EIC TECH REPORT 2024

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TABLE OF CONTENTS

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Deep Tech Europe

European Innovation Council Tech Report 2024

EISMEA - European Innovation Council and SMEs Executive Agency

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THE EUROPEAN INNOVATION COUNCIL

TECH REPORT 2024

FOREWORD

"With the pressing need for the world to transition to a more sustainable and resilient future, identifying and nurturing transformative concepts in their early stages has never been more critical. Innovation, and deep tech innovation in particular, can play a pivotal role in addressing these complex challenges from the outset while enhancing Europe's competitiveness, economic security, and strategic autonomy, as underscored in the reports "The future of European competitiveness[1]" and "Align, act, accelerate[2]", coordinated by Mario Draghi and Manuel Heitor respectively.

The EIC is the largest supporter of European deep tech researchers, entrepreneurs, and companies. By offering a one-stop shop to identify and support breakthrough innovations, from early-stage research to market scale-up, it is central to positioning Europe at the forefront of the next generation of deep tech.

This 2024 European Innovation Council (EIC) Tech Report provides an overview of promising emerging developments (henceforth referred to as 'signals') following a thorough analysis of our internal data. The report highlights the scientific and technological novelty of these signals and explores potential areas of impact at both European and global levels over short- to mid-term horizons.

These signals can provide empirically backed references for Europe's priorities, aligning with key EU innovation policy frameworks such as the New European Innovation Agenda (NEIA)[3]. They can also contribute to discussions on novel approaches for tackling pressing issues surrounding climate change, public health, or digital transformations, while showcasing the EU's renewed commitment to fostering the kind of deep tech leadership championed by the EIC.

Furthermore, the ultimate ambition of this report is to inform and stimulate European innovation ecosystems, from academia, industry and markets to venture capital, public investment bodies, or policymakers at regional, national, and EU levels. If you and your organisation are committed to deep tech and aspire to make Europe the best place to grow the world's most exciting innovations, then this report is for you. Thank you for joining us on this exciting journey!"

Jean-David Malo

Director of the European Innovation Council and SMEs Executive Agency (EISMEA)

1 INTRODUCTION

The 2024 European Innovation Council (EIC)[4] Tech Report is a comprehensive watchlist of emerging technologies and breakthrough innovations developed by both funded and aspiring EIC awardees since 2018. It highlights 34 signals, identifying technologies and innovations at early development stages in EIC data that show significant potential for future advancement.

The EIC is the EU's flagship programme to support deep-tech from early-stage research to market scale-up, with a budget of over €10 billion. Our mission is to position Europe at the forefront of global innovation, driving solutions to society's most pressing challenges.

This report follows the success of previous editions[5] and strives to improve their methodology. The chosen approach involved the quantitative identification of a first larger set of 260 signals via data mining and scientometric[6] analytics with support of the European Commission's Joint Research Centre (JRC)[7], followed by a qualitative review and final selection of 34 signals under the leadership of EIC Programme Managers in collaboration with 32 external experts.

All signals were identified and selected through sequential quantitative and qualitative assessments of EIC internal data encompassing submissions for funding at low Technology Readiness Levels[8] (TRL 1-4) between February 2018 and December 2023. This includes both funded projects and proposals that were not funded due to criteria beyond scientific or technological excellence. No specific projects or proposals are mentioned to ensure that no individual entity is singled out and that sensitive or confidential information remains protected by the EIC.

Signals, in this context, refer to early observable indications of potential future advancements that could have significant effects if further developed or even combined with other signals. Their observation can help to identify shifts that may evolve into major trends or disruptive paradigm changes, making signals essential in anticipating tomorrow's challenges. This helps to future-proof and support evidence-based policy making. Furthermore, it is especially valuable in research and innovation spaces where timely recognition and support for early-stage ideas can lead to strategic advantages[9].

With focus on such early-stage ideas, the data sources of this report are derived from the EIC Pathfinder instrument under Horizon Europe, managed by the European Innovation Council and SMEs Executive Agency (EISMEA)[10], and the final stage of its predecessor, the Future & Emerging Technology (FET) programme[11] in the EIC pilot under Horizon 2020 (H2020)[12]. The report includes data from bottom-up or open calls, like EIC Pathfinder Open and FET Open, and data from targeted or topic-driven calls, such as EIC Pathfinder Challenges and FET Proactive or Flagships.

The signals are organised in the report into the three macro-areas of main EIC activity, Green, Health and Digital, Industry and Space. They are linked with critical sectors based on the new EIC taxonomy for deep tech[13], and they are aligned with recent EU policy priorities, such as the Strategic Technologies for Europe Platform (STEP)[14] or the European Commission's lists on critical areas for the EU's economic and technological security[15], and equally aligned with ongoing sector-specific EU policy frameworks, such as the EU's Green Deal Industrial Plan[16], the Pharmaceutical Strategy for Europe[17] or the European Chips Act[18].

Future-oriented monitoring

The objective of the EIC Tech Report 2024 is to emphasise the added value of identifying and monitoring early-stage ideas within EIC internal data, based on quantitative and qualitative observations across funded projects and proposals, and supported by external expert assessments.

These signals are worthy of future-oriented monitoring under the EIC proactive management framework due to early indications of their technological and innovation potential, as well as their relevance to the EU's policy priorities. They also represent an opportunity to extend our internal horizon scanning and place these ideas on the public radar, enabling a collective tracking of their potential development into impactful innovations that could inform discussions on future opportunities and form the foundation for critical breakthroughs shaping Europe's future.

While they can form part of the evidence-based inputs to inform future priorities for the EIC, they should not be interpreted as forecasting indicators of upcoming funding priorities. Such decision-making requires substantial in-depth analysis and benchmarking against wider global technology trends, which are beyond the scope of this report.

2 Watchlist

of EIC signals on emerging technologies and early-stage breakthrough innovation

2.1. GREEN

This section of the report showcases early-potentially transformative innovations in agriculture and food, energy systems, climate and environmental technologies, and the built environment. These domains are critical for Europe's transition toward a sustainable, resilient future and reflect the importance of deep tech in addressing food security, energy transition, climate change mitigation, and other pressing global environmental challenges.

The green macro-area is linked with sectoral priorities essential for achieving Europe's climate and sustainability goals, aligned with key EU strategies, including the Green Deal Industrial Plan[19], the Farm to Fork Strategy[20], REPowerEU Plan[21], Circular Economy Action Plan[22], Critical Raw Materials Act[23]. It highlights the role of early-stage innovations in driving progress across for example food security, energy efficiency, environmental protection, and carbon-neutral infrastructures, and it underscores the value of collective tracking and collaboration in scaling these innovations to address systemic challenges, paving the way for a sustainable, competitive future in line with Europe's long-term strategic vision.

2.1.1. Plant-based biomanufacturing and metabolic reprogramming for climate smart agriculture

What is it?

Plant-based biomanufacturing and metabolic reprogramming are innovative technologies for leveraging the numerous natural capacities present within a plant, influencing metabolic processes and cellular behaviour, in order to adapt to environmental conditions and secure crop yields while producing valuable substances. Metabolic reprogramming in biotechnology refers to the manipulation of cellular metabolic processes to influence cell behaviour and function while experiencing stress. Stresses such as extreme temperatures, droughts, flooding, high salinity can significantly change the ideal growth and development of plants, especially if they are occurring simultaneously. Plant-based biomanufacturing, also known as molecular pharming, leverages the natural capabilities of plants to synthesise complex molecules, such as biopharmaceuticals, proteins, vitamins and enzymes, in turn offering several advantages over traditional manufacturing methods. The combination of those innovative technologies can preserve crop yields, improve food security, and provide cost-effective, scalable, biosafe, and environmentally sustainable production of proteins, enzymes, biopharmaceuticals and other ingredients.

What is new?

The novelty of plant-based biomanufacturing and metabolic reprogramming lies in their innovative approaches in understanding and manipulating cellular functions and producing valuable substances using plant cells. Plant-based biomanufacturing is cost-effective, scalable, and biosafe, by using plants for the sustainable production of food ingredients, biopharmaceuticals and enzymes. Metabolic reprogramming offers deep insights into cellular metabolism, revealing the interconnections between metabolism, immunity, and cell function(s). In agriculture, it enhances the understanding of plant responses to multiple stresses, opening new avenues for cultivating stress-resilient crops. Together, these technologies reduce operational costs, minimise contamination risks, and promote sustainable production, marking significant advancements in biotechnology and agriculture.

How may it impact the next five to ten years?

Metabolic reprogramming has the potential to facilitate a better understanding of the interactions between stress combinations and the occurring responses of plants. While there exists considerable research on metabolic responses to the effect of a singular stress on a plant, the interaction of multiple stresses on a plant represents a more uncharted frontier. The emerging understanding of this dynamic process opens new possibilities for breeding stress-resilient crops and preserving crop yields and food security. The combination with plant-based biomanufacturing could provide cost-effective, scalable, biosafe and environmentally sustainable production of proteins, enzymes, biopharmaceuticals, and other ingredients.

2.1.2. Tri-parental plant breeding for resilient farming

What is it?

Plant breeding involves a large array of different genetic techniques, needed to produce plants with desirable traits that are more beneficial to humans and better adapted to the designated specific environmental conditions. This is done by carefully selecting which plants are allowed to mate and afterwards choosing offsprings displaying the desired traits. By repeating this process over multiple generations, the genetic makeup of the plant population can be altered significantly, surpassing and exceeding what would occur naturally without direct human involvement. Traditional plant breeding occurs between two parents, one mother and one father, but tri-parental breeding refers to a particular technique where the fertilisation occurs between three parents, specifically one mother and two fathers. While this is fatal for animals, certain kinds of plants tolerate this technique surprisingly well, in turn offering interesting opportunities to accelerate plant breeding. It provides opportunities of selecting multiple traits at once, significantly speeding up the selection process. Among other applications, this would be indispensable for developing climate-resilient plants without resorting to direct genetic modification of plants.

What is new?

This novel technology introduces a groundbreaking method for creating polyploid plants with three genetic parents-controlled fertilisation. Unlike in animals, plants can tolerate it, allowing for the hybridisation of three distinct genomes in a single cross. This conventional method not only promotes increased plant size and vigor, but also bypasses traditional genetic barriers, allowing the combination of plants that previously could not be hybridised. In addition, it speeds up the breeding process by combining beneficial traits from three parents. Therefore, offering a powerful tool to accelerate crop improvement(s), especially for challenges pertaining to the adaption of plants to climate change.

How may it impact the next five to ten years?

As the consequences of climate change intensify, we urgently need better adapted crops for challenging environments. The slower-paced traditional breeding methods and natural evolution are insufficient to meet these challenges. Tri-parental breeding could offer a solution by enabling the development of plants with enhanced traits that better respond to stress factors like drought, resistance to pests, and diseases. Furthermore, as global populations rise and agricultural land becomes more limited, increasing crop productivity and resilience is key for ensuring a stable food supply. Tri-parental breeding could play an important role in producing high-yield crops that are better adapted to meeting challenging environments, hence contributing to both the stability and sustainability of the global agriculture and food supply chain.

2.1.3. Biohybrid sensors for next generation precision agriculture

What is it?

Plant-based biohybrid sensors are a novel technology that utilise plants and their metabolic processes as sensor devices. They have been engineered to self-generate, requiring no batteries, and producing signals such as bioluminescence or changes in colour, as a response to stimuli. They enable the detection and measurement of various environmental factors, e.g., ultraviolet radiation, water stress, nutrient requirements, and biotic and abiotic stressors. These insights provide a groundbreaking understanding of plant-level statuses and support a broad range of applications, ranging from precision agriculture and smart farming decision at a plant level, to plant breeding, plant-based biomanufacturing, crop yield optimisation, monitoring environmental conditions to improving both supply chain management and the nutritive value(s) of crops to.

What is new?

The new aspects of plant-based biohybrid sensors lies in their use of living organisms as sensing devices, which is a significant departure from traditional silicon-based or other non-biodegradable sensors. These sensors are environmentally friendly, non-toxic, biodegradable, and capable of reducing CO2 emissions. These sensors can even have the ability to self-generate, thus eliminating the need for batteries. Additionally, plant-based biohybrid sensors are able to provide continuous monitoring, which offers more accurate and timely data than non-continuous measurements, as they can be tailored to specific genotypes or pathogens. This technology represents a significant advancement in the development of green measuring systems.

How may it impact the next five to ten years?

Amending environmental data with specific plant data, especially in regard to the ability of a plant to utilise available resources could push precision agriculture to a new level. This is particularly important when key resources, namely water, are scarce. Wide-scale usage of plant-based biosensors could lead to significant positive impact(s) on food security, human and animal nutrition, soil health, water management, decarbonisation, climate resilience, and biodiversity.

Ivan Stefanic

EIC Programme Manager for food chain technologies, novel and sustainable food

"An analysis of emerging technologies and early-stage breakthrough Innovations is essential for societies that care for long term competitiveness and technological sovereignty. This is further emphasised by the growing importance of environmental sustainability and resilience.

In the agrifood sector the reasons for that are many: a) agriculture in general involves work with living organisms under continuously changing environmental conditions; b) agricultural systems are complex and involve seamlessly integrated core- and key-enabling technologies; c) the food supply system is by far the largest global employer – scaling-up disruptive technologies becomes especially demanding and with several simultaneous technology transfer models; d) it is not only about efficiency and profitability – the long-term effects of deployed (radical) innovations, focused on environmental pollution, biodiversity, and animal- and human well-being should be considered; e) the development of radical agrifood innovations can take in certain cases (e.g. new plant varieties, animal breeds and vaccines), decades and involves numerous rounds of financing – with failure in only a single step enough to cancel the efforts made f) the global food supply chain is scattered globally - food can travel thousands of kilometres before reaching your tables, while impacted by volatile market changes. Ultimately, the food supply chain is heavily dependent not solely on STEM technologies, but also on social sciences, further underscoring the importance where the EIC can support a more efficient, inclusive, resilient, and sustainable food supply system.

The analysis and monitoring of signals on emerging technologies and early-stage breakthrough innovations in the agrifood sector during the past three years has played a very important role in my work with the EIC, namely in the preparation and consolidation of my portfolio."

Carina Faber

EIC Programme Manager for renewable energy conversion and alternative resource exploitation

*“**The transition to a circular economy, driven by renewable energy and alternative resources,** holds immense potential for climate change mitigation. Currently, the linear economy relies on fossil resource extraction and scarce raw materials. In contrast, fuels, chemicals and materials made from renewable energy, water, and simple molecules like CO2 close the loop, providing long-term storage of renewable energy, fossil-free feedstocks for the chemical industry, and a multitude of products ranging from hydrogen to protein-rich powders for the feed sector. Scaling up these technologies remains a critical challenge, but these signals offer a good starting point.*

The development of synthetic aviation fuels, for example, through the Fischer-Tropsch pathway, requires navigating complex value chains—from CO2 sourcing and renewable energy production to refining and final utilisation. These processes must be further optimised to ensure viable business models and genuine CO2 reductions. Emerging technologies, as so-called artificial photosynthesis technologies, which store solar energy directly in chemical bonds, offer further potential. A rich spectrum of approaches is explored, leveraging on advanced electrochemistry, photocatalysis and synthetic biology.

Looking ahead, decentralised production of fuels and chemicals, powered by locally available renewable energy, may be an important building block of a future circular, renewable-driven economy. The goal is full integration where in a single device CO2 and other molecules are transformed into valuable products. A crucial question is where molecular feedstocks can be sourced sustainably at the needed scale. CO2 from the atmosphere is one option, but advances in direct air capture are needed. Plastic waste, rich in carbon, could also serve as a feedstock, contributing to both waste management and fuel production. Microplastics in wastewater may offer another carbon source, simultaneously remediating water resources.”

2.1.4. High-temperature thermal energy storage advancements

What is it?

High-temperature thermal energy storage (TES) is a critical innovation addressing energy efficiency and decarbonisation, especially in industrial heat and power to heat for energy storage. TES involves three main technologies: sensible heat, latent heat and thermochemical energy storage. Although sensible heat storage is considered mature at lower temperatures, high-temperature TES, operating above 600°C, faces substantial challenges. These include material synthesis for storage media, containers and insulation walls, active heat exchangers with embedded storage functionalities and additive manufacturing processes, as well as system integration. Latent heat storage, using phase change materials (PCMs) and thermochemical energy storage, are still at low TRL levels but hold potential for high-temperature applications. Innovations in this area aim to overcome these hurdles to enable more efficient and durable heat storage in industrial sectors and for power system flexibility.

What is new?

The novelties in high-temperature TES span several areas, including material science, process systems engineering, manufacturing and design. Key developments include new solid and liquid sensible heat storage materials like advanced ceramics and molten salts, which can withstand high temperatures while maintaining thermal performance. Additionally, innovations in PCM-based TES and high-temperature thermochemical energy storage are under exploration, pushing the boundaries of material capabilities. A further key novelty lies in the creation of specialised containers or coatings designed to endure high thermal cycling stress. These technological breakthroughs could revolutionise industrial heat storage, especially in systems requiring temperatures from 400°C to over 1000°C.

How may it impact the next five to ten years?

Within the next decade, advancements in high-temperature TES could play a pivotal role in decarbonising industrial heat processes, which account for approximately 22 % of global greenhouse gas emissions. By enabling efficient storage and utilisation of thermal energy in industries such as manufacturing, chemical processing, and power generation, these technologies may significantly reduce energy consumption and emissions. Additionally, high-temperature TES could enhance the stability and reliability of power systems by providing a cost-effective alternative to traditional energy storage solutions like batteries and hydro-storage. This innovation may also foster the development of power to heat to power with reversible heat pumps coupled to TES and able to operate as engines or generators (cCarnot batteries), further integrating renewable energy sources and supporting the EU's goals for energy efficiency, sustainability, and industrial competitiveness.

2.1.5. Enhanced energy density in sustainable fuels for aviation

What is it?

Aviation is a significant contributor to global warming, through carbon dioxide emissions during fuel production, storage, transport, and refuelling, and due to the formation of contrails during the flights. Decarbonising aviation requires a multi-faceted approach, including electrification for short-range aircraft, and sustainable aviation fuels (SAFs) for long-haul flights. Various drop-jet SAFs, such as liquefied hydrogen, ammonia, synthesis fuels (e-fuels), and biofuels, are being explored to meet these needs. This signal focuses on the production, handling and utilisation of SAFs with enhanced energy density, ensuring they are competitive with conventional jet fuels in terms of performance and cost per unit of energy. The innovations aim to make SAFs more efficient and cost-effective while maximising the use of existing infrastructure, thereby supporting the transition to a more sustainable aviation sector.

What is new?

The key novelty lies in the development of SAFs that rival conventional jet fuels in higher volumetric and gravimetric energy densities. These SAFs are designed to offer comparable performance at competitive costs while being produced, stored, and utilised more efficiently. Innovations are particularly focused on addressing challenges associated with fuels like liquefied hydrogen (LH2) and ammonia, which require advanced insulation and storage solutions due to their low boiling points and energy densities. A promising approach involves integrating zero-carbon, high-energy content solid particles into these fuels to enhance their energy output and stability, potentially transforming jet engine and fuel cell-powered aircraft technologies.

How may it impact the next five to ten years?

In the next decade, innovations in high-energy-density SAFs may significantly enhance the competitiveness of the EU aviation industry and its supply chains. These advancements are crucial for maintaining the EU's leadership in sectors such as jet engine manufacturing and sustainable fuel production technologies. The aviation sector, responsible for around 2% of global carbon emissions, holds substantial economic value for the EU. By transitioning to more efficient and sustainable fuels, the sector could reduce its environmental impact while continuing to contribute significantly to the EU economy. Additionally, these innovations might spur the development of new regulatory frameworks and industrial standards, ensuring the safe and widespread adoption of these advanced fuels across the aviation industry.

2.1.6. Thermal management innovations from electric vehicles to data centres

What is it?

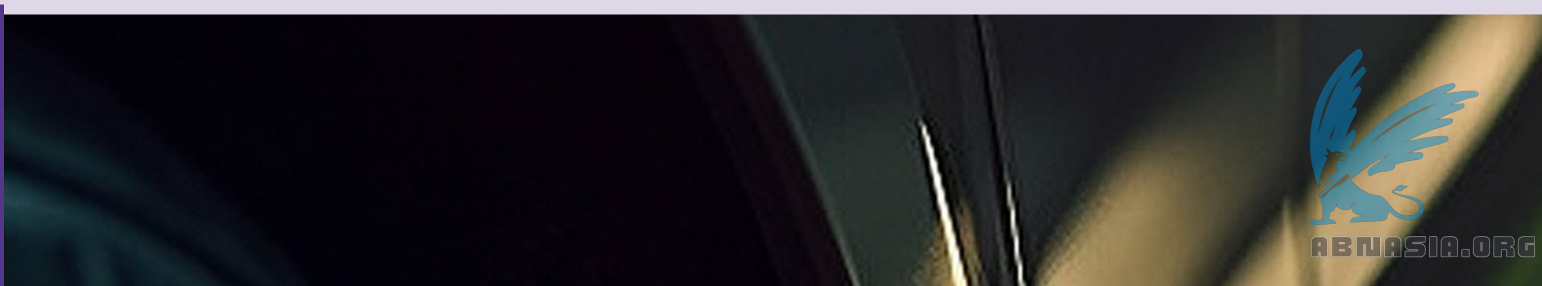
This signal explores advanced thermal management technologies aimed at significantly reducing energy losses and improving operational reliability in data centres, electric vehicles (EVs), and electronic equipment. Traditional energy conversion, transmission, storage, and utilisation processes often result in wasted heat, leading to inefficiencies and high operational costs. The innovation focuses on developing ultra-low thermal resistance devices and technologies that can convert wasted heat into useful energy. These advancements could revolutionise the management of thermal energy in critical sectors by improving energy efficiency and reducing infrastructure investment costs.

What is new?

The primary innovations include the introduction of thermal energy storage (TES) systems in electric vehicles to separate the functions of battery power and thermal management, allowing EVs to operate more efficiently, especially under extreme weather conditions. Additionally, the signal highlights a novel approach to cooling data centres and telecommunication base stations by using thermochemical, sorption or solid state-based technologies that convert low-grade waste heat into cold energy. This not only reduces energy consumption but also enhances the reliability and cost-effectiveness of thermal management systems. These innovations stand out for their potential to create a new energy infrastructure that is both efficient and adaptable to various applications.

How may it impact the next five to ten years?

These advanced thermal management technologies could lead to significant reductions in global energy consumption, particularly in sectors with high thermal energy demands for cooling like data centres and EVs. The integration of TES systems in EVs might extend vehicle range, improve battery safety in extreme conditions, and optimise energy use in cold chain logistics. Additionally, the adoption of thermochemical cooling technologies in data centres could decrease energy costs and infrastructure investments, while also providing a sustainable method for repurposing low-grade waste heat. These advancements are likely to play a critical role in supporting the EU's goals for energy efficiency, competitiveness, and sustainability.



Paolo Bondavalli

EIC Programme Manager for advanced materials for energy

The future of advanced materials for energy is closely tied to addressing strategic challenges that will significantly transform the field in the coming years.

One key challenge is accelerating research in specific areas by leveraging AI to discover and develop new advanced materials capable of enabling devices and systems with drastically improved performance. This includes breakthroughs in energy storage through phase-change materials, thermal, electrochemical, or chemical properties, as well as the uncovering of novel phenomena able to give rise to a new generation of devices.

From the outset, research and development must also focus on characterisation and production methods, with particular attention to scalability from its very beginning. These are fundamental activities to stimulate concrete impact for advanced materials.

Another major area of innovation is energy harvesting, where certain technologies with huge potential, such as thermoelectrics, remain technologically stagnant and new operation principles need to be explored. In this context, the development of advanced materials with significantly enhanced performance, as well as the exploration of new exotic properties (e.g., topological materials, 2D materials), could be transformative. These advancements could shift paradigms in the field, enabling a new generation of entirely novel and highly efficient devices.

Such breakthroughs would directly impact Europe's strategic energy autonomy, substantially reducing energy consumption burdens. Moreover, a systemic approach is needed to optimise the integration of this new generation of energy harvesting and storage devices, which rely on advanced, high-performance materials. This optimisation applies not only to large-scale installations but also to miniaturised systems, such as IoT devices, which could dramatically be impacted reducing their energy consumption and improving efficiency.

Franc Mouwen

EIC Programme Manager for architecture, engineering, and construction technologies

In the coming decades, the construction sector faces a perfect storm of challenges: meeting growing demand for new buildings and infrastructure, handling a wave of renovations, transitioning to carbon neutrality, adopting circular practices, boosting productivity, addressing labor shortages, and controlling escalating costs.

Being one of the EU's largest industries, construction plays a crucial role in realising the important EU policies such as the European Green Deal and the drive to circular economies. However, scaling innovation in this sector is challenging. The ecosystem is complex, fragmented, and dominated by small companies. Additionally, path dependencies linked to standards and codes make rapid change difficult.

As the signals in this report show, construction in the physical world stands to benefit from seamless integration with a realistic, data-driven virtual environment. Such an immersive digital world will in turn enable automated, industrial-scale construction supply chains, blurring the line between offsite and onsite work. Digitalisation will also allow the construction sector to better disseminate learnings and capture economic effects across projects at scale.

Achieving this level of digital transformation requires breakthrough technologies and collaboration across Europe's scientific ecosystems, uniting disciplines like computer science, data science, robotics, engineering, and architecture. This interdisciplinary approach is at the heart of Europe's competitive edge and underpins Europe's leadership in deep tech.

2.1.7. Artificial CO_2 photosynthesis and biomimetic solar energy conversion

What is it?

Artificial photosynthesis is an innovative approach aimed at converting solar energy directly into chemical energy, specifically through the production of renewable fuels and chemicals by mimicking the natural process of photosynthesis. Unlike traditional solar technologies that convert sunlight into electricity or heat, artificial photosynthesis seeks to utilise solar energy to drive chemical reactions, reducing water and CO_2 to generate storable, renewable fuels, and high-value chemicals. This technology holds the potential to decarbonise hard-to-abate industries and contribute to carbon dioxide removal (CDR) efforts by using CO_2 as a feedstock. However, despite its promising applications, the technology is still in its infancy, facing significant challenges related to efficiency, stability, and scalability.

What is new?

The novelty of artificial photosynthesis lies in its biomimetic approach, where solar energy is harnessed not just for immediate power generation but for triggering chemical reactions that produce storable renewable fuels and chemicals. This technology employs photocatalysts, materials that absorb sunlight and catalyse the conversion of CO_2 and water into value-added products. The diversity of catalyst types—ranging from homogeneous and heterogeneous to biocatalysts—allows for the production of various renewable fuels and chemicals. However, the field is still developing, with ongoing research focused on creating more efficient, stable, and scalable systems, particularly in developing catalysts that avoid critical raw materials (CRM).

How may it impact the next five to ten years?

In the next five to ten years, artificial photosynthesis could significantly impact the renewable energy sector by providing a method for producing storable renewable fuels and chemicals, which traditional solar technologies cannot achieve. This could lead to the decarbonisation of energy-intensive industries and the reduction of atmospheric CO_2, contributing to climate change mitigation. Technologically, advancements in this field may foster innovations in catalyst development, reactor design, and interface engineering, possibly leading to industrial-scale applications, but ultimately also facing several technical bottlenecks. Economically, the successful deployment of artificial photosynthesis could reduce dependence on fossil fuels, promoting sustainability and technological sovereignty within the EU.

2.1.8. Innovative urea production through electrosynthesis for environmental sustainability

What is it?

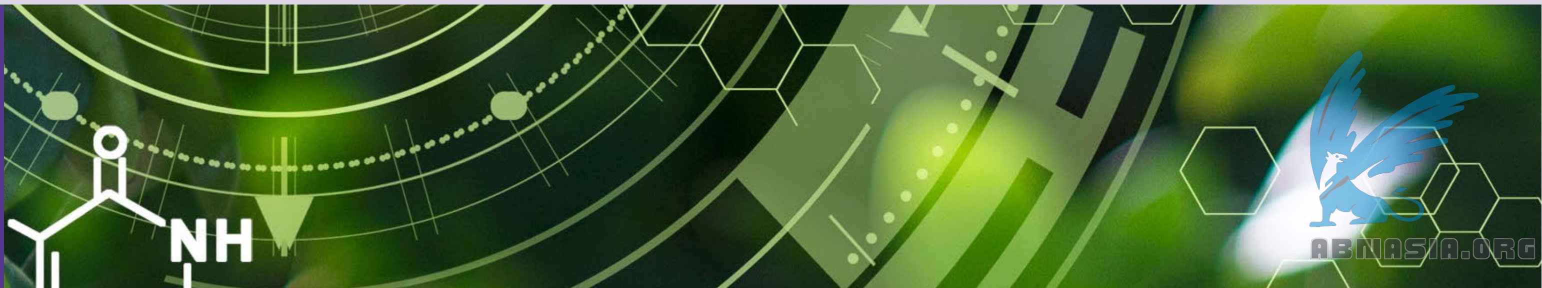
Urea is a vital component in the chemical industry, particularly as a nitrogen-rich fertiliser. Traditionally, urea is produced through energy-intensive processes like Bosch-Meiser and Haber-Bosch, which together account for about 2% of global energy consumption and emit over 300 million tonnes of CO2 annually. As the world shifts towards more sustainable practices, there is a growing need to explore alternatives that reduce carbon emissions and energy use. Electrosynthesis of urea presents a promising alternative by enabling the co-reduction of CO2 and nitrogenous species under ambient conditions, potentially transforming the urea production process into a more sustainable and environmentally friendly method.

What is new?

The novelty of urea electrosynthesis lies in its ability to perform urea production at ambient conditions using electrocatalytic processes, a significant departure from the high temperature and pressure requirements of traditional methods. This innovative approach aims to reduce carbon emissions and energy consumption by co-reducing CO2 and nitrogenous species to form C-N bonds, which are the building blocks of urea. Despite the potential, the technology is still in its early stages and faces challenges such as low catalytic activity, selectivity, and stability of current electrocatalysts. Ongoing research is focused on developing advanced electrode materials and optimising electrochemical cell designs to enhance efficiency and scalability, making the process more viable for industrial applications.

How may it impact the next five to ten years?

The successful development and adoption of urea electrosynthesis could significantly impact the chemical industry by reducing its carbon footprint, enhancing energy efficiency, and advancing technological innovation. Environmentally, this technology may contribute to reducing greenhouse gas emissions and mitigating the environmental impacts of traditional urea production processes, such as eutrophication and air quality degradation. Economically, it could lead to more sustainable agricultural practices by providing a carbon-neutral alternative for nitrogen fertilisers. Significant advancements in the underlying technology might be required, but with better catalysts, optimised reactors, and system integration with existing industrial processes.



2.1.9. Nanostructured materials for removal of persistent, mobile and potentially toxic compounds from water and soil

What is it?

Nanostructured materials are emerging as transformative tools for tackling persistent, mobile, and potentially toxic (PMT) compounds in water and soil. These advanced materials enable innovative technologies, including electrochemical oxidation, catalysis, and photo-electrocatalysis, to degrade pollutants like per- and polyfluoroalkyl substances (PFAS). Known as "forever chemicals," PFAS are resistant to degradation and linked to severe health risks, including cancer and immunotoxicity. Current methods for their removal are energy-intensive and often incomplete. Nanostructured materials, offering high specific surface areas and tunable quantum-scale properties, enhance reactivity and efficiency, providing a more sustainable and precise approach. This technology shows immense potential for reshaping pollution remediation strategies, aligning with the EU's Green Deal objectives for water and soil protection.

What is new?

The novelty lies in the application of nanostructured materials to technologies like photo-electrocatalysis and electrochemical oxidation for PFAS degradation. These materials, currently under experimental investigation, offer unprecedented precision by leveraging their quantum-scale characteristics to degrade even the most persistent pollutants fully. Compared to conventional methods, they promise significantly higher energy efficiency and environmental sustainability. This approach addresses critical gaps in existing treatment strategies, moving beyond mitigation to complete contaminant breakdown. These innovations signal a new frontier in environmental remediation, supporting the EU's Safe and Sustainable by Design framework for eco-friendly solutions.

How may it impact the next five to ten years?

Over the next decade, the maturation of nanostructured material technologies could redefine the landscape of environmental remediation. Their integration into advanced electrodes, adsorbents, and membranes may enable more effective PFAS removal, cutting health-related costs currently estimated at €52–84 billion annually in Europe. Technologically, they represent a shift towards scalable, energy-efficient solutions, reducing reliance on resource-intensive methods. Socially, cleaner water resources will improve public health and environmental resilience. However, further research and regulatory oversight will be critical to ensuring safe adoption and long-term efficacy. This trajectory aligns with the EU's broader sustainability goals, offering a promising pathway for tackling PMTs.

Antonio Marco Pantaleo

ex-EIC Programme Manager for energy systems and green technologies

Economic growth and competitiveness must align with sustainable resource use, zero pollution, biodiversity protection, and climate change targets. The transversal, cross-sectoral role of energy systems for sustainability, industrial competitiveness, and security is crucial in this context. Ensuring secure and affordable energy supply remains a top EU policy priority, influenced by factors such as material costs, environmental protection, and market inefficiencies. However, energy systems cannot be optimised in isolation or through one-size-fits-all solutions.

Addressing security of supply and deindustrialisation requires visionary innovations in energy efficiency, domestic resource use, and circular approaches to materials and processes. These efforts must be supported by system-level thinking to decarbonise supply chains, integrate energy, water, and land use, and enable fair, techno-economic comparisons across technologies and processes to guide policy and industrial strategies.

During my mandate as EIC Programme Manager, analysing and monitoring signals such as those in this Report, namely on emerging technologies and early-stage breakthroughs in the energy sector, has been pivotal in shaping my vision. It has enabled the fostering of innovation and the creation of project portfolios to strengthen EU technological leadership. Strategic areas include AI and energy integration, efficient and clean cooling for data centres, thermal management of electronics, low-temperature heat recovery, and demand-generation matching through optimised infrastructure location.

In domestic resource valorisation and circularity, converting sustainably sourced biomass and biobased materials to bulk chemicals and fuels offers embedded benefits, including refinery reconversion, rural sector valorisation, and optimal carbon management. This requires a multidisciplinary approach addressing biological, engineering, materials science, and economic aspects, reflecting the EIC's ambition to foster transformational research pathways.

Francesco Matteucci

ex-EIC Programme Manager for advanced materials for energy and environmental sustainability

The journey of deep-tech innovation is inherently complex and requires a resilient team capable of integrating multidisciplinary expertise and engaging with multiple stakeholders across the entire value chain of the product or service under development. Successfully scaling clean deep-tech solutions necessitates addressing challenges in technology, science, policy, and business.

AI-powered tools for materials and reactor design, combined with a DBTL (Design-Build-Test-Learn) approach during the proof-of-concept and prototyping phases, can substantially accelerate technical and scientific progress. Additionally, providing policymakers with reliable data and continuous feedback will facilitate the swift establishment of effective regulations.

To overcome business challenges, it is essential to conduct market intelligence studies, regularly update product specifications, prioritize scalability from the outset, and engage in proactive fundraising. The discovery of advanced materials developed under the Safe and Sustainable by Design framework, while reducing dependence on critical raw materials, is also critical for advancing Europe's strategic autonomy in the cleantech sector.

A significant focus within the cleantech domain lies in evaluating risks and pollutant exposure across ecosystems, with an emphasis on understanding how pollutants behave and move within these environments. This task is highly complex, requiring the integration of diverse expertise to develop robust decision support systems powered by cloud platforms and AI. Ultimately, due to the scale and limited effectiveness of removing pollution from oceans, air, and soil, the most effective strategies involve preventing pollution and addressing waste and their circularity at the source.

Let us work together to promote the application of scientific advancements in Cleantech to improve human well-being and restore nature.

2.1.10. Dynamic aeraulics for adaptive optimisation of indoor air quality

What is it?

Smart aeraulic systems integrating artificial intelligence (AI)-assisted management and real-time contaminant monitoring are under development to address the critical challenges of Indoor Air Quality (IAQ). These systems dynamically regulate ventilation, accounting for the accumulation of pollutants such as carbon monoxide, nitrogen oxides, volatile organic compounds (VOCs), fine and ultrafine particulate matter (PM), biological aerosols (viruses, bacteria, pollens, fungi), and radon gas. By simultaneously considering outdoor pollution and energy efficiency, these technologies aim to maintain healthy indoor environments while minimising energy consumption. IAQ, linked to significant health risks including cancer, infections, and respiratory diseases, has emerged as a priority following the COVID-19 pandemic, driving the need for advanced, sustainable solutions.

What is new?

The novelty of smart aeraulic systems lies in their integration of AI with real-time contaminant detection to achieve adaptive indoor air management. These systems analyse pollution profiles in confined environments while accounting for outdoor air quality to dynamically optimise ventilation. This dual focus on pollutant mitigation and energy efficiency represents a significant advancement over conventional ventilation strategies. The ability to address a wide spectrum of contaminants, from VOCs to biological aerosols, using AI-driven insights offers precision and scalability for various indoor settings, from homes to hospitals. Current methodologies for IAQ control are rudimentary, underscoring the transformative potential of these emerging technologies.

How may it impact the next five to ten years?

Smart aeraulic systems are poised to redefine IAQ management by enabling real-time, adaptive control of indoor pollutants. Technologically, they may set new benchmarks in ventilation design by integrating AI and sensor-based monitoring into energy-efficient building systems. Socially, their adoption could significantly reduce health risks associated with indoor contaminants, improving public health outcomes in high-risk environments like schools, workplaces, and healthcare facilities. These advancements align with EU policy objectives, including the Green Deal, by promoting sustainable building practices. However, further research into the sources of indoor contaminants and their detection technologies will be essential to maximise the effectiveness of the smart aeraulic systems and ensure widespread adoption.

2.1.11. Innovative robotics to drive automation in architecture, engineering, and construction

What is it?

Autonomous robotics are poised to transform the Architecture, Engineering, and Construction (AEC) sector by independently executing complex tasks such as site preparation, material handling, welding, and concrete pouring. These low-TRL systems leverage advanced technologies, including Building Information Modelling (BIM) and Robot Operating Systems (ROS), to navigate unstructured and dynamic environments with precision. Incorporating principles from field robotics, these systems are designed for harsh, unpredictable conditions, while swarm robotics enables multiple specialised units to coordinate seamlessly for optimal task distribution. Early applications include hazardous environment operations like nuclear facility decontamination and contaminated site remediation. By addressing labour shortages, safety risks, and inefficiencies, autonomous construction robots mark a significant step towards a more automated and precise construction future.

What is new?

The integration of autonomous robots into a digital construction ecosystem represents a novel approach to AEC practices. Field robotics advancements enable these robots to adapt to diverse and unstructured environments, while swarm robotics facilitates collaborative operations among multiple units. At this stage, the focus is on enhancing interoperability through BIM and ROS to achieve seamless communication and task execution. Emerging applications such as off-site prefabrication, modular housing, and on-site 3D printing highlight the potential to revolutionise construction processes. Autonomous robots capable of deconstruction, tiling, and hazardous site work illustrate their transformative role in creating precise, efficient, and sustainable construction workflows.

How may it impact the next five to ten years?

Autonomous construction robots are expected to drive substantial advancements in the AEC sector. Technologically, their adoption could standardise automation in construction, fostering innovation in areas like prefabrication, 3D printing, and resource optimisation. Environmentally, their precision and efficiency promise reductions in material waste and emissions, contributing to global sustainability objectives. Socially, these robots may address labour shortages and improve site safety, but they might also create major shifts that will not be easy to address beyond workforce reskilling to accommodate automation. Policy developments will be essential to regulate safety, data security, and labour integration, ensuring the equitable and responsible deployment of autonomous robotics in the built environment.

2.1.12. Synthetic data-driven virtual worlds in hyper-realistic digital twins of built environments

What is it?

Digital twin technology, synthetic data, and immersive virtual worlds are now transforming architecture, engineering, and construction (AEC), enabling hyper-realistic models that extend beyond traditional BIM. These ecosystems integrate data from design processes, IoT sensors, and synthetic data to create advanced digital twins that mirror and predict building lifecycle phases. Enhanced by AR/VR, professionals can interact with these twins in immersive environments, testing designs, construction, and operational protocols. Novel AI techniques, from generative adversarial networks (GANs) to deep and multi-agent reinforcement learning (Deep RL, MARL) can generate synthetic data, filling sensor data gaps and simulating complex scenarios, such as structural responses to rare events as flooding. This immersive approach enables real-time collaboration within simulated environments, allowing precise design decisions and operational adjustments previously unattainable.

What is new?

Integrating synthetic data within virtual worlds for digital twins offers a new approach to simulating building environments. While traditional twins rely on real-time sensor data, synthetic data creates scalable simulations that model rare events like earthquakes and predict wear under varied conditions. These data-rich twins can project into real spaces via AR, enabling construction teams, planners, and policymakers to visualise and manipulate designs within real-world contexts. Immersive digital twins in virtual worlds make building features and behaviours accessible in 3D/4D formats. Autonomous systems, such as drones, can interact with these twins using AR instructions, enhancing precision and efficiency in AEC workflows.

How may it impact the next five to ten years?

Synthetic data-driven digital twins with immersive AR/VR will likely impact economic, environmental, and policy domains. Economically, these ecosystems optimise the building lifecycle, reducing rework costs, and improving resource allocation. Environmentally, they enable sustainable practices by simulating material use, energy efficiency, and carbon impacts. In policy, immersive twins and synthetic data introduce new considerations around data ownership, privacy, and virtual property rights, as personal and location data become more integrated. Updated regulatory frameworks are needed to ensure compliance with data protection standards, foster innovation, and promote interoperability across virtual and augmented platforms, supporting secure, scalable deployment in the AEC sector.

2

Watchlist

of EIC signals on emerging technologies and early-stage breakthrough innovation

2.2. HEALTH

This report highlights emerging innovations in health biotech and therapeutics and medical devices and diagnostics within the Health macro-area. These domains are pivotal for advancing Europe's healthcare systems and reflect the essential role of deep tech in addressing pressing global health challenges. They underscore the importance of fostering ideas with the potential to redefine how healthcare is delivered, monitored, and improved.

Aligned with key European initiatives such as the European Health Union[24], and sector-specific initiatives as the European Health Data Space[25], the Pharmaceutical Strategy for Europe[26], or the European Global Health Strategy[27], this macro-area is linked to sectoral priorities that aim to enhance public health and ensure the resilience of Europe's and global healthcare systems. It emphasises innovations that could lead to breakthroughs in personalised medicine, disease prevention, diagnostics, and therapeutics, addressing complex healthcare needs with precision and efficiency.

2.2.1. Metabolomics for discovering new disease mechanisms and targets

What is it?

Metabolism, the process through which food is converted into energy, small molecule metabolites, and cellular building blocks, is at the cusp of transforming healthcare. While traditionally viewed as a mere energy-production system, breakthrough technologies like metabolomics have revealed that metabolism is central in regulating cell behaviour. It has a far-reaching impact on our understanding of human diseases and their cures, particularly in ageing-associated diseases, cancer, neurological disorders, and immunity. For instance, in cancer, metabolites can change how cells behave, metastasise, and promote tumorigenesis. Immune cells also undergo metabolic shifts during pathogen recognition or when encountering non-self cells. These shifts support inflammatory responses and produce metabolites essential for activating key immune functions. Similarly, ageing shows a clear time-dependent metabolic signature, with the accumulation of some metabolites indicative of metabolic dysregulation.

What is new?

Recent advances in analytical platforms and approaches to modify cellular metabolism are providing new avenues for disease diagnostics, monitoring, and treatment. Metabolomics allows the detection of hundreds of metabolites in a single specimen, be it a bodily fluid (urine or blood) or a piece of tissue (a biopsy or a tumour). New developments, particularly in high-resolution liquid chromatography-mass spectrometry, have significantly increased the number of detected metabolites in a sample, allowing scientists to explore cellular metabolism at unprecedented resolution and even identify novel metabolic pathways. These large-scale efforts revealed that many diseases have a unique metabolic fingerprint that can be used for clinical diagnosis, disease stratification, and treatment monitoring. In parallel, innovative approaches to modify cellular metabolism are being developed in different disease areas, for instance, by ectopic expression of metabolic enzymes to reduce specific metabolites or drugs that target the enzymes that produce them in cancer. Similarly, metabolite-producing bacteria can be engineered to augment the availability of nutrients required for optimal immune cell function in cancer.

How may it impact the next five to ten years?

Including metabolomics in the current healthcare pipeline can revolutionise our ability to diagnose disease: metabolomics could be essential to diagnose metabolic disorders or to stratify patients depending on their "metabolic signature", improving our targeted therapies. In addition, modifying disease-associated metabolites provides unique insights into how we can cure diseases, for instance, by blocking proteins that produce aberrant metabolites or providing metabolites with powerful biological activities. Emerging technologies like mass spectrometry imaging promise to expand even further the power of this approach by providing single-cell or subcellular compartment resolution, facilitating the merging of metabolomics to the exciting field of spatial biology. In the next decade, these advances will allow the mapping of metabolite distribution across different cell types, such as cancer cells and immune cells, within a tissue, providing rapid diagnosis of metabolic states to tailoring treatments and monitoring shifts in metabolic signature throughout treatment.

2.2.2. In-situ bioprinting for regeneration of internal tissues

What is it?

In situ bioprinting is an advanced biofabrication technique that involves the printing of biological tissues directly at the site where they are needed, typically in or on a patient's body. Unlike 'traditional' bioprinting, which usually creates 3D hierarchical cellular structures in a lab setting for subsequent maturation and implantation, in situ bioprinting aims to construct tissues or apply cell-laden bioinks directly into or onto damaged areas within the patient. This allows for precise customisation and facilitates the integration with the surrounding biological environment. Although it is currently most widely explored for surface-level applications, its potential uses in the future include the regeneration of deep-tissues, such as bone and cartilage, as well as restoration of complex organ function.

What is new?

It is revolutionising regenerative medicine by enabling the direct printing of living 3D tissue structures, based on the patient's own cells at the site of injury. This patient-specific approach minimises dependence on prefabricated implants, overcoming the need for maturation procedures in the lab, allowing for improved integration with surrounding tissues, and facilitating faster healing. Novel bio-inks are being tailored for specific tissue types to enhance cell viability and incorporate e.g., growth factors to promote tissue regeneration. Additionally, immune-compatible bio-inks can reduce inflammation and improve tissue integration, while encapsulation technologies can protect cells during the printing process. Recent advancements include the use of portable bioprinters that clinicians can apply to deposit bio-inks directly onto damaged tissues, often guided by imaging techniques, like 3D scanning, for enhanced precision. Robotic-assisted bioprinters are being developed with promising results from preclinical studies on skin and auricular reconstruction. Moreover, remote in situ bioprinting techniques, such as acoustic, magnetic, and light-based methods, are arising and allow for precise deposition of bio-inks deep within the body using only minor interventions.

How may it impact the next five to ten years?

In the next decade, in situ bioprinting could transform regenerative medicine by enabling faster, more personalised, minimally invasive treatments for complex injuries and tissue defects. In situ bioprinting may soon allow direct application onto a patient (e.g., the skin) or onto a defected area which is exposed during an operation (e.g., bone defect), thereby accelerating healing. Remote bioprinting methods, like acoustic and magnetic printing, could allow non-invasive internal tissue regeneration, addressing conditions that currently require invasive surgery. These technologies may ultimately also make medical care more accessible, particularly in remote or resource-limited areas, where mobile or teleoperated bioprinting systems could deliver advanced treatments without requiring specialised facilities. Over time, development of appropriate regulatory frameworks and clinical trials will be crucial to establish these bioprinting methods as standard care options, thereby enhancing patient outcomes and broadening the scope of regenerative medicine.

2.2.3. Targeted protein degradation for novel avenues in drug development

What is it?

Targeted protein degradation (TPD) is an emerging pharmacologic modality that eliminates disease-driving proteins by harnessing the cell's natural disposal systems. It employs different strategies to direct unwanted protein targets to cellular degradation pathways. Small-molecules degraders like PROTACs (proteolysis-targeting chimeras) or molecular glue degraders co-opt E3 ubiquitin ligases to induce target ubiquitination and degradation by the proteasome. Beyond proteasomal degradation, antibody-based strategies, such as LYTACs (lysosome-targeting chimeras), unlock access to lysosomal degradation to induce degradation of extracellular or transmembrane target proteins. Small-molecule degraders are already a clinical reality. Several molecular glue degraders are clinically approved in cancer indications or in clinical evaluation. Moreover, more than 40 degraders are currently undergoing clinical investigation with a predominant focus on oncology indications. Degraders have a unique mechanism of action since they lead to complete and catalytic elimination of the disease-driving target, thereby creating a highly potent, durable and deep target disruption. Through this differentiated mechanism, small-molecule degraders can address critical clinical challenges including drug resistance and drug selectivity. Importantly, they can also eliminate disease drivers that have thus far been considered "undruggable", thereby redefining our ability to tackle complex diseases.

What is new?

Through rational discovery approaches, degraders can be identified more efficiently, leading to an ever-increasing understanding and repertoire of degrader mechanisms of action. Integrating these deep mechanistic insights with increasingly sophisticated computational and experimental strategies allows us to efficiently design and develop degraders against therapeutic targets that historically were outside the reach of drug discovery. Among others, this has led to first degraders that can tackle a suite of recalcitrant mutants of KRAS, a protein long known to drive some of the most devastating solid tumours, including pancreatic cancers. Moreover, we see an impact of artificial intelligence (AI) and machine learning (ML) applications leading to in silico designed protein binders that can encode logic for context specific degradation of transmembrane proteins. AI/ML also gains traction in small-molecule degrader discovery, for instance by predicting compatible E3-target protein surfaces. Lastly, we begin to understand the possibilities of selective delivery of small-molecule degraders by leveraging them as payloads in antibody conjugates.

How may it impact the next five to ten years?

Targeted protein degradation is expected to solidify as an essential strategy of how novel and innovative medicines of the future are designed and developed. It has the potential to deliver therapeutic approaches that can eliminate disease-causing proteins that were not actionable with conventional small-molecule drugs or biologics. Therefore, targeted protein degradation can address unmet medical needs and spark breakthroughs in disease areas where conventional drugs failed to deliver impact. While the initial focus of targeted protein degradation has been on oncology indications, it is poised to also deliver on neurodegenerative and immunological diseases. Given their unique mechanism, medicines based on degraders have the potential to be more potent and selective, therefore increasing the therapeutic window and safety. Success in targeted protein degradation has also inspired a range of additional research areas that aim to harness other indigenous cellular pathways to chemically rewire, for instance, signalling networks or gene regulation. These emerging modalities provide a perspective for alternative means for precise and innovative therapeutic interventions.

Orsolya Symmons

EIC Programme Manager for health and biotechnology

"Biotechnology has emerged as a frontier science, harnessing the power of living organisms and biological systems to develop innovative solutions, from disease diagnosis and treatment to improved drug development and biomanufacturing. The signals in this report are representative of the the breadth of this rapidly evolving field. It is crucial to highlight how these and other emerging technologies and early breakthrough innovations supported by the EIC can address a wide range of disease areas, as well as the potential of novel technologies to increase access to life-saving therapies and improve patient outcomes.

However, beyond these opportunities, the scaling up of healthcare biotechnology solutions also presents a complex set of challenges. These include the appropriate matching and adaptation of disruptive technology to relevant unmet health needs and successfully addressing scalability, where a shortage of skilled personnel, manufacturing capabilities and the need for stringent quality control can be major bottlenecks. In addition, ensuring affordable access to biotechnology products, and adherence to strict, multifaceted regulatory frameworks are also critical barriers that innovators must consider during development.

Alongside the Pathfinder instrument, the EIC also supports a vast range of biotechnology innovations at higher technology readiness levels across Transition and Accelerator, overall targeting different healthcare applications and disease areas, and is therefore well-positioned to support Europe's ambitions in biotechnology in the coming years. Moreover, through this rich portfolio, the EIC is also uniquely positioned to strengthen the healthcare innovation ecosystem, for example by bringing together these breakthrough technologies in different areas, and by creating connections with other European initiatives and key stakeholders."

Federica Zanca

EIC Programme Manager for medical imaging and AI in healthcare

The EIC is uniquely positioned to advance Europe's leadership in deep tech by identifying and nurturing transformative innovations that align with a broader vision for predictive, preventive, and personalised healthcare. Signals connect with advances in medical imaging, AI, and regenerative medicine highlight the convergence of emerging technologies with clinical applications, showcasing opportunities for Europe to lead in creating disruptive solutions that improve patient outcomes and redefine healthcare systems.

However, realising the full potential of these technologies requires addressing critical challenges intrinsic to deep tech. For instance, AI-driven diagnostics demand access to high-quality, diverse datasets and explainable algorithms to ensure clinical trust. Regenerative medicine technologies, such as bioprinting, face significant hurdles in scaling from lab to bedside, including reproducibility, cost-efficiency, and compliance with regulatory frameworks. Similarly, disruptive innovations in radiotherapy must achieve rigorous validation to demonstrate their efficacy and safety in complex clinical environments.

The EIC can play a pivotal role in overcoming these barriers by fostering interdisciplinary collaboration, providing patient capital for long-term development, and creating an innovation ecosystem that connects research institutions, startups, and healthcare providers

2.2.4. Ultra-high-dose-rate FLASH radiotherapy for cancer care

What is it?

FLASH radiotherapy is an innovative approach in cancer treatment that leverages ultra-high-dose-rate gamma or particle beams to administer radiation in an extremely short time, ideally within less than a second. This rapid delivery not only improves tumour control but also offers significant protection to surrounding healthy tissues compared to conventional radiotherapy methods. Current advanced techniques like Intensity-Modulated Radiation Therapy (IMRT), Radiosurgery, and Volumetric Modulated Arc Therapy (VMAT) are expected to be complemented by the FLASH effect. Moreover, particle therapies, such as proton therapy, may also benefit from this emerging technology, potentially redefining the standards of care in radiotherapy.

What is new?

The novelty of FLASH radiotherapy lies in its ability to deliver a radiation dose at rates several magnitudes higher than those used in conventional radiotherapy. While early animal studies and initial human trials have shown promising results, the exact biological mechanisms - such as potential oxygen depletion and improved DNA repair responses - remain under investigation. Current radiotherapy devices, including those used for particle therapy, are not yet equipped to optimally deliver FLASH therapy, necessitating the development of next-generation machines capable of generating these ultra-high-dose rates. Continued research is essential to refine dose rates, radiobiology, and dosimetry systems to translate this innovation into clinical practice.

How may it impact the next five to ten years?

If validated by further clinical trials, FLASH radiotherapy might significantly increase the global role of radiotherapy in cancer treatment by offering faster, safer, and less toxic options. This technology could potentially widen the therapeutic window, allowing for dose escalation without increasing side effects, thus enhancing tumour control. Additionally, the efficiency of FLASH radiotherapy could lead to shorter treatment times and reduce issues related to organ motion during therapy, increasing the number of patients who could benefit. A breakthrough in treating inoperable tumours may be on the horizon, disrupting the global radiotherapy machine market as new, specialised equipment will be required to deliver this cutting-edge therapy.

2.2.5. Digital biomarker-based health status prediction with AI-driven techniques

What is it?

Digital biomarkers are increasingly recognised as powerful tools for predicting health status and guiding personalised treatments. These biomarkers, which can include biological molecules found in blood, genetic expressions, imaging data, and more, provide critical digital inputs that quantify various physiological processes. Leveraging AI techniques, these biomarkers can be integrated to offer a more comprehensive understanding of a patient's health trajectory. This approach is particularly promising for managing chronic diseases and understanding patient-specific responses to therapies. The integration of diverse biomarkers, combined with AI, allows for the development of predictive models that can forecast disease progression and optimise treatment plans, making it a rapidly evolving field with significant implications for healthcare.

What is new?

The novelty of this technology lies in its ability to process vast datasets composed of multiple, diverse biomarkers. AI-driven models are designed to handle the complexity of patient-specific data, accounting for variability among patients, time-based changes, and the interplay of multiple diseases. Advances are being made in several areas: the development of new sensors and wearable devices for continuous monitoring, the combination of various biomarkers to enhance predictive accuracy, and the creation of AI models that can analyse large datasets while focusing on both common and rare disease trajectories. The potential to standardise and optimise biomarker inputs across different platforms and the use of synthetic data and digital twins for AI training are particularly noteworthy advancements.

How may it impact the next five to ten years?

In the next five to ten years, the application of digital biomarkers in conjunction with AI techniques may revolutionise healthcare by enabling more accurate disease predictions and personalised treatment strategies. This technology might lead to significant improvements in managing common diseases such as cancer, cardiovascular conditions, and diabetes, as well as in monitoring aging populations. The healthcare sector could see enhanced patient outcomes and reduced costs due to the precise and timely interventions these technologies facilitate. Additionally, European companies may benefit from investing in harmonised biomarker technologies, AI development, and innovative approaches like digital twins, potentially positioning the EU as a leader in this advanced healthcare domain.

2.2.6. 3D and 4D bioprinting for personalised wound treatment solutions

What is it?

3D and 4D bioprinting technologies are advancing wound management by enabling the creation of highly customised, biocompatible tissue constructs tailored to individual healing needs. Using digital models, 3D bioprinting layers natural and synthetic biomaterials, such as hydrogels and polymers, to produce scaffolds that fit the specific dimensions and shapes of wounds. These scaffolds are infused with bioactive molecules, including growth factors, antibiotics, and living cells, to promote cell growth and accelerate healing. This technology is particularly effective for treating chronic wounds and burns, as it allows for engineering skin substitutes and advanced dressings that mimic the body's extracellular matrix, providing essential structural support and enhancing tissue recovery. Building on the foundations of 3D bioprinting, 4D bioprinting introduces the capability for these constructs to evolve over time, responding to environmental stimuli like temperature and moisture changes within the wound site. This dynamic adaptation is critical for addressing the challenges of chronic wounds, as it enables the constructs to modify their mechanical properties and therapeutic agent release profiles as the wound's healing requirements change.

What is new?

The primary novelty of 3D and 4D bioprinting in wound management lies in their ability to fabricate complex, multi-layered tissue constructs that cater to the dynamic needs of individual wounds. 3D bioprinting allows for the integration of multiple materials and bioactive compounds within a single scaffold, facilitating the targeted delivery of therapeutic agents, such as growth factors and antibiotics, where they are needed most. This enhances the effectiveness of the healing process. Furthermore, 4D bioprinting extends this functionality by enabling the constructs to adapt over time to changes in the wound environment, which is particularly crucial for chronic wounds. These 4D constructs can adjust their mechanical properties and release profiles of bioactives in response to stimuli such as changes in temperature or pH, aligning closely with the wound's healing stage. This dynamic interaction with the healing environment represents a significant advancement in personalised medical treatment and active wound management.

How may it impact the next five to ten years?

Over the next decade, 3D and 4D bioprinting technologies may revolutionise wound management, significantly improving patient outcomes through personalised treatments for chronic wounds—a growing concern in aging populations. This technology could stimulate the development of new medical devices and reduce the production costs of bioinks, opening new markets in advanced wound care products. Economically, the widespread adoption of bioprinting might reduce long-term healthcare costs by providing more effective interventions. Additionally, this shift may prompt regulatory updates to ensure the safe integration of these technologies into clinical settings, enabling broader acceptance and implementation. Ultimately, the adoption of 3D and 4D bioprinting could improve the quality of life for millions of patients suffering from chronic wounds.

2 Watchlist

of EIC signals on emerging technologies and early-stage breakthrough innovation

2.3. Digital, Industry, and Space

This section of the report showcases cutting-edge innovations across advanced manufacturing and materials, AI, data and ICT, quantum and advanced computing, semiconductors, electronics and photonics, and space technologies and systems. These domains represent the backbone of Europe's digital transformation and industrial leadership, underscoring the importance of deep tech in securing Europe's competitiveness and strategic autonomy.

The digital, industrial and space macro-area is aligned with EU sector strategies in the EU's digital, industrial and space domains with topics relevant for the Digital Markets Act[28], EU Chips Act[29], EU AI Act[30], the Advanced Materials for Industrial Leadership[31], or the EU Space Programme[32]. It highlights relevant topics for strengthening Europe's technological sovereignty and ensuring resilient, sustainable industrial ecosystems, from new approaches to advanced materials, quantum technologies or photonics, to the intersection of edge computing and AI and enabling technologies for space operations.

2.3.1. Advanced manufacturing with single-atom photocatalysis techniques

What is it?

Single-Atom Photocatalysis (SAP) represents a breakthrough in the domain of advanced manufacturing, particularly within the broader field of Single-Atom Catalysis (SAC). SAP leverages the unique chemical activity of isolated atoms or metal clusters, where even the addition or removal of a single atom can result in dramatic changes in reactivity. This precise control over catalytic processes enables the manufacturing of materials with highly specific properties, using minimal amounts of metal catalysts. SAP technology involves stabilising isolated atoms on inert supports, which allows for precise reactions and easy separation of products, making it an ideal tool for manufacturing applications that require high levels of control and efficiency. Although SAC has been extensively studied since 2011, SAP remains a relatively new and underexplored area, particularly in its application to material synthesis and manufacturing.

What is new?

The main novelty of Single-Atom Photocatalysis in advanced manufacturing lies in its ability to enable highly controlled and efficient synthesis of materials at the atomic level. This technology allows for the production of materials with tailored properties, which is crucial for applications requiring extreme precision, such as in electronics, nanotechnology, and specialised industrial processes. By utilising single atoms as catalysts, SAP offers unprecedented selectivity in manufacturing processes, reducing waste and improving efficiency. The potential for SAP to revolutionize manufacturing lies in its ability to drive chemical reactions that were previously challenging to control, such as the synthesis of high-value chemicals or advanced materials with specific mechanical and thermal properties.

How may it impact the next five to ten years?

Single-Atom Photocatalysis could profoundly impact the field of advanced manufacturing by enabling the production of materials with unmatched precision and efficiency. Technologically, SAP may lead to the development of new manufacturing techniques that significantly reduce the material and energy inputs required for high-value chemical and material synthesis. This could result in cost reductions and increased sustainability in manufacturing processes. Economically, SAP could foster the growth of new industries focused on high-precision manufacturing, potentially creating new markets for specialised materials. The environmental impact of SAP could also be significant, as the technology promotes more sustainable manufacturing practices by minimising waste and reducing the need for scarce resources. As research progresses, SAP is likely to influence policy decisions related to industrial innovation, sustainability, and competitiveness, aligning with the EU's broader goals for technological sovereignty and green manufacturing.

2.3.2. Computational approaches for next-generation and high-entropy materials

What is it?

Computational sciences and technologies are playing an increasingly pivotal role in the development of advanced materials, significantly influencing sectors such as energy, manufacturing, and electronics. This innovation focuses on the integration of simulation, numerical algorithms, physical modelling, and data-driven technologies to design and discover materials with tailored properties. Key advancements include the development of high-entropy materials (HEMs) such as high-entropy alloys and ceramics, which possess exceptional mechanical, thermal, and chemical properties. Computational tools also facilitate the design of bifunctional catalysts for energy applications, the creation of sustainable and biodegradable materials, and innovations in printed electronics, which offer more sustainable alternatives to traditional manufacturing methods. These computational approaches enable precise control and optimisation of material properties, contributing to significant technological advancements and sustainability in critical industrial sectors.

What is new?

The main novelty lies in the integration of advanced computational tools with physical and data-driven models to discover and design new materials with tailored properties. This approach enables the development of high-entropy materials that exhibit superior performance in extreme conditions, making them suitable for high-temperature applications and cutting tools. Additionally, the combination of high-entropy engineering with 2D materials has led to breakthroughs in catalyst design for hydrogen and oxygen evolution reactions. Furthermore, computational methods are transforming printed electronics by reducing material waste and production costs, aligning with sustainability goals. The ability to design biodegradable and sustainable materials through computational approaches also represents a significant advancement, supporting the EU's Safe and Sustainable by Design (SSbD) framework.

How may it impact the next five to ten years?

Computational materials science may drive transformative changes across multiple sectors in the short to medium-term. Socially, it could lead to the development of more sustainable products and manufacturing processes, reducing environmental impact and promoting a circular economy. Technologically, it may enhance the efficiency of energy systems, such as hydrogen production, and improve the performance and durability of materials used in critical industries like aerospace and automotive. Economically, these advancements could boost the competitiveness of the European manufacturing sector by enabling the production of high-performance materials at reduced costs. Additionally, the integration of AI and multi-scale modelling techniques could accelerate innovation, leading to new applications and markets for advanced materials. These developments might also contribute to achieving the EU's strategic objectives in digitalisation, sustainability, and industrial leadership.

2.3.3. Low-impact and bio-based materials for sustainable electronics

What is it?

The transition to sustainable electronics is becoming increasingly critical as the global electronics industry faces rising scrutiny over its environmental impact. Traditional electronics manufacturing relies heavily on metals and metal oxides that are difficult to recycle and require energy-intensive production processes. Emerging technologies are now exploring the use of natural, bio-based materials, such as cellulose, textiles, and other biocompatible substrates, to create flexible electronic devices. These innovations leverage advanced fabrication techniques, such as additive manufacturing and printed electronics, to produce devices that are more energy-efficient and environmentally friendly. The development of electronic circuits and sensors on biodegradable substrates like paper or textiles, using organic semiconductor inks, represents a significant step forward in reducing the ecological footprint of electronic products.

What is new?

The primary novelty of this signal lies in the development and application of bio-based and biodegradable materials for electronics, which offer a sustainable alternative to conventional electronic components. These materials, including silk fibroin, chitosan, and lignin, are used to create flexible, low-impact electronic devices through innovative processes like screen-printing and spray coating. Additionally, new platforms are emerging that integrate biodegradable polymers with natural materials, such as lignocellulose, to fabricate sustainable electronic devices. These advancements not only reduce the reliance on toxic and non-recyclable materials but also pave the way for electronics that align with circular economy principles. As these technologies mature, they hold the potential to revolutionise the electronics industry by significantly lowering its environmental impact.

How may it impact the next five to ten years?

In the coming years, the adoption of bio-based and biodegradable materials in electronics could lead to substantial environmental benefits by reducing the industry's contribution to global greenhouse gas emissions and electronic waste. This shift may also drive innovation in recycling processes, enhancing the ability to reclaim and repurpose electronic components. Socially, the movement toward sustainable electronics could result in the widespread availability of eco-friendly consumer products, promoting more responsible consumption patterns. Furthermore, the establishment of standardised processes for material fabrication and recycling could foster greater collaboration across the electronics supply chain, encouraging the development of shared databases and cross-compatible systems that streamline production and reduce waste. This transformation aligns with the EU's broader goals of promoting sustainability, technological sovereignty, and competitiveness in the global market.

2.3.4. Ultra-thin 2D and ultra-wide band gap materials for power-efficient electronics

What is it?

Advanced materials play a pivotal role in reducing energy consumption in electronic systems, particularly through the use of innovative two-dimensional (2D) semiconductors, such as transition metal dichalcogenides (TMDs), MXenes, and twisted 2D materials. These materials are emerging as strong candidates for future channel materials in field-effect transistors (FETs), especially for applications involving very large-scale integration, sensors, and quantum engineering. Due to their ultra-thin body thickness (tbody) of less than 1nm and the absence of dangling bonds, monolayer TMDs like MoS_2, WS_2, $MoSe_2$, and WSe_2 demonstrate very good electrostatic control, high bandgaps (1.6-2 eV), enabling extremely low off-state currents and power consumption. The scalability and superior electronic properties of these 2D materials open up possibilities for more aggressive channel-length scaling and enhanced electrostatic gate control in both logic applications and Beyond-CMOS technologies, such as 2D-based tunnelling FETs (TFETs). Complementary materials like twisted 2D structures and MXenes further enhance the material properties for applications across quantum sensing, optoelectronics, and environmental monitoring. On the other hand, ultra-wide bandgap (UWBG) semiconductors such as AlN, Ga_2O_3, and diamond show very interesting electrical properties for power electronics applications.

What is new?

The main innovation in advanced 2D materials lies in their ability to deliver unparalleled properties for electronic applications, such as ultra-low power consumption and superior scalability. The ultra-thin body and absence of dangling bonds allow for enhanced transport properties, unmatched by thinned 3D crystals, enabling aggressive miniaturisation and circuit integration. Moreover, twisted 2D materials present unique opportunities for tuning intrinsic properties like optical behavior and interlayer coupling through adjustable twist angles, fostering novel applications in light-matter interactions and quantum technologies. MXenes, on the other hand, offer promising capabilities for developing multifunctional sensors and power electronics. On the other hand, ultra-wide bandgap semiconductors such as AlN, Ga_2O_3, and diamond show potential to outperform traditional wide bandgap semiconductors in high-efficiency power devices, high-temperature applications, and solar-blind photodetectors.

How may it impact the next five to ten years?

The adoption of these advanced materials could drive significant technological and economic advances. Technologically, their integration into electronic systems may lead to improved performance in low energy electronics applications, power electronics, optoelectronics, and sensors, offering better energy efficiency and miniaturisation, aligned with EU initiatives like the Chips Act and the Materials 2030 Manifesto. Economically, these materials may enable Europe to establish leadership in semiconductors, power systems, and quantum technologies, promoting competitive industries and supporting the EU's digital transition. Socially and environmentally, low-energy electronic systems could contribute to sustainable technologies, while the sensor applications of MXenes might enhance environmental monitoring and healthcare diagnostics.

2.3.5. Brain-inspired computing with advanced neuromorphic chips

What is it?

Brain-inspired computing, particularly through the development of neuromorphic chips, represents a significant advancement in the quest to reduce the energy consumption of artificial intelligence (AI) systems. Unlike traditional computing architectures, which rely heavily on power-intensive CPUs and GPUs, neuromorphic computing mimics the operation of the human brain's neurons and synapses to achieve greater computational efficiency. These neuromorphic circuits, which can be digital, analog, or mixed, integrate with memory cells to form architectures that excel in tasks such as pattern recognition, data mining, and other AI-driven applications. The emerging technology behind neuromorphic chips includes non-volatile memory devices like ReRAM, phase-change materials (PCM), and FeFETs, which serve as potential candidates for synaptic elements. By moving away from the conventional von Neumann architecture and employing novel materials and structures, neuromorphic chips aim to drastically reduce the power consumption of AI systems while increasing their integration density, paving the way for more sustainable computing.

What is new?

The core novelty of neuromorphic computing lies in its ability to replicate neural functions with extreme power efficiency, a significant departure from the energy-intensive processes of traditional AI hardware. Neuromorphic chips utilise non-von Neumann architectures, where elements like memristive devices and photonic synapses work in tandem with CMOS circuits to simulate neural activities. These innovations enable the circuits to exhibit machine learning capabilities, particularly in pattern recognition tasks, with drastically reduced energy consumption. For instance, phase-change material synapses integrated with nanostructures like carbon nanotubes have demonstrated sub-femtojoule (sub-fJ) energy operation per bit, highlighting the potential for substantial improvements in energy efficiency. This approach not only enhances the computational capabilities of AI but also aligns with the long-term vision of creating AI systems that operate with energy levels comparable to the human brain.

How may it impact the next five to ten years?

Neuromorphic computing and brain-inspired chips could have a transformative impact across various sectors by enabling more energy-efficient AI systems. This technology may significantly lower the global energy consumption associated with information and communication technologies (ICT), which, if unchecked, is projected to match global energy production by the mid-21st century. The deployment of neuromorphic chips in AI-driven applications such as image and speech recognition, data mining, and real-time processing could lead to breakthroughs in fields like healthcare, cybersecurity, and autonomous systems. Moreover, the integration of high-end VLSI CMOS technology with multistate probabilistic memristor synapse systems may lead to the development of AI systems that are not only more powerful but also far more sustainable, thereby supporting global efforts to mitigate climate change and reduce the environmental footprint of digital technologies.

2.3.6. Emerging non-charge-based memories for specialised semiconductor applications

What is it?

Emerging non-charge-based memories represent a significant innovation within the broader field of semiconductor technology, particularly as alternatives to traditional NAND Flash storage. Unlike conventional charge-based memory technologies, these non-volatile memories (NVMs) operate through resistive or capacitive mechanisms, exemplified by ferroelectric RAM (FeRAM), magnetic RAM (MRAM), phase-change RAM (PCRAM), resistive RAM (ReRAM), and ferroelectric FET (FeFET). As the scaling of 2D NAND Flash reaches its physical limits due to statistical fluctuations in charge storage, the development of these non-charge-based memories has become increasingly crucial. Even with the advent of 3D NAND, which mitigates some of these scaling issues, the low voltage operation, reduced power consumption, and random-access capabilities of emerging memories make them attractive for a range of specialised applications. These technologies are particularly relevant for markets where Europe has a competitive advantage, such as IoT, automotive, and low-power applications.

What is new?

The novelty of non-charge-based memories lies in their ability to overcome the limitations of conventional charge storage methods by utilising alternative mechanisms for data retention. These emerging memories typically feature a two-terminal structure, such as resistive or capacitive elements, which are distinct from traditional charge-based architectures. However, these new technologies face several challenges, including variability, retention at high temperatures, and density, issues that are critical for their commercial viability. Despite these hurdles, various proofs of concept have demonstrated the potential of these memories for specific applications, particularly in embedded systems where Europe could maintain a competitive edge. Moreover, these technologies also hold promise for neuromorphic computing applications, though they require further refinement to meet stringent specifications.

How may it impact the next five to ten years?

Emerging non-charge-based memories could have a transformative impact on multiple industries by providing more efficient and specialised storage solutions. These technologies are particularly suited for embedded memory applications in sectors such as automotive, IoT, and low-power devices—areas where Europe has the potential to lead. However, the path to commercialisation is fraught with challenges, as these new memory types must overcome issues related to reliability, performance consistency, and scalability. As research continues to clarify which of these technologies holds the most promise for specific applications, Europe could position itself as a leader in the development and deployment of these next-generation memory solutions. The success of emerging non-volatile memories will likely depend on the ability to refine these technologies to meet industry specifications while navigating the competitive landscape of global semiconductor markets.

Isabel Obieta

EIC Programme Manager for sustainable semiconductors

The significance of sustainable electronics in achieving EU industrial autonomy, particularly in a decarbonised and digital society, is substantiated in multiple signals selected in this report. Innovations related to reducing the environmental load of the electronic industry by shifting from traditional manufacturing methods to innovative methods and materials with a lower environmental impact or exploring new solutions that can significantly reduce the energy consumption of devices are clearly highlighted.

Only by decreasing the environmental footprint of the devices themselves will their very significant role in "greening" the environment be reassessed and potentially amplified. Internet of Things (IoT) connected devices and systems to monitor and manage environmental parameters is just one example.

Aligned with the EU Circular Economy Action Plan, the European Chips Act, the Critical Raw Materials Act, Advanced Materials initiative, and within my current portfolio activities, three key topics merit highlight in this context: a) Reducing power consumption through novel solutions such as 2D and ultra-wide bandgap materials, photonic integrated circuits, emerging memories, and brain-inspired computing can contribute to power-efficient electronics; b) Reducing critical raw materials and hazardous chemicals thanks to the use of bio-based materials and novel manufacturing processes can minimise the negative environmental impact of electronics; and c) Novel integration, assembly, and packaging for reusability and recyclability applied to device design will help in reducing electronic waste.

I'm optimistic about the potential of sustainable electronics to drive innovation and am really glad to see that with the Pathfinder and Transition Challenges, we are stimulating the European innovation ecosystems, and engaging core stakeholders, towards greener electronics.

Samira Nik

EIC Programme Manager for quantum technologies and electronics

Europe has positioned itself as a global leader in quantum technologies through world-class research institutions, outstanding start-ups, significant investments, strategic initiatives, and a collaborative ecosystem. The EIC is the largest public investor in quantum technologies, supporting exceptional start-ups and research groups advancing quantum computing, sensing, communication, and simulations.

Current early-stage technologies in this space still face challenges, nonetheless. Noisy Intermediate-Scale Quantum (NISQ) devices struggle with maintaining coherence and suffer from high error rates. Fault-Tolerant Quantum Computing (FTQC), a transformative technology that employs sophisticated error correction techniques, offers the potential to overcome these limitations and achieve reliable quantum coherence. In the meantime, maximising the performance of NISQ devices and improving the efficiency of future FTQC systems is critical. Quantum compilers play a pivotal role by dynamically optimising quantum circuits, addressing challenges such as qubit connectivity issues and high error rates. This innovation accelerates quantum application development, making complex computations more feasible, accessible, and energy-efficient. Another key challenge is scalability, constrained by large external control systems. Miniaturisation and integration of quantum systems—incorporating qubits with control and readout electronics directly on a single chip—can reduce noise, minimise signal delays, and enhance coherence times in quantum operations.

The EIC can play a vital role in addressing these challenges and more by fostering breakthrough innovations and enabling collaboration across academia, start-ups, and industry. Through its support, the EIC strengthens Europe's quantum ecosystem and can ensure that it remains at the forefront of global advancements.

2.3.7. Innovative photonic integrated circuits for next-generation computing and ICT

What is it?

Photonic Integrated Circuits (PICs) are cutting-edge technologies that integrate passive and active optical components to enhance data capacity and reduce power consumption in Information and Communication Technology (ICT). Silicon-based photonics (SiPh) is key to these circuits, enabling advanced data transmission methods like Mode-Division Multiplexing (MDM) and Wavelength-Division Multiplexing (WDM). Recent advancements include incorporating non-native materials, such as thin-film lithium niobate (TFLN), which supports high-speed data modulation. These innovations aim to improve the scalability and efficiency of photonic technologies, marking a significant advancement in the development of energy-efficient and high-capacity data systems.

What is new?

The primary novelty of Photonic Integrated Circuits (PICs) lies in their integration of non-native materials, allowing for specialised optical components like laser sources and modulators to be efficiently scaled. The development of programmable photonic chips adds further versatility, particularly for quantum computing and AI. TFLN's non-linear properties enable the creation of high-speed data components, crucial for next-generation ICT infrastructure. These innovations enhance the performance and flexibility of photonic systems, supporting their broader adoption in various advanced applications.

How may it impact the next five to ten years?

The integration and scalability of Photonic Integrated Circuits (PICs) could have profound social, technological, economic, environmental, and policy impacts, both in the EU and globally. PICs are set to drive significant advancements in ICT, enabling more energy-efficient and higher-capacity data networks. Their adoption could bolster Europe's position in the global semiconductor market, fostering competitiveness in critical sectors like telecommunications, aerospace, and healthcare. The reduced power consumption associated with PICs aligns with the EU's green transition goals, potentially leading to lower carbon emissions across ICT infrastructures. The emergence of PICs underscores the need for updated regulatory frameworks to ensure secure and sustainable integration of these technologies, particularly on data privacy and networked quantum systems.

2.3.8. Quantum compilers for enhanced circuit optimisation and reliability

What is it?

Quantum compilers represent a cutting-edge innovation within quantum computing, focusing on the optimisation of quantum circuits. This emerging technology translates high-level quantum algorithms into low-level instructions that quantum hardware can execute. The process includes advanced techniques such as parameterised circuit instantiation, circuit optimisation, gate-set transpilation, and adaptive measurement. These methods improve the quality and portability of quantum circuits while minimising the number of gates required for computations. Quantum compilers are highly adaptable, capable of targeting any gate-set, making them particularly useful for Noisy Intermediate-Scale Quantum (NISQ) computing, which characterises the current phase of quantum computing with systems that are neither error-free nor fully scalable. By recompiling circuits into alternative topologies with fewer gates, quantum compilers play a crucial role in enhancing the reliability and efficiency of quantum computations, especially in algorithms for dynamical simulations and eigensolving.

What is new?

The primary innovation in quantum compiler technology is its ability to dynamically optimise quantum circuits, addressing the unique challenges posed by quantum computing, such as qubit connectivity issues and high error rates. Unlike classical compilers, quantum compilers optimise qubit routing and gate operations, significantly reducing computational overhead and improving efficiency. A notable advancement is the technology's capacity to recompile circuits into alternative forms with fewer gates, enabling more efficient execution of NISQ-era algorithms. Additionally, the novel approach of mitigating measurement errors through state-dependent bias exploitation further enhances the accuracy and reliability of quantum computations. This multi-layered optimisation in circuit design, gate operations, and error mitigation marks a significant stride towards making quantum computing more practical and scalable.

How may it impact the next five to ten years?

Quantum compiler technology is poised to have a profound impact across various sectors, both within the EU and globally. By increasing the reliability and efficiency of quantum computations, this technology could drive breakthroughs in critical fields such as cryptography, pharmaceuticals, and materials science, thereby advancing public health, security, and technological innovation. The enhanced optimisation and error mitigation capabilities of quantum compilers are likely to accelerate the development and deployment of quantum applications, making complex quantum computations more feasible and accessible. Furthermore, by reducing computational overhead and improving circuit efficiency, quantum compilers could lower the operational costs associated with quantum computing, making it a more economically viable option for businesses and research institutions. Additionally, the optimisation of quantum circuits could lead to energy savings, as more efficient circuits would require less computational power and resources, contributing to broader sustainability.

2.3.9. Fault-tolerant quantum computing to tackle decoherence and noise

What is it?

Fault-Tolerant Quantum Computing (FTQC) is an emerging and transformative technology in the realm of quantum computing, designed to overcome the persistent challenges of quantum decoherence and noise. Unlike current Noisy Intermediate-Scale Quantum (NISQ) devices, which struggle with maintaining coherence and suffer from high error rates, FTQC implements advanced quantum error correction codes (QECCs), such as Low-Density Parity-Check (LDPC) codes and surface codes, to preserve quantum information with high fidelity. This innovation is made possible through breakthroughs in qubit architectures, including hybrid superconductor-semiconductor platforms and topologically protected qubits, which offer enhanced stability and error resistance. The goal of FTQC is to maintain quantum states over longer durations, enabling the execution of complex algorithms that would be unfeasible on error-prone, NISQ systems.

What is new?

The key novelty of FTQC lies in its ability to reliably maintain quantum coherence through sophisticated quantum error correction techniques, marking a significant leap beyond the limitations of NISQ devices. This is achieved by employing advanced QECCs that detect and correct errors in real-time, allowing quantum systems to perform accurate, large-scale computations. Moreover, recent innovations in qubit design, such as topologically protected qubits, provide a robust foundation for these error correction methods, further enhancing the reliability of quantum operations. As the technology continues to develop, FTQC is expected to overcome the barriers that have hindered the scalability of quantum computing, paving the way for applications that require high precision and computational power.

How may it impact the next five to ten years?

The development and implementation of FTQC could profoundly impact various sectors by enabling reliable and scalable quantum computations. In cryptography, FTQC may render current encryption methods obsolete, prompting a re-evaluation of security protocols globally. In scientific research, particularly in drug discovery and materials science, the precision offered by FTQC could lead to groundbreaking discoveries that are currently beyond the reach of classical computing. Additionally, the progress in quantum computing hardware and error correction techniques is likely to stimulate further investment and research in quantum technologies, solidifying EU goals in digital sovereignty and global research and innovation leadership.

2.3.10. Miniaturisation and integration of quantum systems on a chip

What is it?

The miniaturisation and integration of quantum systems represent a significant step forward in the field of quantum computing, focusing on reducing the size and improving the efficiency of quantum processors. This innovation involves integrating qubits with their necessary control and readout electronics directly on a single chip, thereby reducing noise, minimising signal delays, and enhancing the overall coherence times of quantum operations. Traditionally, quantum computing setups have relied on large, external control systems, which contribute to inefficiencies and complicate system design. A notable development in this domain is the advent of cryo-CMOS technology, which operates efficiently at cryogenic temperatures necessary for superconducting qubits. Additionally, the integration of cryo-electronics with qubit arrays aims to minimise the size and power requirements of quantum computers, making them more viable for practical and commercial applications.

What is new?

The primary novelty of miniaturising and integrating quantum systems lies in the seamless combination of qubits and control electronics on a single chip, a breakthrough that significantly enhances the performance and scalability of quantum computers. This approach addresses critical challenges related to quantum coherence and operational fidelity by reducing external noise and signal interference. Cryo-CMOS technology, which operates at the low temperatures required by superconducting qubits, exemplifies the potential of this innovation to create more compact and energy-efficient quantum processors. These advancements not only facilitate the transition from bulky, laboratory-scale systems to more streamlined, commercially viable quantum computers but also pave the way for more widespread adoption of quantum technologies.

How may it impact the next five to ten years?

The miniaturisation and integration of quantum systems are likely to have transformative impacts on the quantum computing landscape, enabling more practical and scalable applications across various industries. This technology could lead to the development of portable quantum devices and processors, making quantum computing more accessible for commercial use. In sectors such as cybersecurity, pharmaceuticals, and materials science, the enhanced performance and reduced size of quantum systems could accelerate breakthroughs that are currently hindered by the limitations of classical computing. Furthermore, the shift toward integrated quantum systems is expected to drive further innovation in quantum hardware, fostering a more robust ecosystem for quantum technology development and positioning Europe as a leader in the global quantum race.

2.3.11. Knowledge-driven AI powered by graph technologies

What is it?

AI technologies leveraging graph structures are advancing data representation and analysis, enabling systems to understand and utilise complex interdependencies. These include graph machine learning methods such as Graph Neural Networks (GNNs), which operate on non-Euclidean data structures to perform tasks like node classification, link prediction, and clustering. Knowledge Graphs (KGs) organise data into networks of entities, relationships, and properties, enhancing AI's reasoning and contextual understanding. Ontologies, as formal shared specifications of domain concepts and their interrelations, provide consistent, interpretable structures for data, promoting semantic interoperability and logical reasoning across applications. Together, these techniques enable AI to model intricate relationships in data, resulting in systems that are more accurate, interpretable, and contextually aware.

What is new?

Recent developments are advancing graph-driven AI systems, including GNNs, emerging graph transformers, and scalable graph databases, to improve link prediction, classification, and explainability. KGs integrated with generative AI, such as large language models (LLMs), enhance factual accuracy and support domain-specific personalisation in fields like healthcare and finance. Retrieval-augmented generation systems (RAGs) further optimise question-answering tasks. Ontologies facilitate logical reasoning, semantic interoperability, and compliance with regulatory frameworks such as the GDPR and the EU AI Act. Current trends include self-supervised learning on graphs, multi-modal KGs, and hybrid neuro-symbolic systems, pushing the boundaries of scalability, efficiency, and transparency. Advances in scalable graph databases are also driving significant market impact.

How may it impact the next five to ten years?

Graph-centric AI technologies have the potential to empower individuals by granting greater control over their data while transforming industries through data-centric and knowledge-driven AI. These systems may improve AI's capacity to understand complex relationships, enhancing transparency and privacy by enabling users to manage and authorise their data usage more effectively. Explainable GNNs and interpretable KGs would provide insights into data flows, fostering trust in AI-driven decisions. Ontologies could further support compliance with data privacy regulations and enable more sustainable AI systems by reducing computational resources. Cross-domain applications integrating KGs and ontologies would address challenges in public health, climate change adaptation, finance, and food security, advancing knowledge representation and decision-making in critical global issues.

Hedi Karray

EIC Programme Manager for Artificial Intelligence

The EIC is driving Europe's AI leadership by supporting cutting-edge research and innovation, fostering an ecosystem where groundbreaking AI technologies thrive, driving economic growth and societal benefits while adhering to European values of human-centricity.

We are making significant strides. Our beneficiaries are exploring key AI trends, pushing the boundaries of AI and setting the stage for future advancements.

Technically, we are shaping a technological ecosystem enabling cyber-physical-social systems embodying the 5.0 paradigm (e.g., Industry 5.0). AI is embedded on the edge of decentralised physical systems acting as autonomous and collaborative agents. These agents are empowered with capabilities to resolve complex problems and perform complex tasks while being context-aware, leveraging graph-driven technologies to complement generalised models. Cognitive twinning enables systems to simulate multiple possibilities, allowing them to adapt, react, and fine-tune their behaviour. The challenge is to breakthrough on frugal AI models, scalability of multimodal data streams, effective cross-domain integration, and next-generation hardware.

Safety, ethics, and regulatory compliance are integral to our vision. We remain committed to responsible AI by aligning our programmes to these requirements.

To further progress, we will prioritise funding for high-risk, high-reward projects pushing the boundaries of AI capabilities and safety. By investing in pioneering research and innovative startups, we aim to accelerate the development of transformative AI technologies addressing complex challenges across sectors including health, manufacturing, environment, and science.

Proactivity is key to our strategy. Through portfolios, we build synergy between academia, industry, startups, and investors, creating a dynamic environment for knowledge and resource sharing. This approach ensures innovative ideas are rapidly translated into practical applications, driving commercialisation and market adoption.

By strengthening this vision of a technological value chain and building on our successes, we believe we can advance Europe's position in AI, fostering an environment where pioneering talents outshine, and disruptive innovations flourish.

Stella Tkatchova

EIC Programme Manager for space systems and technologies

Orbital debris comes in various sizes and orbits, with more than 13,000 tonnes of space objects in Earth's orbits and 40,500 debris objects larger than 10 cm. The threat of space debris is rapidly growing. Increased satellite launches and break-ups of satellites are resulting in higher risks of Kessler collision events, leading to complex mission scenarios and rising costs of space operations, while threatening the EU's space infrastructure. Uncontrolled re-entry of space debris poses hazards to human populations, air, naval, and ground traffic. Preserving Earth's orbits is of critical importance.

Europe is well-positioned to become a leader in the space debris sustainability field, particularly in the domains of space debris mitigation, remediation, and in-space recycling.

To achieve this, we need capabilities to inspect and characterise both cooperative and non-cooperative space debris. High-precision LiDAR technologies are essential for detecting and characterising debris of all sizes—small, medium, and large—and represent a critical technology for Space Domain Awareness (SSA).

We must also develop the ability to capture and remove debris from key orbits. This could be achieved through various de-orbiting mechanisms such as magnets, nets, harpoons, physical sweepers, tethers, solar sails, space-based lasers, laser-pushed light sails, and others.

In the long term, there will be a need for green, compact, interoperable, and affordable technologies for space debris mitigation, active debris removal, and in-space recycling. Autonomous recyclers in orbit could collect, recover, and transform debris into usable materials.

Flexible PCBs, along with advancements in surface mount technologies, additive manufacturing, and miniaturisation, will enhance system designs. These advancements can support integrated electronic controls for flexible solar panels and reduce spacecraft mass by minimising harnessing requirements.

European deep-tech researchers and start-ups are well-positioned to lead in the space sustainability domain.

2.3.12. Hybrid approaches in agentic AI for decentralised decision-making

What is it?

Agentic AI represents a paradigm that integrates autonomous, goal-directed, and interactive agents with diverse AI techniques to achieve specific, often intricate objectives. These intelligent systems function independently, adapting continuously to their environments and interacting dynamically with both other agents and the broader ecosystem in which they operate. Unlike conventional systems, this paradigm involves initiating actions, establishing sub-goals, and dynamically adjusting strategies in response to new information. This blend of self-direction and guided control enables these systems to respond flexibly to changing environments with minimal human oversight while remaining aligned with intended objectives.

What is new?

Recent advancements in this domain involve hybridising agent-based systems with machine learning (ML) models, including Large Language Models (LLMs), deep reinforcement learning, federated learning, edge AI, and other specialised approaches. This hybrid strategy combines adaptive agent behaviour with advanced AI techniques. However, integrating these technologies presents challenges, such as balancing efficiency, ensuring data privacy, and managing computational constraints. Addressing these challenges requires sophisticated engineering and resource allocation, shaping the scalability and responsible deployment of these autonomous systems.

How may it impact the next five to ten years?

This paradigm could drive transformative changes across the EU, particularly where decentralised, adaptable, and responsive decision-making is critical. Its ability to simulate and predict social system behaviours suggests potential value in addressing complex societal issues, including food security, migration, and ecological resilience. By enabling decentralised decision-making, such systems may respond swiftly to localised disruptions, improving crisis response and maintaining stability without centralised control. Economically, they hold promise for enhancing supply chain adaptability and reducing dependency on global networks. These technologies could autonomously balance renewable energy in smart grids, optimise resource allocation, and advance various industries, from transportation to healthcare and smart cities. Managing biases, ensuring accountability, and promoting transparency will remain crucial to fostering fair and trustworthy decision-making as these systems evolve.

2.3.13. Edge AI for more sustainable and accessible technologies

What is it?

AI deployed at the edge of networks represents a computational paradigm where tasks such as model training and deployment occur close to end devices in distributed environments. Unlike centralised, cloud-based AI systems with extensive computing power and data storage, this paradigm operates on less computationally capable edge devices. These devices enable delay-sensitive applications by accessing vast data volumes generated by the Internet of Things (IoT). Key benefits include reduced latency, lower energy consumption, decreased network congestion, and enhanced privacy and security, positioning this approach as a significant shift in how AI interacts with distributed networks.

What is new?

This computational approach integrates data sensing, transmission, and AI-based computation, driven by recent advances in several enabling technologies. Novel hardware developments, such as high-performance microchips, AI hardware accelerators, and compute-in-memory (CIM) architectures, enhance edge device capabilities. Networking technologies, including self-learning network orchestration, intelligent reflecting surfaces, and 6G advancements, further support this evolution. On the AI front, optimised methods like Binary and Spiking Neural Networks, TinyML, and federated learning enable efficient training and deployment on resource-constrained devices. These innovations open applications in robotics, autonomous vehicles, human-machine interaction, and privacy-preserving medical data processing.

How may it impact the next five to ten years?

The potential of this paradigm to decentralise computation may drive environmental sustainability by reducing reliance on high-energy cloud infrastructures and minimising data transfer costs. Intelligent infrastructures could self-optimise energy efficiency, supporting applications like smart grid management with near real-time responses to energy network changes. This approach also holds promise for regions with poor internet access, enabling applications such as air and water quality monitoring and disaster prediction using drone swarms. By reducing costs and hardware demands, it may democratise AI innovation for SMEs and start-ups, boosting EU competitiveness in the AI sector while promoting equitable access to intelligent services.

2.3.14. Novel technology enablers for very low Earth orbit satellites

What is it?

Very Low Earth Orbits (VLEO), ranging from 100km to 450km in altitude, offer significant advantages over traditional Low Earth Orbits (LEO), particularly for earth observation missions that require very high-resolution imagery, potentially reaching 10cm. Operating in the VLEO environment presents unique challenges due to increased aerodynamic forces impacting the orbital and attitude dynamics of satellites. To successfully deploy and maintain VLEO satellites, advancements are needed in several areas, including low-drag materials, surface coatings, aerodynamic attitude control technologies, and propulsive drag compensation models. Novel propulsion systems, such as atmosphere-breathing electric propulsion (ABEP), are particularly promising for sustaining operations at these altitudes.

What is new?

The novelty of this signal lies in the development of atmosphere-breathing electric propulsion (ABEP) systems, which utilise residual gases in the upper atmosphere as propellants, thereby extending the satellite's operational lifespan and reducing associated costs. This innovative approach mitigates the need for on-board propellants, significantly decreasing the mass and volume required for fuel. ABEP systems work by absorbing atmospheric air, generating plasma, and using it as a propellant to maintain the satellite's orbit. However, VLEO operations will have high requirements for AOCS, as GNCs will have to compensate for drag-related instability. Operating at VLEO altitudes introduces unique challenges, such as material stress and disturbances not encountered at higher altitudes, necessitating further innovation in satellite design and materials.

How may it impact the next five to ten years?

In the next five to ten years, VLEO satellites may enable high-resolution imaging for various applications, including disaster management, surveillance, and real-time monitoring, offering social, economic, environmental, and policy benefits. Additionally, VLEO satellites might contribute to a more sustainable space environment with faster decay, but atmospheric impact may be the same. VLEO satellites can carry sensors generating higher quality data that could be particularly relevant for policymakers, industry leaders, and researchers focusing on space technology.

2.3.15. High-precision LiDAR instruments for atmospheric and environmental monitoring

What is it?

LiDAR (Light Detection and Ranging) is a sophisticated remote sensing technology that utilises reflected laser beams to generate precise observations of target areas, whether on land or within the atmosphere. By measuring the return time of laser pulses, LiDAR constructs detailed three-dimensional maps of surfaces and atmospheric profiles. The technology is categorised into three primary types: topographic LiDAR, which uses near-infrared lasers to monitor land; bathymetric LiDAR, which employs water-penetrating lasers to map seafloor and riverbed elevations; and atmospheric LiDAR, which measures backscattered laser light to monitor clouds, aerosols, and various atmospheric parameters. The applications of LiDAR are extensive, from producing digital elevation models and mapping forests for climate monitoring to developing ocean topography maps and conducting atmospheric profiling for weather forecasting and air quality monitoring.

What is new?

The key innovation of LiDAR systems lies in their ability to achieve high measurement accuracy, which surpasses that of traditional remote sensing instruments like electro-optical imagers and radars. This accuracy is particularly beneficial for both land and atmospheric monitoring. The uniqueness of LiDAR technology is in meeting a specific combination of technical specifications—such as a high signal-to-noise ratio and extensive swath width—that enable continuous, precise monitoring. Achieving these capabilities requires significant advancements not only in the payload instrumentation but also in the power, communication, and thermal control systems of satellites. This end-to-end innovation is essential for the operational deployment of satellite-based LiDAR systems, making them a cutting-edge tool for Earth observation.

How may it impact the next five to ten years?

The wide-ranging applications of LiDAR technology suggest potential impacts across multiple domains. Environmentally, LiDAR's ability to accurately map ecosystems and biodiversity could enhance conservation efforts, leading to more effective and actionable environmental policies. Economically, improved mapping of forests and oceans could support more sustainable activities, such as better forest management and efficient navigation. LiDAR-based atmospheric monitoring may also provide more accurate air quality assessments, which could significantly impact public health initiatives by addressing the dangers associated with air pollution. The relevance of LiDAR spans across various stakeholders, including policymakers, industry leaders, and environmental researchers, positioning it as a vital technology for Europe's twin transitions.

2.3.16. Flexible printed circuit boards for multi-level space sub-systems improvements

What is it?

The emerging trend of flexible Printed Circuit Boards (PCBs) and Electronic Assemblies (EA) in space systems is gaining momentum, particularly as these technologies synergise with advancements in power generation systems like thin-film and flexible solar panels. PCBs and EAs are integral to all basic and advanced functions of space systems, and their ubiquity underscores the critical need for innovation in this domain. Flexible PCBs offer significant potential for improving mission performance across various applications by enabling more streamlined and lightweight designs, reducing harness requirements, and integrating electronics more seamlessly into mechanical components. Recognised as a critical area for European investment, particularly under the EU CHIPS Act, the development of flexible PCBs could lead to the establishment of European champions in the supply chain, ensuring stability and scalability in space-grade production.

What is new?

The novelty of flexible PCBs in space applications lies in their ability to significantly enhance design flexibility and improve at multi-level space sub- systems. These technologies reduce the need for extensive wiring harnesses, leading to mass savings and fewer points of failure, which is crucial for mission reliability. Additionally, flexible PCBs enable the full integration of electronics into single mechanical parts, such as control systems, antennas, and sensors, further optimising system design. Innovations in materials, such as polyimide, Kapton, polycarbonates, and other polymers, are central to the development of flexible PCBs, along with advancements in surface mount technologies, additive manufacturing, and miniaturisation. These innovations hold strong potential for high-value applications in space, particularly for missions requiring lightweight and highly integrated electronic systems.

How may it impact the next five to ten years?

Flexible PCBs and Electronic Assemblies will provide significant advantages in various space missions and applications over the next five to ten years. These technologies could lead to optimised system designs, including integrated electronic controls for flexible solar panels, reduced mass budgets due to less harnessing, and the elimination of single points of failure. Additionally, flexible PCBs might enable more effective system stowage and deployment, maximising space utilisation under fairings. In human spaceflight, these technologies could contribute to advanced wearable electronics and improved habitat environments, enhancing astronaut support systems. The strategic development and integration of flexible PCBs align with EU priorities for reducing technological dependencies and fostering innovation in critical sectors of space technology.

ANNEX

Methodological framework of the 2024 EIC Tech Report

Aiming to refine the methodological framework of the previous editions of the EIC Tech Report[33], the 2024 Report adopts a more rigorous two-stage process. While preserving the core strengths of these preceding reports, it also addresses the knowledge gaps identified in the previous cycles, with:

- Quantitative analytics via text mining and scientometric analytics.
- Qualitative expert-based reviews via sector-specific assessment panels.

This guarantees that the report relies on solid, measurable data, enhanced by the insights of leading deep tech researchers and innovators, under the direction of EIC Programme Managers and bolstered by the contributions of 32 external experts from EIC evaluator and stakeholder networks.

As a global leader in supporting deep tech researchers, entrepreneurs, and companies, the EIC must effectively leverage and share its accumulated expertise. The 2024 EIC Tech Report supports this goal, building on the institution's knowledge production and management capacity, and helping it to expand its leadership into broader areas such as anticipatory intelligence and strategic foresight.

The signals are structured in the report following the three macro-areas of primary EIC activity, Green, Health, and Digital, Industry and Space. Each area includes critical sectors for Europe based on a new EIC internal taxonomy for deep tech[34] and is aligned with sector-specific and broader policy priorities.

A. Data mining and quantitative horizon scanning

The first stage of the methodology involved a quantitative review of over 6.650 proposals submitted to the EIC for evaluation between 2018 and 2023, via EIC Pathfinder or FET under the EIC Pilot. This included around 720 beneficiary projects and approximately 5.940 non-funded proposals.

This review was supported by the European Commission's Joint Research Centre (JRC) under an ongoing partnership with the EIC for anticipatory intelligence and strategic foresight. It was mainly conducted via advanced text mining and signal clustering techniques through the JRC Tools for Innovation Monitoring (TIM)[35] enhanced by GPT@JRC machine-based inputs[36], and supplemented by scientometric indicators for empirical classification, validation, and benchmarking, including patent data from the European Patent Office (EPO) PATSTAT[37] and scientific publication data from the SCOPUS database[38].

The data mining and scientometric analytics were overseen by the JRC Competence Centre on Text Mining and Analysis[39]. Additional quantitative scanning inputs, from taxonomy-based classifications to a preliminary sensemaking process on the mining outputs before the next stage, were steered by the JRC Competence Centre on Foresight[40] in collaboration with the EIC Coordination and Analytics Team.

This stage resulted in the identification of around 300 individual signals of emerging technologies and nascent breakthrough innovations that revealed novelty and potential for future development within the three EIC macro-areas. After data cleaning and additional filtering, more than 260 signals were selected for the second stage of qualitative assessment containing data elements such as: number of EIC funded projects and / or non-funded proposals in which the signal was visible, top keywords for the signal in projects and / or proposals, number of patents and / or scientific publications in which the signal was visible, and index of signal activeness, a JRC custom-built indicator to rank signals from a ratio between signal occurrences retrieved in internal and external data for y – 2 (previous 2 years).

B. Expert-based qualitative assessments

The second stage of the methodological approach for the 2024 EIC Tech Report was led by EIC Programme Managers and involved expert-based qualitative assessments of the more than 260 signals selected in the first stage, ending in the final selection of 34 signals. This was carried out by 11 panels corresponding to the sectors within the three EIC macro-areas:

- Agriculture & Food
- Built Environment
- Energy Systems
- Environmental & Climate Technologies
- Health Biotech & Therapeutics
- Medical Devices & Diagnostics
- Advanced Manufacturing & Advanced Materials
- Artificial Intelligence, Data & ICT
- Quantum & Advanced Computing,
- Semiconductors, Electronics & Photonics.
- Space Technologies & Systems

Each panel was coordinated by one or more EIC Programme Managers. All panels included 1 to 4 external experts selected for their recognised expertise in the respective sectors.

In addition to the signals identified in the first stage, if the quantitative analysis did not reveal enough appropriate topics according to the EIC Programme Managers and / or external experts, the assessment panels were also provided with supplementary material to augment the main data set. This included:

- Portfolio assessments internally conducted by the EIC.
- Other expert assessments on EIC projects and / or proposals developed for the EIC.
- Literature reviews and other horizon scanning developed by the JRC for the EIC.

The primary assessment and selection criteria for all signals in the 11 panels were:

- Scientific and / or technological novelty of the signal at EU and global levels.
- Potential for development, scaling and / or market uptake in five to ten years.
- Relevance for sector-specific and general EU policy priorities

We also introduced filtering criteria where priority was given in the 2024 EIC Tech Report to:

- Signals not considered as main topics for EIC Challenges during the 2018-2023 period.
- Signals not featured in previous EIC reports or communication outputs.

The count of funded projects or non-funded proposals associated with the signal was used only as an indication during the qualitative stage. This variable was not central to the decision-making process and is not included in the signal descriptions that follow. Similarly, evidence in EIC data of a signal emerging from projects, proposals, or both was not considered a key factor. Although signals in funded projects might be more prevalent, underlying the novelty pull of EIC Pathfinder or the legacy FET programme, this variable was also not considered to be a decisive factor in this Report.

The aim is not to feature only signals that are quantitatively representative, but all that are significant due to their emergence or impact potential even if having low data points or not being the main focus of the specific projects or proposals in which they were identified. During both quantitative and qualitative assessments, every effort was made to minimise the possibility of noise or bias resulting from a higher concentration of specific topics under targeted or topic-driven calls in this period.

The sensemaking process by the expert panels concluded the selection of the most relevant individual signals or their grouping in larger signals. It resulted also in the enrichment of the quantitative data by adding additional detail and context on major novelty factors of the signal and its likely future impacts in social, technological, economic, environmental, and policy (STEEP) domains[41].

About the European Innovation Council (EIC)

Europe must increasingly champion its role as a global leader in research and innovation and the European Innovation Council (EIC) is at the forefront of this effort. The EIC is the EU's flagship initiative for supporting emerging technologies and breakthrough innovations.

Launched as a pilot in 2018, and fully established under Horizon Europe in 2021 with a budget exceeding €10 billion Euros, the EIC is tasked with identifying, developing, and scaling the most advanced and promising deep tech through grant and equity support. It plays a crucial role in Europe's innovation ecosystems by supporting visionary researchers, entrepreneurs, and companies across all Technology Readiness Levels (TRL) in critical sectors that can enhance Europe's leadership.

Building on a legacy of cutting-edge EU funding, including the Future and Emerging Technologies (FET) programme[42], the EIC currently operates three main funding schemes that bridge the gap between groundbreaking science and market-ready solutions:

- EIC Pathfinder[43] fosters high-risk early-stage research focused on scientific or technological breakthroughs with high potential for innovation.
- EIC Transition[44] bridges the gap between laboratory and commercialisation by advancing projects into applications that can scale and attract investment.
- EIC Accelerator[45] supports startups and SMEs through grant funding and equity deals to fully develop their innovations at market-levels.

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