EIC Tech Report 2026

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THE EUROPEAN INNOVATION COUNCIL

Tech Report 2026

FOREWORD

Technological change is accelerating and global competition is intensifying. By the time new technologies become widely known, either through markets or public debate, many of the decisions that shape their trajectory have already been taken. Anticipating emerging deep-tech developments early is therefore essential for Europe's competitiveness and sovereignty.

The European Innovation Council (EIC) occupies a unique position in this regard. By supporting breakthrough innovations across the full lifecycle, from early-stage research to market deployment and scale-up, the EIC engages with technologies at the stage when their future is still unclear. This vantage point allows us to support bold innovators and to identify novel ideas that may soon shape our daily lives.

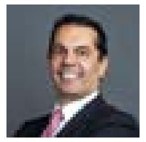
The 2026 EIC Tech Report builds on this perspective. Drawing on insights from the EIC data and expertise, it identifies emerging technologies and translates programme experience into structured knowledge that can inform strategic discussions. In doing so, it provides policymakers, innovators and investors with a shared base of real-world evidence on frontier technologies and their possible applications. It also positions the EIC within a broader set of Commission initiatives, including work led by DG R&I and the JRC to develop a new Observatory of Emerging Technologies, as well as actions steered by DG CONNECT on horizon scanning of digital enabling technologies, or the Competitiveness Coordination Tool envisaged for the next Multiannual Financial Framework.

This year's report highlights innovation emerging from current and aspiring EIC beneficiaries, with particular attention to their potential to contribute to Europe's resilience and strategic autonomy. These objectives are practical rather than abstract and the topics included in this report can support them, from Europe's ability to build and sustain its own critical capabilities to the need to avoid structural lock-ins beyond its control in a shifting global landscape.

Shaping Europe's technological future requires foresight, investment and close cooperation across our innovation ecosystems. By identifying early signals of transformative technologies, the EIC Tech Report aims to support informed decision-making and help ensure that Europe remains at the forefront of deep-tech innovation.

Momchil Sabev

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



LIST OF SIGNALS

Digital & Space Technologies

- 2D materials for advanced memory and memristive devices
- Scalable MXene manufacturing for industrial electromagnetic applications
- Quantum repeaters for trusted-node-free quantum networks
- Embedded Zero Trust Architectures for distributed and federated AI systems
- Bio-inspired AI for emerging self-organising and resource-efficient systems
- Embodied AI for adaptive agents in open and dynamic environments
- Edge computing for scalable and loss-tolerant satellite operations
- Graphene-based coatings and composites for performance-critical space systems
- Advanced in-space servicing robotics for orbital infrastructure maintenance and reuse

Clean & Resource-Efficient Technologies

- Microbial biomining for secondary metal recovery and bioremediation
- Capacitive deionization systems for low-energy water desalination and treatment
- Electrochemical treatment systems for destruction of persistent contaminants in water
- Advanced thermoelectric materials for low- and mid-temperature waste heat recovery
- Spin-caloritronic materials for solid-state heat-to-electricity conversion and sensing
- Inverse design with digital twins for predictive materials manufacturing
- Passive cooling and gravity-based storage for energy-active buildings

Biotechnologies & Health

- Mycelium-based hybrid fermentation for whole-food production
- Biotech-enabled perennial crops for regenerative agricultural systems
- Novel microbiome therapeutics for preventive and personalised health
- Computational protein design for accelerated drug and enzyme discovery
- Automated manufacturing technologies for scalable CAR immune cell therapies
- Biohybrid microrobots for cellular-scale therapeutic interventions
- Autonomous robotic systems for integrated surgical workflows
- Noninvasive and minimally invasive brain interfaces for adaptive therapeutic modulation
- Portable and ultra-low field magnetic resonance imaging for distributed clinical uses

INTRODUCTION

The European Innovation Council (EIC)[1] is the European Union's flagship programme for identifying, supporting, and scaling up breakthrough deep-tech innovation under Horizon Europe, with an overall budget of more than EUR 10 billion for the 2021-2027 period.

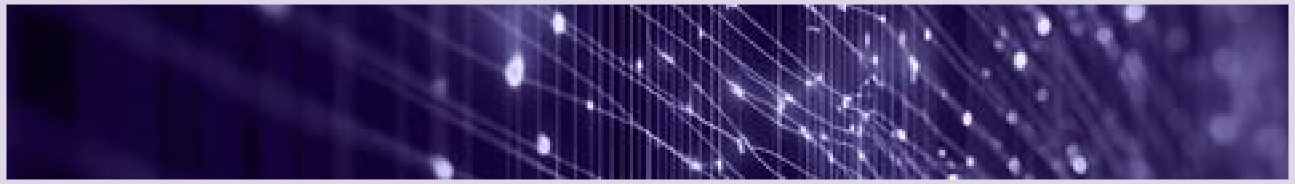
The EIC Tech Report 2026 presents the results of a structured horizon-scanning exercise based on data from funded projects and applications submitted to the EIC. It identifies 25 signals corresponding to emerging technologies that show early indications of scaling potential at low to mid-maturity levels, paying particular attention to their possible applications in strengthening Europe's resilience and strategic autonomy.

The EIC covers the innovation lifecycle from early scientific developments and proof of concept to technology validation, market deployment, and follow-on investments. This support is delivered in the form of grants and investments, as well as through tailored acceleration services, targeting high-risk, high-impact deep-tech areas where research and commercial uncertainty remain significant.

A substantial body of data is generated from applications to EIC instruments and from the proactive portfolio management activities of EIC Programme Managers[2]. A combined quantitative and qualitative analysis of this information enables the identification of signals at early stages or as innovations that have yet to consolidate into established trends. Signals are early observable indications that may evolve into more defined trajectories if further validated or combined with complementary advances within their domains or across sectors[3].

The 25 signals identified and assessed in this edition originate from internal EIC data derived from funded projects and proposals submitted to the EIC between Q2 2021 and Q1 2025, under both Open and Challenge calls of the Pathfinder, Transition and Accelerator instruments managed by the European Innovation Council and SMEs Executive Agency (EISMEA)[4]. The inclusion of data from the three instruments broadens the scope of the report's scanning activities compared to previous editions, while maintaining the emerging scientific and technological novelty lens that anchors all EIC Tech Reports.

The assessment and selection criteria for the signals were guided first by their breakthrough potential and additionally by their possible relevance to Europe's strategic objectives for resilience and autonomy, in line with EIC institutional ambitions and with policy initiatives such as the Strategic Technologies for Europe Platform (STEP)[5].



The EIC Tech Report 2026 builds on the EIC mandate to provide evidence-based feedback to policy and aims to strengthen EU foresight capacity in emerging deep-tech domains. It is underpinned by a rigorous data-driven methodology supported by the European Commission's Joint Research Centre[6] and enhanced by insights from all 10 EIC Programme Managers and 25 top-tier external experts, positioning the analysis as an anticipatory intelligence resource for advanced future-oriented technology analysis[7].

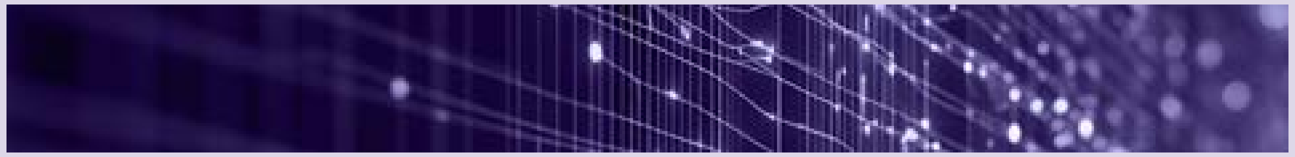
The main objective is to highlight the added value of systematically identifying and assessing novel deep-tech developments within the scope of EIC activities and to enable a shared conversation across EIC stakeholder communities, from policymakers and R&I institutions to beneficiaries and investors, to inform reflection, support monitoring, and stimulate discussion on their potential trajectories and implications.

This work reinforces the future-proofing of EIC operations and contributes to a structured knowledge production and management framework that informs EIC reflections on tomorrow's opportunities, complementing other internal exercises such as thematic foresight exercises[8] and business intelligence scanning and benchmarking[9].

The list is not exhaustive and reflects topics identified within the specific data scope considered, serving as a curated snapshot rather than a comprehensive mapping of emerging technological developments across Europe's innovation ecosystems. These signals should not be interpreted as predictive indicators of forthcoming priorities or funding recommendations, as such decisions require broader assessment, benchmarking against global developments, and alignment with EU policy objectives. Furthermore, inclusion of specific signals does not constitute any form of preferential treatment or imply ranking of any sort, nor does exclusion imply a lack of relevance or potential.

The signals are organised into three thematic chapters that reflect the structure of the EIC internal deep-tech taxonomy[10] and are adapted to ensure alignment with the core sectors of STEP, thereby situating the analysis within a broader EU policy framework.

- **Digital & Space Technologies – covering advanced semiconductor materials, secure computing and AI systems, quantum communication technologies, and space infrastructure and operations.**
- **Clean & Resource-Efficient Technologies – addressing secondary raw material recovery, electrochemical water treatment, advanced heat-to-electricity conversion materials, AI-enabled materials design, and building-integrated energy systems.**
- **Biotechnologies & Health – encompassing biological production platforms, genomics-enabled crops, computational protein design, scalable cell and gene therapy manufacturing, precision medical intervention technologies, and distributed imaging and diagnostic systems.**



CHAPTER 1

DIGITAL & SPACE TECHNOLOGIES

Advanced semiconductor materials, secure computing architectures, artificial intelligence systems, quantum communication components, and space infrastructures define the scope of this chapter. The selected signals concern foundational components that shape how systems are designed, interconnected, and operated in these domains. They are positioned at a stage where technical standards and integration pathways are still being defined, and where early design choices can influence how capabilities consolidate.

Within the EIC scope, several of these technologies are progressing through validation and system-level experimentation, clarifying performance limits, manufacturing constraints, interoperability requirements, and emerging external dependencies. This phase generates structured evidence on the development of secure connectivity, trusted data infrastructures, and space-based capabilities, with direct implications for the reliability and continuity of critical services such as communication, navigation, and observation systems relevant to Europe's future.

1.1. 2D materials for advanced memory and memristive devices

What is it?

Two-dimensional (2D) materials are atomically thin solids whose electronic, optical, magnetic, and ferroelectric properties differ from bulk materials due to quantum confinement and high surface-to-volume ratios. Beyond graphene, research has expanded to transition metal dichalcogenides (TMDs), metal oxides, hexagonal boron nitride (h-BN), black phosphorus, and van der Waals (vdW) heterostructures. In these materials, resistive memories such as ReRAM and PCRAM, as well as memristive devices for neuromorphic computing, rely on mechanisms including redox reactions, vacancy migration, phase transitions, Schottky emission, conductive nanofilament formation, and charge trapping and de-trapping. Integration of optoelectronic functionality with memristors is emerging as an additional direction. In parallel, advances in 2D-material-based spintronics, particularly vdW heterostructures and co-integration with conventional microelectronics, are opening perspectives for MRAM at advanced nodes. The observation of ferroelectricity in several 2D vdW materials further expands the functional scope of atomically thin systems for memory and logic.

What is new?

Recent progress in 2D-material-based memristors shows improved performance, including high on/off ratios, low SET voltages, fast switching, strong retention and endurance, and low energy consumption. Materials such as MoS_2, $HfSe_2$, and h-BN enable vertically stacked devices and dense crossbar arrays. Semiconducting TMDs, including MoS_2 and WSe_2, support-controlled modulation of resistive states for neuromorphic computing. Photon sensitivity in graphene and MoS_2 is being exploited in optoelectronic memristive devices. In spintronics, 2D materials are explored as atomically precise alternatives to MgO tunnel barriers. Ferroelectric behaviour induced by ionic displacement or polar molecular groups has been demonstrated in multiple 2D vdW systems, enabling new FeRAM and FeFET concepts.

How could it matter for Europe's resilience and strategic autonomy?

Atomically thin memory and memristor technologies respond to structural challenges faced by Europe in sustaining competitiveness in advanced semiconductor value chains. Two-dimensional materials offer options to improve energy efficiency, functional density, and heterogeneous integration at advanced technology nodes, supporting objectives related to technology sovereignty, reduction of strategic dependencies, and strengthening of industrial capacity. These characteristics are directly relevant to priorities under the European Chips Act and the Strategic Technologies for Europe Platform (STEP), particularly for emerging memory, neuromorphic, and in-memory computing architectures. Their suitability for embedded and low-power applications aligns with key European industrial sectors such as automotive, industrial automation, and IoT. More broadly, energy-efficient memory technologies can contribute to sustainable digital infrastructures and support trustworthy and human-centric computing systems, reinforcing Europe's long-term sustainability vision for balanced economic security in critical digital technologies.

EIC Deep-Tech Taxonomy: Quantum, Advanced Computing & Semiconductors (Semiconductors & Integrated Circuits / Advanced Materials; Memories & Data Storage / Advanced Computing & Logic Systems / 2D & Nanomaterials)
Strategic Technologies for Europe Platform (STEP): Advanced semiconductors technologies (Memory and resistive switching materials)

1.2. Scalable MXene manufacturing for industrial electromagnetic applications

What is it?

MXenes are a rapidly expanding class of two-dimensional materials composed of transition metal carbides, carbonitrides, and nitrides, with the general formula Mn+1XnTx, where M denotes an early transition metal, X is carbon and/or nitrogen, and T represents surface terminations such as hydroxyl, oxygen, or fluorine. These atomically thin nanosheets, typically 1–5 nm thick, are produced by selectively etching layered precursor phases. MXenes combine high mechanical strength, rich surface chemistry, and metallic electrical conductivity, reaching up to 35,000 S/cm for solution-processed films, while also offering the possibility of tunable electronic bandgaps. More than 50 compositions have been experimentally synthesised, with hundreds more theoretically predicted, making MXenes one of the fastest-growing families of 2D materials. Their property set enables applications in electromagnetic interference (EMI) shielding, energy storage, water purification, flexible electronics, sensing, optoelectronics, and wireless communication systems.

What is new?

A key recent advance is the transition from laboratory synthesis to scalable manufacturing. Kilogram-scale production of MXenes with reproducible properties has been demonstrated within hours, while European research teams have achieved controlled batch synthesis with precise tuning of flake size and surface chemistry. This level of control enables optimisation for specific applications, particularly electromagnetic shielding, where MXene films as thin as 6–15 µm achieve shielding effectiveness an order of magnitude higher than conventional materials at substantially lower weight. New surface passivation strategies extend material stability from days to several months, addressing a major barrier to industrial deployment. Advanced processing routes now support MXene-based transparent conductive films, active sensing layers, and flexible electronic components. At the same time, computational tools, including density functional theory and machine learning, are increasingly used to predict structure–property relationships. Recent developments also include lanthanide-doped MXenes with semiconducting and magnetic behaviour, room-temperature gas sensors, improved supercapacitor and battery electrodes, and MXene-based bioelectronic and tissue engineering platforms.

How could it matter for Europe's resilience and strategic autonomy?

Scalable MXene manufacturing may enhance Europe's position in advanced materials by enabling high-performance electromagnetic shielding solutions that can be produced within European industrial ecosystems. By providing lightweight, flexible alternatives to rare-earth-intensive materials, MXenes could help reduce strategic dependencies in sectors such as telecommunications, automotive electronics, and sensing, consistent with priorities set out in the European Economic Security Strategy and the Critical Raw Materials Act. Their use in protecting 5G and emerging 6G infrastructure may support objectives related to secure connectivity and industrial competitiveness under the Net-Zero Industry Act. At the same time, strengthening European capabilities in MXene processing, qualification, and reliability testing could contribute to more autonomous advanced materials value chains, while supporting sustainability and innovation objectives embedded in EU industrial and research policy.

EIC Deep-Tech Taxonomy: Advanced Manufacturing & Advanced Materials (Advanced Materials; 2D & Nanomaterials / Nanotechnology & Miniaturisation / Industrial & IP/Core Design)
Strategic Technologies for Europe Platform (STEP): Advanced materials, manufacturing and recycling (Nanomaterials and smart materials)

1.3. Quantum repeaters for trusted-node-free quantum networks

What is it?

Quantum repeaters are enabling devices designed to overcome the distance limitations of quantum communication. Unlike classical repeaters, which amplify signals, quantum repeaters cannot copy quantum information due to the no-cloning theorem. Instead, they establish, store, and distribute entanglement across intermediate nodes, which can be connected via entanglement swapping. This allows quantum information to be transmitted securely over hundreds or potentially thousands of kilometres. Current quantum key distribution networks, including those developed under the European Quantum Communication Infrastructure, largely rely on trusted relay nodes, which introduce security and governance constraints. Quantum repeaters provide an alternative by enabling end-to-end, entanglement-based security without trusting intermediate nodes. As such, they are a foundational component for future quantum networks supporting secure communications, distributed quantum computing, and advanced cryptographic services.

What is new?

Quantum repeaters are transitioning from theoretical constructs and laboratory demonstrations toward deployable system components. Recent progress includes quantum memories with storage times sufficient for synchronisation across long-distance links, based on rare-earth-doped crystals and cold atomic ensembles, offering improved coherence and multiplexing capabilities. Advances in deterministic single-photon sources, frequency conversion interfaces, and integrated photonic circuits are addressing scalability and telecom compatibility. In parallel, new repeater architectures are emerging. One-way quantum repeaters based on photonic cluster states and quantum error correction could significantly improve transmission rates and robustness while reducing hardware complexity. At the network level, integration of quantum repeaters with software-defined control planes and multiplexed channels is progressing, enabling coordination with classical telecom infrastructure. Together, these developments mark a shift from proof-of-principle experiments toward system-level designs compatible with real-world quantum communication networks.

How could it matter for Europe's resilience and strategic autonomy?

Quantum repeaters could become a critical enabler for moving the European Quantum Communication Infrastructure beyond trusted-node architectures toward end-to-end entanglement-based security, directly addressing long-term sovereignty and security requirements identified under EuroQCI and the EU's Quantum Strategy. Their development may support European control over key layers of future secure communication stacks, from photonic components and quantum memories to network orchestration. By enabling secure cross-border communication without reliance on trusted intermediaries, quantum repeaters could strengthen resilience of governmental, financial, and critical infrastructure communications, while reinforcing Europe's capacity to define standards, certification approaches, and deployment models for quantum-secure networks consistent with EU values and regulatory frameworks.

EIC Deep-Tech Taxonomy: Quantum, Advanced Computing & Semiconductors (Quantum Technologies / Photonics; Quantum Communications / Lasers & Optical Systems)
Strategic Technologies for Europe Platform (STEP): Quantum technologies (Quantum communications)

Isabel Obieta

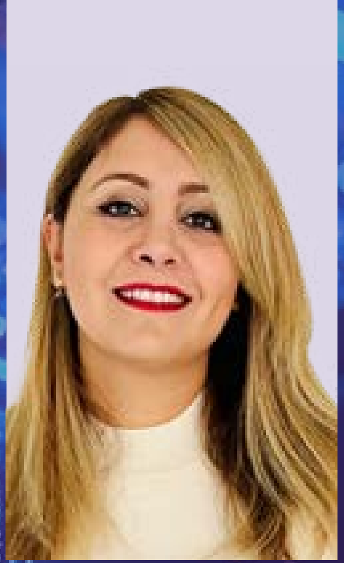
EIC Programme Manager for Sustainable Semiconductors

> *Energy-efficient semiconductor devices increasingly hinge on novel materials and outstanding architectures. Supporting proof-of-concept developments and early connections between key actors within the European ecosystems enable our researchers and entrepreneurs to examine feasibility within future production environments and relevant use cases. By funding breakthrough R&I at this stage, the EIC can help retain critical know-how in Europe as device paradigms shift toward new materials and architectures.*

Samira Nik

EIC Programme Manager for Quantum Technologies and Electronics

> *Quantum architectures and enabling technologies remain fluid across competing technical trajectories. Backing high-uncertainty components and integration concepts should allow EU players to remain engaged in shaping the foundational layers of secure communication and computation via Quantum systems. Early identification and positioning of emerging technologies may determine Europe's role in configuring secure quantum infrastructures rather than adapting to externally defined architectures.*



1.4. Embedded Zero Trust Architectures for distributed and federated AI systems

What is it?

A critical challenge for European industry is to leverage artificial intelligence technologies without sharing proprietary, sensitive, or personal data with third parties, whether for training or for inference. Distributed Zero Trust Architecture (ZTA) approaches for AI address this challenge by enabling decentralised AI training and inference infrastructures in which no component is assumed to be trusted. In practice, such architectures function as a secured AI execution fabric, comparable to a virtual private network for AI workloads. Zero Trust AI architectures are designed around the assumption that any system component, including hardware, software, networks, or users, may be compromised. As a result, they rely on continuous verification and dynamic mechanisms for prevention, detection, isolation, and recovery. Achieving this requires coordinated development of chip-level security primitives, system software, protocols, and orchestration layers. Key elements include chip–software co-design to ensure immutability, advanced key management and signature schemes, quantum-robust encryption, and interoperability across heterogeneous security technologies. New forms of hardware acceleration are also required to support distributed AI paradigms such as federated learning and agentic AI alongside AI-enabled threat management.

What is new?

The novelty lies in the emerging ability to integrate Zero Trust principles directly into distributed AI infrastructures at semiconductor, system, and orchestration levels, rather than implementing security as an external layer. Recent approaches embed isolation, attestation, and encryption features within AI accelerators and AI-enabled chips, securing data flows from local memory through on-chip interconnects to network interfaces handling large data volumes. In parallel, distributed key management based on post-quantum cryptographic schemes introduces new constraints related to scalability, latency, and resilience. AI models, orchestration protocols, and runtime environments are also being adapted for Zero Trust operation, incorporating privacy-preserving computation, continuous attestation, and AI-driven threat detection. Together, these developments form a coherent hardware-centric platform for secure distributed and federated AI.

How could it matter for Europe's resilience and strategic autonomy?

Distributed Zero Trust architectures for AI directly address European priorities related to data sovereignty, cybersecurity, and the secure deployment of AI across fragmented and cross-border infrastructures. By enabling distributed training and inference without centralising sensitive data, these architectures align with requirements under the AI Act and the EU Cybersecurity Act, where continuous risk management and verification are central. Hardware-anchored security and post-quantum cryptographic integration are also relevant to objectives under the Cyber Resilience Act, particularly for strengthening trusted system-level capabilities beyond cloud-centric security models. At system level, Zero Trust AI infrastructures may enable collaboration across health, industry, and public services while preserving control over data and models and reducing reliance on non-European cloud and AI platforms, with continuous verification, human oversight, and enforceable accountability mechanisms in place.

EIC Deep-Tech Taxonomy: Advanced Manufacturing & Advanced Materials (Advanced Materials; 2D & Nanomaterials / Nanotechnology & Miniaturisation / Industrial & IP/Core Design)
Strategic Technologies for Europe Platform (STEP): Advanced materials, manufacturing and recycling (Nanomaterials and smart materials)

1.5. Bio-inspired AI for emerging self-organising and resource-efficient systems

What is it?

Bio-inspired AI refers to approaches that draw on principles from neuroscience, cognitive science, and evolutionary biology to design artificial neural networks with enhanced adaptability, robustness, and resource efficiency. Unlike early biologically inspired models that relied primarily on loose metaphors, current bio-inspired AI focuses on implementing specific mechanisms observed in biological intelligence, such as hierarchical and distributed processing, synaptic plasticity, structural diversity, and adaptive information encoding. These approaches address persistent challenges in artificial neural network design, including sensitivity to local optima, high computational cost, and limited understanding of the relationship between architecture and function. By leveraging how biological systems learn, represent time, and adapt through interaction, bio-inspired AI aims to support continual learning and open-ended adaptation under changing conditions. This makes such systems particularly relevant for non-stationary, adversarial, or long-duration settings, where conventional deep learning approaches often depend on extensive retraining, static architectures, or external intervention to maintain performance.

What is new?

Recent advances increasingly translate biological principles into formal, implementable AI learning and optimisation mechanisms rather than high-level inspiration. Theoretical frameworks such as the Free Energy Principle inform models of perception, learning, and action as continuous processes of uncertainty reduction. In parallel, evolutionary algorithms and neural architecture search are used to explore structural diversity and functional specialisation beyond manually designed topologies. New neuroscience findings also motivate new approaches to temporal learning. Recent work suggests that temporal representations are not hard-wired but learned during interaction and reward-driven adaptation, as illustrated by frameworks in which cue-specific temporal basis functions emerge through localised neural populations and synapse-specific eligibility traces. Complementary efforts focus on systematic evaluation of cognitive capacities in large models, using cognitive science-inspired protocols to probe planning, causal reasoning, or theory of mind. While these developments open pathways toward more adaptive and potentially more controllable AI systems, they also introduce challenges related to interpretability, verification, and stability as architectures become more dynamic and less explicitly specified.

How could it matter for Europe's resilience and strategic autonomy?

Bio-inspired AI is relevant for European priorities on sustainable, responsible, and sovereign AI development, particularly as current scaling-based AI approaches face growing efficiency, control, and governance constraints. By emphasising learning efficiency, adaptive structure, and explicit cognitive evaluation, these approaches align with Commission objectives under the AI Act and the European approach to Trustworthy AI, which stress robustness, transparency, and human oversight. From a strategic autonomy perspective, advancing European capabilities in bio-inspired optimisation and architecture design may reduce reliance on highly resource-intensive AI models developed outside Europe, supporting more diverse and controllable AI development pathways. At the same time, the adaptive and self-modifying nature of these systems raises challenges for evaluation and assurance, reinforcing the need for advanced benchmarking and validation approaches aligned with evolving EU regulatory and scientific capabilities.

EIC Deep-Tech Taxonomy: AI, Data & ICT (Artificial Intelligence; Neural & Cognitive Networks / Machine & Deep Learning)
Strategic Technologies for Europe Platform (STEP): Artificial intelligence technologies (AI algorithms and models)

1.6. Embodied AI for adaptive agents in open and dynamic environments

What is it?

Embodied AI in open environments refers to agent systems that tightly couple perception, internal cognitive or representational priors, and physical or simulated actuation within rich, open-ended settings. These include three-dimensional virtual worlds, physics-based simulations, multi-agent environments, and hybrid virtual–physical digital twins. Unlike isolated benchmark tasks, open environments are dynamic, multi-modal, and partially observable, requiring continuous decision-making, long-horizon planning, social interaction, and adaptation to unexpected disturbances. A practical formulation distinguishes three interdependent components: scalable priors, such as large language models or learned world models; environments that expose action spaces with physical costs and explicit reasoning steps; and algorithms that exploit both priors and environment structure through relatively simple, scalable controllers. Embodiment in this context refers to the coupling between what the agent knows, what it experiences through ongoing interaction, and what it can do, including treating reasoning itself as an explicit form of action embedded in the environment.

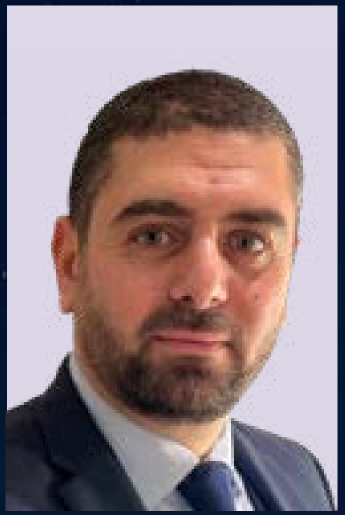
What is new?

Recent work reflects a shift away from training embodied agents to solve narrowly defined benchmarks toward designing environments and action spaces that support more general adaptive competence. Rather than learning from scratch or relying on fixed policies, current approaches increasingly build on large multimodal or learned world-model priors that are adapted online through closed-loop perception–action cycles. Progress is driven by the integration of hierarchical memory, combining short-term context with longer-term episodic or skill representations that can be written, retrieved, and recomposed during operation. Temporal structure is no longer assumed to be hard-coded, as recent frameworks show that task- and cue-specific temporal representations can be learned through interaction and reward. Intrinsic motivation approaches, such as the Maximum Occupancy Principle, and methods like TANGO support zero- and few-shot generalisation through memory-based exploration, repositioning embodied AI around continual online learning in realistic environments.

How could it matter for Europe's resilience and strategic autonomy?

Embodied AI approaches based on large-prior agents place increasing strategic importance on who controls the environments, simulation platforms, and evaluation settings in which advanced AI systems are trained and validated. These approaches intersect with Commission work on foundation models for robotics and physical AI, digital twins, or cyber-physical systems under the AI Act and the EU Industrial Strategy, where adaptability, resource efficiency, and long-term system reliability are critical. From a strategic autonomy perspective, developing European capabilities in environment-centric training, evaluation infrastructures, and embodied learning frameworks may reduce reliance on externally controlled simulation platforms and proprietary benchmarks that increasingly shape advanced AI development. The persistent interaction of embodied agents with real or human-inhabited environments also highlights a need for EU-based approaches to testing, monitoring, and lifecycle management of adaptive AI systems, beyond one-off conformity assessments.

EIC Deep-Tech Taxonomy: AI, Data & ICT (Artificial Intelligence / Robotics; Robotics & Autonomous Agents / Neural & Cognitive Networks)
Strategic Technologies for Europe Platform (STEP): Robotics and autonomous systems (AI-enabled autonomous systems)



Hedi Karray

EIC Programme Manager for Artificial Intelligence

> *“Novel AI architectures are proliferating across heterogeneous computational models and cognitive paradigms. EIC programmes must actively preserve this experimental diversity while embedding responsible AI principles before market scaling consolidates technical standards. These early architectural choices will define how advanced AI systems integrate into Europe’s economic and societal systems over the coming decade and beyond.”*

Stela Tkatchova

EIC Programme Manager for Space Systems and Technologies

> *“EU’s next generation of space infrastructure will depend on greater onboard autonomy, innovative materials, and in-space robotic capabilities. These capabilities will support autonomous space mission operations, reduced mass efficiency and improved thermal performance of spacecraft and opportunities for in-orbit spacecraft maintenance and modular architectures for improved resilience and autonomy in orbit. Thus, contributing to protecting and building a resilient EU space infrastructure.”*

1.7. Edge computing for scalable and loss-tolerant satellite operations

What is it?

Edge computing in space refers to the processing of data directly onboard satellites, spacecraft, or orbital platforms, rather than relying exclusively on transmission of raw data to ground stations. This approach responds to structural constraints in space operations, including limited bandwidth, high latency, intermittent ground contact, and the rapidly growing volume of data generated by modern sensors. As satellite constellations increase in size and missions extend further from Earth, continuous ground-centric supervision becomes increasingly difficult to sustain. By analysing data at the source, satellites can filter, classify, and prioritise information before transmission, sending only critical or refined outputs to Earth. Onboard processing supports more autonomous behaviour, including local decision-making and coordination, and reduces dependence on constant ground intervention. These capabilities are relevant across a range of missions, including Earth observation, deep-space exploration, debris mitigation, and on-orbit servicing, where timely response and operational continuity cannot always rely on ground-based control alone.

What is new?

The novelty of edge computing in space lies in its changing role within satellite systems, shifting from optional data pre-processing toward mission- and safety-relevant autonomy at scale. While onboard processors and data handling functions are already deployed in space missions, their integration into loss-tolerant, operational decision-making remains at an early stage. Traditional space operations depend heavily on centralised ground control, which becomes a bottleneck when managing large constellations, dense orbital environments, or missions operating beyond continuous Earth contact. Edge computing enables satellites to perform functions such as image classification, anomaly detection, collision assessment, and coordination with other spacecraft without waiting for ground commands. This transition is particularly relevant as orbital density increases and missions require faster local responses, for example in debris avoidance, swarm coordination, and autonomous in-space servicing. Rather than introducing new applications, the key shift is the elevation of onboard computation into a system-level requirement for managing complexity and autonomy in space operations.

How could it matter for Europe’s resilience and strategic autonomy?

As European space systems scale through large constellations and more autonomous missions, dependence on continuous ground-based control increasingly constitutes a resilience risk. Edge computing directly relates to objectives under the EU Space Programme and the EU Space Strategy for Security and Defence, which emphasise robust, resilient, and secure space infrastructures. By enabling loss-tolerant operations and reducing reliance on vulnerable ground links, onboard processing supports operational continuity, space safety, and debris mitigation. From a technology sovereignty perspective, strengthening European capabilities in onboard processing architectures and software-defined satellite systems aligns with Strategic Technologies for Europe Platform (STEP) priorities on advanced digital technologies. At the same time, increased onboard autonomy raises challenges around verification, responsibility, and safe behaviour in shared orbits.

EIC Deep-Tech Taxonomy: Space (Satellite Communications & Space-based Connectivity; Satellite Communications Systems / Cloud, Edge, Mesh & Other Advanced Architectures)
Strategic Technologies for Europe Platform (STEP): Advanced connectivity, navigation and digital technologies (Satellite-based secure connectivity)

1.8. Graphene-based coatings and composites for performance-critical space systems

What is it?

Space systems face persistent constraints related to mass reduction, thermal dissipation, multifunctionality of structures, and protection of sensitive components in harsh orbital environments. Conventional materials used in spacecraft structures, thermal control systems, and electronic shielding often require trade-offs between mechanical strength, thermal conductivity, electrical performance, and resistance to radiation or corrosion. Graphene-based materials offer a pathway to address several of these constraints simultaneously. Graphene consists of a single atomic layer of carbon arranged in a two-dimensional honeycomb lattice, which can be integrated into space systems as thin films, coatings, fillers, or multilayer composites. Its combination of high mechanical strength and flexibility, exceptional electrical and thermal conductivity, strong barrier properties, favourable tribological behaviour, and high electron density enables multifunctional performance at very low mass. In spacecraft and launch vehicles, graphene supports applications in thermal management components, structural and composite materials, radiation protection layers for electronics, and functionalised surfaces for antennas, radiators, tanks, and other subsystems.

What is new?

The novelty of graphene in space systems lies not in the discovery of the material, but in the growing feasibility of integrating and qualifying it for operational use. Although graphene has been extensively characterised since its isolation in 2004, space applications have largely remained at laboratory or early validation stages. Recent progress in production methods, including liquid phase exfoliation, chemical vapour deposition, and mechanical exfoliation, enables graphene to be supplied in forms compatible with coatings, composite reinforcement, and thin-film deposition for space-grade components. In parallel, European supply capabilities have matured through coordinated research and industrialisation efforts, notably under the Graphene Flagship, improving material consistency and scalability. These advances support a transition from exploratory use towards system-level integration in structural materials, thermal control components, radiation shielding layers, functionalised surfaces, and ultra-thin space structures. Key challenges remain in long-term reliability, repeatable performance under space conditions, and qualification processes.

How could it matter for Europe's resilience and strategic autonomy?

As space missions place increasing pressure on mass efficiency, thermal performance, and system integration, graphene-based materials may contribute to incremental but system-relevant gains across European space infrastructures. Strengthening Europe's capacity to produce, qualify, and integrate graphene for space applications aligns with objectives under the EU Space Programme and the Secure Connectivity Programme (IRIS²), while reinforcing the Advanced Materials pillar of the Strategic Technologies for Europe Platform. Reducing reliance on non-EU sources for high-performance space materials supports supply-chain resilience and technology sovereignty in critical subsystems. Broader deployment will require coordinated efforts on material standardisation, certification, workforce skills, and safe handling of nanomaterials to ensure reliability and long-term system robustness.

EIC Deep-Tech Taxonomy: Space (Propulsion Technologies, Launch Vehicles & Spacecrafts / Advanced Materials; Thermal & Structural Engineering / 2D & Nanomaterials / Thin Films, Coatings & Surfaces)
Strategic Technologies for Europe Platform (STEP): Advanced materials, manufacturing and recycling (Nanomaterials and smart materials)

1.9. Advanced in-space servicing robotics for orbital infrastructure maintenance and reuse

What is it?

Advanced in-space servicing robotics refers to a set of technologies enabling autonomous or semi-autonomous execution of complex operations directly in the space environment, with minimal human intervention. These operations include inspection, repair, refuelling, relocation, assembly, and end-of-life handling of spacecraft and orbital assets, as well as the extraction, processing, and transformation of materials already present in orbit. Current spacecrafts are predominantly designed as non-serviceable systems, with limited recyclability and no capacity for post-launch maintenance, making unexpected failures largely irreversible and contributing to cumulative space debris. In-space servicing robotics aims to address these structural limitations by enabling robotic manipulation, docking, tool-based operations, and assembly under microgravity conditions. When combined with in-space assembly and manufacturing and in-situ resource utilization, these capabilities may support the maintenance, reuse, and gradual refurbishment of orbital infrastructure, including defunct satellites or upper launcher stages. This is particularly relevant for increasingly congested Low Earth Orbit and for emerging cis-lunar mission architectures requiring long-term operational continuity.

What is new?

The novelty of in-space servicing robotics lies in the transition from isolated, mission-specific demonstrations toward integrated and repeatable maintenance and reuse concepts for orbital infrastructure. Recent developments focus on robotic-assisted assembly, coordinated manipulation using organised clusters of simpler robotic arms, and in-orbit additive manufacturing as part of broader in-space assembly and manufacturing architectures. These approaches aim to mitigate constraints imposed by launcher size, payload volume, and launch frequency by enabling in-orbit repair, modification, and partial recycling of medium- and large-scale structures. In parallel, feasibility studies indicate that existing space debris, including upper stages of large rocket launchers, could be reused as feedstock for in-space manufacturing. Additive manufacturing techniques such as Direct Energy Deposition and Laser Powder Bed Fusion are being explored alongside in-situ resource utilization pathways. Most enabling technologies remain at low to mid readiness levels, with autonomy, reliability, and qualification as key challenges.

How could it matter for Europe's resilience and strategic autonomy?

As European orbital infrastructures grow in scale and congestion, the inability to maintain, adapt, or reuse assets once deployed increasingly represents a strategic and economic vulnerability. In-space servicing robotics may reduce exposure to irreversible failures, launch disruptions, and supply-chain constraints by enabling life extension, controlled refurbishment, and selective reuse of critical space systems. These capabilities intersect with EU priorities on space safety, sustainability, and economic security, including initiatives on the long-term sustainability of outer space activities and the development of a European approach to space traffic management. Developing trusted European capabilities in autonomous in-space maintenance and reuse could strengthen operational resilience and strategic autonomy, provided that such topics as safety and verification models, transferable skills and structured qualification frameworks, or the governance of autonomous operations in shared orbits are addressed coherently.

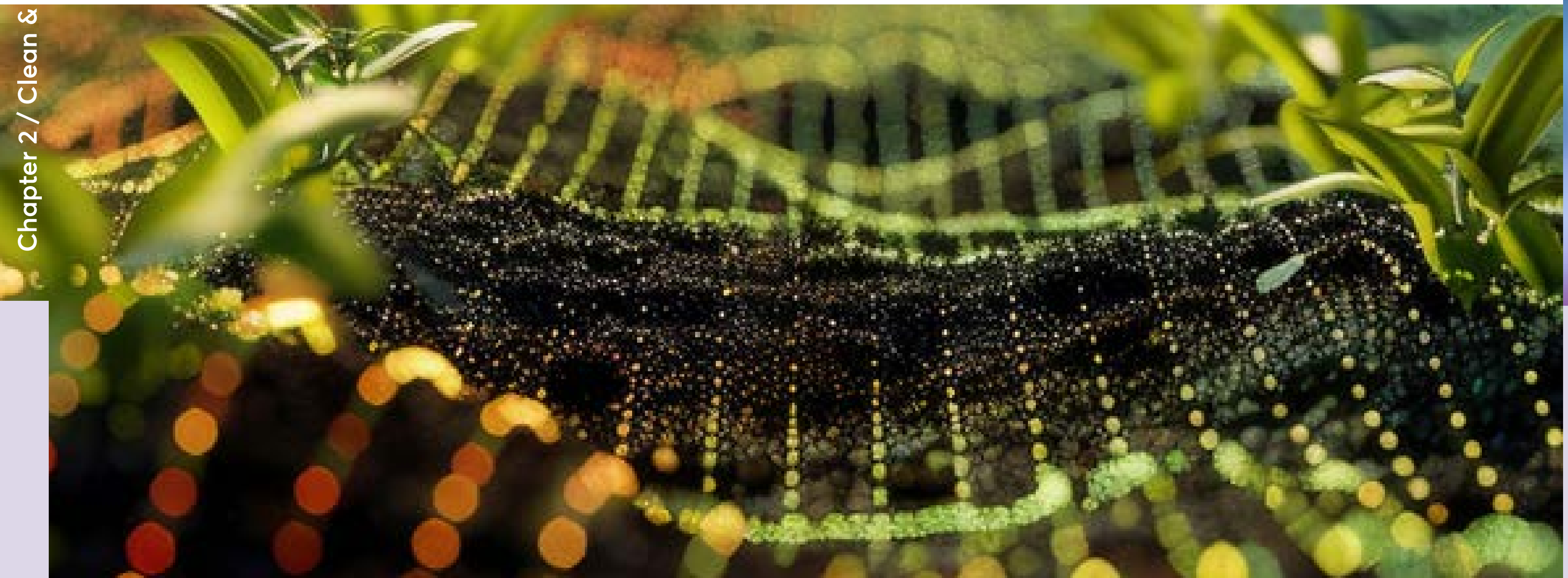
EIC Deep-Tech Taxonomy: Space (In-Space Servicing, Assembly & Manufacturing / Robotics; Space Missions, Operations & Ground Segment / Industrial Robotics, Advanced Machinery & Tooling)
Strategic Technologies for Europe Platform (STEP): Robotics and autonomous systems (Autonomous uninhabited space vehicles)

CHAPTER 2

CLEAN & RESOURCE EFFICIENT TECHNOLOGIES

This chapter brings together emerging technologies that cover the physical management of materials, water, heat, and energy within industrial and built systems. The selected signals address processes such as secondary metal recovery, electrochemical contaminant destruction, low-temperature heat conversion, predictive materials manufacturing, and building-integrated energy functions. They emerge from domains where efficiency gains, selectivity, durability, and controllability determine whether technical alternatives can move beyond laboratory performance.

Several of these developments come through the EIC via funded projects and proposals where integration into treatment plants, industrial facilities, or construction contexts is becoming tangible. Operational stability, installation and maintenance requirements, energy demand, materials compatibility, and reproducibility begin to define technical viability. Highlighting signals at this stage provides insight into how individual process technologies may respond to operational constraints, informing forward-looking reflection on integration requirements and potential development trajectories.



2.1. Microbial biomining for secondary metal recovery and bioremediation

What is it?

Microbial biomining is a biotechnological process that applies extremophilic microorganisms to extract metals from ores, solid materials, water, and waste streams under highly acidic conditions. The microorganisms involved are acidophilic, thriving at very low pH values (approximately pH 0.05–3.0), and include thermophilic bacteria, archaea, and acido-thermophilic microalgae. These microbes obtain metabolic energy by oxidising metal sulphides present in ores or contaminated substrates, a biochemical process that releases metal ions into solution and facilitates their recovery. Metals commonly targeted through microbial biomining include gold, silver, uranium, nickel, cobalt, copper, lithium, and zinc. In parallel, certain acidophilic photosynthetic microorganisms, such as red microalgae from the Cyanidiales group, can capture metal ions from industrial waste sites, including acid mine drainage environments, through intracellular accumulation or biosorption at the cell surface. Owing to their metabolic flexibility, these organisms can also tolerate and remediate co-occurring stresses such as high salinity, enabling combined metal recovery and bioremediation in heavily polluted, acidic environments.

What is new?

Recent developments extend microbial biomining beyond primary ores to substrates such as mine tailings, industrial residues, e-waste, and urban wastewater, enabling recovery of critical and rare elements for energy, transport, and advanced materials applications. Technical innovations focus on improving metal selectivity and extraction efficiency through bioengineered surfaces, synthetic peptides, and customised microbial or cellular collections. Multi-omics analysis, synthetic biology, and adaptive laboratory evolution are being used to re-engineer thermo-acidophilic microorganisms for targeted biomining and bioremediation. In parallel, AI-supported design of de novo enzymes is being explored to enable highly specific bioleaching reactions under ambient conditions. Additional work investigates biomining under extreme physical conditions, including microgravity and Mars-analogue environments.

How could it matter for Europe's resilience and strategic autonomy?

Access to metals from secondary and unconventional sources increasingly depends on processes that can operate on low-grade ores, mine tailings, acid mine drainage, and complex waste streams under chemically extreme conditions. Such routes intersect with the Critical Raw Materials Act, which emphasises strengthening secure and sustainable supply, including greater recovery and processing capacity within Europe, while also engaging permitting, land-use, and legacy pollution constraints that shape domestic sourcing. At system level, coupling metal extraction with bioremediation creates options to embed recovery within existing industrial or post-mining sites. This logic aligns with policy directions under the EU Circular Economy Action Plan, aimed at strengthening secondary raw-material markets and high-quality recycled inputs.

EIC Deep-Tech Taxonomy: Climate & Environmental Tech (Circular Economy & Recycling / Industrial Biotech & Biomanufacturing; Resource Management & Valorisation / Waste & Pollution Management / Alternatives to Critical Raw Materials)
Strategic Technologies for Europe Platform (STEP): Advanced materials, manufacturing and recycling (Technologies for extraction, processing, and recycling of critical raw materials)

2.2. Capacitive deionization systems for low-energy water desalination and treatment

What is it?

Capacitive deionization (CDI) is an electrochemical water treatment technology that removes dissolved ionic species by applying an electrical potential difference between two electrodes, typically composed of carbon-based materials with high specific surface area. When a voltage is applied, cations migrate toward the negatively charged electrode and anions toward the positively charged electrode, where they are adsorbed within electrical double layers formed at the electrode–electrolyte interfaces, reducing water salinity. Once the electrodes approach saturation, the system is regenerated by reversing or removing the applied voltage, releasing the adsorbed ions into a concentrated waste stream. CDI operates at relatively low voltages and without hydraulic pressure, distinguishing it from pressure-driven membrane processes such as reverse osmosis. These operating conditions reduce mechanical stress and enable improved fouling control, particularly in the treatment of low- to moderate-salinity waters such as brackish water or partially treated wastewater.

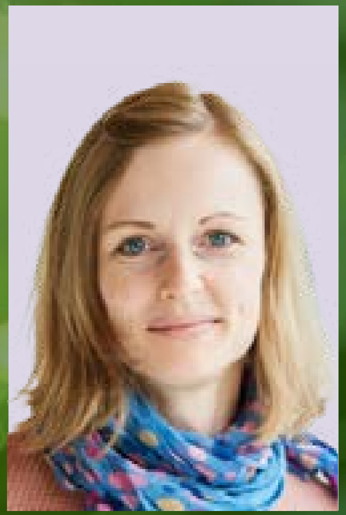
What is new?

Recent advances in CDI focus on electrode materials and cell architectures that enhance performance and broaden applicability. High-surface-area carbon materials, including carbon nanotubes and graphene, increase charge storage capacity and ion adsorption kinetics. Novel configurations such as membrane capacitive deionization, which integrates ion-exchange membranes with electrodes, and flow-electrode CDI, which employs conductive slurries for continuous operation, improve salt removal efficiency and operational flexibility. In parallel, Faradaic electrodes based on redox-active materials are being explored for higher ion selectivity, increased salt removal capacity, and improved cycling stability. These developments extend CDI towards higher-salinity streams while maintaining lower energy demand compared to purely capacitive processes.

How could it matter for Europe's resilience and strategic autonomy?

Reliable access to water resources increasingly depends on treatment technologies that can operate efficiently on brackish water, wastewater, and variable-quality industrial effluents. Electrochemical desalination approaches such as CDI intersect with priorities set out in the European Water Resilience Strategy, which emphasises water efficiency, diversification of supply options, and resilience to scarcity and pollution. At system level, low-voltage and pressure-free processes that enable selective removal of salts, nutrients, or heavy metals create options for decentralised water treatment and resource recovery in agricultural, industrial, or urban contexts. These characteristics are also relevant to objectives under the Water Framework Directive, where improved chemical status and pollution control remain central. Together, such capabilities may contribute to Europe's resilience and strategic autonomy by reducing energy intensity and operational dependencies in water management, while supporting competitiveness in advanced water treatment technologies.

EIC Deep-Tech Taxonomy: Climate & Environmental Tech (Water Management & Resilience; Resource Management & Valorisation / Circular Economy & Recycling)
Strategic Technologies for Europe Platform (STEP): Other sustainability technologies (Water purification and desalination technologies)



Carina Faber

EIC Programme Manager for Renewable Energy Conversion and Alternative Resource Exploitation

> ***"Emerging biological and electrochemical conversion approaches are opening new pathways to clean up our water and soil from pollutants, and to recover metals for reuse. Support to early validation and scale-up of these technologies should enable Europe to develop domestic recovery capacities, strengthening long-term resilience in resource access and environmental management."***

Paolo Bondavalli

EIC Programme Manager for Advanced Materials for Energy

> ***"Backing the early incorporation and performance assessment of novel advanced materials through funding programmes like those offered by the EIC can greatly emphasise how cutting-edge research and innovation can more effectively engage with new energy systems and meet their demands. In times of energy instability and rapid transitions, investing in this capacity within Europe is crucial for the continent's strategic energy self-sufficiency in future changing contexts."***

2.3. Electrochemical treatment systems for destruction of persistent contaminants in water

What is it?

Per- and polyfluoroalkyl substances (PFAS) are a large group of synthetic fluorinated chemicals characterised by very strong carbon–fluorine bonds, resulting in extreme environmental persistence. Exposure to PFAS is associated with multiple adverse health outcomes, including thyroid dysfunction, immunotoxicity, reproductive effects, and cancer, and regulatory thresholds in drinking water are set at very low concentrations. In parallel, plastic pollution is pervasive, with microplastics (particles <5 mm) and nanoplastics (<1 µm) detected across aquatic environments. These particles can act as carriers for other pollutants, including PFAS, and their ageing can release highly toxic additives and transformation products such as 6PPD and 6PPD-quinone from tyre-derived particles. Electrochemical water treatment systems address these contaminants directly in the aqueous phase, aiming to chemically transform or mineralise PFAS and degrade plastic particles rather than transferring them into secondary waste streams.

What is new?

Electrochemical treatment systems are being developed to enable complete defluorination of PFAS and degradation of nano- and microplastics in water. Conventional electrochemical oxidation using commercially available anodes is constrained by high energy demand, mass-transfer limitations at trace contaminant levels, and the formation of chlorinated by-products. Recent research focuses on advanced electrode materials and architectures, including three-dimensional graphene-based electrodes, that enhance electrocatalytic activity while suppressing unwanted by-product formation. These systems are designed to operate at ambient conditions and to improve interaction between persistent pollutants and reactive electrode surfaces. The integration of electrochemistry, nanomaterials, and environmental chemistry enables direct contaminant destruction pathways that are not dependent on separation or concentration steps.

How could it matter for Europe's resilience and strategic autonomy?

Managing highly persistent chemical pollution increasingly depends on treatment approaches capable of destroying regulated substances within the water cycle. Electrochemical systems that enable defluorination of PFAS and degradation of micro- and nanoplastics address challenges central to EU chemical safety and water quality governance, including requirements under the Drinking Water Directive and the implementation of REACH restrictions on PFAS. At system level, modular electrochemical processes that operate without added reagents and at ambient temperature create options for decentralised treatment of industrial effluents and local contamination hotspots. These characteristics are aligned with priorities of the European Water Resilience Strategy, supporting reduced environmental liabilities, improved water quality management, and greater control over advanced water treatment capabilities relevant to Europe's resilience, strategic autonomy, and competitiveness.

EIC Deep-Tech Taxonomy: Climate & Environmental Tech (Waste, Pollutants & Contaminants / Water Management & Resilience; Waste & Pollution Management)
Strategic Technologies for Europe Platform (STEP): Other sustainability technologies (Water purification and desalination technologies)

2.4. Advanced thermoelectric materials for low- and mid-temperature waste heat recovery

What is it?

Thermoelectric materials convert heat directly into electricity when exposed to a temperature gradient, primarily through the Seebeck and Nernst effects. Their performance is governed by the thermoelectric figure of merit, zT, which reflects the balance between electrical conductivity, Seebeck coefficient, and low lattice thermal conductivity. Thermoelectrics are particularly relevant for harvesting low- to mid-grade waste heat, where conventional heat-to-power technologies are inefficient. Advanced thermoelectric materials include established systems such as bismuth telluride (Bi_2Te_3), lead telluride (PbTe), skutterudites, and half-Heuslers, alongside emerging classes such as magnesium-based compounds, organic and polymer thermoelectrics, and organic–inorganic hybrids. Beyond intrinsic material properties, practical use depends on mechanical, chemical, and thermal stability under cycling, as well as integration into modules with low contact resistance, effective thermal management, and scalable manufacturing.

What is new?

Recent progress in thermoelectrics focuses on overcoming long-standing performance and deployment constraints rather than discovering entirely new effects. For low- to mid-temperature regimes below approximately 300 °C, magnesium-based thermoelectrics are being explored to address material criticality and sustainability concerns. In parallel, increasing attention is given to materials with topological band structures, magnetic interactions, or correlated electron effects, where unconventional carrier dynamics, Berry curvature contributions, and enhanced Seebeck or Nernst responses may relax the traditional trade-off between electrical and thermal conductivity.
Incremental gains in zT continue in established materials through advanced doping, resonant impurity effects, nanostructuring, interface engineering, and thin-film or heterostructure approaches, with reported values approaching $zT \approx 2$ in favourable temperature windows. High-throughput computational screening, theory-driven design, and AI-assisted optimisation are increasingly used to explore compositions, phonon–electron scattering mechanisms, and operating windows. Organic and polymer thermoelectrics are also advancing for low-grade heat harvesting, where improvements in power factor, alignment, and composite design are central. Scaling from materials to durable, efficient modules remains an early-stage challenge.

How could it matter for Europe's resilience and strategic autonomy?

Advanced thermoelectric materials may strengthen Europe's energy resilience by enabling recovery of low- and mid-grade waste heat across industry, mobility, and the built environment, supporting efficiency objectives under the updated Energy Efficiency Directive and the European Green Deal. From a strategic autonomy perspective, reducing reliance on thermoelectric materials based on critical or toxic elements such as tellurium or lead aligns with Strategic Technologies for Europe Platform (STEP) priorities on advanced materials and clean energy technologies. Building European capabilities across materials discovery, greener synthesis, module engineering, and system integration could reinforce industrial competitiveness, provided that durability, lifecycle impacts, and safe material use are addressed alongside performance gains.

EIC Deep-Tech Taxonomy: Energy (Energy Generation & Conversion / Advanced Materials; Heating & Cooling / Glass & Ceramics)
Strategic Technologies for Europe Platform (STEP): Energy system-related efficiency technologies (energy system-related energy efficiency technologies)

2.5. Spin-caloritronic materials for solid-state heat-to-electricity conversion and sensing

What is it?

Spin caloritronics studies how heat, spin, and electrical transport interact in materials, with the aim of enabling alternative solid-state approaches to convert heat into electrical signals or power. Unlike conventional thermoelectrics, which rely on charge carrier diffusion along a temperature gradient, spin-caloritronic systems exploit spin currents and magnetic excitations generated by thermal gradients in magnetic or spin–orbit-coupled materials. Key effects include the spin Seebeck effect, where a temperature gradient generates a spin current in a magnetic material, as well as magnon-related contributions to thermopower and transverse thermoelectric responses such as the anomalous Nernst and magneto-Seebeck effects. These phenomena allow heat-induced electrical signals to be generated without requiring high charge mobility. Spin caloritronics is therefore relevant for low-grade heat harvesting, thermal sensing, and temperature control in situations where classical thermoelectric materials face efficiency, stability, or integration limitations.

What is new?

Recent work focuses on translating spin-caloritronic effects from thin-film laboratory experiments toward more robust and scalable material systems. One important development is the emergence of bulk and nanostructured spin Seebeck composites, such as yttrium iron garnet combined with platinum in three-dimensional architectures. These structures improve electrical conductivity and mechanical robustness while preserving measurable spin-based thermal signals, addressing a key limitation of planar devices. In parallel, magnetic doping and phase engineering are being explored to enhance thermoelectric responses through spin-related mechanisms. Examples include magnetic dopants in complex alloys that modify electronic states near the Fermi level, and magnetic phase transformations that strengthen magnon-related contributions to thermopower. Growing interest also surrounds transverse thermoelectric effects in materials with strong spin–orbit coupling, as well as flexible and printable spin Seebeck devices aimed at sensing and low-power applications. Despite progress, efficiencies remain modest, performance mechanisms are still being clarified, and module-level integration remains at an early stage.

How could it matter for Europe's resilience and strategic autonomy?

Spin-caloritronic materials may broaden Europe's technological options for low-grade heat recovery and thermal sensing by introducing energy-conversion mechanisms that do not rely solely on conventional thermoelectric performance. This diversification is relevant for improving energy efficiency and reducing energy losses in line with the updated Energy Efficiency Directive and the European Green Deal, particularly where low-temperature waste heat remains difficult to exploit. From a strategic autonomy perspective, advancing European capabilities in magnetic materials, spin-based transport, and composite device architectures aligns with the Strategic Technologies for Europe Platform (STEP) on advanced materials and clean energy technologies. Given the early maturity of spin-caloritronic systems, sustained European research capacity will be needed to address stability, scalability, and long-term reliability before wider deployment becomes viable.

EIC Deep-Tech Taxonomy: Advanced Manufacturing & Advanced Materials (Advanced Materials; 2D & Nanomaterials / Spintronics & Magnetronics)
Strategic Technologies for Europe Platform (STEP): Energy system-related efficiency technologies (energy system-related energy efficiency technologies)

Franc Mouwen

EIC Programme Manager for Architecture, Engineering, and Construction Technologies

> *"New construction paradigms aim to reduce both embedded and operational carbon by deeply digitalising the built-environment value chain. High-fidelity digital twins, AI-enabled design optimisation, and building-integrated energy systems support lifecycle decision-making from materials to operation. Frontier approaches linking design logic, material performance, and energy use enable measurable carbon reductions, continuous performance tracking, and transparent traceability aligned with evolving policies, regulations, and construction practices."*

2.6. Inverse design with digital twins for predictive materials manufacturing

What is it?

This emerging approach explores how inverse design methodologies for materials, combined with digital twins of buildings and infrastructure systems, may reshape how new materials are discovered, optimised, and deployed in manufacturing. Traditionally, materials development has relied on slow, empirical trial-and-error processes, often resulting in long development cycles and suboptimal alignment with evolving performance, sustainability, and resilience requirements.

By integrating AI-driven inverse design with digital representations of the built environment, materials can be designed with explicit consideration of their operational context from the outset. In this configuration, digital twins do not act as standalone urban models, but as environments in which candidate materials are virtually tested, compared, and refined before physical manufacturing. This enables a more predictive and adaptive approach to materials innovation, linking material composition, manufacturing processes, and real-world performance within a single development loop.

What is new?

The main novelty lies in the convergence of inverse design algorithms, high-performance computing, and physics-based simulation to explore vast material design spaces in a goal-oriented manner. Inverse design applies techniques such as topology optimisation, generative models, and physics-informed neural networks to identify material formulations and microstructures optimised for specific performance criteria, including mechanical strength, thermal emissivity, embodied carbon, durability, or fire resistance. Digital twins of buildings and infrastructure systems are increasingly used as validation layers, allowing candidate materials to be assessed virtually under realistic operating conditions, such as variable climate exposure, dynamic energy demand, degradation over time, or reuse within circular construction cycles. This creates a closed feedback loop between material discovery, manufacturing constraints, and system-level performance, representing a shift away from linear research and development workflows toward more integrated and adaptive materials manufacturing pipelines.

How could it matter for Europe’s resilience and strategic autonomy?

Inverse design–enabled materials manufacturing may strengthen Europe’s resilience by accelerating the development of advanced materials tailored to European industrial, environmental, and regulatory conditions. By shortening design-to-manufacturing cycles and reducing reliance on trial-and-error experimentation, these approaches could support objectives of the Net-Zero Industry Act and the Updated Industrial Strategy for Europe, particularly in scaling clean and resource-efficient manufacturing technologies. The integration of digital twins as validation tools may also contribute to more reliable deployment of novel materials across construction and industrial sectors, supporting circular economy objectives under the EU Circular Economy Action Plan. Together, these capabilities could reinforce European value chains in advanced materials and manufacturing, reducing dependence on external suppliers and strengthening long-term technological sovereignty.

EIC Deep-Tech Taxonomy: Built Environment (Buildings & Real Estate / Advanced Materials; Architecture, Design & CAD / Engineering Simulation & BIM / Digital Twins & Virtual Identities)
Strategic Technologies for Europe Platform (STEP): Advanced materials, manufacturing and recycling

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2.7. Passive cooling and gravity-based storage for energy-active buildings

What is it?

A new paradigm in urban energy management is emerging in which passive daytime radiative cooling and gravity-based energy storage are integrated into the built environment. Across Europe, façades, roofs, and urban infrastructure represent vast surface areas that currently serve mainly protective or structural functions. When equipped with advanced materials and coatings, these surfaces can reflect incoming solar radiation, radiate heat to the sky, and contribute to indoor thermal regulation without consuming electricity. In parallel, gravity-based energy storage systems can transform tall buildings or underground shafts into mechanical energy reservoirs by lifting and lowering heavy masses in response to energy availability. When combined, these approaches could allow buildings to move from being passive energy consumers to active components of urban energy systems, reducing cooling demand while locally storing excess renewable energy. This integration opens pathways toward more adaptive, resilient, and decentralised energy management at the scale of individual buildings and neighbourhoods.

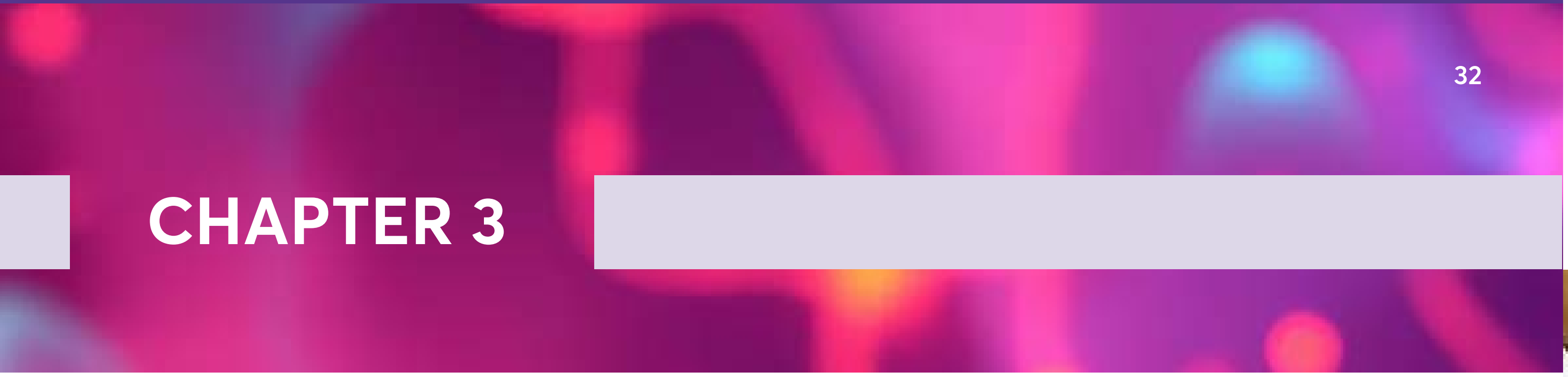
What is new?

Recent advances enable the practical coupling of passive cooling and mechanical energy storage within building-scale systems. Nanomaterial-based coatings are being engineered to create photonic bandgaps that reflect most incoming solar radiation while emitting infrared heat through the atmospheric transparency window, enabling passive daytime radiative cooling under direct sunlight. At the same time, gravity energy storage concepts are being adapted for the built environment, converting surplus renewable electricity into potential energy by lifting solid masses and releasing it during periods of higher demand. Together, these approaches form an emerging closed-loop configuration that reduces cooling loads while smoothing energy demand at local scale. Looking ahead, functionalised coatings may incorporate thermoelectric elements to convert waste heat into electricity, while personal thermal management integrated into walls, furniture, or textiles could deliver comfort more efficiently at the level of individual occupants. Inverse design methods supported by AI are accelerating the optimisation of materials and system configurations for specific climates and building typologies.

How could it matter for Europe’s resilience and strategic autonomy?

Passive cooling and gravity-based energy storage for energy-active buildings may support Europe’s resilience by reducing cooling-related electricity demand during heatwaves, a priority under EU climate adaptation and energy security objectives. By lowering reliance on active cooling systems and electrochemical batteries, these approaches could contribute to the newest version of the Energy Performance of Buildings Directive and the EU Renovation Wave, particularly in dense urban areas. From a strategic autonomy perspective, building-integrated cooling materials and mechanical storage systems may strengthen European value chains in construction materials and advanced coatings, reducing exposure to imported HVAC equipment and battery supply chains, in line with the European Economic Security Strategy and the Net-Zero Industry Act. Improved thermal comfort with low energy input could also support energy affordability and public health objectives.

EIC Deep-Tech Taxonomy: Built Environment (Buildings & Real Estate / Advanced Materials; Building Operations & Maintenance / Heating & Cooling / Energy Efficiency)
Strategic Technologies for Europe Platform (STEP): Energy system-related efficiency technologies (energy system-related energy efficiency technologies)



CHAPTER 3

BIOTECHNOLOGIES & HEALTH

This chapter addresses emerging deep tech developments that intervene in biological systems and clinical environments, spanning novel production pathways in food chains, engineered therapeutic modalities, precision intervention tools, and distributed diagnostic systems. These signals concern capabilities that influence how biological functions are designed, manufactured, controlled, and deployed across agricultural and healthcare contexts.

These technologies are entering phases where translational feasibility, manufacturing scalability, clinical integration, and regulatory alignment become tangible constraints rather than abstract considerations. Biological variability, process reproducibility, quality control, workflow compatibility, monitoring requirements, and organisational readiness begin to determine technical viability beyond laboratory optimisation. Identifying signals at this stage helps clarify how biological and medical technologies are being configured for translation, manufacturing, and clinical use, contributing to anticipatory understanding of how bio-production and therapeutic platforms may take shape in the near term.

3.1. Mycelium-based hybrid fermentation for whole-food production

What is it?

Current food biotechnology is largely dominated by ultra-processed products based on isolated ingredients produced through single-organism fermentation. Mycelium-based hybrid fermentation introduces a more integrated biotechnological approach, using fungal mycelia as a structural scaffold combined with bacteria, yeasts, algae and or plant-derived components within a single bioconversion process. The resulting systems yield novel whole-food products with complex textures, flavours and functional properties, including nutritional and antimicrobial characteristics. Multi-kingdom microbial consortia are engineered and cultivated using advanced mycelium growth methods such as liquid fermentation, three-dimensional structuring, bioink-based processing and fogponic-inspired cultivation. Agricultural residues and food-industry side streams serve as feedstocks, supporting circular production models. Digital fabrication techniques and AI-supported process control may be integrated to manage growth dynamics and product consistency. Development of these novel food products requires close alignment with existing regulatory frameworks and, where appropriate, the definition of new terminology reflecting whole-food, multi-organism fermentation systems.

What is new?

Existing mycelium-based technologies primarily target single-organism mycoprotein production or non-food material applications. The novelty here lies in shifting toward complex whole-food products generated through systematically engineered multi-species fermentation, in which fungal mycelium functions as the main structural matrix. While earlier work has demonstrated proof-of-concept co-cultivation of mycelium with bacteria, yeasts or algae, this approach scales toward more complex, intentionally designed microbial communities. By integrating all functional components into a single fermentation step, production processes are simplified and value chains shortened. Technological innovation also stems from transferring advanced bioconversion methods originally developed for engineered materials into food biotechnology, alongside the introduction of digital fabrication and AI-driven automation. Moving beyond the reductionist logic of precision fermentation, this approach introduces a holistic food design paradigm that more closely emulates natural fermentation ecologies while remaining compatible with industrial production requirements.

How could it matter for Europe's resilience and strategic autonomy?

Mycelium-based hybrid fermentation may strengthen Europe's capacity to develop resilient, low-input food biotechnologies that go beyond ingredient-level precision fermentation. By enabling integrated whole-food production from locally available agricultural residues, this approach could contribute to objectives under the EU Bioeconomy Strategy and the Farm to Fork Strategy, while aligning with Strategic Technologies for Europe Platform (STEP), particularly around process biotechnologies. Its potential to shorten value chains and reduce reliance on imported proteins or fermentation-derived inputs may support economic security in the agri-food sector. In addition, cross-sector applications in materials and industrial bioprocessing could reinforce Europe's strategic position in bio-based manufacturing, with particular attention to questions around whole-food classification, safety assessment of multi-organism fermentation, and consumer transparency are addressed within existing EU food safety and novel food regulatory frameworks.

EIC Deep-Tech Taxonomy: Agriculture & Food (Agrifood Biotechnology / Industrial Biotech & Biomanufacturing; Precision Fermentation / Regenerative Farming & Agritech for Sustainability / Resource Management & Valorisation)
Strategic Technologies for Europe Platform (STEP): Process biotechnology techniques (Fermentation and biorefining)

3.2.

Biotech-enabled perennial crops for regenerative agricultural systems

What is it?

Regenerative agriculture is an approach to food production that prioritises soil health, biodiversity, and long-term ecosystem functioning while maintaining agricultural productivity. Perennial grain crops are a core component of this approach, as they allow multi-year harvests without annual tillage and can substantially reduce fertiliser, pesticide, and energy inputs. Despite these advantages, perennial grains have so far seen limited adoption due to persistent yield gaps compared to annual cereals such as wheat or barley. Perennial grains can be developed either through wide hybridisation or through de novo domestication of wild perennial species. While wide hybridisation has enabled successful examples such as perennial rice, where yields comparable to annual rice have been achieved alongside significant reductions in labour and input costs, this approach is not feasible for several major crops due to chromosomal incompatibilities. In such cases, progress depends on de novo domestication, a process that has traditionally been slow and labour-intensive.

What is new?

Recent advances in new genomic techniques and artificial intelligence offer the possibility to substantially accelerate the domestication and improvement of perennial grain crops. Closing existing yield gaps would allow perennials to compete directly with annual staples, enabling a transition toward low-input production systems that reduce reliance on chemical inputs such as glyphosate, stabilise soils, limit nutrient leakage, and enhance carbon sequestration. Technologies such as genomic selection, genome-targeted screening approaches including TILLING and FIND-IT, and AI-assisted breeding pipelines can shorten breeding cycles that currently delay the market readiness of perennial crops. By improving trait selection efficiency and enabling faster iteration, these tools address one of the main structural barriers to scaling perennial agriculture. Compared to conventional breeding approaches, the integration of NGTs and AI may enable competitive perennial varieties to be developed within timelines compatible with current agricultural and market dynamics.

How could it matter for Europe's resilience and strategic autonomy?

Accelerated domestication of perennial grains could support EU objectives related to food security, soil protection, and reduced dependency on imported fertilisers, in line with the Common Agricultural Policy, the EU Soil Strategy for 2030, and the Farm to Fork Strategy. By enabling low-input cropping systems, perennial grains may reduce environmental and economic costs linked to nitrate pollution, soil degradation, and input volatility. Strategic investment in genomics-enabled breeding approaches could strengthen Europe's capacity to develop regionally adapted crop varieties, reinforcing resilience of agri-food supply chains. At the same time, the deployment of such technologies will need to align with evolving EU frameworks on new genomic techniques, including safeguards related to sustainability, traceability, and coexistence.

EIC Deep-Tech Taxonomy: Agriculture & Food (Agrifood Biotechnology / Crops; Regenerative Farming & Agritech for Sustainability)
Strategic Technologies for Europe Platform (STEP): DNA & RNA technologies (New genomic techniques)

3.3.

Novel microbiome therapeutics for preventive and personalised health

What is it?

Microbiome therapeutics are a new class of therapies that target microbial communities and their functions to improve host health. They are often described as ecosystem therapies, as they act by reshaping the ecological balance of the microbiome rather than acting on a single host protein or pathway. Interventions can include providing nutrients that support beneficial microbes, limiting substrates for harmful microbes, or introducing microbial "friends" to reinforce health and "foes" to suppress pathogens. Therapeutic approaches range from live biotherapeutics, including single strains, defined consortia, and engineered microbes with programmed functions, to small molecules derived from microbial metabolites, bacteriophages that selectively deplete pathogens, and dietary modulation to steer microbial metabolism. Early empirical approaches such as faecal microbiota transplantation are increasingly giving way to standardised products developed under pharmaceutical frameworks. Applications extend beyond gastrointestinal disorders to oncology, autoimmunity, infections, and neurological conditions, reflecting the systemic role of the microbiome.

What is new?

Microbiome therapeutics are progressing from exploratory concepts toward clinically relevant, mechanism-driven ecosystem therapies. This transition has been enabled by advances in large-scale sequencing and high-throughput cultivation techniques that allow previously unknown or unculturable microbes to be identified and characterised. Improved spatial sampling along the gastrointestinal tract has revealed site-specific microbial functions with implications for both local and systemic disease. Synthetic biology is enabling engineered strains that sense disease states or deliver therapeutic molecules in situ, while bacteriophages and phage-derived enzymes provide precision tools to selectively target pathogens. Targeted delivery technologies, including colon-release formulations and 'sense-and-respond' engineered microbes, support context-aware interventions. These approaches are now entering clinical trials across oncology, metabolic disease, and immunology, with early proof-of-concept signals emerging. In parallel, large participatory cohorts involving hundreds of thousands of volunteers are generating integrated diet–microbiome–metabolome datasets that underpin more predictive and personalised therapeutic strategies.

How could it matter for Europe's resilience and strategic autonomy?

Microbiome therapeutics could contribute to Europe's resilience by supporting a shift toward preventive and personalised health interventions, in line with objectives of the Pharmaceutical Strategy for Europe to improve access, innovation, and long-term sustainability of healthcare systems. Their development depends on capabilities where Europe is structurally strong, including population cohorts, regulated clinical research, and food–health interfaces. From a strategic autonomy perspective, establishing EU-based manufacturing and regulatory pathways for live biotherapeutics, bacteriophages, and microbiome-derived products may reduce reliance on externally developed therapeutic platforms. Furthermore, microbiome therapeutics illustrate how data-intensive life sciences and biological production can converge into new health value chains that Europe can shape, standardise, and scale responsibly, consistent with the Strategic Technologies for Europe Platform (STEP).

EIC Deep-Tech Taxonomy: Health Biotechnology (Therapeutic Drugs & Biologics; Microbiome / Biomarkers & Precision Medicine / Drug Discovery) **Strategic Technologies for Europe Platform (STEP):** Process biotechnology techniques (Process improvement for advanced therapy medicinal products)

Ivan Stefanic

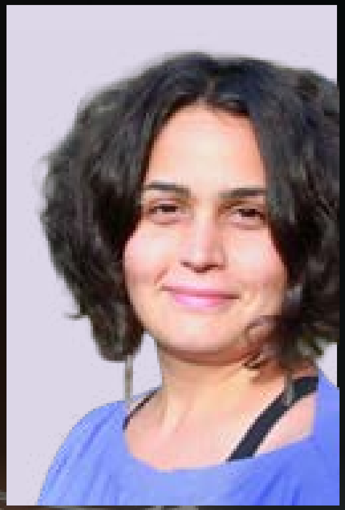
EIC Programme Manager for Food Chain Technologies, Novel and Sustainable Food

> *"The EU's food system stands at a crossroads: climate shocks, biodiversity collapse, and social inequities demand radical innovation, not incremental fixes. Through the European Innovation Council, we're backing deep-tech pioneers to rebuild our agrifood sector from the ground up: regenerative soil systems, advanced fermentation, and circular bio-based materials that turn waste into wealth. But food is more than fuel - it's medicine, culture, and resilience. By embedding precision nutrition, biotech remediation, and inclusive supply chains, we're not just securing Europe's food sovereignty; we're redefining health, longevity, and planetary stewardship."*

Orsolya Simmons

EIC Programme Manager for Health and Biotechnology

> *"Biotechnological innovation in healthcare increasingly combines computational design, the development of programmable biology platforms, cellular engineering, and advanced bioprocessing developments. By facilitating the value chain from high-risk experimentation through iterative scale-up by means of financial and operational support, cutting-edge public funding bodies such as the EIC can transform emerging technology into clinically and industrially viable R&I platforms."*



3.4. Computational protein design for accelerated drug and enzyme discovery

What is it?

Computational protein design is a discipline within protein engineering that uses data-driven approaches, including machine learning and artificial intelligence, alongside biophysical models of protein folding, to predict protein structures and functions from amino acid sequences. By leveraging the relationship between sequence, structure, and function, it enables the design of novel protein sequences that reliably fold into predefined topologies and perform targeted biological tasks. Applications range from the de novo design of small binding proteins that recognize specific epitopes, to the optimization of enzymes for improved stability, selectivity, or catalytic efficiency in biocatalysis. Beyond enzymes, computational protein design has expanded into therapeutic and vaccine development. A notable example is a computationally designed protein nanoparticle carrying the SARS-CoV-2 spike protein, licensed as the SKYCovione vaccine, demonstrating that AI-designed proteins can meet real-world regulatory and clinical requirements. These capabilities position AI-assisted protein design as a general-purpose technology for programmable biology across health, industry, and materials science.

What is new?

Recent advances in machine learning and AI have significantly improved the ability to model complex relationships between protein sequence, structure, and function. Deep learning architectures trained on large structural and sequence datasets have increased the reliability of structure prediction and have reduced historical bottlenecks related to protein expression, stability, and solubility. As a result, AI-assisted protein design is increasingly combined with high-throughput protein synthesis, expression, and rapid functional screening, forming integrated design–build–test cycles. This workflow has become transferable across different protein classes and application domains. Current research efforts are shifting from structure prediction toward more accurate and generalizable prediction of protein function, which remains a major scientific challenge. Iterative optimization strategies that integrate experimental feedback are therefore central to current progress. These developments are enabling broader application of AI-designed proteins in areas such as immunotherapy, green chemistry, industrial biocatalysis, and functional biomaterials, moving the field beyond proof-of-concept toward scalable innovation.

How could it matter for Europe's resilience and strategic autonomy?

AI-assisted protein design could strengthen Europe's position in high-value biotechnology by shortening discovery-to-production cycles for therapeutics, enzymes, and vaccines, directly supporting technology sovereignty in health and industrial biotechnologies. By enabling faster and more predictable protein engineering, it may reduce dependence on non-European platforms for biologics discovery and advanced biomanufacturing. This aligns with EU priorities under the Strategic Technologies for Europe Platform, the Pharmaceutical Strategy for Europe, and the EU framework for advanced therapy medicinal products, where speed, reliability, and secure innovation pipelines are critical. In parallel, the diffusion of open and interoperable design tools could support skills development and a distributed innovation base, reinforcing economic security while remaining consistent with EU regulatory and safety frameworks.

EIC Deep-Tech Taxonomy: Health Biotechnology (Therapeutic Drugs & Biologics / Data & Advanced Analytics; Drug Discovery / Machine & Deep Learning / Genetic Engineering & Synthetic Biology)
Strategic Technologies for Europe Platform (STEP): Proteins & other molecules (Sequencing, synthesis, or engineering of proteins and peptides)

3.5. Automated manufacturing technologies for scalable CAR immune cell therapies

What is it?

Chimeric Antigen Receptor (CAR) immune cell therapies use engineered immune cells as living drugs to recognize and fight diseases, by modifying them to recognize specific target cells and to perform desired immune functions. This concept is already advanced for T cells, with oncology as the primary application, and six CAR T cell products approved in the European Union for hematological malignancies. Manufacturing these therapeutics is typically a complex, multi-step process, often involving highly variable starting material from patients to create personalized treatments. This variability, combined with labor-intensive and centralized production models, has historically limited scalability, increased costs, and constrained patient access. Next-generation CAR immune cell therapies aim to address these barriers by improving scalability, safety, cost-effectiveness, and consistency, with innovations in manufacturing, automation, and cell engineering playing a central role.

What is new?

Immune cell therapy manufacturing is evolving through the introduction of new tools and strategies that address key bottlenecks. Miniaturization and automation now enable semi-closed or fully closed manufacturing platforms, supporting decentralized or near-clinic production and reducing contamination risks, production times, and costs. Non-viral engineering approaches, including mRNA delivery and transposase systems, provide greater flexibility and improved safety profiles compared to viral vectors. Allogeneic "off-the-shelf" CAR immune cell products represent another major step forward, relying on alternative cell sources with reduced alloreactivity or on gene editing and immune-shielding strategies to limit rejection and toxicity. Early clinical trials report encouraging safety and efficacy signals. In parallel, in vivo CAR engineering approaches are under active investigation, aiming to introduce CAR constructs directly into immune cells within the patient, thereby bypassing ex vivo manufacturing and further simplifying delivery.

How could it matter for Europe's resilience and strategic autonomy?

Advances in CAR immune cell manufacturing and automation directly intersect with the Strategic Technologies for Europe Platform focus on biotechnologies, particularly on cell and tissue engineering and process biotechnology, which are identified among Europe's critical technology domains. Progress in automated, closed, and decentralised manufacturing models could support secure EU-based production of Advanced Therapy Medicinal Products under the ATMP regulatory framework, while reducing exposure to external supply dependencies in vectors, reagents, and cell-processing infrastructure. Scalable and standardised manufacturing may also contribute to the Pharmaceutical Strategy for Europe objectives on security of supply and faster patient access to innovative therapies. In this context, CAR manufacturing platforms could become strategic assets within Europe's health innovation ecosystem, supporting economic security and long-term technological sovereignty in next-generation immunotherapies.

EIC Deep-Tech Taxonomy: Health Biotechnology (Regenerative Medicine; Cell & Gene Therapies / Industrial Biotech & Biomanufacturing / Drugs & Pharma Processing)
Strategic Technologies for Europe Platform (STEP): Cell & tissue culture and engineering (Cell therapies)

3.6. Biohybrid microrobots for cellular-scale therapeutic interventions

What is it?

Biohybrid microrobots are small engineered systems that integrate synthetic materials with living biological components to perform tasks at cellular or tissue scale. Unlike purely mechanical micromachines, these systems exploit biological functions such as motility, sensing, and adaptability for propulsion and environmental interaction, while synthetic frameworks provide controllability, robustness, and the ability to carry functional payloads. Biological components can include bacteria, microalgae, stem cells, immune cells, or contractile proteins, combined with microfabricated structures and nanoscale materials. When coupled with bioconvergence, defined as the integration of biology, nanotechnology, artificial intelligence, and advanced engineering, biohybrid microrobots can be designed to navigate complex biological environments and deliver drugs, imaging agents, or gene-editing tools with high spatial precision. These capabilities position biohybrid microrobots as emerging tools for minimally invasive diagnostics, regenerative medicine, and targeted therapeutic interventions where conventional delivery approaches face limitations.

What is new?

Recent innovations focus on improving propulsion, targeting, and control of biohybrid microrobots through advanced materials integration and AI-supported coordination. New designs increasingly combine biological propulsion units such as bacteria, microalgae, picoeukaryotes, or mammalian cells with synthetic components including magnetic nanoparticles or responsive polymers, enhancing navigation and manoeuvrability in confined, heterogeneous, or fluid-dynamic microenvironments. Targeting strategies incorporate ligands or antibodies that recognise disease-specific molecular markers, enabling more selective localisation and reduced off-target effects. AI-enabled control frameworks support real-time interpretation of local biochemical or physical cues and adaptive behaviour during operation. Parallel efforts address biocompatibility, immune interaction, scalability, and reproducibility, alongside early work on prolonged tissue or organ retention. Together, these developments move biohybrid microrobots beyond proof-of-concept demonstrations toward more controlled, application-relevant systems suitable for preclinical evaluation and, in the longer term, clinical translation.

How could it matter for Europe's resilience and strategic autonomy?

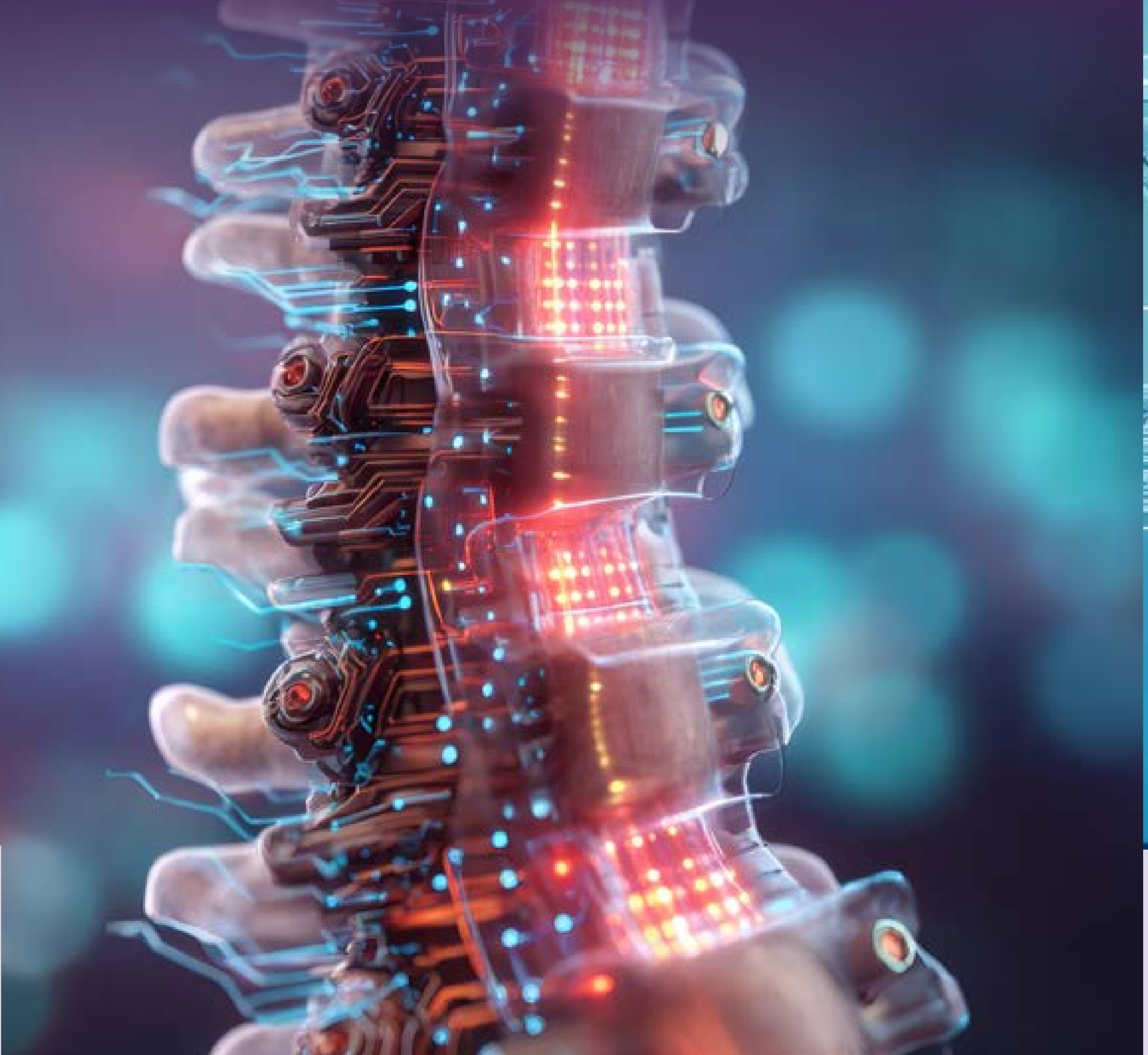
Biohybrid microrobots sit at the intersection of several critical technology domains for Europe, notably advanced materials, biotechnology, artificial intelligence, and medical technologies. As a convergent capability rather than a single-purpose device class, they illustrate the type of cross-domain innovation targeted by the Strategic Technologies for Europe Platform (STEP), where upstream control over design, integration, and early manufacturing is strategically important. Strengthening European capacity in biohybrid microrobotic platforms may reduce dependence on non-European supply chains for high-value therapeutic delivery and minimally invasive intervention technologies. At system level, the ability to engineer precision interventions at cellular scale raises regulatory and safety challenges that align with existing EU frameworks for medical devices, advanced therapies, and AI-enabled systems, where controllability, traceability, and clinical validation remain central.

EIC Deep-Tech Taxonomy: Medical Technologies (Invasive Medical Devices / Cell & Gene Therapies; Surgery & Wound Management / Robotics & Autonomous Agents / Genetic Engineering & Synthetic Biology)
Strategic Technologies for Europe Platform (STEP): Robotics & autonomous systems (Robot-controlled precision systems)

Federica Zanca

EIC Programme Manager for Medical Technologies and AI in Healthcare

> *Emerging AI and other deep-tech enabled medical systems require iterative validation beyond controlled laboratory conditions. Supporting early clinical translation and system refinement allows novel approaches to be tested within European healthcare contexts. The way these technologies mature, through support such as that provided by the EIC, will shape how the most advanced and data-driven care models move from experimentation into routine clinical practice.*



3.7. Autonomous robotic systems for integrated surgical workflows

What is it?

Autonomous robotic surgery refers to the integration of robotics, artificial intelligence, and multimodal imaging and sensing with the objective of performing surgical tasks with minimal human intervention. While robotic surgery is already established to enhance precision, ergonomics, and dexterity, current commercial systems operate primarily as surgeon-controlled instruments. Fully autonomous surgical systems, capable of independent decision-making and execution across complex procedures, remain underdeveloped. Existing research largely targets narrowly defined tasks such as knot-tying, suturing, or trajectory planning, rather than the full surgical workflow. Achieving clinically meaningful autonomy requires robust systems with situational awareness, adaptability to anatomical variability, and the capacity to integrate visual, force, and physiological data during surgery. Engineering resilient robotic platforms that can respond to dynamic intraoperative conditions and approximate human-level dexterity and judgement is central to progressing from robotic assistance toward genuinely autonomous surgical interventions.

What is new?

Recent advances shift the focus from isolated task automation toward more integrated, workflow-oriented autonomous surgical systems. Rather than targeting single actions in isolation, current research increasingly addresses how autonomous functions can be embedded across consecutive phases of a surgical procedure. Deep learning-based computer vision enables real-time identification of anatomical structures, surgical phases, and instrument motion, supporting context-aware assistance and partial automation of subtasks such as suturing, resection, or tissue manipulation. In parallel, robotic platforms are incorporating force sensing, haptic feedback, and adaptive control mechanisms to improve precision, robustness, and safety in dynamic intraoperative environments. The integration of multimodal intraoperative data, including imaging, kinematics, and physiological signals, enables closed-loop control and predictive modelling approaches that can anticipate deviations or complications. Together, these developments represent incremental but tangible progress toward safe, reliable autonomous surgical functions embedded within broader clinical workflows.

How could it matter for Europe's resilience and strategic autonomy?

Autonomous robotic surgery is relevant to Europe's objectives on technology sovereignty, industrial capacity-building, and security of supply in advanced medical technologies. At system level, incremental autonomy in surgical robotics may support workforce resilience in specialised clinical settings, while maintaining human oversight remains essential for accountability and clinical acceptance. As a robotics- and AI-enabled system within the scope of the Strategic Technologies for Europe Platform, it aligns with priorities to strengthen European capabilities in high-value health technologies and reduce dependencies on non-European platforms at both hardware and software levels. Progress in this area is shaped by requirements under the Medical Devices Regulation and the AI Act, where safety, reliability, transparency, and traceability in high-risk applications are central, highlighting the role of EU-based validation, qualification and certification capacities for surgical robotic systems.

EIC Deep-Tech Taxonomy: Medical Technologies (Invasive Medical Devices; Surgery & Wound Management / Robotics / Patient Monitoring Systems)
Strategic Technologies for Europe Platform (STEP): Nanobiotechnology (Drug delivery, diagnostics, and biomanufacturing tools)

3.8. Noninvasive and minimally invasive brain interfaces for adaptive therapeutic modulation

What is it?

Noninvasive and minimally invasive brain interfaces are technologies designed to interact with neural activity without requiring highly invasive neurosurgical procedures. These systems combine sensing modalities such as electroencephalography, functional magnetic resonance imaging, functional ultrasound, and near-infrared spectroscopy with effector technologies including transcranial magnetic stimulation, targeted electrical fields, and focused ultrasound. By integrating neural sensing and stimulation, closed-loop brain interface systems can be established to monitor brain dynamics and modulate neural activity in real time. Therapeutic applications include treatment of epilepsy, psychiatric disorders, and neurological conditions, as well as emerging approaches for tumour targeting. Minimally invasive variants extend these capabilities through miniature implants with autonomous power supply and wireless communication, enabling more precise targeting while preserving limited invasiveness. Beyond medical applications, brain interfaces are also explored for human–machine interaction in areas such as robotics, vehicle control, and immersive digital environments. Innovation increasingly arises from combining established neurotechnologies with adaptive computational approaches.

What is new?

Recent advances are driven by the convergence of multimodal neural sensing, adaptive stimulation, and artificial intelligence into integrated brain interface platforms. Combined acquisition of electroencephalography, functional magnetic resonance imaging, transcranial functional ultrasound, and near-infrared spectroscopy improves both spatial and temporal characterisation of neural activity. Parallel progress in effector technologies enables more precise, adaptive focused ultrasound and closed-loop transcranial magnetic or electrical stimulation, allowing stimulation parameters to respond dynamically to ongoing brain states. Minimised, wireless implants further extend minimally invasive approaches by enabling targeted intervention with reduced procedural burden and continuous operation. AI-based methods are increasingly applied to decode complex neural dynamics, identify pathological patterns, and adjust stimulation strategies in real time. Together, these developments move brain interfaces from open-loop or episodic use toward responsive systems capable of monitoring and modulating neural activity continuously across a broader range of neurological and neuropsychiatric conditions.

How could it matter for Europe's resilience and strategic autonomy?

Non-invasive and minimally invasive brain interfaces are relevant for European priorities where advanced neurotechnologies must be deployed safely within existing healthcare systems. Their development aligns with requirements under the Medical Devices Regulation, particularly for high-risk devices combining sensing, stimulation, and adaptive software. The integration of AI-driven decoding and closed-loop modulation also intersects with the AI Act, where transparency, human oversight, and post-market monitoring are central. From a health-system perspective, brain interfaces that reduce reliance on highly specialised neurosurgical infrastructure could support more resilient and distributed care models, including neurology and mental health. At the same time, their reliance on sensitive neural data makes alignment with the European Health Data Space essential, reinforcing European control over neurodata governance, clinical validation pathways, and ethical deployment standards.

EIC Deep-Tech Taxonomy: Medical Technologies (Non-invasive Medical Devices / Digital Health; Patient Monitoring Systems, Neural & Cognitive Networks, Artificial Intelligence)
Strategic Technologies for Europe Platform (STEP): Advanced sensing technologies (Magnetometers and magnetic gradiometers)

3.9. Portable and ultra-low field magnetic resonance imaging for distributed clinical uses

What is it?

Portable and ultra-low field (ULF) magnetic resonance imaging (MRI) aims to overcome structural constraints of conventional high-field MRI, which relies on cryogenically cooled superconducting magnets operating at several tesla. ULF MRI operates in the microtesla to tens of millitesla range, allowing simplified magnet designs that may tolerate or exploit magnetic field inhomogeneities. This reduces the engineering complexity associated with generating highly homogeneous fields and enables compact, lightweight, and mobile imaging systems. To compensate for intrinsically lower signal-to-noise ratios, ULF MRI integrates advances in hardware design, signal reconstruction, and computational processing. These systems can be deployed at the bedside, in intensive care units, or in settings where conventional MRI infrastructure is impractical. By removing dependence on cryogenic superconducting magnets, portable ULF MRI lowers infrastructure, energy, and maintenance requirements, expanding the range of environments in which diagnostic MRI can be performed and broadening access to magnetic resonance imaging.

What is new?

Recent developments replace massive superconducting magnets with lightweight coils, open geometries, and field-tolerant configurations, significantly reducing system complexity at ultra-low magnetic fields. These hardware advances are combined with progress in quantum sensing, including optically pumped magnetometers, nitrogen-vacancy centres in diamond, and compact superconducting quantum interference devices, which enable detection of very weak nuclear spin signals in the microtesla to millitesla range. At the same time, AI-based denoising and computational reconstruction techniques mitigate intrinsically low signal-to-noise ratios and support clinically interpretable image quality. Field-cycling approaches further introduce contrast mechanisms linked to tissue relaxation dynamics that are not accessible at conventional field strengths. Together, these developments shift ULF MRI from laboratory demonstrations toward portable imaging platforms. Key challenges remain in integrating miniaturised quantum sensors, establishing robust low-field biomarkers, and validating standardised acquisition and reconstruction pipelines for routine clinical uses.

How could it matter for Europe's resilience and strategic autonomy?

Portable and ultra-low field MRI matters for Europe's resilience and strategic autonomy by addressing structural dependencies in advanced medical imaging technologies. By reducing reliance on cryogenic superconducting magnets and large-scale fixed infrastructure, these systems align with EU priorities on technology sovereignty, security of supply, and industrial capacity-building in health and quantum technologies, as reflected in the Strategic Technologies for Europe Platform (STEP). European strengths in quantum sensing, medical devices, and AI-based signal reconstruction position ultra-low field MRI as a domain where upstream component control and system integration can be retained within Europe. More distributed and lower-infrastructure imaging capabilities also support resilient healthcare delivery models, while energy and maintenance reductions are consistent with sustainable-by-design approaches embedded in EU health and digital policy frameworks.

EIC Deep-Tech Taxonomy: Medical Technologies (Medical Imaging; Magnetic Resonance Imaging)
Strategic Technologies for Europe Platform (STEP): Advanced sensing technologies (Magnetometers and magnetic gradiometers)

COORDINATION AND ACKNOWLEDGEMENTS

The EIC Tech Report 2026 was coordinated and edited by the EIC Coordination and Analytics Team (Alexandre Pólvora, project lead; Marta Wysoczynska, Team Leader) and by the EIC Programme Manager's Office (Maria del Sorbo, project lead; Anne-Marie Sassen, Head of Unit).

The qualitative stage of the assessment panels was led by the EIC Programme Managers: Paolo Bondavalli (Advanced materials for energy), Carina Faber (Renewable energy conversion and alternative resource exploitation), Hedi Karray (Artificial Intelligence), Franc Mouwen (Architecture, engineering and construction technologies), Samira Nik (Quantum technologies and electronics), Isabel Obieta (Sustainable semiconductors), Orsolya Symmons (Health and biotechnology), Ivan Stefanic (Food chain technologies, novel and sustainable food), Stela Tkatchova (Space systems and technologies), Federica Zanca (Medical imaging and AI in healthcare).

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METHODOLOGICAL APPROACH

The EIC Tech Report 2026 shifts from a bottom-up horizon scanning used in the previous edition[11] to a more targeted approach to signal detection and assessment, which covers primarily scientific and technological novelty in a quantitative stage while also considering EU policy priorities as complementary criteria in a qualitative stage. The current methodology in this context improves the two-stage quantitative-qualitative framework with:

- Advanced Machine-based Quantitative Signal Filtering: Quantitative filtering via data mining and scientometric analytics with machine-enhanced identification and filtering of signals, supported by the Joint Research Centre (JRC) in collaboration with the EIC Coordination and Analytics Team.
- Expert-Led Qualitative Assessment Panels: Qualitative expert-based assessments panel with a new targeted focus on both novelty and EU policy priorities, led by the EIC Programme Managers Office in collaboration with 25 top-tier external experts, and supported by the EIC Coordination and Analytics Team for final selection and review.

A) Quantitative filtering via data mining and scientometric analytics

The first stage of the methodology involved a quantitative review of over 13,380 proposals submitted to the EIC for support in all 3 main EIC funding schemes, Pathfinder, Transition and Accelerator, between 2021 Q2 and 2025 Q1, of which nearly 1,270 were funded.

An enlarged data scope was chosen for this stage to avoid repetition from previous editions of the EIC Tech Report, expanding the analysis beyond EIC Pathfinder with the inclusion of project and proposal data from Transition and Accelerator. This substantially increased the scoping universe and enabled the extraction of new insights that helped to substantiate the idea that novelty can emerge at any TRL or maturity level. Nonetheless, the emerging scientific and technological novelty lens that anchors EIC Tech Reports is maintained, and all signals were selected at low to mid-maturity in this framework, even when originating from projects and / or proposals at higher TRL levels from Transition or Accelerator.

This stage was supported by the European Commission's 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)[12] enhanced by GPT@JRC AI and machine-based clustering and inputs[13], supplemented by scientometric indicators for empirical classification, validation, and benchmarking, including patent data from the European Patent Office (EPO) PATSTAT[14] database, scientific publication data from the SCOPUS database[15], and Horizon Europe data on non-EIC funded projects extracted from the CORDIS database[16].

The data mining and scientometric analytics were overseen by the JRC Text Mining and Analysis Competence Centre[17] and the JRC Foresight Competence Centre[18]. Additional analytics, from classifications based on the EIC taxonomy to initial sensemaking of the mining results before the second stage, were steered by the EIC Coordination and Analytics Team supported by the JRC Foresight Competence Centre.

This stage resulted in the identification of 411 signals of emerging technologies selected for the second stage of qualitative assessment. To support the panel reviews, all signals provided to EIC Programme Managers and external experts were accompanied by contextual hard data, including, but not limited to, elements such as:

- Signal Summary and Full Description based on original sources (titles, abstracts and keywords from projects and proposals)
- Primary category of internal EIC deep tech Taxonomy[19]
- IDs and number of projects and proposals associated with signal (total, and per year 2021-2025)
- Hits per EIC Call (both Open and Challenge Calls)
- Potential TRL (keyword analysis by GPT@JRC, based on SCOPUS and PATSTAT benchmarking)
- Total Benchmarking Hits (SCOPUS, PATSTAT, CORDIS)
- Associated Keywords by Node Strength (SCOPUS, PATSTAT, CORDIS)
- Top Journal Categories (activeness of signal in relation to SCOPUS)
- Persistence (count of years since first appearance, SCOPUS as main entry point for +90% of the signals)
- Activeness 2021-2025 (ratio between hits in this time period and total count of documents retrieved for such period; proxy indicator where higher activeness may correspond to higher novelty factor, especially above 50-70% threshold)

B) Qualitative expert-based assessments panels

The second stage of the methodological approach for the current EIC Tech Report 2026 was led by EIC Programme Managers and involved expert-based qualitative assessments of the original 411 signals selected in the first stage, resulting in a final set of 25 signals.

Building on the successful experience of the 2024 edition, the assessment was carried out by 9 expert panels aligned with the primary categories of the EIC taxonomy. Each panel was coordinated by one or more EIC Programme Managers and included one to three external experts selected for their recognised expertise in the respective sectors, for a total of 25 experts across all panels.

The primary assessment and selection criteria for all signals were:

- Scientific and technological novelty of the signal at EU / global levels.
- Relevance of the signal for the selected policy-relevant domains (digital technologies and space; clean and resource efficient technologies; biotechnologies and health), in alignment with both EIC deep tech taxonomy and STEP sectors[20] [21], and targeting dimensions such as EU resilience and strategic autonomy.

The number of funded projects or proposals linked to a signal was considered only as supporting information during the qualitative review. It was not a deciding factor and does not appear in the final signal descriptions. Similarly, whether a signal surfaced in projects, proposals, or both was not treated as a key criterion. While signals found in funded projects can appear more visible, this was not given weight in the final selection.

No specific projects or proposals are mentioned in connection to any of the signals to ensure that no individual entities are singled out and that all sensitive or confidential information remains protected by the EIC.

The intention was not to prioritise signals with large volumes of data, but to retain those judged relevant because of their emergence or potential influence, even when they appeared infrequently or were not the focus of the underlying projects or proposals. Across both analytical stages, attention was given to limiting possible distortions linked to topic concentrations in targeted or challenge-based calls during the reference period.

The sensemaking process carried out by the expert panels resulted in the selection of the most relevant individual signals and their consolidation into slightly larger groupings while still maintaining adequate granularity. Each signal focuses on one to two emerging technologies, with at most three other related technologies included to better frame the final signal. This is meant to avoid broad thematic clusters and ensure a level of detail suitable for both technical and non-technical audiences. All signals incorporate potential applications and use cases to illustrate how these technologies could contribute to key developments for the EU.

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10. EIC deep-tech taxonomy for internal reporting and Feedback to Policy (F2P), created by the EIC Coordination and Analytics Team, with inputs from the EIC Programme Managers Office, DG RTD, DG CNECT, and the European Investment Bank, in alignment with sector-specific taxonomies and EU policy priorities (not publicly available).
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