-powered nanomotors, MOFs and biohybrid components**, i-NANOSWARMS has been showcasing how nanobots exhibiting autonomous motion, environmental sensing and emergent swarm behaviour can modify their surroundings and guide subsequent agents[xxi]. This entirely new paradigm for nanoscale self-organisation has received public attention, as shown in this highlight. Using state-of-the-art imaging (PET–CT), i-NANOSWARMS demonstrated active nanobot swarms in vivo, which represents a major leap in nanomedicine imaging and safety validation. Functionally, peptide-modified nanobots were shown to eradicate bacterial biofilms in infected tissue, with self-propulsion proving critical to therapeutic efficacy. By integrating AI for tracking and control, the project bridged active matter physics and biomedical engineering, positioning nanoswarms as a potential next-generation platform for targeted therapy, biosensing, and smart diagnostics.


Transmission electron microscopy image of urease-powered nanomotors (Hortelao et al. 2021, SciRobotic).

In the subsequent PoC project, MucOncoBots, Sánchez and his team used this technology to develop a novel therapeutic platform for pseudomyxoma peritonei (PMP) and related mucinous cancers, which are resistant to conventional chemotherapy due to the presence of a protective mucus barrier. The project designed enzyme-powered nanobots capable of both degrading this barrier and delivering anticancer drugs directly to tumour sites, enabling targeted and minimally invasive therapy. The nanobots demonstrated superior tumour inhibition in patient-derived organoids and mouse models compared to free drug administration, marking a step towards non-surgical, precision treatments for PMP and other mucin-rich cancers[xxii].



Chemical Integration of Piezoelectric Oxides Nanomaterials for Improved Sensors

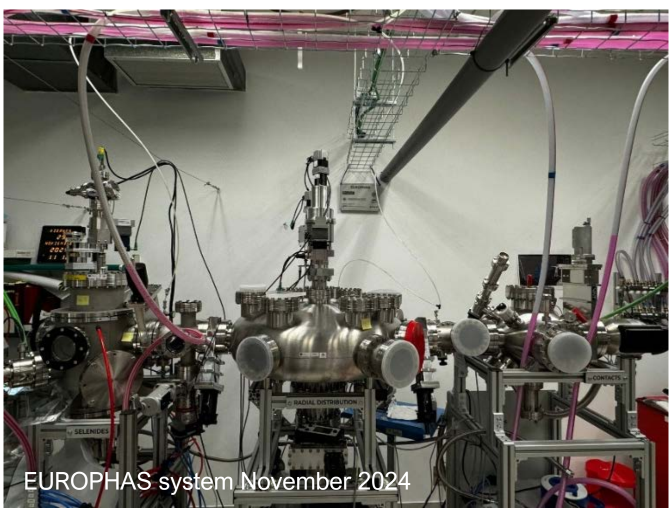
Working at the nanoscale creates value across various sectors. A demonstration of this potential is showcased in the project SENSiSOFT, led by Adrien Carretero and his team at CNRS in France, where they have developed innovative strategies to create sustainable, efficient and non-toxic **nanosized piezoelectric materials**. The project combines soft-chemistry approaches with microfabrication techniques to create industrially scalable piezoelectric sensors with multiple applications in the healthcare, environmental and energy sectors. An example of its potential in healthcare lies in the materials' extremely high sensitivity. Leveraging this potential, the team has created **α-quartz-based piezoelectric biomedical micro-electro-mechanical systems (BioMEMS)** capable of selectively detecting emerging arboviruses, such as Chikungunya, with greater accuracy. This new BioMEMS device has demonstrated a detection limit in liquid conditions that is five times more sensitive than conventional ELISA tests. Another example is the production of piezoelectric nanostructured cantilevers, which allow for high-resolution force measurements in situ, potentially applicable to qualifying cellular forces. A real-world application of this project's results is a product called FakirSlides, which is being marketed by the company Idylle. Additionally, the project has generated several patents, high-impact publications, and international recognition, shaping a new generation of scalable, eco-designed piezoelectric technologies[xxiii].

Frontier research at the interface between advanced electronics and biology/medicine

In addition to the three main categories of materials described above, a significant fraction of health-related projects focused on the interface between the fields of advanced electronics and biology/medicine.

Research in this field strives towards the development of implantable medical devices that can sense and modulate biological signals that, for example, could mimic the nervous system itself. This area includes projects focused on novel semiconductors and dielectrics tailored for several purposes, including: bioelectronic medicine, the development of advanced interfaces between electronic and biological systems, and allowing improved communication and therapeutic interventions.

At the intersection of bioelectronics and non-invasive diagnostics, the project NANOZ-ONIC, led by Christophe Moreau at the CNRS in France, proposed developing a bio-inspired electronic nose capable of detecting volatile biomarkers in exhaled breath with high specificity and sensitivity. The project relied on the development of hybrid biosensors based on artificial receptor–ion channel proteins coupled to single-wall carbon nanotube field-effect transistors. These devices mimic the function of biological olfactory systems, generating electrical responses upon recognition of disease-related volatile organic compounds. In a significant extension of scope, NANOZ-ONIC also demonstrated virus detection capabilities, including reusable field-effect transistors for H1N1 and SARS-CoV-2 pseudoparticles, highlighting the versatility of the platform. All in all, this project showcases how advanced hybrid biosensors may be key to the next generation of rapid, painless and low-cost biosensing systems capable of identifying early-stage diseases with minimal invasiveness, enabling screening for several diseases, including cancers, diabetes, neurodegenerative disorders and airborne diseases.


EUROPHAS system November 2024

Shifting focus to wearables and implantable electronics, the project POWERbyU, led by Marisol Martin Gonzalez from the Spanish National Research Council (CSIC), is redefining the future of this field by creating self-powered wearable systems that harvest thermal and mechanical energy from the human body, enabling continuous operation without recharging. At its core, POWERbyU developed **flexible thermoelectric generators** on **high-thermal-conductivity polymer substrates**, enabling efficient conversion of body heat into electrical energy while maintaining mechanical flexibility and comfort. The team pioneered three-dimensional **3D anodic aluminium oxide** templates with tuneable pore sizes (30–350 nm) and successfully infiltrated polymers into these templates using custom high-vacuum systems, significantly improving thermal management at the nanoscale. To facilitate integration into real devices, the team designed ultra-low-input DC–DC converters and began embedding thermoelectric layers into textiles, demonstrating the feasibility of energy-harvesting fabrics. Collectively, these advances mark major progress in materials science and energy engineering, enabling the development of self-powered monitoring systems for continuous health assessment.

A paper-based DNA testing for possible use as a self-administered DNA test

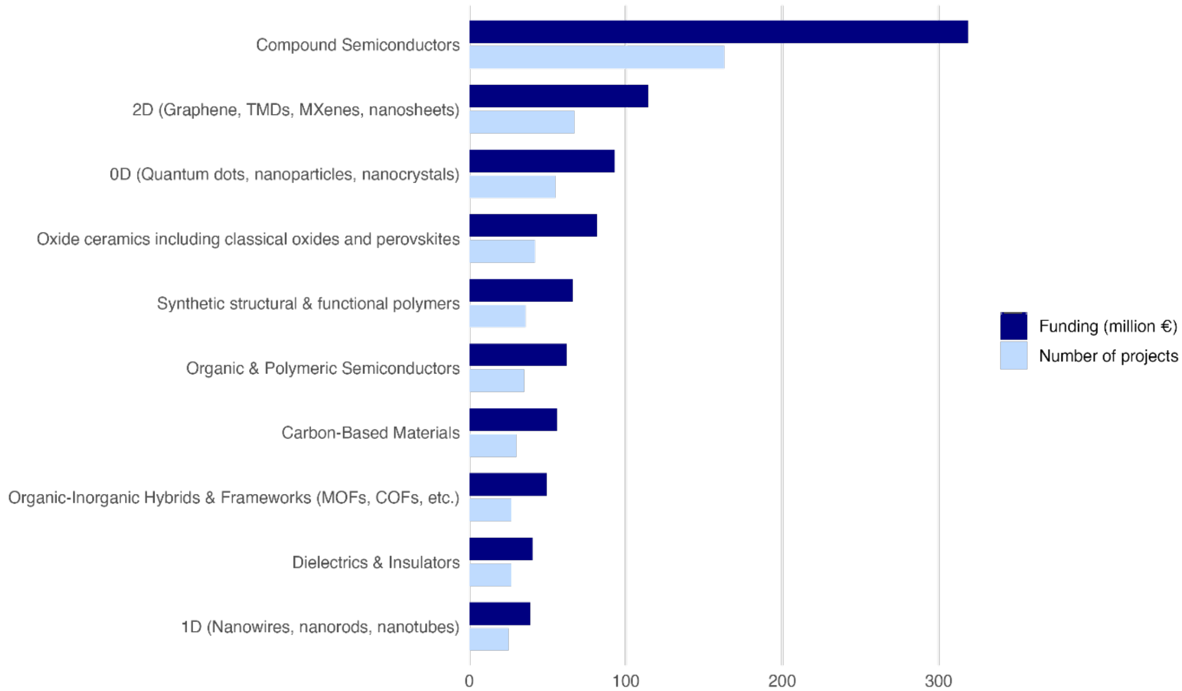
The field of bioelectronics also holds promise to accelerate the development of rapid, affordable and portable molecular diagnostic tools for the detection of pathogens (such as HIV, Ebola and antibiotic-resistant bacteria, and, most recently, the Covid-19 virus). The project iMDx, led by Max Hamedi at the Royal Institute of Technology in Sweden, developed a comprehensive toolkit of new materials and methods to enable fully integrated, disposable nucleic acid testing devices for point-of-care and home use. At the centre of the project is the development of **3D Microfibre Electrofluidics**, which is a radically simple, yet powerful technology based on porous materials such as paper, textiles and fabric composites. These platforms can integrate 3D microfluidics, embedded microelectronics, electrochemical sensing elements, stored reagents and cellular manipulation into a single, printable architecture. The result is a powerful technology that performs all-round preparation, amplification and electrochemical detection of DNA from biological samples, all in a high-throughput manner. Further advances included open-source, portable polymerase chain reactor systems and low-cost electronic controllers, offering a modular toolkit for rapid test development. Collectively, these innovations bring molecular diagnostics closer to universal and decentralised healthcare, where testing can occur outside traditional laboratories.

VI. Advanced electronics

Materials underpin all advanced electronic technologies — from processors and circuits to displays and sensors — shaping the devices that drive a rapidly-evolving digital society. The materials examined in this section are characterised by specific electrical and magnetic properties which, when precisely engineered, enable novel functionalities in everyday technologies. Innovation in this area is essential, as it leads to faster computing, lower energy consumption, more efficient and sensitive detection systems and, critically, more sustainable production with reduced reliance on critical raw materials.

ERC-funded research in advanced electronics has predominantly focused on compound semiconductors, recognising their strategic role in high-performance electronic and optoelectronic systems such as power electronics, light-emitting diodes (LEDs) and high-frequency transistors. Research on 2D materials (e.g. graphene), 0D quantum dots and oxide ceramics further reflects strong activity in nanoscale engineering and novel electronic phenomena. These materials complement traditional semiconductor technologies and enable next-generation miniaturised, high-efficiency devices (Figure 20).

Figure 20: ERC advanced materials projects in advanced electronics by material class



Novel or engineered semiconductors

Semiconducting materials are at the heart of any electronics device and represent the basis of the current technological revolution. ERC-funded projects have been exploring this family of materials from different perspectives. Conventional inorganic semiconductors, such as silicon or III-V compounds have been reconsidered in new geometry and dimensionality, such as in nanowires or integrated architectures to enhance their functionalities. Research has been conducted on novel oxides and their application, for example in transparent electronic components or in resistive switching devices for neuro-inspired computing.

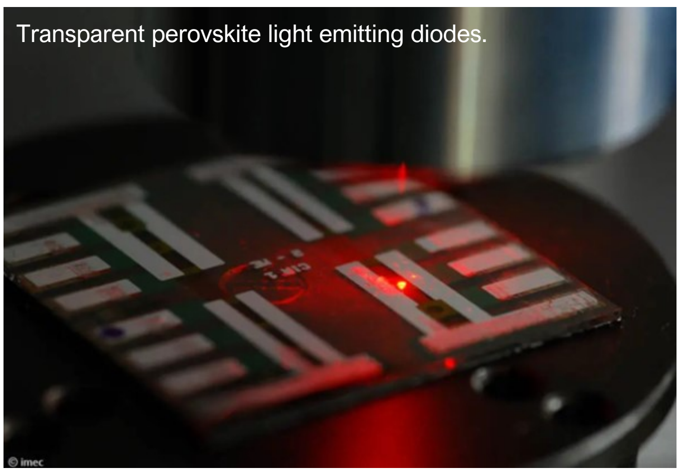
The tremendous advancement in perovskite compounds knowledge in the photovoltaic field is also reflected in ERC-funded projects that have aimed at tailoring the properties of these low-cost processability and efficient charge transport materials for novel electronics and optoelectronics devices. ERC-funded projects have also been focused on emerging 2D materials, from graphene to transition metal dichalcogenide and Xenes, as well as their organisation in van der Waals heterostructures.

In traditional computers, the processor and memory are physically separate units: data are stored in the memory and transferred to the CPU whenever needed. Neuromorphic computers, on the other hand, follow a parallel processing architecture that is inspired by the human brain, where artificial neurons and synapses operate in parallel, enabling faster and more energy-efficient processing. The project EROS, led by Judith Driscoll at the University of Cambridge in the UK, studies novel oxides and their combinations for non-volatile memory and neuromorphic computing with improved efficiency and robustness. The project has developed a new nanocomposite material, which efficiently changes its resistance in response to an applied electric field — a phenomenon known as resistive switching, and which enables applications in non-volatile memory technologies for personal computers[xxiv]. Driscoll also funded the start-up company

Nanoprint Innovations, which deals with the deposition process while patents have been filed for novel oxides and architectures.

New semiconducting properties are emerging in the so-called 2D materials, that is, materials that are extremely thin as they are formed by atomic thin layers. The project Mol-2D, led by Eugenio Coronado Miralles at the University of Valencia in Spain, pioneered an innovative approach to developing 2D materials, in which metal–organic 2D magnets and heterostructures were realised and their properties tuned through active control of the hybrid interface. The high-quality of prepared molecular/2D heterostructures makes them suitable for direct applications such as in ultrathin spin valve devices and robust electronic devices based on spin crossover/2D heterostructures, with application in nano/microelectronics. The project also impacted the field of energy storage devices for green hydrogen production, with several patents[xxv] and supported the creation of a spin-off company 2D-Match S.L., a precursor to Matteco.

Lighting is another area where improved materials can enhance performance in devices such as TV, PC and smartphone displays, along with traffic signals and aviation lighting. LED technology, followed by organic LED (OLED) technology, forms the basis of current lighting, but both have limited peak brightness.



Transparent perovskite light emitting diodes.

The project ULTRA-LUX, led by Paul Heremans at the Interuniversity Microelectronics Centre in Belgium, focused on the light-emission properties of perovskites for high brightness LEDs and even laser devices. By studying new perovskite compositions and device stack combinations, and by advancing device fabrication, the team demonstrated that ultra-high current densities can be supported, as required for electrically generated stimulated emission. The project has demonstrated that the perovskite LED, a new type of light-emitting diode, is 1 000 times brighter than regular OLEDs. Two patents have been produced: one is at the level of device layout and consists of an innovative approach to integrating multiple optoelectronic devices on a single substrate; the other one is a compact device solution for modulation of the optical signal and has applications in holographic images and in optical central processing units[xxvi]. The work continued with the development of injection lasers within the EIC Pathfinder project SUPERLASER. Read more in this article.

Organic materials/flexible electronics

Materials for electronic applications have, for a long time, been based on inorganic, solid state compounds, which require complex synthesis and deposition processes at the basis of the semiconductor technological chain.

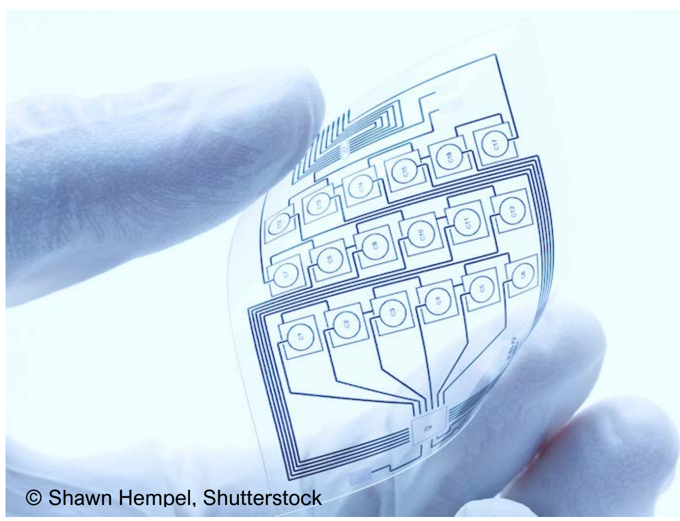
However, in the last decades, a new large category of materials of great interest has emerged, namely organic electronic materials. This category embraces conjugated polymers, small molecules and carbon-based nanomaterials that are soft, low cost and are easily processable[xxvii]. Moreover, they are characterised by unique properties, such as high electrical conductivity and mechanical flexibility, making them suitable for applications in electronic signal transduction and chemical modification. They can be manufactured in an environmentally friendly way, and they may lead to biodegradable and even biocompatible/biometabolisable electronics, including for *in vivo* applications[xxviii].

ERC-funded research in this field has involved the design of new molecules with tailored electromagnetic properties and the development of novel approaches and synthetic pathways for the preparation of organic electronic materials, as well as processes for their large–scale deposition as thin films. Fundamental studies were conducted to further understand molecular energy, charge transport and photophysics, as well as to provide new design rules for molecular electronics, optoelectronics, computing and sensing.

Some projects explored how organic compounds can be architectured or combined in hybrid and multilayered configurations with other materials to be integrated into optoelectronic and electronic devices with enhanced functionalities. Others focused on different layouts and compositions for organic field effect transistors and OLEDs to improve their performance, such as frequency range or efficiency, or reducing the use of non-abundant and toxic resources.

Finally, a large component of research focused on using organic semiconductors to interface the living world with projects studying fundamental aspects such as hybrid solid–liquid systems to novel design of bioelectronic devices.

The project e-GAMES, led by Marta Mas Torrent at CSIC in Spain used organic molecules to fabricate electronic devices. The project successfully demonstrated single molecules anchored to conducting surfaces as active components for conceptually new memory devices. The project also demonstrated the possibility to control the surface chemical properties and wettability in order to, for example, control water actuation for the development of lab-on-a-chip sensors. Moreover, the team demonstrated the fabrication of high performing organic transistors through low cost and scalable techniques and with exceptional stability in air.



In the project HEROIC, led by Mario Caironi at the Italian Institute of Technology, the aim was to push the organic transistor technology to the radio frequency range to exploit them in wireless communicating devices with low power consumption. The project combined high-resolution printing and direct writing of solution-processable functional materials with the use of high-capacitance, solution-processable hybrid dielectrics, advancing high-throughput patterning and high-speed production of polymer electronics. Finally, Caironi demonstrated directly written polymer transistors entirely fabricated on plastic and operating at 160 MHz. The project activity towards solution processed dielectrics, involving bio- and food-based materials, contributed to shaping the new field of research of 'edible electronics', for which Caironi was awarded another ERC grant for the project ELFO. Read more about how the project HEROIC succeeded in generating novel electronics to operate at frequencies not imagined before.

Quantum materials

A large portion of ERC-funded projects in solid state physics and materials science covered what are called exotic states of matter, that is, superconductors, superfluids, topological insulators and emerging quantum systems (such as topological surface states and fractional quantum Hall states).

These states go beyond classical thermodynamic states and embrace quantum mechanical principles. They arise from unexplored combinations of advanced electronic and magnetic properties of materials, driven by complex physics effects like symmetry breaking, entanglement and quantum coherence.

The ERC has supported fundamental research in this area since the Seventh Framework Programme (FP7), continuing through Horizon 2020 and Horizon Europe. More recently, new research directions have emerged that explore these states in materials, such as transition metal oxides, layered 2D materials and complex inorganic compounds. These advances are opening new technological opportunities in spintronics, quantum computing and energy materials.

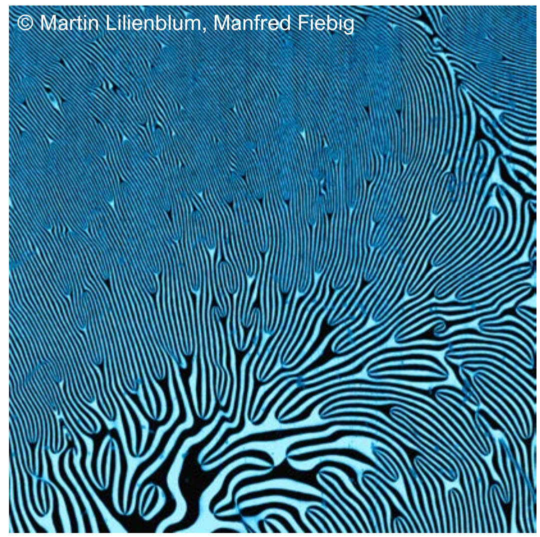
One pioneering project in the field was IDEA HEUSLER, led by Claudia Felser at the Max Planck Society in Germany. The project studied Heusler compounds, a large family of binary, ternary and quaternary compounds that exhibit a wide range of chemically- and structurally tuneable properties of both fundamental and potential technological interest. Magnetic Heusler compounds were discovered with high potential for multiple applications such as spintronics, multi-ferroics, spincalorics and rare earth-free hard magnets. Felser was also awarded another ERC grant for the project TOPMAT, which allowed her and her team to discover new topological materials currently investigated by many scientists worldwide for applications in topological quantum computer and spintronics.

The project MINT, led by Manuel Bibes at the CNRS in France, investigated strongly correlated electron physics, microelectronics and spintronics in oxides to craft new electronic phases controllable by external stimuli (strain engineering, interfacial charge/orbital/spin reconstruction and octahedra connectivity control). The project was particularly successful in shedding light on the fundamental properties of low-dimensional correlated systems and in realising a new transistor design. Bibes also received another ERC grant for the project FRESCO**,** in which ferroelectric materials were experimentally exploited to create energy-efficient spintronics to be used in data storage and transfer. FRESCO has already contributed to the important technological development of a low-power method for controlling electron spin, which could help to maintain the historic rates of progress occurring in computational power. Bibes' research has led to several patents[xxix], to the PoC project UPLIFT and to the creation of a spin-off company NELLOW, addressing the energy consumption of microelectronic devices for AI and logic chips thanks to the invention of the new type of technology based on multiferroic and ferroelectric materials[xxx].

The projects 0MSPIN and ALTERMAG, both led by Tomáš Jungwirth at the Institute of Physics in Czechia, delve into the properties of magnetic materials. OMSPIN focused on microelectronic and optoelectronic devices based on antiferromagnets, as opposed to most common technologies based on ferromagnets. Previously, the control by any practical means of antiferromagnets was intrinsically difficult to achieve since they lack the external magnetic fields associated with ferromagnets. Instead, Jungwirth demonstrated that the complex crystal properties of certain antiferromagnets, combined with the relativistic quantum mechanical nature of the electrons, mean that antiferromagnetism can be controlled using electrical currents. The concept was experimentally demonstrated in the complete write/store/read functionality of an antiferromagnetic memory, representing a major scientific breakthrough in the field of condensed matter physics, and opening new avenues for ultrafast solid-state memories. In the ongoing project

ALTERMAG, Jungwirth is focusing on a phenomenon termed altermagnetism, which combines aspects of both ferromagnetism and antiferromagnetism.

The project INSEETO, led by Manfred Fiebig at ETH Zurich, Switzerland, developed a new non-destructive method based on laser-optical light frequency doubling, also called second harmonic generation (SHG), to observe and control key electronic and magnetic properties of oxide thin films and layered materials during growth. By applying SHG during film deposition, the team tracked in real time how electric polarisation and related phenomena emerge and evolve, and how they are influenced by strain, defects, and interfaces at the nanoscale. The technique was successfully applied to a range of technologically relevant materials, revealing the onset of ferroelectric behaviour, domain formation, and the role of surfaces and interfaces in determining the final properties of ultrathin films. Compared with existing approaches, SHG provides rapid, direct, and immediate feedback without damaging the material or requiring electrical contacts. Overall, INSEETO delivered novel insights into the formation of functional properties in complex oxides and laid the scientific foundations for in-situ process monitoring.



Ferroelectric domains in hexagonal $ErMnO_3$. Opposite brightness represents positively and negatively charged regions on the crystal surface. Image width is about 100 µm.

Building on these results, Fiebig also received a PoC grant for POLARIS, which focused on translating the SHG-based approach into a prototype for a future market-ready monitoring tool. The project resulted in a compact setup integrating a small-footprint laser and optical components that can be easily attached to existing thin-film growth chambers and operated under realistic laboratory or industrial conditions. Successful testing demonstrated its ability to monitor the emergence of application-relevant properties in ultrathin films in real time, opening the way to faster optimisation of ferroelectric heterostructures and accelerating the development of next-generation electronic and energy-efficient devices. After advancing the prototype into a marketable device, the result of the INSEETO project is now sold through the ETH Spinoff Company 3Wave Instruments with Fiebig as one of its co-founders.

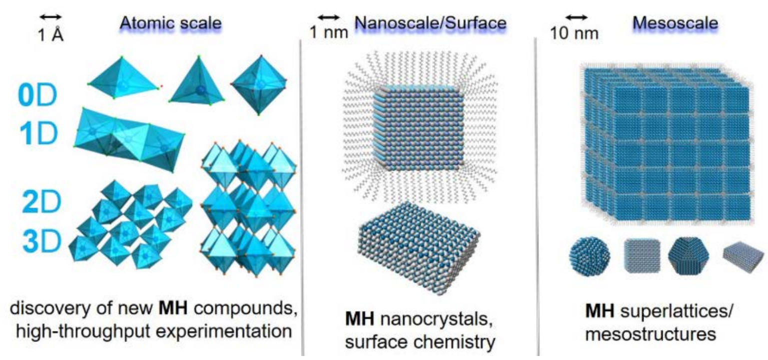
Nanomaterials

Along with topological materials, which also exploit quantum effects, a large subset of ERC-funded projects focuses on quantum phenomena in nanomaterials and on the application of novel materials in a variety of quantum technologies, including photonics, computation, simulations, communications and sensing. Quantum optical technologies, for example, harness the properties of certain materials to manipulate light and matter at the nanoscale, and find application in secure communication networks, efficient computer algorithms, sensing and metrology, medicine and biology[xxxi].

Quantum dots are artificially crafted nanostructures of inorganic semiconductors, and they can be obtained in the solid state or in forms of colloidal nanoparticles. In the last decades, solid state quantum dots have been widely studied and engineered towards applications in quantum optics, quantum optoelectronics and quantum information processing. Colloidal quantum dots have been the subject of specific studies on their synthesis and assembly to engineer their chemical and structural properties, and to integrate them into more complex platforms, such as metallic metamaterials or organic semiconductor molecules. Moreover, they have been investigated and tailored for solution-processed optoelectronics, for example to improve the efficiency of LED technology (CQWLed), to develop infrared optoelectronics for gas sensing or night vision (INFRADOT and BlackQD), or to enable new quantum technologies such as single photon emitters (SINSLIM, ColloQuantO, NANOLED). They also find application in the field of energy, for example to realise low-cost and environmentally friendly solar cells (HEINSOL). This area of research is currently moving towards sophisticated nanomaterials where unexplored compositions could enable advanced functionalities, such as the fine tuning of catalytic or optical properties (Time4Nano).

The project PHOENiCS, led by Mete Atatüre at the University of Cambridge in the UK, demonstrated reliable and efficient solid-state quantum networks. The project achieved the generation of quantum entanglement in distant spin qubits, developed high-quality solid state/photon interfaces and accomplished the large-scale fabrication of single-photon sources in a 2D system. These results paved the way for scalable quantum information processing, leading, in turn, to several patent applications and the creation of the spin-off company, Nu Quantum.

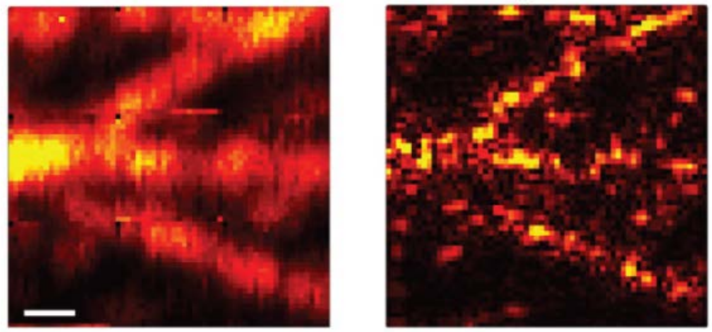
The project NANOSOLID, led by Maxim Kovalenko at ETH Zurich in Switzerland, proposed and developed new strategies and chemical approaches for the bottom-up assembly of inorganic nanocrystals, with various dimensionalities. The project explored the field of novel types of nanocrystal superlattices and demonstrated a new class of colloidal semiconductor quantum dots — caesium lead halide perovskite. The new materials can be used in thin-film devices for cost-effective energy conversion and storage. The results on metal halide emitters formed the basis of another ERC project by Kovalenko SCALE-HALO, which deepened the knowledge of these nanomaterials as versatile photonic sources. Their applicability in LEDs, image sensors, scintillators and thermographic technologies has likewise been demonstrated.



SCALE-HALO: Multiscale engineering of metal halides

The project TRANS-NANO, led by Liberato Manna at the Italian Institute of Technology, studied the chemical and structural effects induced by nanofabrication conditions when colloidal quantum dots are incorporated into practical devices. The project unveiled new insights on how colloidal quantum dots evolve under, for example, heat, irradiation and mechanical stress, and developed guidelines and tools for fabrication of optoelectronic devices based on these materials. Manna is currently leading the ongoing ERC project NEHA that explores the synthesis and realisation of nanocrystals based on metal halide heterostructures to further extend their potential applications in photocatalysis, photo-harvesting and photonic devices.

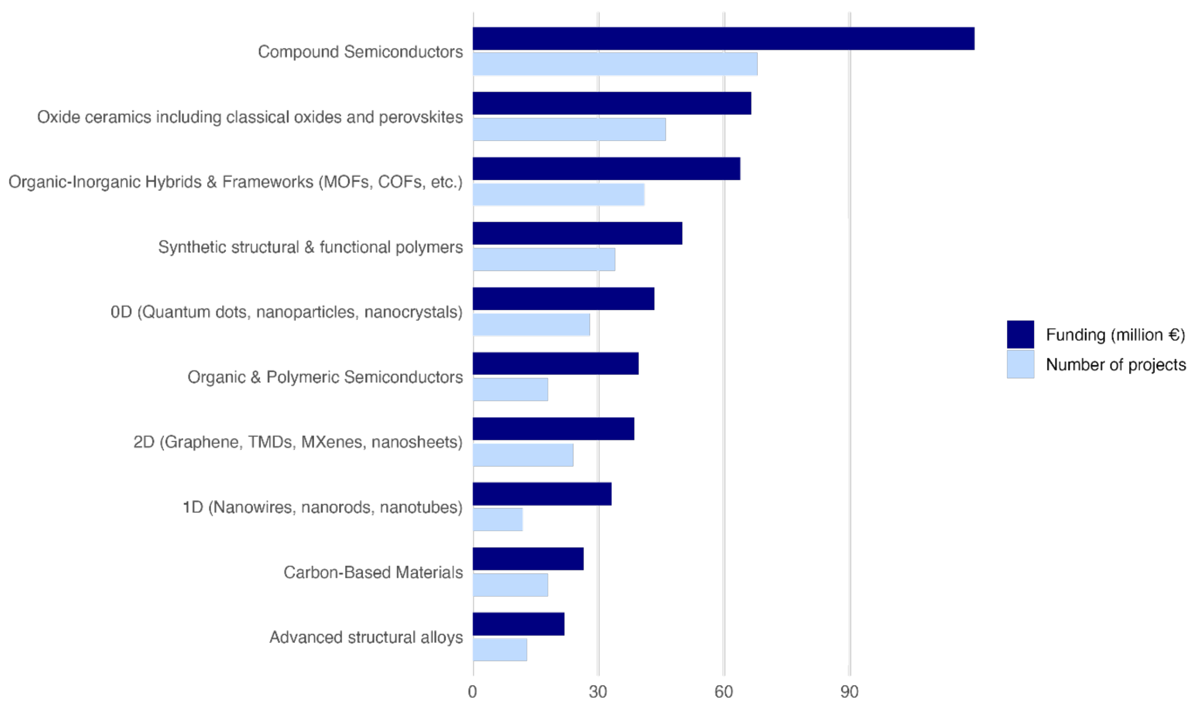
In the project ColloQuantO, led by Dan Oron at the Weizmann Institute in Israel, new types of semiconductor colloidal quantum dots have been studied as sources of quantum states of light with non-classical emission properties. The project demonstrated the application of these materials for sub-diffraction limited microscopy, providing quantum super-resolved images of biological samples.



VII. Energy

ERC-funded research in advanced materials covers a broad portfolio of materials for energy generation, conversion and storage. These projects tackle not only the main challenges in renewable energy generation / conversion (i.e. thermal, nuclear, solar and wind), — including efficiency improvements, long-term stability and reliability, — but also the development of novel 2D materials, MOFs, polymers or other hybrid alloys with enhanced functional properties and/or energy density, better stability or lower cost (Figure 21).

Figure 21: ERC advanced materials projects in energy by material class



The following sections discuss selected areas of a vast field of research, focusing on the cycles of energy generation, storage and the improvement of energy efficiency.

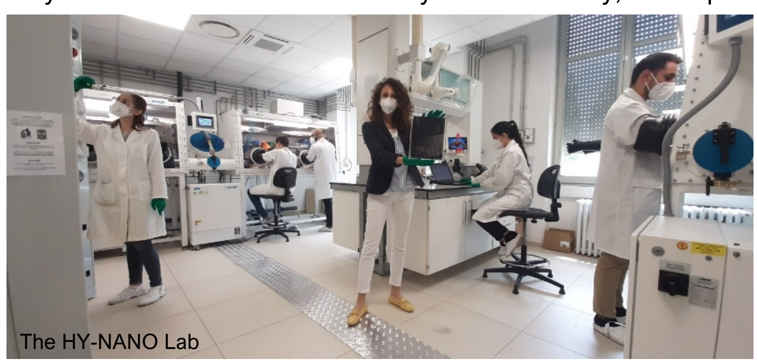
Perovskite materials

Perovskite solar cells are considered the next big step in solar energy. They use a special family of materials called perovskites, which have a crystal structure that makes them very good at absorbing light. Compared to traditional silicon panels, perovskite solar cells can: i) capture more of the sunlight and reach higher efficiency; ii) be made more easily and at lower cost and iii) bend and flex, which means they can be used even on curved surfaces. ERC-funded research has played a pivotal role in the rise of perovskite solar panels; more information can be found in this report. A few notable project examples are presented below.

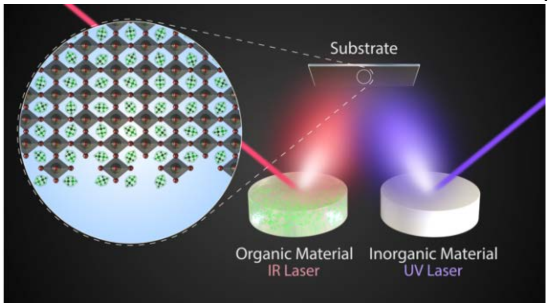

© Michael Grätzel

The project MESOLIGHT, led by Michael Grätzel at EFPL in Switzerland, was pioneering in achieving a higher power conversion efficiency (PCE) in perovskite solar cells. Based on MESOLIGHT, Grätzel received a PoC grant for his project PRINTSolar, which focused on upscaling the novel perovskite solar cells and demonstrating their long-term stability. The 1cm^2 size of the laboratory cell sample, with a PCE of ~21%, was upscaled to a commercially relevant size of 100 cm^2 — with a PCE of ~10%. This result was achieved through a collaboration with the industry partner Greatcell Solar. Read more about Grätzel's work.

One of the major problems of perovskite solar cells is poor long-term stability and toxic lead content. When panels degrade, the water-soluble lead can leak into soil and groundwater causing serious environmental and health risks. The project HY-NANO, led by Giulia Grancini at the University of Pavia in Italy, developed eco-friendly 2D/3D solar cells based on hybrid perovskites. Grancini and her team demonstrated that the instability and environmental risk of common hybrid lead-halide perovskites, due to their uncontrolled release of toxic lead, can be greatly mitigated by using multidimensional hybrid interfaces with MOFs functionalised as selective lead receptors.

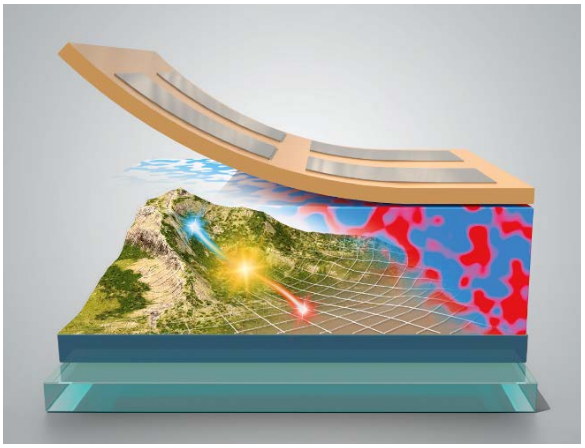

The HY-NANO Lab

The precise control of hybrid film (i.e. organic–inorganic film) growth is essential for the success of lead-free halides in photovoltaics. In the project CREATE, led by Monica Morales Masis at the University of Twente in the Netherlands, a vacuum technique (i.e., pulsed dual-laser deposition method) was used to overcome volatility and solubility issues of hybrid films and halide perovskites. Morales Masis and her team fabricated a range of organic–inorganic films and demonstrated the strong potential of this technique for designing complex hybrid perovskite structures containing two organic cations. Their results show promising avenues for the future development of lead-free perovskite solar cells.



Representation of the Pulsed Dual Laser Deposition (PDLD) method.

Perovskites have excellent optical properties, such as a tuneable bandgap and a high absorption coefficient, which make them highly attractive for developing optoelectronic devices, including LEDs. Understanding the lifetime evolution of energy levels in hybrid perovskites is key to improving their efficiency. This challenge was tackled in the project ENERGYMAPS, led by Yana Vaynzof at the Dresden University of Technology in Germany. Vaynzof and her team developed an advanced ultraviolet photoemission spectroscopy technique that enables accurate measurement of the true energy levels of organic, inorganic and hybrid (perovskite) materials — a capability not achievable with conventional methods. They also created dedicated software for data analysis. Using the newly developed spectroscopic platform, the researchers conducted pioneering studies on the energy landscapes within real multilayer optoelectronic devices, including photovoltaics and LEDs.



Visualising the Vertical Energetic Landscape in Organic Photovoltaics

Materials for electrochemical storage

Energy storage plays a key role in the green energy transition from fossil fuels to renewable energy sources. It is crucial for capturing excess energy from photovoltaics or wind stations when demand for electrical energy is low and for releasing it during peaks. Energy storage systems prevent wasting the produced green energy and help stabilise the power grid during calm and peak demand periods. Many different energy storage technologies have been developed in the past decades, including pumped hydro, thermal storage, batteries and green hydrogen. Among these technologies, batteries can be found in many devices ranging from mobile phones, electric vehicles and other electric devices and, more recently, as stationary energy storage solutions. The ERC has funded many frontier projects advancing the field of materials for batteries including those used in lithium-ion batteries, sodium-ion batteries and, more recently, also those for non-conventional batteries such as polymer batteries.

Lithium batteries

Research on lithium batteries has primarily focused on enhanced energy storage and safety. The pioneering project ARPEMA, led by Jean-Marie Tarascon at CNRS in France, aimed to explain the fundaments of lithium-based capacitors. Tarascon and his team focused on lithium-based capacitors' energy storage capacity within anionic/cationic reactions. This innovative concept of anionic redox chemistry can lead to a new family of lithium-based batteries with more than 20% higher energy storage capacity than current batteries. Based on the project results, Tarascon received the 2020 Balzan Prize (environmental challenge category: material science for renewable energy) along with several other awards and obtained significant technological transfers represented by several patents[xxxii]. The project also contributed to policy documents through multiple channels. For example, at least three publications stemming from the project were referenced in the Batteries Technology Development Report 2020, published by the Joint Research Centre. Research output was also cited in the Substitution and Reduction of Critical and Strategic Raw Materials in Clean Energy Technologies report, also published by the Joint Research Centre.

The project BATNMR, led by Claire Grey at the University of Cambridge in the UK, contributed to the development of cleaner, more efficient rechargeable batteries by creating new ways to study how their internal layers behave and change during use. By revealing how key processes such as lithium growth, ion movement and material degradation occur, the project provided insights that can help design longer-lasting and safer next-generation batteries. The project successfully developed powerful Overhauser dynamic nuclear polarisation methods, achieving unprecedented signal enhancements and enabling detailed studies of lithium dendrite growth, electrolyte breakdown, cross-over reactions and protective interphase behaviour. These insights, combined with investigations of fast-charging anode materials, provide new strategies for stabilising lithium metal and improving battery performance. The results have been widely disseminated through scientific conferences, public outreach and industry engagement, including a spin-off company focused on fast-charging technologies. Read more about the project in this article.

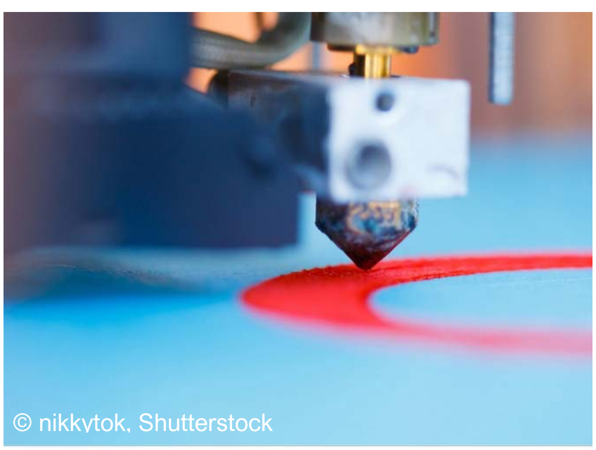
Sodium-ion batteries

Given the environmental and social concerns associated with lithium and cobalt extraction, the difficulties of battery disposal and the increased fire risk of lithium-ion systems, researchers are actively exploring alternative energy-storage technologies. One of the possible candidates to replace lithium-ion batteries is sodium-ion batteries, particularly for large-scale energy storage. Sodium-ion batteries are cheaper, less flammable and perform well at low temperatures, and they are also easier to recycle. However, they have a lower energy density than lithium-ion batteries and a shorter cycle life, as the larger size of sodium ions causes greater structural stress in the materials. In the PoC project HiNaPc, led by Yong Lei at the Ilmenau University of Technology in Germany, upscaling of the Sodium-ion battery coin cells, developed within the main research project ThreeDSurface, into pouch cells was realised, reaching a commercially interesting energy capacity of 30–50 Ah. Importantly, Lei and his team developed 3D electrodes and materials for high energy sodium-ion batteries with enhanced performance.

The project 4SBATT, led by Matteo Bianchini at University of Bayreuth in Germany, aims to develop a solid-state battery based on sodium, rather than lithium, representing the best solution in terms of four key parameters: sustainability, energy density (specific and volumetric), readiness of adoption (i.e. compatibility with existing lithium-ion production lines) and safety. Bianchini and his team combine computer simulations and laboratory experiments to design new sodium-based materials for all parts of the battery and test their performance. Ultimately, the project seeks to build solid-state sodium batteries that use abundant elements such as iron, manganese and silicon, are non-flammable and can deliver very high energy density for future electric vehicles.

Polymer-based and other material-based batteries

Polymers are essential for our society, offering low-cost, lightweight, durable and versatile materials for a wide range of applications, including electronics, clothing, packaging, medical devices, transportation and energy. They are extensively studied across many scientific fields, including polymers for application in energy storage and batteries. In the project BattSkin, led by Minghao Yu at the Technical University of Dresden in Germany, Yu and his team are exploring a new way to improve magnesium-based batteries by using specially-designed 2D crystalline polymers as an ultra-thin 'skin' on the electrodes. This polymer coating is intended to control the difficult movement of magnesium ions at both the positive and negative electrodes — a key obstacle that currently limits the performance of magnesium batteries. The team is studying how magnesium ions move through these tailored polymer layers to develop molecular design guidelines for creating more effective electrode coatings. Based on these insights, they will propose practical battery designs that could make magnesium-based energy storage safer, more efficient and more suitable for real-world use.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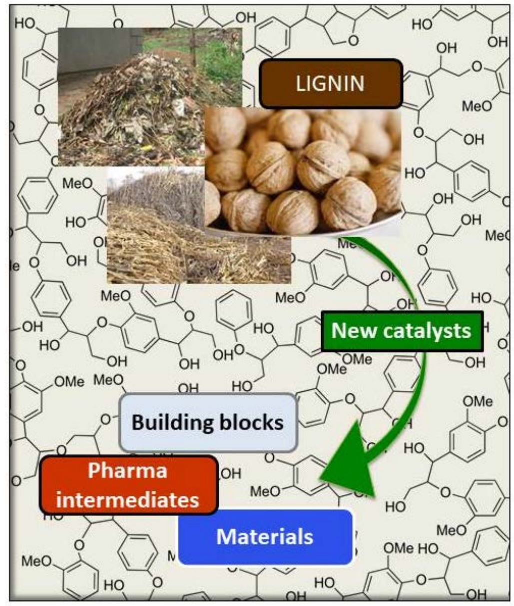
Current manufacturing of batteries, especially their electrodes, is time consuming and involves many steps. In addition, conventional batteries are rigid, which limits them to shapes such as cylinders or rectangular blocks. In contrast, 3D printing is widely used across industry for prototyping and for creating complex structures in arbitrary shapes. The PoC project iPES-3DBat, led by David Mecerreyes Molero at the University of the Basque Country in Spain, designed polymer-based batteries using 3D printing technology. Mecerreyes Molero and his team developed 3D printable inks with energic polymers and demonstrated its potential in an all-polymer battery prototype. Based on their results of the project, the spin-off company Polykey was established. Read more in this article.

Catalytic materials

Catalytic materials enable speeding up chemical reactions, making it possible to significantly lower the required energy for these processes, especially for hydrogen production or CO2 conversion. The ERC has funded many pioneering projects addressing this topic. One of these is the project CatASus, led by Katalin Barta Weissert at the University of Graz in Austria. Weissert and her team set out to transform the production of amines — key components in pharmaceuticals, agrochemicals, surfactants and advanced materials — by shifting their origin from fossil resources to renewable lignocellulose waste. By developing innovative catalytic methods to both break down complex plant biomass into well-defined platform chemicals and convert these intermediates into high-value amines, the project demonstrated a fully sustainable pathway for producing this essential class of compounds. Central to the work was the design of efficient catalysts based on Earth-abundant elements, enabling environmentally responsible transformations that avoid reliance on scarce precious metals. Through this combined 'cleave and couple' strategy, Weissert has advanced the field well beyond the existing state-of-the-art, showing that lignocellulose can serve as a versatile feedstock for fine chemicals, polymers, bio-based surfactants and even aviation fuels. Weissert's achievements open new opportunities for the chemical and agricultural sectors and contribute meaningfully to the development of a resilient European bioeconomy. Weissert also received an EIC Transition grant PureSurf in 2021.



Towards valuable products from lignin.

The CO2 reduction reaction holds great promise for conversion of the greenhouse gas CO_2 into chemical fuels. However, the absence of catalytic materials demonstrating high performance and high selectivity currently hampers practical demonstration. The project 2D-4-CO2, led by Damien Voiry at CNRS in France set out to create new, highly efficient catalysts made from advanced 2D materials. Because CO_2 is difficult to dissolve and convert in liquid systems, the work focuses on gas-phase reactions using gas-diffusion electrodes, where 2D materials can offer major advantages thanks to their unique structures and electronic properties. Voiry and his team developed novel 2D catalysts — such as engineered silver nanoprisms, single-atom nickel sites on ultrathin carbon sheets and surface-modified copper materials — to improve both the efficiency and selectivity of CO_2 conversion. These tailored materials have already shown remarkable performance, from almost perfectly selective CO production to significantly enhanced formation of valuable multi-carbon products like ethylene and ethanol. By combining advanced materials engineering, detailed characterisation and new photocatalytic designs based on van der Waals heterostructures, the project is laying the groundwork for future devices capable of storing solar energy directly in the form of clean, energy-rich fuels.

Electrolysers are used to produce green hydrogen. A drawback of the current technologies is the relatively high cost of these devices, which makes the cost of hydrogen not yet economically competitive. In the project PRODUCE-H2, led by Vincent Artero at the French Alternative Energies and Atomic Energy Commission, a prototype of a low-cost catalytic system for electrolysis was developed in collaboration with Toyota Motor Europe. The catalysts were based on polymers with coordinating function linked to redox-active disulfide ligands. In their electrolyser prototype, the expensive platinum was replaced by an amorphous bimetallic iron-molybdenum sulphide catalyst opening the door for designing low-cost electrolysers. A patent application[xxxiii] was also filed based on the project results. Read more about Artero and his team's clean hydrogen production with bio-inspired catalysts.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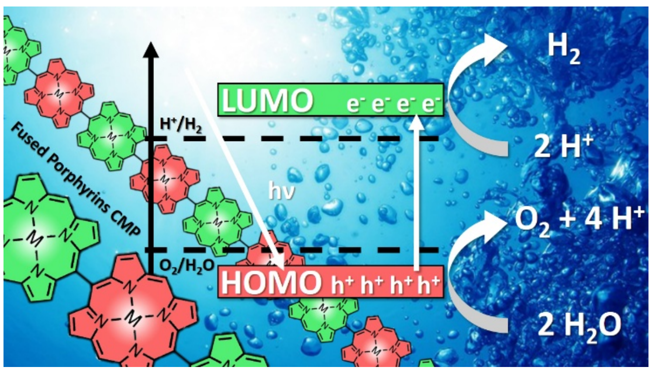


The project CLEANH2, led by Nicolas Boscher at the Luxembourg Institute of Science and Technology, developed a new generation of materials capable of producing clean hydrogen using only sunlight and water — a process known as solar water splitting. To achieve this, Boscher and his team focused on metalloporphyrins, a family of molecules that nature uses for essential chemical reactions such as oxygen transport and photosynthesis. Using an innovative gas-phase technique, the team was able to directly build thin, conductive films made of 'fused' metalloporphyrins, creating robust catalysts that efficiently generated hydrogen and oxygen. This method allowed the materials to be synthesised and deposited in a single step, enabling the design of entirely new structures that were difficult or impossible to produce with traditional solution chemistry. The fused porphyrin films demonstrated strong catalytic activity for both halves of the water-splitting reaction, and their properties could be tuned by adjusting the metal atoms or chemical groups they contained. By combining different porphyrins into mixed-metal systems, the project opened the door to catalysts that mimic the cooperative behaviour found in natural enzymes. Overall, CLEANH2 delivered low-cost, scalable materials that could support future energy systems powered by green hydrogen instead of fossil fuels. Read more about how Boscher and his team developed new, cleaner ways of generating hydrogen in this article.

VIII. Construction and mobility

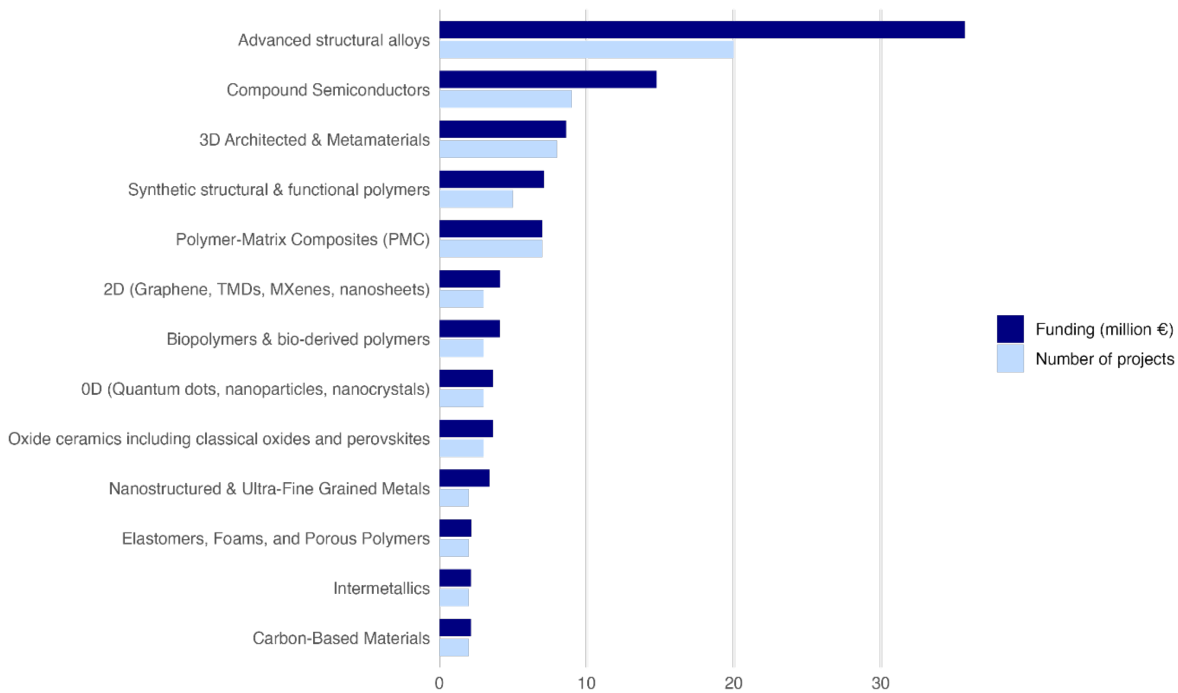
This section presents ERC-funded research that advances materials with application potential across the construction and mobility sectors, spanning from fundamental materials development to applied solutions.

Advanced structural alloys, architected and metamaterials, polymer-matrix composites (PMCs), as well as synthetic structural and functional polymers and compound semiconductors are the key materials classes dealt with by the projects across these two sectors.

Generally, the research supported by the ERC has focused on key challenges in infrastructure and transport — including non-destructive testing, structural health monitoring, computational materials design, additive manufacturing and energy-efficient, sustainable construction — with a view to improving performance and sustainability by reducing energy use, extending material lifetimes, enhancing recyclability and developing bio-based alternatives.

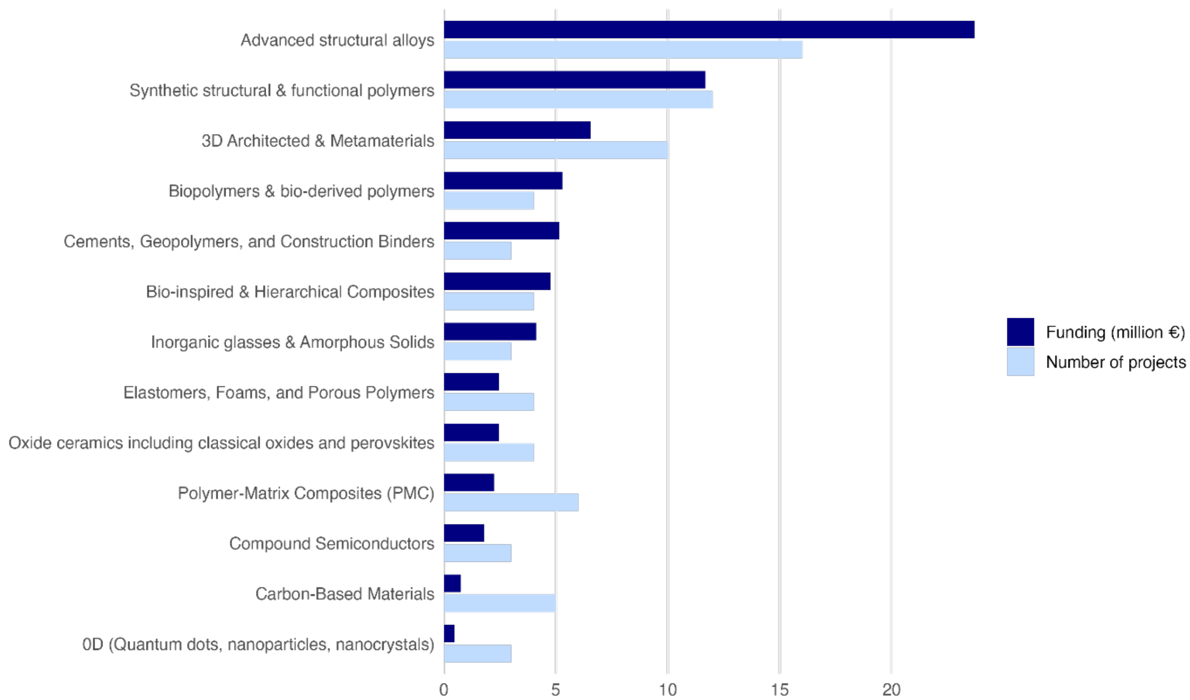
More specifically, in the transportation domain, high-performance structural materials clearly dominate the portfolio, reflecting the sector's focus on lightweight, durable and energy-efficient solutions for mobility and infrastructure (Figure 22).

Figure 22: ERC advanced materials projects in mobility by material class



In the construction sector, high-performance structural materials are the dominant category, reflecting the sector's emphasis on strength, durability and adaptability, combined with a growing interest in smart and responsive functionalities (Figure 23).

Figure 23: ERC advanced materials projects in construction by material class



Advanced structural alloys

Advanced structural alloys are a class of high-performance metallic materials engineered to outperform conventional alloys, particularly in demanding operating conditions.

The strong focus on advanced structural alloys in ERC-funded projects with potential for application in transport and mobility highlights the need for lightweight, high-strength and durable materials to boost efficiency, safety and performance in vehicles, infrastructure and buildings. Key innovations arising from these projects include non-destructive testing methods for detecting defects, cracks and stress corrosion in pipelines, bridges, railways and aerospace components. Several projects advance computational techniques such as virtual design, processing and testing of metallic materials through multiscale modelling. Others focus on manufacturing improvements, including casting simulation, enhanced lubrication to reduce friction and wear and welding optimisation. Projects also develop novel alloys, nanostructured and ultra-fine-grained metals, intermetallics for extreme environments, and pursue sustainable metal recycling and reprocessing.

Growing interest in space is driving accelerated innovation in aerospace technologies, along with demand for high-performance materials for solid-state additive manufacturing. The project MA.D.AM, led by Benjamin Klusemann at the Helmholtz Centre for Materials and Coastal Research in Germany, advances solid-state additive manufacturing of high-strength aluminium alloys by combining friction extrusion and friction surfacing to produce wires and layers with tailored microstructures and properties. The team has identified key friction extrusion modes, mapped periodic grain structures in friction surfacing parts, and characterised multilayer interfaces. A digital twin integrating experiments, simulations and machine learning enables predictive design with minimal trial-and-error. The project delivers lighter, stronger and more reliable components, setting new benchmarks for next-generation aerospace and mobility manufacturing. Read more on the project website.

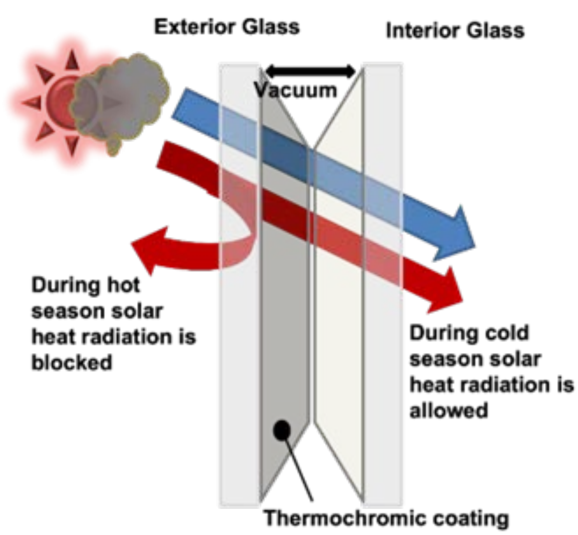
Steel is primarily produced from oxide minerals in blast furnaces, with carbon then partially removed in converters. This process emits about 2.1 tons of CO_2 per ton of steel, making steelmaking one of the world's largest greenhouse gas sources. To address this issue, the project ROC, led by Dierk Raabe at Max Planckmint Institute for Sustainable Materials in Germany, introduces fundamental scientific changes in the process for drastic cutting of CO2 emissions by at least 80%. The project's disruptive approach involves the replacement of carbon with hydrogen as a reductant and merging the multiple process stages into a single oxide melting plus a hydrogen-based reduction process using green electricity. Read more about the project here and watch the videos explaining how Raabe and his team advance this innovative green technology.

Synthetic structural and functional polymers

Structural and functional polymers are innovative materials engineered to be stronger, lighter, and more durable, offering solutions that enable safer and more efficient construction and transport applications.

Polymer science is advanced by ERC funded projects for application in both construction and mobility contexts. Innovations include polymerisation-induced self-assembly for creating nanoparticles with controlled morphologies, stereo controlled polymerisation for precision molecular architecture and computational modelling of complex mechanical phenomena in polymeric systems. Sustainability is addressed through bio-derived polymers, recyclable polymer systems and reduced environmental impact manufacturing.

The project IntelGlazing, led by Ioannis Papakonstantinou at University College London in the UK, developed smart window coatings that dynamically adapt to outdoor conditions to cut building energy use, which currently accounts for 40% of EU energy consumption. Using thermochromic vanadium dioxide (VO_2) coatings and bio-inspired nanostructures, the technology modulates solar gain by over 220 W/m² while maintaining high transparency and providing glare reduction, self-cleaning, antimicrobial and dew-repellent properties. To address the large stock of existing windows, the team created polymer/VO_2 nanoparticle films suitable for easy retrofitting.



Prototypes and building simulations show up to 22% annual energy savings in temperate climates. By expanding the material platform to silicon and polymers, the team also opened pathways for applications beyond construction, including solar cells, packaging and personal devices, delivering a versatile and sustainable glazing technology with broad industrial potential. Read more in this article about how IntelGlazing advances energy efficiency.

The project POLYHEAL, led by David Gonzalez Rodriguez at the Autonomous University of Madrid in Spain, developed next-generation self-healing polymers — smart materials that can repair damage autonomously or when triggered by heat, light or pressure. Conventional polymers degrade over time, but society increasingly needs materials that remain safe, durable and resource efficient. Building on earlier ERC research (PROGRAM-NANO), the team uses *cooperative effects* inspired by biological systems to create supramolecular polymers that combine strong mechanical performance with the ability to heal at room temperature. POLYHEAL has optimised production methods, tested key properties and begun identifying market opportunities, showing that these materials are promising candidates for commercial self-healing thermoplastic coatings.

Biopolymers and bioderived polymers

Recent advances in polymer science within the ERC portfolio also address the environmental footprint of materials, with a focus on reducing the formation and persistence of microplastics through improved degradation pathways and fully circular polymer life cycles. The next two frontier projects illustrate the move toward degradable and circular polymers, aiming to limit microplastic formation and promote a more sustainable materials future.

The project DEEPCAT, led by Stefan Mecking at the University of Konstanz in Germany, addresses the persistence of polyethylene, the most widely used plastic in Europe and a major source of marine microplastics, by redesigning the material at the molecular level. The project uses advanced chemical methods to add degradable groups directly into polyethylene chains, allowing the plastic to break down by light or water instead of forming persistent micro- and nano-plastics. DEEPCAT produces functionalised polyethylene that keeps its strength and usability for demanding applications in transportation, energy storage and beyond, while also enabling closed-loop recycling. Marine-relevant degradation studies can link material morphology, including the formation of microplastics, to environmental fate, charting a path toward high-performance plastics that are engineered to degrade reliably and help prevent long-term accumulation in oceans and other ecosystems.

The project NaCRe, led by Francesco Stellacci at EPFL in Switzerland, seeks to reinvent plastic recycling by drawing inspiration from how nature recycles biological polymers. Just as proteins can be broken down into their amino acid building blocks and then reassembled into entirely different proteins, NaCRe aims to show that synthetic (and biological) polymers can also be broken down and rebuilt in a fully circular, waste-free process. NaCRe has designed synthetic polymers that can be depolymerised together from a mixed feed and then rebuilt orthogonally, opening the door to fully circular, waste-free polymer life cycles. These results point to a transformative approach for plastics, enabling sustainable, high-performance materials while reducing plastic waste and the generation of microplastics.

Architected and metamaterials

Architected materials are materials, the properties of which are created by carefully designing their internal structure — often using repeating patterns or lattice-like geometries — rather than relying only on their chemical composition. By controlling their architecture at the micro- or nanoscale, these materials can be made exceptionally light, strong, flexible or energy-absorbing.

Metamaterials are a special type of architected material designed to interact with light, sound, or other waves in unusual ways. Their precisely engineered structures give them properties not found in nature, such as bending light in unexpected directions or blocking specific sound frequencies.

ERC-funded projects addressing architected and metamaterials with potential application in the construction and transport sectors push the frontier of materials design through deliberate structuring at multiple length scales to achieve unprecedented properties not found in conventional materials. Innovations include lattice materials with optimised multi-phase architectures for lightweight structures with exceptional strength-to-weight ratios, computational homogenisation techniques for designing hierarchically structured materials and advanced surface engineering for ultra-precision applications.

METAFOAM is a PoC project led by Marc Geers at Eindhoven University of Technology in the Netherlands, that tackled the challenge of low-frequency noise pollution, a major health and quality-of-life issue in urban and industrial environments. Conventional foams perform well at mid- and high frequencies, but METAFOAM introduced 'acoustic metafoams' — conventional foams enhanced with embedded masses that combine visco-thermal dissipation with local resonance. Building on model-based insights from the project MECHMAM, METAFOAM develops scalable manufacturing methods and tests real-world acoustic performance. The result is a cost-effective, high-performance solution for low-frequency noise reduction with applications in buildings, transport and industrial settings.

The project MULTILAT, led by Norman Fleck at Cambridge University in the UK, developed new classes of lattice materials by combining advances in manufacturing, experimental testing and numerical modelling. The team created systematic design rules for single- and multi-phase lattices, establishing scaling laws that link stiffness, strength and fracture resistance to the properties of their constituent materials and architectures. They explored how manufacturing imperfections affect performance, developed methods for fabricating novel lattice topologies and demonstrated how tailoring two interpenetrating networks can greatly improve toughness and tear resistance. MULTILAT also produced innovative protective structures, nanoscale lattices with exceptional strength, and infilled lattices with high stiffness and damage tolerance. These breakthroughs show how micro-architected materials can unlock combinations of low weight, high strength and resilience, opening pathways to new engineering devices and even applications such as solid-state batteries. Read more about the project's contribution to improving lithium-ion batteries in this article.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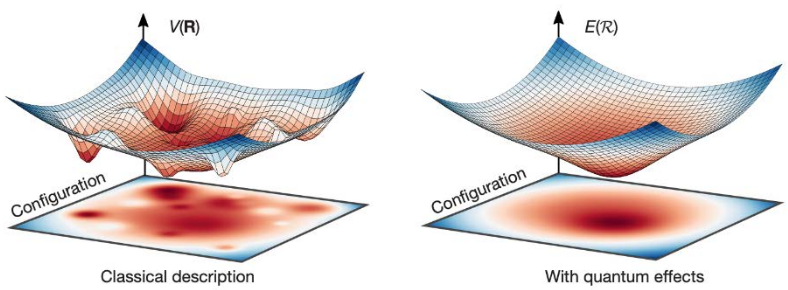
Compound semiconductors

Compound semiconductors are semiconducting materials made from two or more different elements, such as gallium arsenide or indium phosphide, rather than from a single element such as silicon. Because their atoms can be combined in different ways, they offer tuneable electrical and optical properties, making them essential for high-speed electronics, LEDs, lasers and advanced communication technologies.

ERC-funded projects in this sub-group explore advanced semiconductor materials, targeting optoelectronic, sensing and energy applications relevant to intelligent mobility systems. Key innovations include terahertz receivers for remote sensing and environmental monitoring, high-temperature superconductors for energy-efficient power systems and multispectral photodetectors combining 2D materials with silicon for enhanced sensing capabilities.

In the project ENRICH, led by Georgios Kampitsis at the University of Patras in Greece, addresses a major challenge for a carbon-neutral future: creating compact, lightweight and highly-efficient power electronics. Today's power converters are constrained by semiconductor limits and bulky magnetic components, hindering efficiency and miniaturisation in electric vehicles, aircraft and building energy systems. ENRICH develops new multilevel converter designs based on gallium nitride semiconductors and introduces a solid-state selector switch that removes the need for magnetic parts, enabling monolithic integration of entire inverters. By uniting advances in materials science, control theory and power electronics, the project delivers smaller, lighter and more efficient power processors with a significant impact on electric mobility, aerospace and energy-efficient buildings.



Cartoon representing the impact of ionic quantum effects on the energy landscape.

The project SuperH, led by Ion Errea at the University of the Basque Country in Spain, develops advanced first-principles methods to accurately predict superconductivity in hydrogen-based materials, the behaviour of which is dominated by strong quantum effects. Existing computational tools often fail for these compounds, but the project's new approaches, such as improved modelling of atomic vibrations and electron–phonon interactions, allow researchers to understand why certain hydrides reach very high critical temperatures and how some can remain stable even at ambient pressure. Using these methods, the team has identified clear structural features that correlate with high superconducting performance and has predicted new candidate materials, including hydrides that might superconduct around 100 K after being synthesised under moderate pressure. If realised experimentally, such materials could lead to highly efficient power systems, enabling lighter and more energy-efficient electric motors, generators and power electronics for future transport and mobility applications. Read more in this article.

Polymer-matrix composites

Polymer-matrix composites (PMCs) are materials made by embedding strong fibres or particles, such as carbon or glass fibres, within a polymer resin. The polymer provides shape and toughness, while the fibres add strength and stiffness, resulting in lightweight, high-performance materials widely used in aerospace and transportation.

ERC funded projects in this group advance PMC technologies and address critical bottlenecks currently limiting the performance and widespread adoption of composite materials in aerospace, automotive and advanced manufacturing sectors. Among the projects is a strong emphasis on nanomaterial-enhanced composites, with multiple projects exploring graphene, carbon nanotubes, boron nitride nanotubes and other nanofillers to achieve unprecedented combinations of mechanical strength, thermal conductivity, electrical properties and multifunctionality.

The project INELASTIC, led by Pedro Camanho at the Institute of Science and Innovation in Mechanical and Industrial Engineering in Portugal, aims to unlock the full potential of polymer composite materials to create lighter, more efficient aircraft structures. Today's composite designs are limited by narrow design rules and conservative analysis methods, yielding only modest weight savings. The project develops a new multi-scale, systems-thinking approach that links manufacturing conditions, micro- and meso-structures and overall structural performance. By combining advanced experiments, modelling and machine-learning tools, the team will uncover hidden relationships that enable new composite micro-structures, more flexible fibre orientations and unconventional laminate designs. Ultimately, this will bridge the gap between material and structural design and support next-generation lightweight solutions for aviation and other transport sectors.

The POC project BIO-CC, led by Michael Hummel at the Aalto University in Finland, builds on the project WoCaFi, which showed that an entire wood matrix can be transformed into continuous filaments for producing low-cost, bio-based carbon fibres. Since conventional PAN-based fibres are too expensive for mass markets, such as automotive sector and construction, BIO-CC evaluated the technical feasibility, scalability and market potential of this wood-based alternative. The project confirmed that mild pre-treatment makes whole wood spinnable and that the resulting fibres approach the performance needed for mid-grade applications. New collaborations delivered promising results for further development. By enabling cheaper, renewable carbon fibres, the project has opened up opportunities for lighter vehicles, longer-lasting infrastructure and new circular business models based on converting a bio-industrial by-product into a high-value material.

WoCaFi: From tree to carbon fiber. © Valeria Azovskaya

IX. From curiosity-driven discovery to innovation

In materials science, the lines between curiosity-driven basic research and applied research are very porous. This section examines how curiosity-driven research has translated into innovation within ERC-funded advanced materials science.

It begins by assessing the portfolio's innovation potential, examining how application-oriented considerations have been addressed and how they have translated into applied research and patent development. The data presented below demonstrates the strong relevance of application-driven thinking across the portfolio and provides evidence of highly successful translational activities led by principal investigators.

It then takes a further look into the process of spin-off company creation. First, the landscape of spin-offs created from projects, as reported in this specific portfolio, is mapped, providing relevant examples extracted from three sectors in which the vast majority of companies emerge: health, advanced electronics and energy. The companies and projects highlighted cover a wide array of technologies and showcase how researchers can turn scientific breakthroughs into real-world solutions in critical areas (from non-invasive cancer diagnosis to antibiotic resistance, from enhancing the efficiency and capacity of data centres to green energy production). It then analyses some of the main enablers and barriers impacting the passage from curiosity to innovation.

a. Characterising innovation potential

Exploring potential applications

Over half of the projects in this portfolio explore potential applications of cutting-edge scientific advances. This is due, in part, to the high proportion of PoC grants in the portfolio. In addition, exploring potential applications is also central to the main grants (StG, CoG, AdG) — over half of the main grants analysed in this report have been classified as application-oriented.

In some cases, the quest for potential applications has been central to the definition of the project's research objectives from the outset.

For example, in his project PV-COAT, Patrizio Lancellotti from the University of Liege in Belgium, attempted to improve the haemocompatibility and long-term in-vivo performance of mechanical prosthetic heart valves by implementing a novel bioactive polymer surface coating that can reduce contact-induced thrombosis and therefore the need for life-long anticoagulant treatments for patients with mechanical valves.

The project developed an innovative bioactive coating technology, which showed remarkable results, not only in preventing prothesis associated thrombosis, but also in providing anti-bacterial infection protection, thereby potentially reducing the risks of endocarditis. The project resulted in several high-impact publications and several patents[xxxiv].

A subsequent PoC project CMD-COAT, allowed the research team to continue exploring the applicability of this technology to peripheral and central venous catheters. The project supported the team in demonstrating the efficacy of the technology, but also in the development of the first market analysis and industrial development plan and establishing contacts with industry partners. The principal investigator and his main collaborator also established the spin-off company CMD-COAT S.A. (now CM4CURE), with the aim of bringing this technology to the market.

In most cases, however, the exploration of potential applications seems to come as part of the natural evolution of the research programme. This shows how the flexibility of ERC grants, in which principal investigators are given the freedom to follow their curiosity, encourages cross-fertilisation between fundamental and applied scientific research endeavours. As noted by Henry Snaith, principal investigator of the project HYPER:

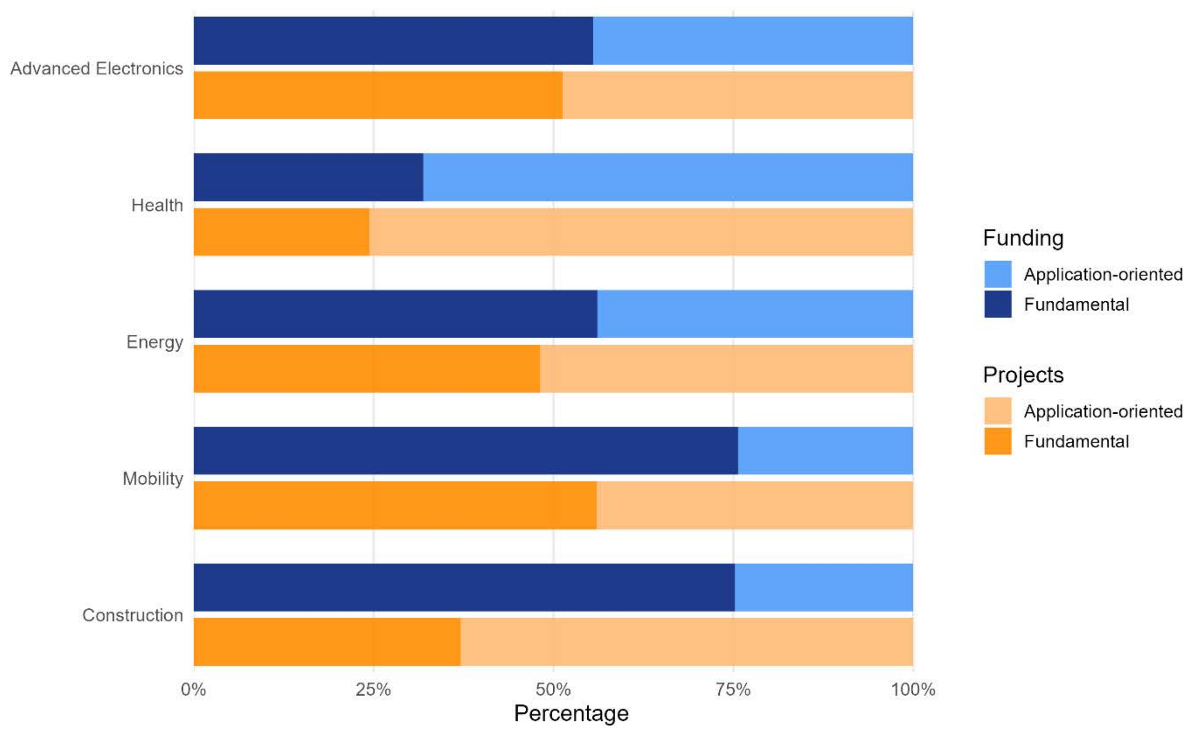
> *[ERC funding] made a very measurable difference to my ability to push ahead with this technology in competition with the rest of the world. It's an example where applied and fundamental research are both really important and you have to be open to surprising things happening along the way[xxxv].*
>
> *Henry Snaith – HYPER*

Corentin Coulais proposed to uncover the extreme mechanics of metamaterials under more realistic conditions of loading, disorder and energy dissipation. A metamaterial is an engineered material, the properties of which arise not from the chemical composition of its base substances, but from their deliberately designed internal structure. In his project Extr3Me, Corentin introduced a new class of metamaterials: granular metamaterials. These materials are made from particles with an unconventional tuneable property: a negative Poisson's ratio[xxxvi]. Coulais and his team observed that these granular metamaterials have a tenable elasticity and rheology and flow more easily and absorb more energy when they are confined. This discovery led the research team to start exploring potential applications already within their StG[xxxvii].

The ensuing 2023 PoC grant MetaVib explored the use of granular metamaterials to create lightweight structures that are orders of magnitude more dissipative than the state-of-the-art. A second PoC grant in 2024 MetaSafe is allowing the team to establish such metamaterials as a commercially-viable solution for a new generation of battery boxes for electric vehicles. These metamaterials will not only increase the safety of electric vehicles but can also reduce their CO_2 footprint by making the battery boxes lighter. The research team is now in the process of incorporating recently a spin-off to exploit these results.

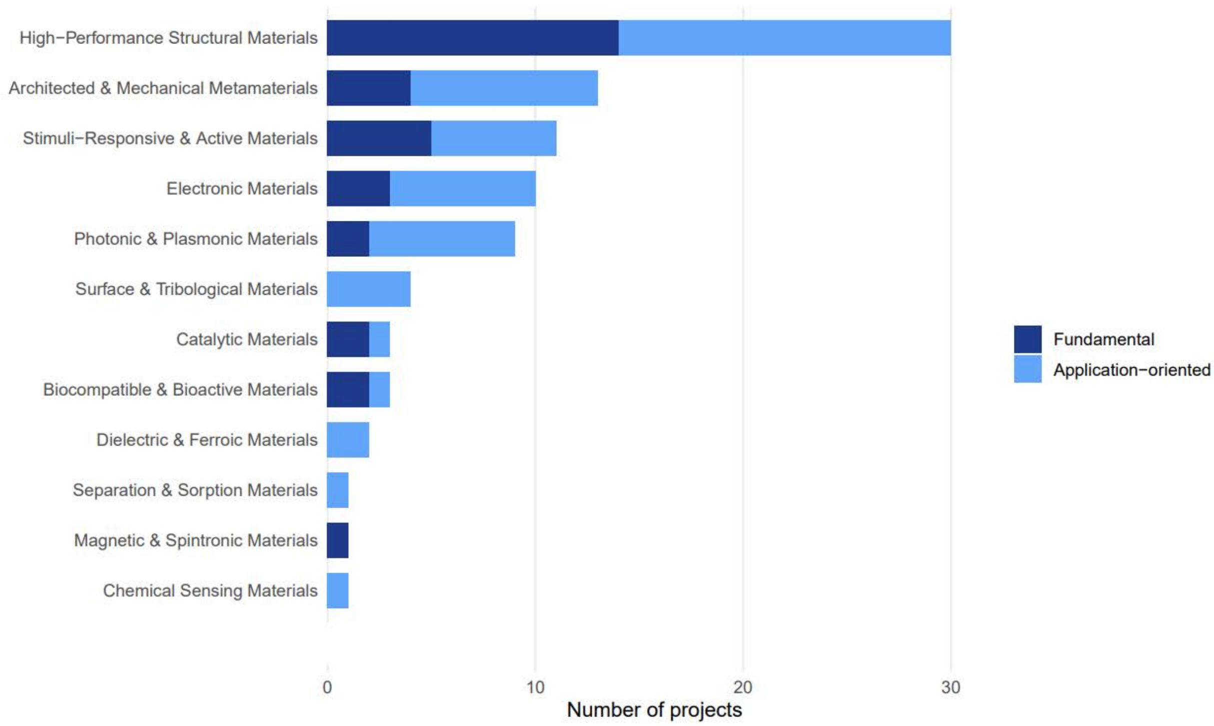
An analysis by policy sector, reveals that research connected to construction, health and energy has been particularly oriented towards the exploration of applications. The marked divergence between the shares of projects and funding in the construction sector is driven by the high prevalence of PoC projects. In comparison, research connected to advanced electronics has displayed a higher percentage of projects working on fundamental research (Figure 24).

Figure 24: Percentage of fundamental vs application-oriented projects and funding by policy sector (including PoC)



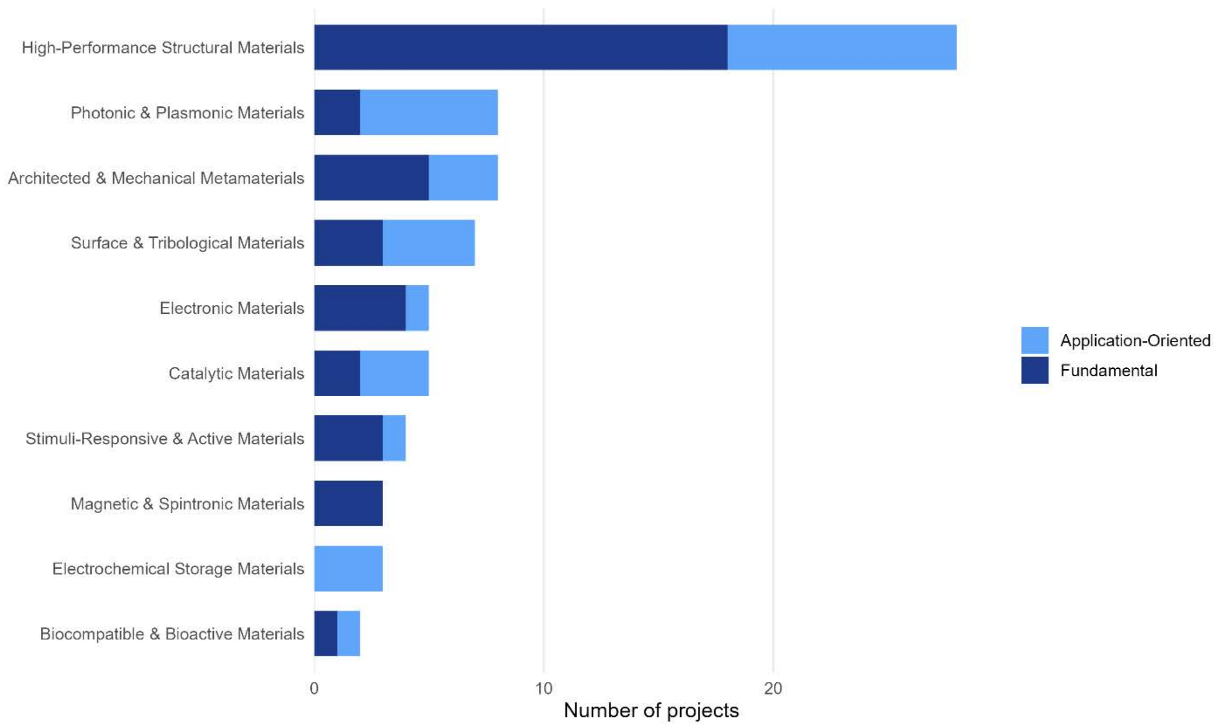
In the construction sector, the analysis of material functionalities shows that the shift towards applied research is evident across all major categories (Figure 25).

Figure 25: Number of fundamental vs application-oriented projects in construction by function of material



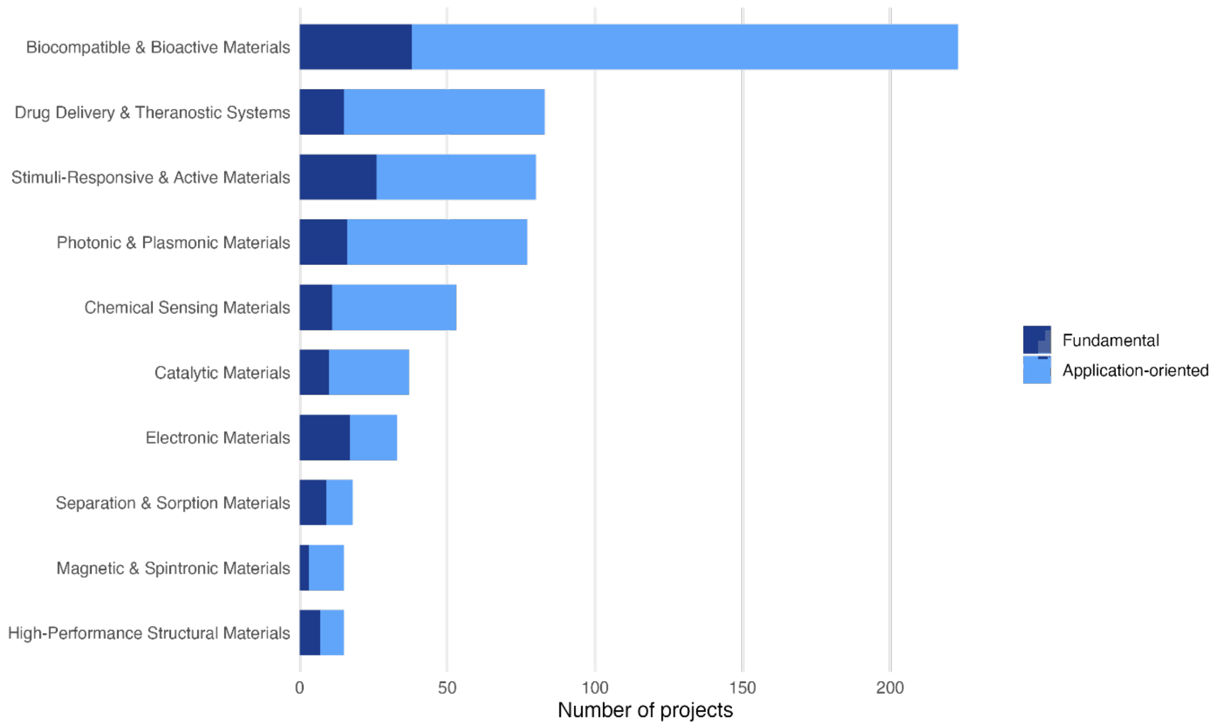
In the mobility sector, the share of application-oriented research projects is lower. Among the top categories, application-oriented research is particularly prominent in photonic and plasmonic materials, and surface and tribological materials. Fundamental research is dominant in research on high-performance structural materials and architected and mechanical metamaterials (Figure 26).

Figure 26: Number of fundamental vs application-oriented projects in mobility by function of material



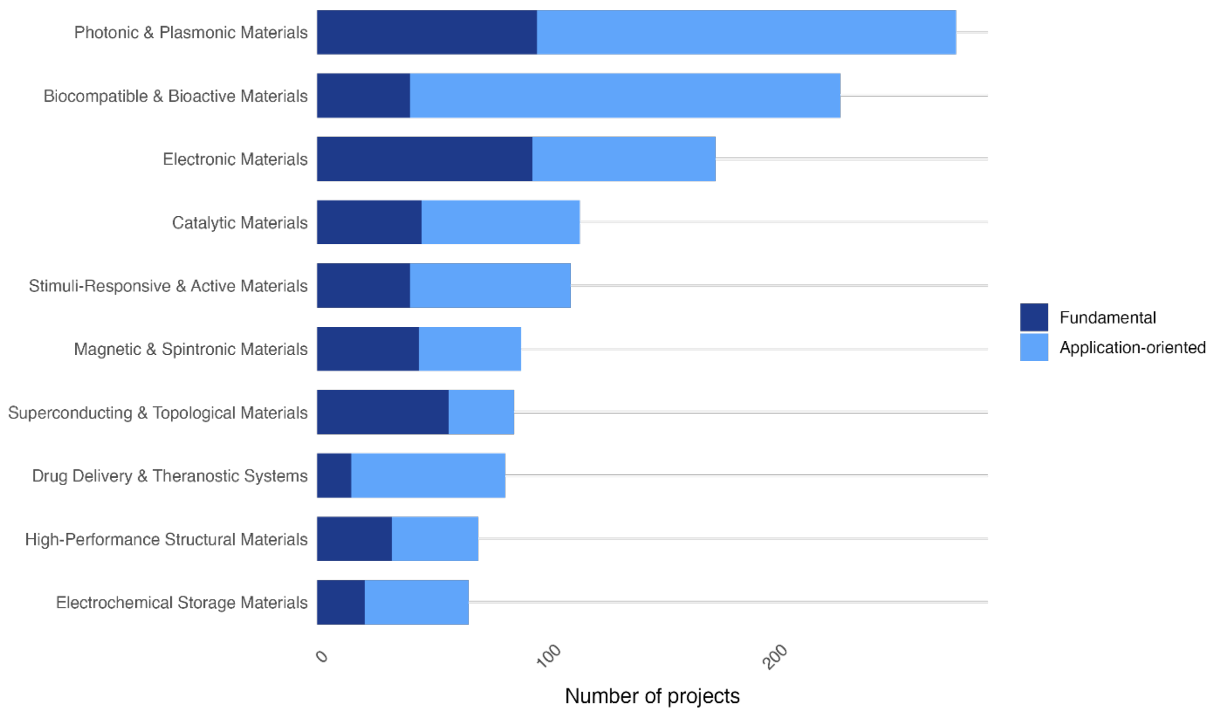
In the health sector, applied research is particularly strong in bioactive and biocompatible materials, but is evident across all material functionalities in the portfolio (Figure 27).

Figure 27: Number of fundamental vs application-oriented projects in health by function of material



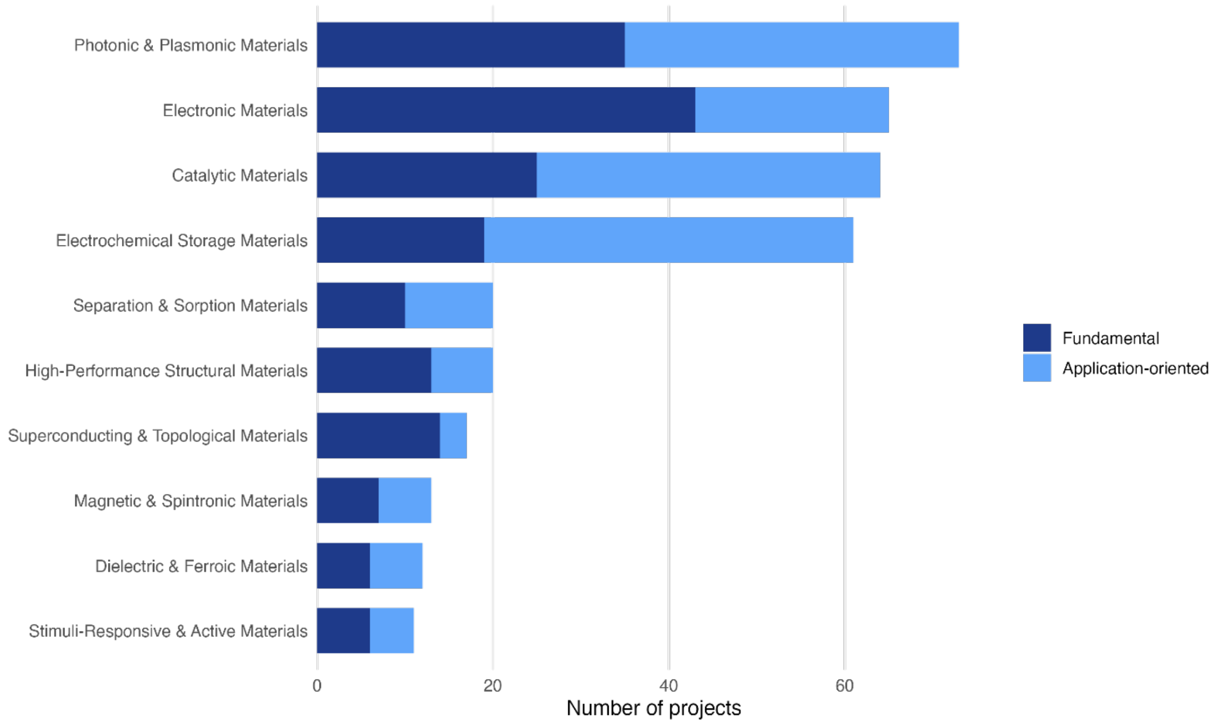
By comparison, the data for the sub-group of projects on advanced electronics shows a much more balanced picture between basic and applied research across most materials functionalities (Figure 28).

Figure 28: Number of fundamental vs application-oriented projects in advanced electronics by function of material



Similarly, the data for the sub-group of projects on energy depicts a balanced picture between fundamental and applied research across most materials functionalities (Figure 29).

Figure 29: Number of fundamental vs application-oriented projects in energy by function of material



Translational research funding: PoC grants and the EIC Transition scheme

A closer look at the PoC projects in this portfolio provides additional insights into their innovation potential. The following distribution by sectors and applications is seen[xxxviii]:

- Roughly half of the PoC projects in the portfolio (199) are linked to applications in the **health sector**. These cover projects aimed at the development of therapeutic drugs (15%), industrial biomanufacturing (15%), regenerative medicine (12%), optoelectronics (7%) and the development of medical devices (7%).
- **Advanced electronics** projects account for 20% of all PoC grants in the portfolio. Of these, 42% focus on photonics and optoelectronics, 16% on metrology, 13% on semiconductors and integrated circuits, and 10% on quantum technologies.
- 19% of PoC projects target the **energy sector**, primarily energy storage (30%) and energy conversion technologies (25%).
- 12.5% of PoC projects develop **novel construction technologies**.
- 5% of projects address **mobility and transport infrastructure**.

Moreover, the researchers in this portfolio have proven quite successful at securing additional scale-up funding through the EIC Transition scheme. 16 researchers who received a PoC grant related to advanced materials have also received an EIC Transition grant. They represent 30% of all the ERC PoC beneficiaries that have received a subsequent EIC Transition grant[xxxix].

In line with the data presented previously, the development of health-related technologies (drug delivery systems, therapeutics and diagnostic tools) remains the most prevalent area of work. Other interesting areas include the development of novel sensors and photonics devices, energy storage technologies or 3D printed micro-optics.

One notable aspect in the trajectories of these researchers is the fact that the scientific point of departure of their research programmes can sometimes be very different from the innovation areas where they try to apply the results of their research.

One example of this is Alijani Farbod from the Delft Technical University in the Netherlands. His project ENIGMA studied the nonlinearities of one-atom-thick graphene membranes and provided a better understanding of the mechanical properties of this material. The project also aimed at improving nanomaterials characterisation methods[xl].

The research team developed a novel interferometry set-up which could probe the forces that are generated by gas molecules passing through nanopores in graphene and a protocol for measuring the nanomotion of graphene in real time through a nonlinear optical field. Their work showed that this platform could also be used for measuring tiny forces that are generated by microorganisms[xli]. New collaborations were then initiated with a biophysicist, and breakthrough experiments were performed that led to the measurement of nanoscale vibrations of a single bacterium. Most importantly, it was found that nanoscale motion diminishes if the bacteria are dead and persists as long as the bacteria are kept alive, thus providing new means for screening the effectiveness of antibiotics. Finally, the project also showed that by engineering microwells, bacterial cells can be trapped in a laser spot, and laser intensity fluctuations can be used to determine whether bacteria are resistant to antibiotics or not. These advancements crystalised in the PoC grant GRAPHITI and built the foundation of the spin-off company SoundCell.


Bacteria interacting with graphene sensor

The EIC Transition grant BE FAST is supporting Farbod and his team to mature the SoundCell technology into a high-throughput cost-effective antibiotic susceptibility testing platform. The company is expecting to put its first commercial product on the market by 2027. This prototype will be able to test up to 9 antibiotics, at different concentrations, moving from a single antibiotic screening on a chip to a full antibiogram determination, significantly enhancing antibiotic susceptibility testing as compared to the current state-of-the-art, especially in the context of complex cases such as sepsis.

In other cases, researchers have engaged in the development of broad technological platforms, which then progressively find their application niche and market position.

Andrea Ferrari's project NANOPOTS, based at the University of Cambridge in the UK, aimed at developing a new class of polymer-based optoelectronic devices, embedding the optical and electronic functionalities of carbon nanotubes and graphene. Novel mode-locked lasers and detectors, with state-of-the-art performance in terms of wavelength range, tuneability, power and repetition rate, were fabricated[xlii]. These devices combined the fabrication advantages of polymer photonics, with the tuneable active and passive optical properties of carbon nanotubes and graphene. An additional Synergy Grant allowed Andrea Ferrari and his team to further explore the creation of novel optical devices that would leverage the multiple properties of 2D materials through their combination in 3D stacks[xliii].

A subsequent PoC grant GSYNCOR allowed Ferrari and his team to explore the applicability of these novel optoelectronic devices to the development of cost-effective non-invasive cancer diagnosis tools. The project developed a compact, portable dual-cavity laser designed specifically for coherent Raman microscopy that can be tuned to analyse cancerous tissue with real-time image acquisition speeds[xliv]. The technology was matured to investor-ready development and a business plan was prepared for full commercial exploitation. This plan included forming the new spin-off company Cambridge Raman Imaging Ltd, with a subsidiary in Italy, CRI Sprl.

The EIC Transition grant CHARM has allowed CRI Sprl to take the Raman imaging technology to the next level. The project has coupled the microscopy technology developed in the project GSYNCOR with a powerful AI module for tissue analysis, capable of measuring the molecular composition of the patient tissue samples and classifying with a high degree of accuracy the tumour in a completely label-/stain-free way. The new probe will offer histopathologists a fast and low-cost clinical decision support system for cancer diagnosis and personalised cancer therapy.

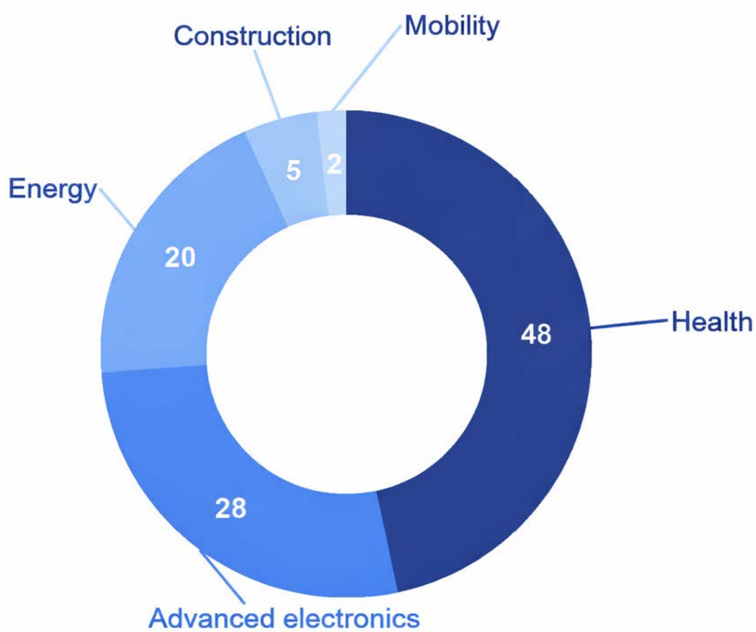
Patents and citations in patents

The data show that (at least) 94 grants have declared having filed at least one patent. This represents almost one-third of all the grants that have declared filing patents[xlv]. Of these, 47 are PoC grants, 20 are StGs, 15 are CoGs, 11 are AdGs and 1 is a SyG.

This confirms the important role that PoC grants play in supporting ERC-funded researchers both in further developing innovative technologies and in pursuing the valorisation and protection of research results.

The sectoral analysis shows that the projects resulting in patents are concentrated in three main sectors: 48 projects are in the health sector, 28 projects in the advanced electronics sector, while 20 projects are in the energy sector (Figure 30).

Figure 30: Number of projects reporting patents by policy sector (note that one project can be relevant for more than one sector)



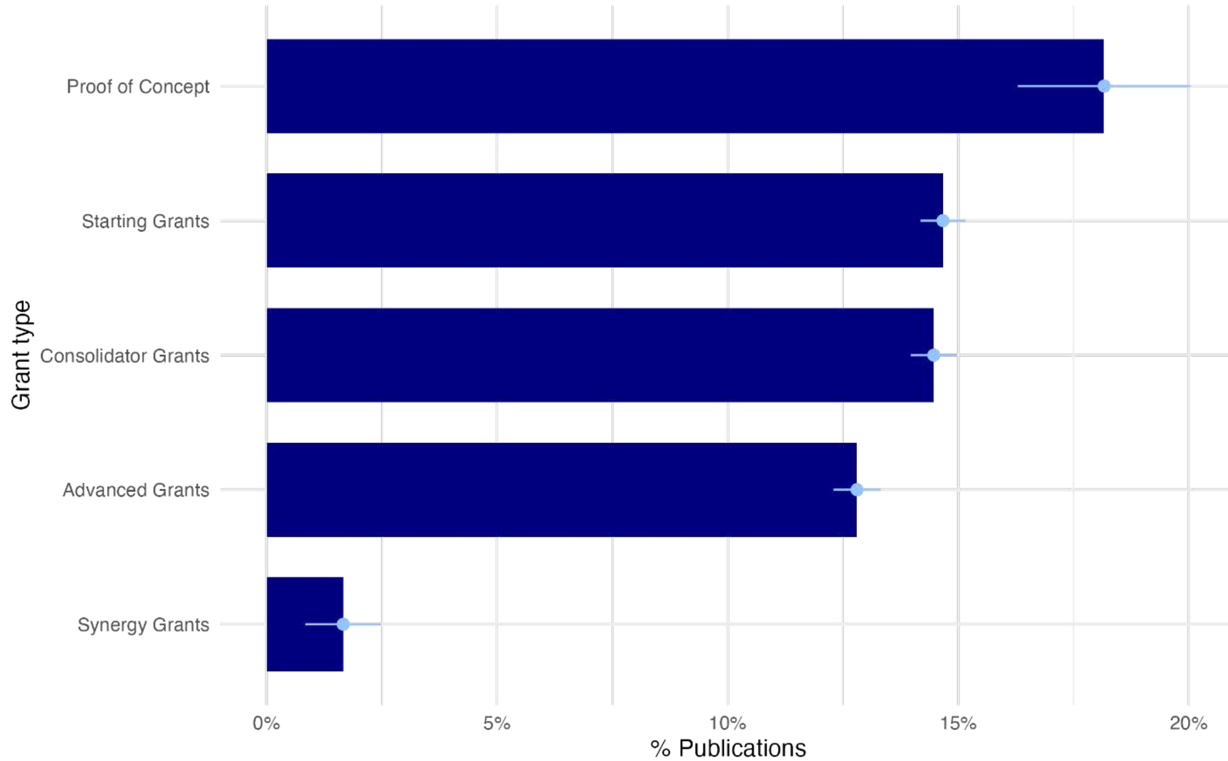
Institutions in Spain (17 projects), the UK (16), the Netherlands (10), Germany (10) and Switzerland (8) account for two-thirds of all patent-filing projects.

In addition to patent production, patent citation data offer further insight into how ERC-generated scientific knowledge is taken up in technology development and innovation.

Approximately 15% of all the publications associated with the projects in this portfolio have been cited in at least one patent[xlvi].

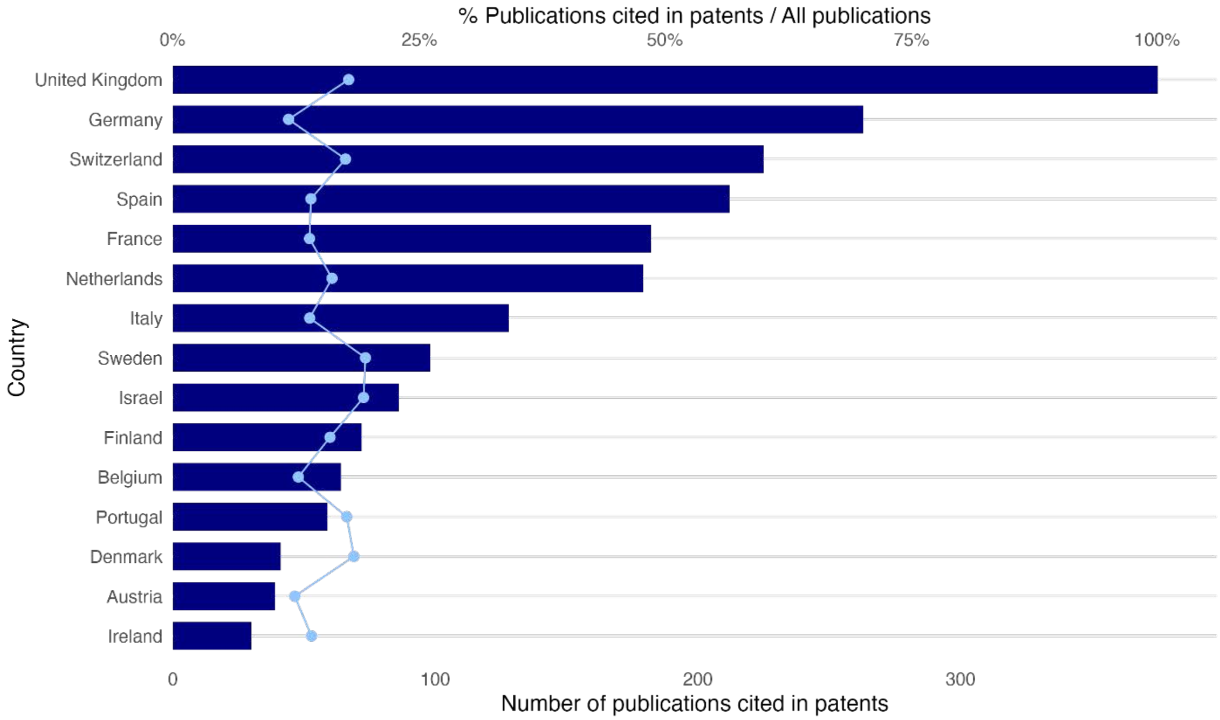
The citation pattern for ERC-funded research in patents varies slightly across grant types. PoC projects show the highest percentage of patent-cited publications (18.2%), StG (14.7%) and CoG (14.5%) projects follow, while AdG projects (12.8%) show a slightly lower share. SyG projects (1.7%) exhibit the lowest percentage, which is linked to the limited number of projects and the early stage of implementation during the analysed period (2018–2020). Across sectors, the highest percentage is observed in health (15%) and advanced electronics (13.7%). Slightly lower shares are seen in construction (13.1%), energy (12.9%) and transportation (9.8%) (Figure 31).

Figure 31: Percentage of project publications cited in patents by grant type



In geographic terms, institutions in the UK record the highest number of patent-cited outputs (375 publications), followed by Germany (263) and Switzerland (225). Once normalised by total publication output, institutions in Sweden and Israel join those in the UK and Switzerland, with approximately 19% of their publications cited in patents. In contrast, some countries with high publication volumes show much lower patent citation shares (e.g. Germany (11.8%), France (13.9 %) and Spain (14 %)). (Figure 32).

Figure 32: Percentage (line) and number (bars) of project publications cited in patents by country of host institution

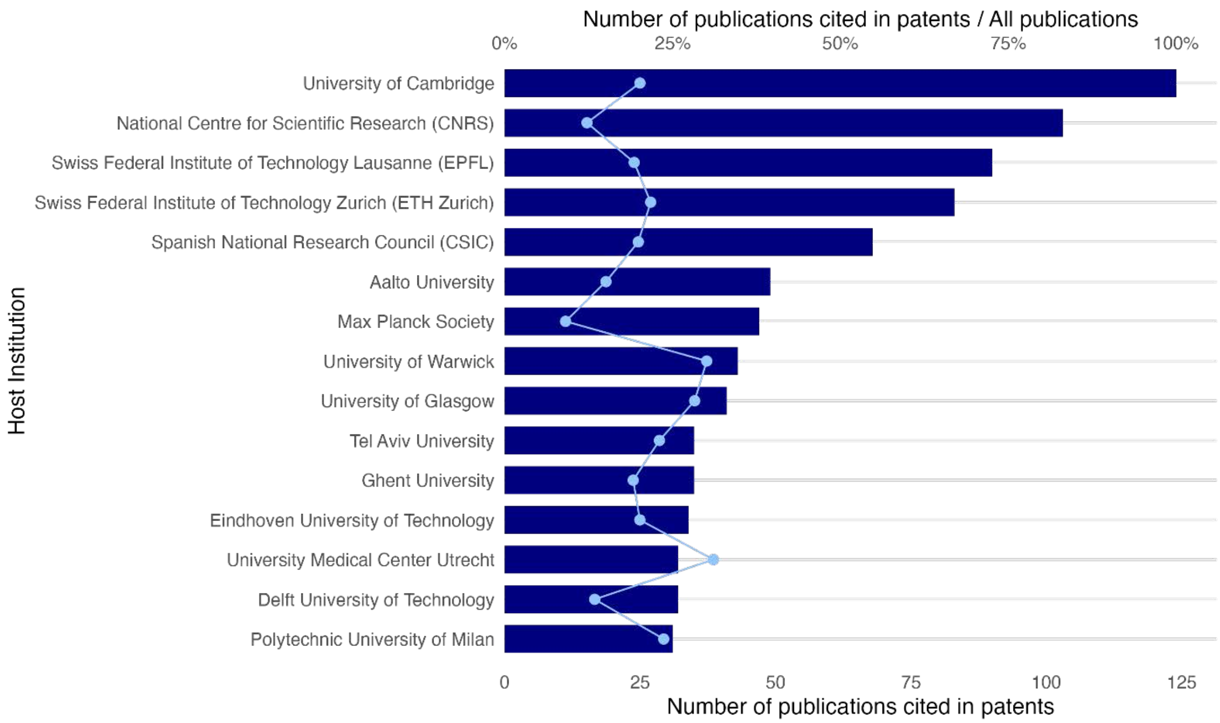


Most patent-cited publications originate from leading European research institutions, such as the University of Cambridge, CNRS, EPFL, ETH Zurich, CSIC, Aalto University and the Max Planck Society.

Across host institutions, the share of ERC-funded publications cited in patents ranges from around 9% to >30%. Institutions with strong engineering, applied science or biomedical profiles — such as the University Medical Center Utrecht (31%), the University of Warwick (30%) and ETH Zurich (22%) — show particularly high technological impact. In contrast, broad-based research organisations, such as the Max Planck Society (9%) and CNRS (12%), display lower shares (Figure 33).

Overall, these patterns suggest that institutional mission, disciplinary orientation and links to innovation ecosystems may play a key role in facilitating the translation of ERC-funded research into technological applications.

Figure 33: Percentage (line) and number (bars) of project publications cited in patents by host institution

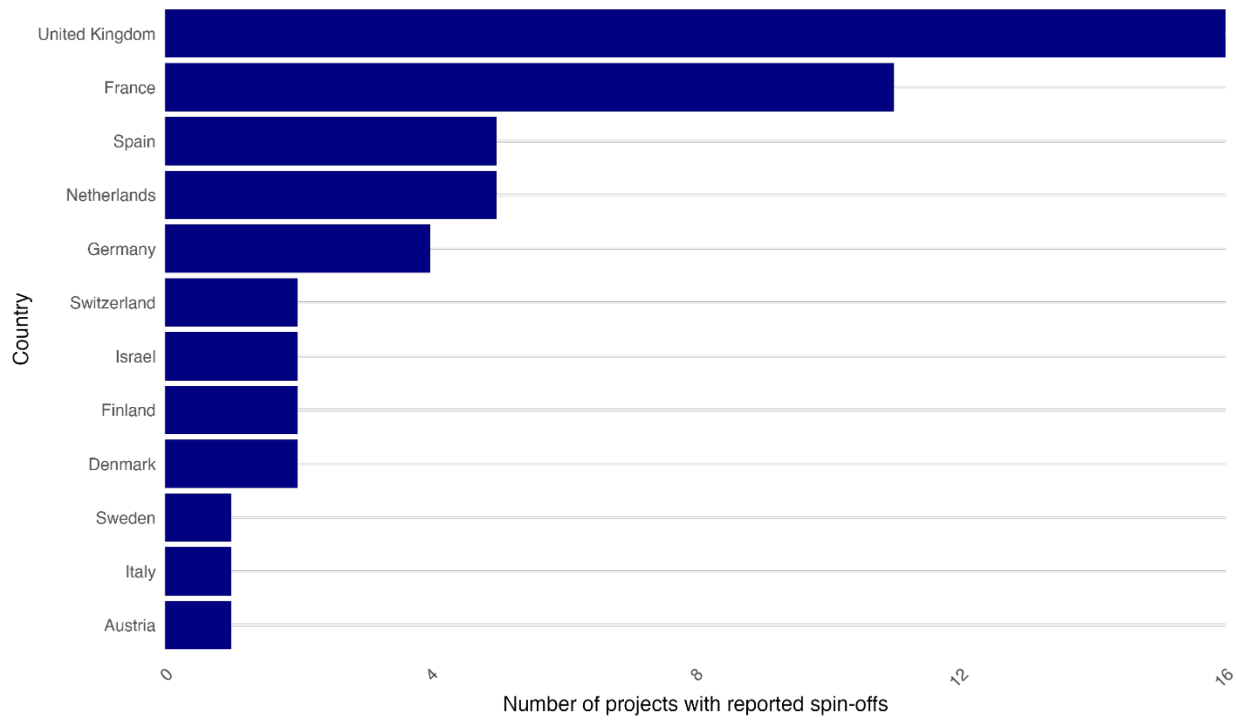


b. From lab to fab: Spin-off in the advanced materials portfolio

Overview of projects and spin-off companies

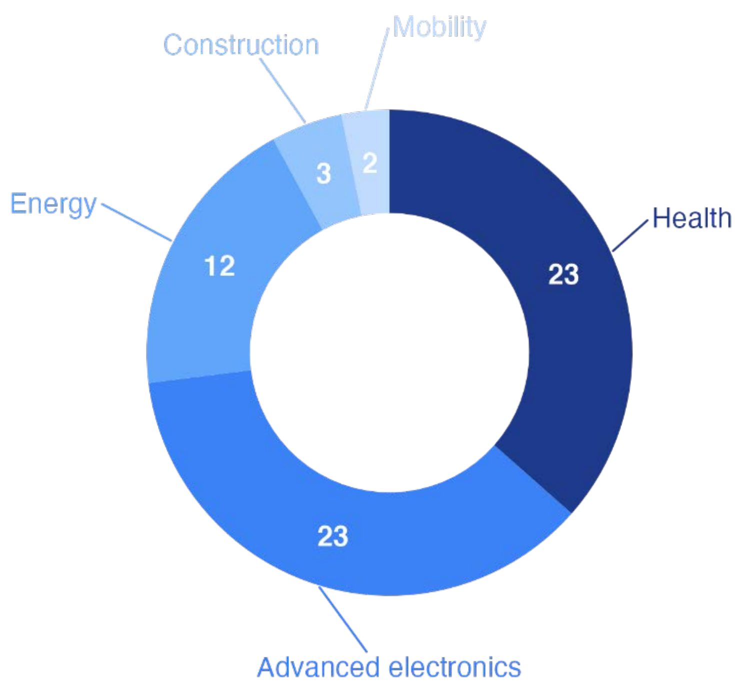
Based on available data, (at least) 52 projects (in 12 countries) in this portfolio have led to a spin-off company[xlvii]. Most of these are based in the UK (16 projects), France (11), Spain (5). the Netherlands (5) and Germany (4) (Figure 34).

Figure 34: Number of projects with reported spin-offs by country of host institution



The projects that led to the incorporation of spin-offs are concentrated in three sectors: health (23 projects), advanced electronics (23 projects) and energy (12 projects) (Figure 35).

Figure 35: Number of reported spin-offs by policy sector (note that one project can be relevant for more than one sector)



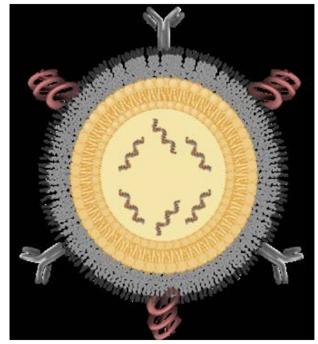
Health

Projects leading to the creation of spin-offs in the health sector have mostly focused on the development of applications of bioactive and biocompatible materials as well as stimuli responsive materials. In addition, companies working on novel drug delivery systems and applications of photonic materials (see above) are also prevalent in the portfolio.

Valeria Chiono, from the Polytechnic University of Turin in Italy, sought to address current limitations of cardiac regeneration strategies through a novel multidisciplinary approach. Her project BIORECAR integrated nanomedicine, biomaterials science and tissue engineering, with the aim of developing a safe and efficient method for cell reprogramming through RNA molecules. The project designed hybrid polymer-lipid nanoparticles to target and direct the reprogramming of human cardiac fibroblasts into cardiomyocytes and a minimally-invasive injectable hydrogel to release the nanoparticles[xlviii].

In a subsequent PoC project POLIRNA, Chiono and her team further developed polymer-lipid nanocarrier kits. Polymers were used to create a hybrid nanoparticle system composed of a lipidic core for efficient

RNA encapsulation, a polymeric shell for enhanced stability and controlled release, and tailored surface ligands for targeted delivery[xlix]. This strategy moved beyond the current paradigm dominated by lipid nanoparticles, which is limited by instability, immunogenicity and poor tissue specificity.



POLIRNA: Nanoparticle

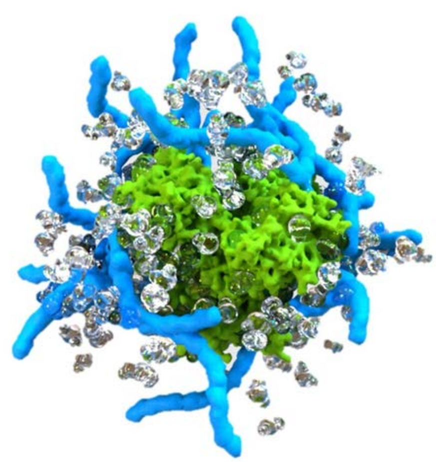
This resulted in a patent filing for the technology, and in 2024, the project led to the creation of PoliRNA Srl, a spin-off company from the Polytechnic University of Turin in Italy dedicated to commercialising the platform. By expanding RNA therapy applications beyond COVID-19 vaccines and liver-related diseases, the technology paves the way for next-generation RNA therapeutics with improved safety, tissue specificity and translational potential.

Andrew Livingston's EXACTYMER project, based at the University of London, Queen Mary College in the UK, has revolutionised the production of synthetic polymers with precisely-defined monomer sequences for drug development[l]. EXACTYMER created new super-stable, ultra-selective nanomembranes, with high permeances, enabling rapid, repeated purifications and a novel method for growing polymer chains[li]. Monomers are attached to a central hub molecule to create a macromolecular homostar with enhanced molecular size, promoting accurate separation of the growing synthetic polymer from reaction debris via nanomembrane processing. The resulting technology, the Nanostar Sieving™ platform, was transferred to a newly incorporated spin-off Exactmer Ltd.

Exactmer Ltd was the beneficiary of the PoC Grant NANOLIGO and the EIC Transition grant AltOligo, through which it continues to refine and scale-up the capabilities of this technology platform and develop a commercialisation strategy, including partnerships with major pharmaceutical companies.

Anwesha Sarkar's project LUBSAT, based at the University of Leeds in the UK, aimed at developing a fundamental understanding of the molecular interactions on the tribological, surface and structural levels of mouth-food biomolecules mixtures. The ultimate goal was to establish bottom-up principles that would, in the future, allow the design of satiety-targeted foods. The project delivered major breakthroughs. It developed the first biomimetic tongue-like surface using silicone via 3D printing and soft lithography, accurately reproducing tongue deformability, texture and wettability. It also advanced the understanding of salivary lubricity and created a super-lubricating protein–starch microgel, demonstrating high performance in oral-mimicking tribological tests.

Building on these findings, Sarkar's team developed fat mimetics that provide a pleasurable mouth feel without added high-calorie fat. These formulations improved hydration, lubricity and sensory quality in otherwise astringent plant proteins[lii]. Finally, through combined in-vitro and in-vivo trials, the project was the first to show that oral coating and lubricity significantly influence appetite and food intake.



AQUALUB: Protein-based microgel and polysaccharide coating.

The subsequent PoC grant AQUALUB further explored the scalability of the protein-based lubricants and assessed the commercialisation of this bio-inspired aqueous lubricant technology through a feasibility study, intellectual property protection and market research[liii].

With the main application area foreseen as being xerostomia (dry mouth), AQUALUB successfully translated its protein-based lubricants into a scalable product with superior lubrication performance. Beyond its potential application for dry mouth, AQUALUB's biomimetic hydrogel offered a broad platform with multiple promising biomedical applications — including ocular, vaginal and joint lubrication — and food industry applications.

The project supported the establishment of MicroLub Ltd to exploit these possibilities. The company is now successfully focusing on next-generation protein technologies that address challenges in both the food and personal care industries.

In the project 4DBIOSERS, Luis Liz-Marzan from the Centre for Cooperative Research in Biomaterials in Spain, pioneered a groundbreaking platform to recreate and monitor artificial tumour models in 3D, offering an ethical and highly-realistic alternative to animal testing in oncology research.

The project developed 3D bioprinted scaffolds with embedded metallic (gold) nanoparticles, which work as nanosensors for surface-enhanced Raman scattering[liv]. This breakthrough allows for the detection of molecular and metabolic changes within tumour microenvironments in real time with high sensitivity and at single-cell spatial resolution. Thanks to this advanced plasmonic nanomaterial, researchers can now study cellular dynamics under varying stimuli, such as pH, temperature or drug exposure, providing unprecedented insight into tumour heterogeneity, metastasis and immune evasion. Beyond its scientific breakthroughs, which have been highlighted elsewhere, 4DBIOSERS established a patented platform for anticancer drug testing based on patient-derived organoids, facilitating the transition towards precision medicine[lv].

A subsequent PoC grant 3DTUMOUR supported the automation and scale-up of tumour model fabrication, moving towards high-throughput production for pharmaceutical screening. It also allowed Paula Vazquez Aristizabal, a PhD candidate at the time, to be hired who has since then led the process of incorporation of the spin-off ONKOREPLICA, to provide solutions for the precise identification of the pharmacological effect of drugs across various cancer phenotypes.

Philippe Nghe's project AbioEvo, hosted at the Ecole Superiore de Physique et de Chimie Industrielles de la Ville de Paris in France, set out to study the process of abiogenesis — the transition from non-living to living matter at the origin of life — and more specifically the mechanisms whereby small RNA molecules can self-organise into reaction networks capable of evolution in open environments. The project was successful in demonstrating that several molecular mechanisms necessary for evolution can be integrated in the same reaction network, purely made of RNA, using open reactors made with microfluidics. A subsequent PoC grant SYNEBIO allowed Nghe and his team to explore the potential applicability of the technological platform and the methods developed in this project to devise a novel microfluidic device for 3D culture and high throughput screening of drug combinations, which will allow HTS in advanced cell models[lvi]. The project was successful at developing a microfluidic device compatible with pharmaceutical industry standards and use protocols ready for large-scale production. It also established novel scalable methods for creating cell-embedded hydrogels and live-cell staining protocols adjusted for microfluidics and AI models for automatic image analysis and predicting drug responses. Finally, the project developed a comprehensive business plan, investor deck and strategic roadmap, which facilitated the establishment of the spin-off company Syntopia.

Led by Salvador Pané i Vidal at ETH Zurich in Switzerland, the project ELECTROCHEMBOTS successfully developed a comprehensive platform for wireless magnetoelectric stimulation at the micro- and nanoscale, bridging material science with biomedical and environmental engineering. The main goal of the project was to develop untethered micro- and nanodevices capable of converting wireless magnetic input into electric output to drive electrochemical reactions for biological and environmental applications. The project successfully synthesised biphasic composites (magnetostrictive phase + piezoelectric phase) and single-phase multiferroics at the nanoscale. These materials were then integrated into specific device configurations (Janus particles, nanowires, scaffolds) to address three distinct fields: targeted anti-cancer drug delivery, cell stimulation and tissue engineering, and water remediation.

A subsequent PoC grant SMART saw the team further developing this nanotechnology to create specialised membranes for water purification that remove per- and polyfluoroalkyl substances (PFASs)[lvii] for safer wastewater discharge into the environment. The team successfully created a portable reactor that can treat 1,000 litres of water a day and could be used for treating industrial and hospital effluents, where the wastewater treatment can be decentralised. Based on the project's results, the research team founded the spin-off company Oxyle in 2020.

Advanced electronics

Nearly half of the projects leading to the creation of spin-offs in the advanced electronics sector have focused on the development of applications around photonic and plasmonic materials. Other relevant areas of application include superconducting and topological materials, and biocompatible and bioactive materials.

Based at the Chalmers Institute in Sweden, Victor Torres-Company's project DarkComb addressed the problem of single-mode fibre capacity to continue managing increasing internet data traffic. He proposed combining space-division multiplexing and microresonator frequency combs to scale up fibre-optic communications capacity. The project demonstrated an integrated photonic platform based on dispersion-engineered silicon nitride with a loss of performance significantly beyond what is commercially available and at the forefront of the research landscape[lviii]. More importantly, it demonstrated a fibre-optic communication system in the petabit per second regime using a single microcomb.

The subsequent PoC grant H2Microcomb allowed Torres-Company and his team to explore the innovation potential of this breakthrough technology. The project assessed the yield and reproducibility of the silicon nitride devices, including photonic molecule microcombs, across multiple wafers and chips. A process design kit was then developed. This design kit was compatible with standard software tools and enabled the users to design and fabricate customised photonic integrated circuits using silicon nitride technology. Finally, the project investigated the freedom to operate and produced a market evaluation, which served the process of incorporation of Iloomina AB (currently Solinide Photonics).

Based on the novel power-efficient, scalable and mass-manufacturable microcomb technology developed with ERC support, Solinide Photonics can revolutionise mass-market photonic applications such as data-centre interconnects, by replacing the current technology with much needed improvements of energy efficiency and scalability in data-management rates.

Clara Saraceno's project TerAqua, based at the University of Bochum in Germany, pushed the frontiers of research in the field of THz spectroscopy by developing a novel table-top strong-field THz with high repetition rate. The project demonstrated several record-holding laser sources and extended these demonstrations to shorter pulse durations based on the new gain material Ho:CALGO. Similarly, the THz sources realised by the project re-defined the state-of-the-art for sources based on nonlinear crystals and the project put in place the highest average power laser-driven THz source so far demonstrated.

The ensuing PoC grant Giga2u allowed the research team to extend the performance of the new laser technology developed in the TerAqua project. The entire laser platform was developed in a modular and practical way to make it more adaptable to parameters required by future customers. Furthermore, it helped to identify risks in the supply chain of the unique laser crystals that support the performance of the laser and devise alternative technologies to mitigate these risks. The project also supported the development of market studies and the development of a new implementation of an amplifier geometry that could support future technology developments.

Most importantly, the spin-off company Rayven was set up. This company has moved to secure additional funding in Germany through the EXIST Transfer of research programme and very recently an EIC Pathfinder grant (starting in 2026). As the company moves forward, its laser technology is expected to revolutionise industrial material processing, scientific research and gas sensing.

Energy

Projects in the field of energy leading to the establishment of spin-offs have mostly focused on the development of applications around photonic and electrochemical storage materials.

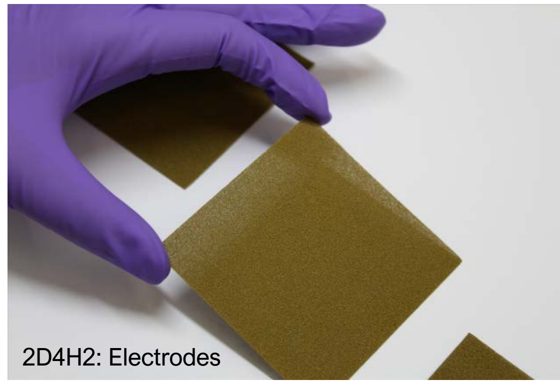
Henry Snaith's project HYPER, based at the University of Oxford in the UK, set out to investigate several new materials that could be used to make solar cells more cheaply. The project aimed to deliver a new concept for 'highly-efficient' (>10% PCE) hybrid solar cells. Among the materials explored was the perovskite class of compounds. These had been studied by Japanese researchers a few years earlier but not taken further. The research team found that perovskites absorbed light incredibly strongly and worked very well in thin-film photovoltaics. The project soon demonstrated that cells with a perovskite layer performed far better than anyone had expected. Perovskite solar cells delivered over 20% PCE, rivalling the performance of crystalline silicon. At the same time, they relied on an inexpensive material, which requires low temperature processing and had a less demanding manufacturing process[lix]. Snaith repurposed a previously established spin-off company Oxford PV Ltd to exploit these discoveries.

A subsequent PoC grant NEM helped the research team to explore the stability factors that needed to be addressed for the realisation of the perovskite solar cells and to accelerate the production of a stable technology[lx]. These discoveries significantly enhanced the value of the intellectual property, which helped in raising venture capital funding for further commercialisation activities. The project also supported the realisation of deep freedom to operate studies. Finally, beyond the field of photovoltaics, the research team also started exploring the possibility of developing perovskites for light-emitting applications, such as LEDs for displays and solid-state lighting. This line of research was picked up by a new PoC grant PLE and, eventually, a new spin-off company Helio Display Materials.

Oxford PV already produces tandem modules that are 25% more efficient than conventional solar panels. By 2035, it has targeted a 35% increase in module efficiency, significantly enhancing the ability to convert the sun's energy into clean renewable electricity.

The project 2D-PnictoChem, led by Gonzalo Abellán from the University of Valencia in Spain, set out to explore the chemistry of a novel class of graphene-like 2D-layered elemental materials: the pnictogens. The project delivered significant advances in 2D-pnictogen synthesis and assembly in complex hybrid heterostructures using a cross-disciplinary approach combining inorganic- and organic chemistry with solid-state physics. In addition, the project explored relevant challenges in batteries, electronic devices and catalysis. The project led to significant advances in 2D materials fundamental science (with more than 50 papers). It also engaged in technology transfer activities. The project produced 3 patents based on 2D materials for green hydrogen production, scalable colloidal synthesis of bismuthene and metal collectors-free lithium-ion batteries[lxi].

As a follow-up, the PoC project 2D4H2 allowed Abellán's team to continue exploring the translation of the 2D material technology for green hydrogen production developed in his previous grant. The project focused on the development of an advanced anion exchange membrane water electrolyser (AEMWE) stack to enhance the green production of hydrogen through water electrolysis. The electrocatalysts and the AEMWE stack developed by the project team was critical raw materials-free and incorporated breakthrough electrodes (anodes) made of 2D nickel–iron layered double hydroxide materials with outstanding catalytic performance[lxii].


2D4H2: Electrodes

The spin-off Matteco was established in 2023, focusing on innovative catalysts for green hydrogen production globally. In two years, Matteco established a modular advanced materials factory. The company has successfully secured an EIC Transition grant MATCATH 2.0 and additional funding for collaborative research under the Horizon Europe-funded SEAL HYDROGEN project, with Siemens Energy, Horiba, HI ERN and the University of Valencia. It has also received Next Generation EU funding and raised equity investment. The company was selected as a finalist for the prestigious Future Unicorn Award 2025.

Key enablers and barriers in the pathway to innovation

The companies highlighted above represent a sample of the various pathways from discovery to spin-off creation identified within the ERC's portfolio.

The factors impacting this process, both positively and negatively, have been extensively discussed and are well-documented in the relevant scientific literature[lxiii]. They range from individual-level considerations, such as entrepreneurship skills, to cultural and institutional influences. Examples include the role of technology transfer offices (TTOs), entrepreneurship promotion programmes, innovation clusters, relationships with industry and networking. Additionally, dedicated funding schemes, the regulatory environment, and the career paths and professional opportunities available to researchers within their host institutions also seem to play a significant role.

This section examines the influence of some of these factors on the pathways followed by the principal investigators identified in this portfolio analysis. Rather than adopting a case-centred narrative, this section provides an aggregated analysis of how these factors have impacted the stories and trajectories of the companies mentioned earlier. The analysis is rooted in the results of 20 in-depth interviews with principal investigators (see the Methodology section for more details).

The information collected from these interviews indicates that:

1. **University TTOs generally play a pivotal role in guiding researchers through the spin-off creation process**, providing access to resources, networks and expertise. However, the capabilities and involvement of TTOs can vary significantly across countries and institutions, thus affecting their ability to play a positive role.
2. **Public funding, such as ERC and EIC grants, is irreplaceable in de-risking early stages of spin-off creation**, supporting proof-of-concept activities and recruiting talent. These grants provide flexibility, simplicity and access to ancillary services, which are critical for spin-off success.
3. **Access to private capital remains one of the core challenges in the process of spin-off incorporation**. Hurdles can emerge linked to the company's governance and ownership structure, and the general attractiveness of some technologies for investment. Moreover, mobilising private capital investment requires resources (including significant time dedication from principal investigators) and skills that may sometimes be out-of-reach for early-stage spin-offs.

4. **Interactions with industry partners are critical** for understanding market needs, operational standards and regulatory barriers. Industry engagement can lead to mentorship, access to relevant experience and knowledge, and potential partnerships, which can help spin-offs refine their products and business plans.
5. **Researchers often rely on their peers and colleagues for advice, guidance and encouragement**. Exchanges involve both local and international networks. The latter can help with the identification of potential markets, funding and investment opportunities, and how to approach them, or the functioning and comparative advantages of entrepreneurship support programmes in various countries.
6. **Navigating regulatory environments can be a significant barrier, particularly with regards to intellectual property protection, technology transfer and licensing agreements**. Principal investigators often require professional support to navigate these complex frameworks, which can delay the spin-off creation process.
7. **Institutional and individual cultural barriers, such as traditional views on science and career paths, can deter researchers from engaging in innovation-oriented activities**. Additionally, lack of professional arrangements to facilitate innovation activities can make it challenging for researchers to balance their academic responsibilities with spin-off creation, highlighting the need for supportive environments and resources.

The next sections provide a more detailed account of the role of these factors in the stories of the principal investigators contacted for this study.

Institutional support

The interviews underscore the crucial role of host institutions' TTOs in spin-off creation[lxiv]. These offices have been vital in guiding researchers through intellectual property protection and company registration processes. They support researchers in assessing commercial feasibility and assist them in moving towards spin-off incorporation. Many universities cultivate vibrant innovation ecosystems and networks, significantly aiding researchers' access to industry players and private investors. Often, industrial parks and facilities are strategically located near university campuses, facilitating early-stage contacts and networking during the technology maturation process.

Additionally, TTOs have been reported to facilitate access to training and other resources, such as fellowship programmes, market consultants and intellectual property lawyers. These resources play a substantial role in the initial stages of spin-off creation by embedding essential skills and knowledge within the company teams.

However, data from our interviews confirm variations in the capabilities and involvement of TTOs across the different countries studied[lxv]. Moreover, the interviews reveal that the perception of the role of TTOs evolves as the dynamics and stakes of spin-off creation change. In the early stages, researchers view TTOs as key providers of critical resources, particularly support during the patenting process. As spin-off creation progresses, relationships can become more complex, especially during the phase of spin-off incorporation, when negotiating the university's role and equity in the company becomes crucial[lxvi].

At the same time, most of the interviewees observed that the role of TTOs has evolved significantly over time. On the one hand, principal investigators noted that they engaged with their TTOs for extended periods — some for over a decade — creating opportunities to renegotiate terms and reassess the university's role within the company structure, a common theme among the interviewees.

On the other hand, a general shift towards strengthening the university role as key enablers of early-stage company development and growth (as opposed to privileging shorter-term strategies) was noted by most interviewees. Such an approach is viewed as enhancing success and, in the medium term, yielding greater returns, such as through successful company sales.

Funding

Public funding

The data collected through interviews highlight the irreplaceable role of public funding in de-risking the early stages of spin-off creation. All the principal investigators interviewed reported relying on grants, entrepreneurial fellowships and other funding schemes to sustain their path towards spin-off creation. These funds enabled them to conduct proof-of-concept activities, recruit necessary talent, support company incorporation, manage intellectual property and test the product's market viability.

EU-level funding, such as through ERC or EIC grants, is often complemented by local funding. This is particularly true for researchers in France, Germany, the Netherlands and the UK who benefit from support programmes managed by universities and dedicated national programmes for innovation and entrepreneurship.

Interviewees have generally praised the ERC PoC grants for their flexibility and simplicity, notably at the application and evaluation stages. These grants help lower entry barriers during the early, exploratory stages of commercialisation. The most appreciated feature of these grants is the ability to combine experimental work with other ancillary activities, such as hiring intellectual property and business development experts for market characterisation studies and freedom-to-operate analyses. Furthermore, PoC grants have often enabled principal investigators to recruit postdoctoral researchers interested in pursuing a career beyond academia. In many cases, these researchers have been central to the company's establishment[lxvii].

While all principal investigators interviewed in this study recognise the positive impact of the PoC scheme on spin-off establishment, some have pointed out that the funding amount (€150 000 per grant) limits its potential.

> *Once we understood how [the technology] worked and why, then it was very clear that we wanted to patent it. It was very good that we could pursue the patent in my ERC Consolidator grant. I contacted the project officer - Hey! We have ended up in this situation. Would it be OK if we cover some of the patent costs through the ERC? And then the answer was yes! as long as it's fine with the university and within the scientific scope of the ERC grant. Thanks to that, we could cover the cost for drafting the patent, so all the consultancy fees that went into that.*
>
> *Victor Torres Company – Solinide AB*

The EIC Transition scheme also received praise from many principal investigators interviewed for this report, regardless of whether they were direct beneficiaries[lxviii]. Like the PoC scheme, the added value of EIC grants largely lies in the access they provide to ancillary services and capacity development, which are crucial for developing the skills needed to build a successful company.

In most cases, dedicated translational grant schemes (such as those mentioned above) have been pivotal in the incorporation of spin-offs. However, in a few instances, steps towards establishing the spin-off were supported through the main ERC grant itself. Principal Investigators could use funds in their main grant to advance the protection of intellectual property resulting from their research projects.

Such flexibility in the use of ERC main grant funding has been praised in interviews as a significant factor in ensuring the timelines of financial support and mitigating financial risks during the early stages of spin-off incorporation. Importantly, principal investigators acknowledged the investigator-driven and idea-centred nature of ERC and EIC grants as key enablers throughout the process.

> *The ERC Advanced Grant, the PoC, but also the EIC Transition grant, they were all critical. I think it was really important that they were researcher focused. You can get funding for an idea; you receive a grant to follow an idea and then you can transition that idea through to a business. I do think they are uniquely useful.*
>
> *Andrew Livingston – Exactmer Ltd*

Private funding

Private funding, whether from industry or private capital, plays a crucial role in ensuring the viability and sustainability of companies. However, it often arrives later in the process of technology maturation and spin-off development.

Half of the principal investigators interviewed have successfully completed one or more funding rounds, primarily seed funding and Series A funding. The remainder are in the process of launching their first fundraising events. Early-stage industry financial support, in the form of small grants, is more the exception than the norm — documented in only three cases. Corporate venture capital investment, where large corporations invest in startups for strategic reasons rather than purely financial returns, was not reported in the interviews.

Private capital and industry funding accessibility varies in the cases analysed, with local innovation ecosystems playing a key enabling role, especially when galvanised by the universities' TTOs[lxix].

However, this does not replace the need for principal investigators and their teams to actively engage in investor identification and engagement. The ability of principal investigators to maintain and leverage multilevel networks — local, national and international — was crucial in securing private capital investment in all cases analysed, often aided by the prestige of ERC grants.

Principal investigators, or team members, often dedicate substantial resources to developing the skills necessary to identify and interact with private investors, frequently being supported by incubators and local entrepreneurship support schemes. Pitching ideas to investors and consolidating networks is described in most interviews as one of the most time-consuming activities in spin-off creation. In the most successful examples of companies in the sample, professional chief executive officers (CEOs) with extensive experience in start-up creation and development were recruited to lead private capital fundraising efforts.

Access to private capital remains a core challenge in spin-off incorporation. Significant hurdles often emerge related to the company's governance and ownership structure, and the general attractiveness of 'hard tech' investment[lxx]. Some principal investigators describe difficulty in finding the right investors who understand the actual value of the end-product, are willing to accept high initial capital demands and recognise longer technology development timelines — especially compared to other 'deep-tech' sectors that are less capital intensive[lxxi].

The interaction between public and private funding, where it co-existed, was not reported as particularly challenging or problematic.

The role of industry

Engaging with industry partners is crucial for spin-off creation. Some principal investigators noted that their previous industry experience or ongoing collaborations with industry played a key role in launching spin-offs. All interviewed researchers emphasised that initial interactions with industry are essential for understanding the challenges of translating technology from the lab to real-world applications.

In several cases, industry interactions led research teams to re-evaluate their products and business plans. This often resulted in pivoting away from original plans towards new technological applications and markets, sometimes considerably different from the initial idea.

The project NICEDROPS, led by Manish Tiwari from University College London in the UK, focused on understanding icing and condensation to create surfaces that improve heat transfer and energy efficiency. The project used eco-friendly methods to achieve nanoscale morphology control and developed coatings with superhydrophobic properties, avoiding using harmful substances such as PFAS. The ensuing PoC project SUNCOAT explored applying these coatings to wind turbine blades. However, industry interactions revealed extended development timelines with uncertain applicability, prompting a pivot to replacing PFAS in textiles and potential medical applications.

Tim Liedl's project ORCA at Ludwig-Maximilians University Munich (Germany) developed DNA-assembly techniques to create nano-sized objects for optical functionalities and novel sensors. The team advanced DNA-based fabrication to design materials with unique optical responses for cryptography and product safety in the grant DNA Funs. A follow-up PoC grant, NanoPUF, explored nanotechnology-based tags for banknote or pharmaceutical products authentication but found the technology too advanced for current sector needs, instead shifting focus to commercial testing strips and a single-molecule sensing device, a technology that had been partially explored under the ORCA project, leading to the formation of the spin-off Amplifold GmbH.

> *We were in contact with this large international security technology company operating in the field of currency technology. We had this nanotechnology-based unclonable tags, which are 100% secure, and we thought that they could be ideal for banknotes or pharmaceuticals. But they told us that physical unclonable function technology is not picking up in Europe because apparently it is not really needed yet; counterfeiting risks can be addressed effectively with much simpler technology.*
>
> *Tim Liedl – Amplifold GmbH*

These examples showcase the iterative nature of innovation and the value of early industry engagement — a success factor consistently reported in interviews.

Industry engagement also provided significant added value through mentoring and knowledge sharing, which helps companies develop business acumen, skills, and technical expertise needed for growth. Integrated innovation clusters facilitate more effective ‘knowledge transfer’, as universities and TTOs often play active roles. Networking remains key to knowledge transfer, with Principal Investigators frequently attending international industry conferences to expand their networks.

Participating in business events and initiatives was extremely valuable, as it enabled us to receive entrepreneurship training from expert mentors and to establish connections with a wide range of stakeholders, investors and industry partners. As a result, we won an industry prize with a major pharmaceutical company, which enabled direct interactions with them. This was particularly beneficial, as they provided strategic guidance on the further development of the technology and on the validation tests to be prioritised. The mentoring program is still ongoing.

Valeria Chiono – POLIRNA Srl

Collaborations sometimes formalise as partnerships with industry labs for testing or small financial support. Occasionally, collaborative grant applications arise, involving academics, industry partners, and start-ups, though these were less common in the study.

The role of peers

The analysis of the interviews highlights the crucial role of peer support and networking in facilitating spin-off creation. Researchers often rely on peers and colleagues for advice, guidance, and encouragement while navigating the process of establishing a start-up company.

The best way for hard-tech companies to mature the technology is to partner with industry and co-develop the research. It is the only way to bring down the wall between academics and industry; even if these projects can be very challenging in many ways.

Gonzalo Abellán - Matteco

Peer support manifests in various forms, such as mentoring and collaboration. At institutions with a strong entrepreneurial culture, peer exchanges are often encouraged within the local innovation ecosystem.

[…] in the last three years we have had many interactions with industry saying ‘ok your product seems great, but it will not fit our requirements’. I think we continued because we have the lab and the people, but also because we have the ecosystem helping us to decrypt and to understand what we should do next. The process was quite long but once you are into it, time passes quickly.

Adrien Rennesson – CEO Syntopia

International peer-to-peer exchanges also significantly impact the spin-off process. Most researchers interviewed for this study reported leveraging their international networks at various stages and for numerous purposes. These purposes include mentorship, understanding key aspects of the process — such as technology protection and incorporation methods — identifying potential markets, accessing funding and investment opportunities, and learning about entrepreneurship support programmes' functioning and advantages in different countries.

Regulatory environment

Researchers face significant challenges in navigating regulatory environments, impacting spin-off creation on two main levels:

The process of spin-off creation

In the early stages, implementing rules for intellectual property protection and management proves challenging for many principal investigators. Understanding various strategies for intellectual property protection — such as trade secrets vs. patents — and their implications, as well as developing a sound approach, is often the first hurdle. Most intellectual property strategies are developed with support from host institutions, peer networks, and informal information sharing. As noted above, ERC funding plays a key role in supporting costs through PoC or main grants.

The greatest challenges arise during spin-off incorporation, where regulatory aspects compound with divergent interests between company founders and universities, causing friction and delaying incorporation. Principal investigators report lengthy, complex technology transfer and licensing negotiations, alongside equity retention discussions, as primary difficulties[lxxii].

Two factors underlie these challenges: the complexity of applicable legislative frameworks — including intellectual property, corporate, tax law, university by-laws and entrepreneurship regulations — and universities' often formalistic, inflexible management culture, which can negatively impact company development[lxxiii]. Many principal investigators also contend with strict conflict of interest rules, resulting in additional administrative burdens[lxxiv].

> "*The most difficult part is bringing an academic from the lab into a world of lawyers and interests.*"
>
> *Gonzalo Abellan - Matteco*

Many academics lack understanding of these complex frameworks. This is where professional CEOs with start-up experience become crucial for successful incorporation, although finding such profiles — especially outside dynamic innovation clusters — is not straightforward. In some cases, principal investigators rely on motivated yet less experienced postdoctoral researchers to lead this process.

Product development process and regulatory standards

Regulatory aspects related to product or technology development featured less prominently in the interviews but still pose significant barriers. Principal investigators in the field of biomedical innovation describe complexities in approval and certification of medical devices and treatments. Some find the regulatory pathway complexity pushes them away from certain biomedical applications.

In energy innovation, standards concerning materials toxicity, recyclability and reducing dependencies on critical raw materials are central to product development. Principal investigators often need to rethink production processes for scale, meeting environmental sustainability or safety requirements.

Regulatory complexity coupled with insufficient installed capacity — such as specialised lawyers, compliance experts and engineers — can create bottlenecks. Despite this, most principal investigators in the sample viewed these challenges as intellectually stimulating or central inspirations for the spin-off.

Cultural barriers and professional constraints

The interviews indicated that successful spin-off creation often occurs in institutional contexts that place a strong emphasis on entrepreneurship and the valorisation of results. This environment has proven to be a key motivator for some principal investigators, who acknowledged they might not have engaged in spin-off creation otherwise.

At the individual level, some principal investigators faced challenges in overcoming entrenched views regarding what constitutes 'real science' and whether activities linked to spin-off creation align with these views. They described discovering fascinating research challenges when they began engaging in result valorisation activities.

The interviews underscored also the influence of traditional views on science when they shape career path definitions. In the absence of a robust institutional culture and means to encourage valorisation activities, such views can deter researchers from pursuing innovation-oriented activities.

The stories collected through the interviews demonstrate that innovation flourishes in environments that foster cross-fertilisation between curiosity-driven fundamental research and applied research. In these settings, researchers are encouraged to freely explore multiple dimensions of their scientific programmes. Engaging in applied research endeavours has opened new opportunities for identifying novel fundamental questions, broadening their scientific horizons and establishing a vital feedback loop from applied to fundamental frontier research. All principal investigators continue developing their research programmes alongside supporting the spin-off creation process, often serving as chief scientific advisors.

However, despite these positive aspects, many principal investigators cite the lack of suitable professional arrangements to facilitate innovation activities as a significant barrier. They often juggle the demands of spin-off creation alongside their already demanding academic responsibilities, such as securing research funding, publishing in high-impact journals and teaching.

> *If I'd have to do it all over again, I don't know if I'd have the bandwidth to really do it. It's quite a lot of work […] in addition to everything you're doing as an academic: writing your next grant and you know, building your team and everything. So, this becomes quite a heavy thing. What can be quite an interesting bit to think about is that you don't need a year, but you need some sort of a very short period of time, maybe 2 or 3 months to focus on the creation of the spin-off.*
>
> *Anwesha Sarkar – Microlub Ltd*

c. Recommendations from interview participants

During the interviews, principal investigators were invited to identify recommendations they wished to convey to policymakers. This section summarises the responses provided. These recommendations reflect the perspectives of a subset of ERC grantees who have engaged in the pathway from discovery to innovation. They should not be interpreted as representing the views of the ERC or its Executive Agency. For clarity of presentation, the recommendations have been grouped into four categories corresponding to the principal enablers and barriers discussed in the preceding sections of this report.

Funding and financial support

A first set of recommendations concern the availability and timeliness of funding mechanisms. They also address aspects concerning what is being supported by existing funding mechanisms, the diversification of funding stakeholders, and how innovation funding can be monitored and followed up.

1. **Expansion of innovation grants:** The interviewees generally advocated for boosting the availability and size of innovation grants, providing ample support for technology transfer and commercialisation phases. In some cases, this recommendation was addressed specifically to the ERC's PoC grants, which are seen by some ERC grantees as offering limited funding.

2. **Prototype-to-product funding schemes:** The interviewees supported the development of more targeted funding initiatives that could cover the gap between prototype development and reaching a market-ready product stage. Current funding predominantly supports research and innovation activities, overlooking subsequent stages such as ensuring regulatory compliance. Some of the interviewees advocated for the use of **milestone-based funding models** to ensure sustained project support and a rigorous evaluation of progress and outcomes towards market exploitation. Such models should contemplate regulatory compliance as a significant milestone.

3. **Enhancing public funding support and investment to stabilise and de-risk start-up and scale-up phases:** The interviewees considered that this is especially important for both 'deep-tech' and 'hard-tech' companies. Consistent public investment in such sectors can offer a much-needed stable financial landscape, both mitigating private sector volatility while de-risking venture capital investment in these companies.

4. **Enhancing the support structure for accessing funds and developing common practices:** Enhancing the role and availability of supportive structures (e.g. incubators and entrepreneurship centres, but also technology transfer offices in universities) was seen as critical in facilitating start-up access to crucial funds and resources. An important aspect, highlighted in the interviews, is the need to work towards developing shared standards at EU level based on existing good practices and successful support programmes across the EU. This is seen by grantees as having potential to contribute to reducing existing differences in the functioning of innovation support structures and unleashing innovation outside more traditional innovation clusters and regions in the EU.

Simplification and intellectual property management

A second set of recommendations focus on simplification and improving support around the process of intellectual property management. They specifically address the simplification of regulations and administrative process (e.g. laws regulating the spin-off company incorporation process but also some key aspects of its functioning, such as procurement) and the need for more efficient processes and capacities around the management of intellectual property.

5. **Intellectual property strategy guidance:** Many principal Investigators believe it is important to offer better educational support and capacity building to scientists regarding intellectual property strategies encompassing optimised patenting and publication practices. Such support is critical to empower researchers in the earlier stages of the process of spin-off creation and incorporation and reduce vulnerabilities.

6. **Efficient intellectual property management systems:** In addition, the principal investigators interviewed advocated for more accessible and efficient systems for intellectual property management in universities, accelerating commercialisation timelines and facilitating smoother transitions from discovery to innovation. Besides questions of resources (financial and human), such improvements could be harnessed through exchanges of good practice at the European level and the development of comparative operational standards in the EU (in line with Recommendation 4).

7. **Streamlining administrative processes:** Besides the need for more streamlined systems for managing intellectual property, the simplification of bureaucratic procedures in areas such as procurement and project management was highlighted as a way to promote swifter collaborations with private sector and industry partners in the process of spin-off establishment, notably in early research-intensive stages of the product development process, where the company may still be bound by university procedures.

Entrepreneurial ecosystems and industry engagement

A third set of recommendations covered questions related to the innovation ecosystem and the engagement of industry in early-stage technology development. Most of the recommendations included here focus on the development of peer and multistakeholder networks, while some researchers also advocated for a more decisive involvement of industry in supporting (financially and technically) early-stage innovative technologies.

8. **Enhancing peer learning opportunities:** Peer-learning played a pivotal role in the stories covered in this report. Most interviewees consider that this process can be further enhanced by creating dedicated spaces where the transfer of knowledge and practice on key aspects of the innovation process (such as licensing) from experienced entrepreneurs to early career researchers (e.g. PhD students and postdocs) could be facilitated. These could be complemented with mentoring programmes at the European scale, which could facilitate additional access to knowledge and information, especially for aspiring entrepreneurs from less dynamic regions in Europe.
9. **Promotion of cross-sector partnerships:** Initiatives such as IAM-i already foster collaborations between academia, industry and public sectors to speed up the innovation processes in advanced materials. Some of the researchers interviewed believed that current initiatives could be complemented with cross-sectoral partnership structures that could contribute to exploring new avenues to support innovations in advanced materials science at the intersection of various domains of application.
10. **Industry support for early-stage technologies:** Most grantees interviewed believe in the need to further encourage the involvement of industry players in supporting early-stage, innovative technologies. In this context, some grantees highlighted the possibility of exploring ways in which industry could be incentivised to play a more active role as a funder of early-stage technological innovation. Others considered that the real added value of industry may be linked to facilitating access of startups and scale-ups to resources (e.g. experimental facilities, data, regulatory standards acumen) which are often lacking at the early stage of the process of product development. They advocated for a more structured space for accessing industry partners (in line with Recommendation 9).

Institutional culture and practice in academic institutions

The final set of recommendations address questions of institutional culture and practice of academic stakeholders to invigorate the translation of fundamental research into innovation. These include:

11. **Expanding the support for curiosity-driven frontier research:** All grantees agreed on the need to continue expanding the role of fundamental research as the bedrock for scientific breakthroughs that can open the door to technological innovation. Some grantees also argued in favour of emphasising potential impact over more conventional metrics during evaluations, thus creating additional incentives for researchers to align fundamental and application-oriented research questions in their research programmes.
12. **Creating better incentives for early-career researchers to engage in entrepreneurship:** Grantees recommended several approaches including: the diversification of career paths in academic institutions; better valorisation of engagement in innovation-related activities as part of the professional development of early career researchers; facilitating time off from other academic responsibilities (such as teaching or publishing) to allow sufficient bandwidth to engage fully in innovation-related activities.

Conclusion

ERC-funded frontier research provides a robust and indispensable scientific foundation for Europe’s leadership in advanced materials. Backed by a substantial and sustained investment from the ERC, advanced materials research represents a structural pillar of the ERC portfolio and is a decisive enabler of Europe’s future sustainable and high-value industries. This investment has generated world-leading scientific breakthroughs and tangible innovation outcomes that underpin key EU strategic priorities.

Looking ahead, continued and predictable investment in curiosity-driven research — complemented by strengthened technology transfer mechanisms, improved access to innovation financing and supportive institutional frameworks — will be essential to accelerate lab-to-market translation, foster sustainable industrial ecosystems and safeguard Europe’s long-term competitiveness and strategic autonomy in advanced materials.

Methodology

a. Portfolio characterisation

The project portfolio analysed was systematically constructed through the identification and selection of ERC-funded projects relevant to advanced materials within the Horizon 2020 and Horizon Europe programmes (2014–2023).

The initial exploratory search involved identifying a comprehensive set of keywords and conceptual terms designed to capture frontier research activities in advanced materials research. This list was subsequently validated by scientific officers with expertise across the relevant materials science domains to ensure accuracy, completeness and disciplinary coverage. Further verification steps were then undertaken using the non-hierarchical Mapping Frontiers Research taxonomy, which classifies the ERC portfolio across numerous topics, including several directly relevant to advanced materials. Together, these resources provided independent support for the selection and robust verification of the final curated project portfolio.

The projects were also classified using the three-layer taxonomy described in Section II, which distinguishes: (i) what the material is; (ii) what the material does; and (iii) the primary policy domain it supports. The taxonomy design and the project classifications were carried out based on a literature review and was refined further through the in-house expertise of the scientific officers and the members of the ERCEA Feedback to Policy team, supported by large language model-based analytical tools.

b. Bibliometric analysis

For the bibliometric analysis, the advanced materials projects funded under Horizon 2020 (2014–2020) were considered (1 121 projects out of a total portfolio of 1 503). For 929 of these 1 121 projects (83%), publications were identified based on data from OpenAIRE and the EU Open Data Portal.

In the next step, relevant bibliometric metadata from these publications was retrieved from OpenAlex and SciVal, using the DOI as a unique identifier. Data from OpenAlex led to 16 177 publications that were associated with the subset of Horizon 2020 projects. Only preprints and articles were considered in the analysis.

Uploading DOIs to SciVal, which draws data from the Scopus database and has a lower coverage of academic literature, reduced the number of publications to 14 289. However, leveraging SciVal introduced a broader array of bibliometric indicators into the analysis. Consequently, for some parts of the bibliometric analysis, this smaller dataset was used (top journals, key themes, citations in patents, citations in policy documents).

c. Interviews

To build the analysis on the factors influencing the process of spin-off creation, in-depth interviews were conducted involving 20 principal investigators.

Participants were selected following purposeful sampling aimed at maximising variation amongst the principal investigator experiences according to institutional and geographic variables[lxxv]. The selection focused first on the countries where spin-off creation was more prevalent in the portfolio. These were the UK, France, Germany, Spain and the Netherlands. Projects based in these countries covered 80% of the total sample of 52 grants identified as leading to the creation of spin-offs. Moreover, they present different innovation profiles according to the EU innovation scorecard[lxxvi]: The UK and the Netherlands are classified in this report as innovation leaders; Germany and France are considered strong innovators; Spain is considered a moderate innovator.

Within each country, at least two principal investigators were chosen, hence trying to maximise the differences around three variables:

- The host institution hosting the projects and supporting the creation of the company. This enabled taking into account variability in the role of universities and technology transfer offices in supporting spin-off creation.
- The geographic location of the company. Companies located both within major innovation clusters (e.g. Paris, London, Oxford–Cambridge, Amsterdam–Rotterdam) and outside of them were chosen to assess the influence of territorial networks and local innovation support ecosystems.
- Technology sectors in which the companies are involved. Interviews included principal investigators whose companies operate in biotechnology, food technology, renewable energy, chemistry and catalysis, green technologies, pollutant substitution, advanced electronics and semiconductors. This enabled capturing potential differences linked to the nature of the products being developed.

Finally, the sampling was further complemented with the inclusion of principal investigators based in Italy and Sweden to provide additional elements for the comparative analysis.

The inclusion of grantees based in Italy was justified as it added additional elements of comparability for interviews with principal investigators based in moderate innovation countries (e.g. Spain). Moreover, Italy is one of the leading EU countries in terms of the number of companies active in advanced materials technologies — only exceeded by Germany[lxxvii].

Sweden belongs to the group of innovation leaders in the EU[lxxviii]. While it was not well represented in the initial sample of 52 projects that led to the creation of spin-offs, it seemed important to include it because the regimen for the protection of intellectual property is quite unique as compared to all the other countries in the study[lxxix].

Interviews were conducted under the principle of non-attribution, unless participants agreed otherwise, in which case quotes were approved by the research participants before their inclusion in this report. In some cases, principal investigators opted for providing their input in writing.

The questionnaire for the interviews was structured to cover the following main themes: the trajectory from discovery to innovation, the main enablers and challenges encountered in the process, the role of collaborations with different stakeholders (public/private), and risks and expectations management strategies. In addition, questions about the perception of the future development of the spin-off and the lessons learned from the process were included to further contextualise the data obtained from each participant.

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Online resources

Strategic Technologies for Europe Platform (STEP) | European Union

ERC Panel Structure – 2024 Calls

Competitiveness compass - European Commission

Under the Horizon Europe programme, the European Commission has delegated a new task to the ERC Executive Agency (ERCEA) to identify, analyse and communicate policy-relevant research results to Commission services. The ERCEA has developed a Feedback to Policy (F2P) framework for ERCEA to guide these activities, adapted to the specificities of the ERC as a bottom-up funding programme. This report is part of a series aiming to highlight the relevance of ERC-funded frontier research, for addressing societal, economic and environmental challenges and thus its contributions towards key EU policy goals. This F2P series does not offer any policy recommendations.
For more information: https://erc.europa.eu/projects-statistics/mapping-erc-frontier-research.

Endnotes

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[i] Advanced Materials for Industrial Leadership - Research and innovation
[ii] Competitiveness compass - European Commission
[iii] Strategic Technologies for Europe Platform (STEP) | European Union
[iv] Commission, 'Recommendation on critical technology areas for the EU's economic security for further risk assessment with Member States' COM (2023) 2113 final
[v] Scientific Advice Mechanism's Scoping Paper on Advanced Materials
[vi] Commission seeks feedback on the future Advanced Materials Act - Research and innovation
[vii] In addition, the in-depth analysis provided for five policy areas covered in this report include projects funded under the FP7 Framework Programme: 1) parent grants of Proof-of-Concept (PoC) grants funded under H2020 and HE; 2) High-profile projects identified by the ERC's Scientific Department over the years for their contribution to the advancement of science. Further details can be found in the Methodology section.
[viii] ERC Proof of Concept grants: Exploring the innovation potential of ERC-funded research.
[ix] ERC Panel Structure – 2024 Calls
[x] Callister, William D., Jr., and David G. Rethwisch. Materials Science and Engineering: An Introduction. 10th ed. Hoboken, NJ: John Wiley & Sons, 2020; National Academies of Sciences, Engineering, and Medicine, Frontiers of Materials Research: A Decadal Survey. Washington, DC: The National Academies Press, 2019. National Academies of Sciences, Engineering, and Medicine, *Frontiers of Materials Research: A Decadal Survey*. Washington, DC: The National Academies Press, 2019.
[xi] Complementary classification schemes can also enrich this perspective, particularly those organised around the origins and primary categories of materials. Such schemes typically distinguish between raw and secondary raw materials, spanning minerals, fossil-based and bio-based feedstocks, as well as recycled, electronic and photonic materials. Building on these origins, more granular taxonomies classify advanced materials into groups such as energy materials, ceramics, advanced metallic materials and high-entropy alloys, hybrid and composite materials, nanomaterials, polymers, and smart or functional materials. While an origin-based perspective could be compatible with the three-layer taxonomy used in this analysis and might help contextualise the diversity of material types, in our study origins were not considered.
[xii] Details on how the CiteScore was retrieved can be found in the methodology section
[xiii] The percentile ranking of the journals in which publications stemming from ERC-funded research has been published has been analysed. Although this metric provides only an indirect measure, it serves as a reasonable proxy for the prestige, selectivity, and field-specific impact of research. For this analysis, SciVal data was used. SciVal ranks journals according to their CiteScore percentile, which is based on the ratio of citations to publications over the preceding four years. As with other bibliometric indicators, these results should be interpreted cautiously. Journal-based metrics act as proxies for research quality and impact; they cannot fully capture the novelty, interdisciplinarity, or societal relevance of the underlying research.
[xiv] Details on how the mapping was retrieved can be found in the methodology section
[xv] Data on citations in policy documents was obtained from SciVal (for more details see the methodology section)
[xvi] Another area of interest discussed in the Scientific Advice Mechanism's Scoping Paper on Advanced Materials is the dual/use and defence applications of advanced materials science. This is not analysed in this report.
[xvii] Trigeminal neuralgia is a rare chronic neurological condition characterised by severe, sudden, shock-like facial pain along the trigeminal nerve distribution.
[xviii] EP4486762A1
[xix] EP3897439B1; EP4547305A1
[xx] The 2025 Nobel Prize in Chemistry was awarded to Richard Robson, Susumu Kitagawa and Omar Yaghi.
[xxi] EP3891094B1
[xxii] WO2025098967A1
[xxiii] EP2875172B1; EP3285075A1; EP4374000A1; EP4558449A1
[xxiv] A resistive switching memory, often abbreviated as ReRAM or RRAM (resistive random-access memory), is an emerging type of memory technology that relies on the principle that certain materials can reversibly switch between high-resistance and low-resistance states when an electric voltage or current is applied. These two states correspond to the binary values 0 and 1, allowing data storage without the need for continuous power.
[xxv] WO2022171855; WO2024121442
[xxvi] EP4481965A1

[xxvii] They can be processed in solution and under ambient conditions, thus being appealing for large scale printing production.
[xxviii] For additional analysis on these kinds of applications, please see the Health section above.
[xxix] 3DWO2023186995A1; 3DWO2023012302A1; EP4381916A1
[xxx] WO2022129306A1; EP4381916A1; WO2023012302A1; WO2023186995A1
[xxxi] In this chapter, the focus is mainly on solid state quantum dots and colloidal quantum dots, as examples of materials science where surface and finite-size effects can lead to several developments for electronics and optoelectronics.
[xxxii] US2024178451A1; US2022263085A1; EP4038670A1
[xxxiii] WO2021219220A1
[xxxiv] EP3292867; EP3509598B1; EP3752506B1; EP4233928A3
[xxxv] Perovskites promise boost for solar power technology | Research and Innovation
[xxxvi] Poisson's ratio measures a material's deformation when stretched or compressed. It quantifies how much it shrinks or expands in directions perpendicular to an applied normal force. A negative Poisson's ratio implies that a material expands laterally when stretched and contracts laterally when compressed, in contrast to most materials, which thin out when stretched.
[xxxvii] WO2025061777A1
[xxxviii] It should be noted that one project can have more than one area of application. Approximately 9% of PoC projects have been categorised as applying to more than one area. To identify the more specific areas of innovation within the broader sectors, PoC projects have been classified using the taxonomy of the European Innovation Council.
[xxxix] The most updated dataset available covers EIC Transition projects with a start date until 01/01/2024.
[xl] NL2023462B1
[xli] EP4069862B1
[xlii] EP2057211B1; US20130107344A1; EP2795690B1
[xliii] As a result of this research a company CamGraPhIC Ltd has been established to exploit additional applications on graphene integrated photonics devices. The company commercialises high-performance photonic integrated circuits (PICs) featuring single-crystal graphene in both the detector and modulator elements of an optical transceiver, offering unparalleled bandwidth density, reduced customer, high traffic capacity, and superior temperature resilience, ensuring scalability to meet future demands. This company has been successful in raising 25 M EUR in start-up investment.
[xliv] US8323789B2; EP2304412B1
[xlv] Data on ERC Horizon 2020 and Horizon Europe projects for declaring patents were retrieved from CORTEX on 21/11/2025.
[xlvi] Data extracted from SciVal, which integrates information from LexisNexis on the citation of scientific publications in patent filings.
[xlvii] Self-reported data have inherent limitations, as they do not capture activities occurring outside the lifetime of a project. In addition, data on the creation of spin-off companies and on industry partnerships have only been systematically collected for projects funded under Horizon Europe. Earlier analyses have nonetheless shown a significant impact of PoC grants on spin-off company creation. A 2017 study, An Empirical Assessment of the ERC PoC Programme, reviewed data from 2011 to 2016 and surveyed 4,378 ERC grantees, of whom 242 had received a PoC grant. Of these PoC beneficiaries, 20% had engaged in launching a spin-off company. A subsequent survey conducted in 2020, targeting 9,270 ERC grantees, found that roughly half of the 491 respondents who had held at least one PoC grant reported involvement in entrepreneurial activities of this kind. See: ERC Proof of Concept Grants: Exploring the innovation potential of ERC-funded research.
[xlviii] EP4452238A1
[xlix] EP4452238A1
[l] WO2025073975A1
[li] US20230140883A1; WO2025133559A1; WO2024201045A1
[lii] EP4565069A1
[liii] EP4153142A1
[liv] WO2024030661A1; WO2022136262A1
[lv] WO2024170549A1; WO2025237975A1; EP3310930A1
[lvi] EP4536401A1

[lvii] PFAS are a large group of synthetic chemicals widely used in industry and consumer products, persistent in the environment, and linked to serious human health and ecological risks.

[lviii] US20250246866A1; WO2024210817A1; WO2025078447A1

[lix] WO2013/171518

[lx] EP3820964B1

[lxi] EP4043404A1; EP4379077A4; EP4632776A1

[lxii] EP4291531A1

[lxiii] Hossinger, S.M., Chen, X., Werner, A. Drivers, barriers and success factors of academic spin-offs: a systematic literature review. Management Review Quarterly 70, 97–134 (2020), https://doi.org/10.1007/s11301-019-00161-w; Correia, M.P., Marques, C.S., Silva, R. et al. Academic Entrepreneurship Ecosystems: Systematic Literature Review and Future Research Directions*.* Journal of the Knowledge Economy 15, 17498–17528 (2024), https://doi.org/10.1007/s13132-024-01819-x; de Falani Bezerra, S.Y.A., Torkomian, A.L.V. Technology Transfer Offices: a Systematic Review of the Literature and Future Perspective. Journal of the Knowledge Economy 15, 4455–4488 (2024), https://doi.org/10.1007/s13132-023-01319-4; Davey, T., Rossano, S., van der Sijde, P. Does context matter in academic entrepreneurship? The role of barriers and drivers in the regional and national context. Journal of Technology Transfer 41, 1457–1482 (2016), https://doi.org/10.1007/s10961-015-9450-7.

[lxiv] See also: Joint Research Centre, Deep tech entrepreneurship in Europe and the crucial role of RTOs fostering impactful industrial spin-offs, Publications Office of the European Union (2025), https://data.europa.eu/doi/10.2760/7964758

[lxv] One interviewee referred to the perceived lack of capacity of the TTO in his institution as a powerful deterrent that has prevented his engagement in results valorisation activities.

Interviews highlighted instances where universities claimed a significant percentage of shares in spin-offs. In other cases, early-stage businesses reported initial intellectual property licensing agreements as financially burdensome, compared to market terms, thus deterring further private investment. Such practices have been widely acknowledged in the literature as negatively impacting entrepreneurship.

[lxvii] Generally, the ability to recruit dedicated and highly motivated talent positioned at the interface between science and entrepreneurship was identified as a key factor in the successful creation of spin-off companies.

[lxviii] In the context of these interviews, four principal investigators have been beneficiaries of EIC Transition grants, which provide non-dilutive funding and tailor-made support to advance the process of technology maturation beyond the experimental proof-of-principle in the laboratory. The specific characteristics of the EIC Transition grants, the amount of funding made available (up to €2.5 million) and the longer time horizon for implementation were highlighted as critical to the successful establishment of the spin-offs. In addition, one principal investigator received an EIC Pathfinder grant, while two principal investigators declared receiving innovation support funds from the European Institute of Innovation and Technology, and the Future Emerging Technologies Programme (predecessor of the current EIC grant schemes).

[lxix] Larger urban centres such as London, Paris, Stockholm or renowned innovation clusters such as the Oxford–Cambridge corridor or the Amsterdam–Rotterdam corridor, Cologne or Munich were mentioned in the interviews as examples of dynamic ecosystems which facilitated the process of securing private venture capital investment.

[lxx] ‘Hard tech’ refers to advancements rooted in physical engineering and science-driven breakthroughs. ‘Hard tech’ innovations can be capital-intensive, requiring substantial investments to develop, commercialise and scale. They also generally have longer research and development cycles before they reach market readiness.

[lxxi] During interviews, principal investigators described their engagement in due diligence activities, often supported by peer networks (both their own and their company’s CEO’s networks, when available) or the TTO, to assess candidate investors’ experience, interests and investment portfolio.

[lxxii] As noted in a recent report, in most of the countries covered by the study there are new rules (legislation, university by-laws) and guidance on these questions aimed at improving and clarifying the frameworks for spin-off incorporation in universities. For example, rules and university by-laws in countries such as the Netherlands, France and Germany have tried to limit the amount of equity stakes that universities can claim in the process of spin-off incorporation. Similarly, in the countries in the sample, non-equity and quasi-equity participation modes are becoming more common in the practice of universities. See: Barrabes, Deep Ecosystems, Leibniz Institute for Research on Society and Space, Start-Up Europe 2025, Spin-offs: Reinforcing a Vector of Value Creation for EU-27. https://digital-strategy.ec.europa.eu/en/library/spin-offs-driving-innovation-across-eu-27

[lxxiii] One principal investigator explained how the spin-off team faced significant administrative burdens when purchasing materials and services through the university, with some suppliers refusing to engage due to the complex documentation requirements.
[lxxiv] In most cases, the research lab provides long-term stability to the whole project of spin-off creation, notably during the early stages of technology maturation (e.g. collaborations between the university laboratory and the company on research and testing as well as facilitating mutual access to equipment).
[lxxv] Purposeful sampling is a non-probability sampling technique used in qualitative research to intentionally select participants who are most likely to provide rich, relevant information about the research topic. See: Ahmad, M., Wilkins, S. Purposive sampling in qualitative research: a framework for the entire journey. Quality and Quantity **59**, 1461–1479 (2025), https://doi.org/10.1007/s11135-024-02022-5.
[lxxvi] The European Innovation Scoreboard provides a comparative assessment of the Research and Innovation performance of EU Member States, other European countries, and global competitors. It helps countries assess the relative strengths and weaknesses of their national innovation systems and identify challenges that need to be addressed. The European Innovation Scoreboard 2025 was released on 15/07/2025 and can be found here.
[lxxvii] According to a study published by the European Commission in 2024, 20.6% of all companies active in advanced materials technologies in the EU are based in Italy — that is roughly 6% of all the companies worldwide, which is equivalent to the proportion of companies based in China (6.7%) or the UK (6.6%). See: Directorate-General for Research and Innovation, IDEA Consult and PPMI. Industrial R&D&I investments and market analysis in advanced materials — Summary report, Publications Office of the European Union (2024), https://data.europa.eu/doi/10.2777/371763.
[lxxviii] Idem.
[lxxix] The ‘teacher exemption’ in Sweden ensures that Swedish academic staff retain ownership over their inventions, research results and, in practice, other intellectual property generated in their professional capacity. This legal regime emphasises academic freedom, individual ownership and the necessity of explicit agreements for commercialisation or third-party licensing. It is a unique model, contrasting with standard employer-centric intellectual property regimens elsewhere.

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Pictures:
Cover: Ferroelectric domains in hexagonal ErMnO3. Opposite brightness represents positively and negatively charged regions on the crystal surface. Image width is about 100 μm.
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