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EYES ON THE FUTURE:

Signals from recent reports on emerging technologies and breakthrough innovations to support European Innovation Council strategic intelligence

VOLUME 1

EU Policy Lab

JRC SCIENCE FOR POLICY REPORT

EMERGING TECHNOLOGIES

DISRUPTIVE INNOVATION

STRATEGIC FORESIGHT

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EYES ON THE FUTURE

Signals from recent reports on emerging technologies and breakthrough innovations to support European Innovation Council strategic intelligence

Volume 1

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This report is part of the project FUTURINNOV, (FUTURe-oriented detection and assessment of emerging technologies and breakthrough INNOVation), commissioned from the European Commission's (EC) Joint Research Centre (JRC) by the European Innovation Council (EIC), the EC's flagship program for deep tech, implemented by the European Innovation Council and SMEs Executive Agency (EISMEA).

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Abstract

This report provides a literature review of publications authored by numerous external organisations. It summarises 34 signals and trends of emerging technologies and breakthrough innovations across the 11 primary categories of a taxonomy defined by the European Innovation Council (EIC). The authors investigate not only what is deemed most novel in multiple application domains but what is worth the attention of European Union (EU) policy audiences involved with priority-setting and decision-making.

This work that has led to this literature review (1) reviews and evaluates 186 reports and articles on emerging technologies, (2) captures 489 signals, of which 86 have been short-listed and 34 selected for this report, (3) creates an internal database of signals which is used to digest and analyse the evolution of signals and novel technologies (4) connects signals with EIC portfolios and other European Commission (EC) initiatives such as policies surrounding critical technologies and Strategic Technologies for Europe Platform (STEP) investments that, together with the primary and secondary levels of the EIC taxonomy, provide multiple types of analysis and insights (5) draws conclusions that aim to support the EIC's funding prioritisation and additionally, provide reflections on EIC portfolio setting.

By using the best publicly-available data to produce a harmonised internal database, along with an appropriate filtering and selection methodology, the authors aim to provide a support platform for future-oriented technology analysis of relevance for other EU policy-making initiatives.

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- Daniel Riveong, Plural Futures, for his support in reviewing the report.
- Michela Bergamini and Marcelina Grabowska of the DG Joint Research Centre unit for Text and Data Mining.
- Alexandra de Maleville of DG Joint Research Centre for her support with signal collection.

Executive summary

Brief description

The report highlights key signals and insights found through a systematic review of emerging technologies and breakthrough innovation publications. It offers insights that can inform the prioritisation of funding for novel, emerging and close-to-market technologies for the European Innovation Council (EIC).

Project context

This report is developed in the context of the project FUTURINNOV - FUTURe-oriented detection and assessment of emerging technologies and breakthrough INNOVation.

FUTURINNOV supports the EIC in building strategic intelligence capacity via foresight and other anticipatory approaches. In this way, it addresses activities focused on funding targets, programme design, policy feedback, and institutional governance.

This is the second collaboration between the European Commission's (EC) Joint Research Centre (JRC) and the EIC, the EC's flagship program for emerging deep tech and breakthrough innovation, implemented by the European Innovation Council and SMEs Executive Agency (EISMEA).

The JRC's mission is to provide evidence-based advice to policy. To this end, the JRC's Competence Centre on Foresight has brought an increased focus on anticipatory thinking and practices, including, but not limited to, the support for public funding of innovation.

Policy context

The report contains signals and insights that can inform funding decisions, particularly in areas of relevance to EU economic security and technical areas of general high uncertainty and complexity. The analysis in the report underscores the importance of taking into consideration in policymaking the interconnectedness of different technologies and their systems.

It aims to provide actionable insights not only to executive agencies providing funding support for deep tech but also to policymakers in areas related to critical and strategic technologies. To deliver this aspect, the authors have considered European initiatives related to these strategic areas in their signal analysis. A challenge shared by multiple entities is how to channel investment into the technology frontier of something that is not yet fully known. This report aims to support this task by providing insights in areas where uncertainties often outweigh knowledge. Technology Foresight leverages systematised processes and collects evidence to support this objective.

Key conclusions

The report reviewed 186 reports and articles, ranging from general sources to sector-specific and specialised ones. It captured 489 signals[1], of which 86 were short-listed and 34 selected for this report. These key signals fit into the 11 primary categories of a new EIC taxonomy[2] to support impact assessments and feedback-to-policy. The categorisation is as follows:

— Agriculture & Food
— Built Environment
— Energy
— Environmental Tech

[1] Number of signals in the database on the date of the decision on the final key signals.

[2] See section 2.1 for more details. Additionally Annex I contains the full list of the EIC Taxonomy with primary and secondary categories. In the current report the JRC used the version of the Taxonomy made available by EIC in December 2023.

- Health
- Space
- Mobility
- Advanced Manufacturing
- Information & Communication Technologies
- Hardware & Semiconductors
- Advanced Materials

An internal database of signals was created to be continuously supplemented via new literature review exercises and horizon scanning workshops. The authors have learned that in addition to drawing on secondary sources such as reports, and considering previous publications (Farinha, Vesnic-Alujevic, Alvarenga, & Polvora, 2023), supplementing this kind of literature review with journal articles and scientific studies is needed to surface additional novelty in certain domains. Thus, a key conclusion is that the numerous generic tech foresight reports published today are not sufficient to identify the latest emerging signals and trends.

The report recommends that the European Innovation Council keep track of signals and trends in different fields and suggests a reflection on the current EIC portfolio setting, to explore relevant areas such as AI, mobility, and synthetic biology.

Other insights can be drawn from this report, namely for priority-setting and decision-making on public funding of innovation. Connecting technologies at a multi-faceted level and setting overarching strategies can provide much-needed directionality and increase the spillover effects of those investments.

Main findings

The main findings relevant for the European Innovation Council are:

- The Agriculture & Food and Space primary levels of the EIC taxonomy[3] contained many convergences. This connection across two seemingly disparate areas may be a new insight for the EIC, and an area to monitor closely.
- The Advanced Materials and Space primary categories contained some new convergences, suggesting that the EIC could benefit by examining the emergence of new materials to handle space power. Convergences between Advanced Materials and Energy tended to describe those materials coming from the secondary category 'Metals and Alloys'.
- Secondary categories are mostly aligned with their associated primary categories. However, Hardware & Semiconductors, and Advanced Materials have the largest spread outside their own domain. The Information and Communication Technologies primary category seems to have the least overlap into secondary areas outside its own area, with the 2 key signals connecting almost exclusively with Artificial Intelligence & Machine Learning.
- Some of the signals where Mobility and AI connect did not find correspondence with current EIC portfolios. Thus, the EIC could consider the creation of a specific portfolio on AI, containing topics associated with Mobility. Additionally, signals on Mobility connect very strongly to secondary categories outside that domain.
- Synthetic biology was identified as an

[3] See section 2.1 for more details. Additionally Annex I contains the full list of the EIC taxonomy with primary and secondary categories. In the current report JRC used the version of the taxonomy made available by EIC in December 2023. Both level categories are occasionally referred to throughout this report as areas or domains.

example of sub-area of a critical technology for the EU's economic security, with five of the six key signals listed in the Health category focused on synthetic biology technologies. The EIC should consider creating a secondary category within the health area of the taxonomy to cover this emerging field.

— Signals in the Built Environment primary category were mostly related to clean tech, but the secondary level does not fully reflect this finding. There are no direct references to clean tech related with Advanced Materials or Energy, for instance, in the secondary level categories for Built Environment.

Related and future JRC work

In the context of the FUTURINNOV project, two additional literature review reports are programmed. For this work, the authors will continue to use the best publicly available data, augmenting and curating the JRC internal database and following the iterative customised methodology developed for this purpose.

1 Introduction

1.1 Anticipation and signals

The present day framework of increasing volatility, uncertainty, complexity, and ambiguity (VUCA[4]) shows how these pose significant challenges to decision making, namely for policy design and implementation, which then requires preparedness and strategic planning.

Anticipatory thinking is crucial in this context to assess possible and plausible signals and trends from short- to long-term futures, along with their potential challenges, opportunities, and impacts. This requires a mix of evidence-based methods and participatory approaches delivered in a systematic manner, aimed at gathering a wide range of perspectives and identifying a broader array of new patterns.

Core anticipatory fields such as future-oriented technology assessment and technology and innovation foresight emerge at the forefront of provision of actionable knowledge for today's and tomorrow's questions. They can be framed as a "systematic exercise aimed at looking into the longer-term future of science, technology and innovation in order to make better-informed policy decisions" (Pietrobelli & Puppato, 2016).

These exercises have an important role to play in enabling a better understanding of the complexity of technology developments and applications (Warnke & Heimeriks, 2008), as well as related societal and other impacts, and can shape potential technological change in the future (Pietrobelli & Puppato, 2016). They serve the purpose of reflecting about upcoming research needs, tomorrow's technology applications, future regulatory and standardisation guidelines, and other relevant topics. In turn, they can also provide insights on drivers, opportunities and challenges related with research, development, and adoption of technologies and innovations.

The concept of signals is key to this framework, and it is one that changes upon context or use case (Rossel, 2012) (van Veen & Ortt, 2021). Nevertheless, the term 'signal' is understood in this report as nascent but tangible manifestations of novelty, not only in science, technology, innovation, or markets, but also other areas such as media or artistic practices, even if these last domains are not in focus.

Signals can also be described as raw informational matter that can drive our focus towards certain possibilities of the future instead of others. Aiming for a better understanding, we can place them next to the other anticipatory concept of trends, as both are usually drawn from novel scientific literature, industrial reports, media outputs, etc, on early research developments, patents, and other data sources.

But trends are often derived from patterns of novelty with upward or downward directions and are more easily identifiable in terms of velocity and duration due to strength. Moreover, trends also have clearer boundaries connected with more defined technology and/or innovation landscapes, while signals can be derived from single occurrences in these same landscapes.

Therefore, it can be considered that trends are more directly inferred from quantitative views of big data and qualitative observations of thick data, while signals are more represented by

[4] The acronym VUCA was first used by Bennis and Nanus (1987) to describe the world at the end of 1980s and its use increased in the last decades in anticipation, foresight and futures studies. An alternative acronym is TUNA (Turbulant, Uncertain, Novel and Ambiguous).

thin data and related to smaller sets of data points or references with less rich contextual meaning (Mortati, 2023).

1.2 Report context and goals

This report is developed in the context of the project FUTURINNOV - FUTURe-oriented detection and assessment of emerging technologies and breakthrough INNOVation.

FUTURINNOV supports the European Innovation Council (EIC) in building strategic intelligence capacity via foresight and other anticipatory approaches. In this way, it addresses activities focused on funding targets, programme design, policy feedback, and institutional governance.

This is the second collaboration between the European Commission's (EC) Joint Research Centre (JRC) and the EIC, the EC's flagship program for emerging deep tech and breakthrough innovation, implemented by the European Innovation Council and SMEs Executive Agency (EISMEA). The JRC's mission is to provide evidence-based advice to policy, and there is an established practice of extending this mission into anticipation and technology foresight.

Following a first successful publication of insights in this space (Farinha, Vesnic-Alujevic, Alvarenga, & Polvora, 2023), the JRC and EIC agreed to set up an improved systematic review of forward-looking information on technology and innovation signals captured in third-party reports, meaning reports published outside EU institutions by research and technical organisations, industrial and market consultants, and other relevant bodies.

The current report is the first of three literature reviews programmed between now and the end of 2024. It contains 34 signals and a brief qualitative analysis. The FUTURINNOV project also supports a parallel approach to EIC portfolios via vertical Horizon Scanning workshops. The results of all these exercises will be published separately.

In the context of this report, signals are extracted from the third-party sources to provide a horizontal perspective across a wide set of technological, environmental, societal, policy and economic areas. The analysis can inform priority-setting from novel (TRL[5] 1 to 3) to emerging (TRL 4-6) and close-to-market (TRL 7 to 9) deep tech and innovation. The authors' understanding is that novelty can occur in all maturity levels, in particular if we look at innovative combinations of established technologies or incremental innovation.

With this report the authors aim to support EIC in answering questions such as:

- Which of these signals should be present on the EIC radar for anticipatory intelligence?
- Which of them connect with emerging deep tech and breakthrough innovations with a likely impact on the EU's future?

To succeed in answering these main questions, the current report is structured according to the 11 primary categories of a new EIC taxonomy[6] to support impact assessments and feedback-to-policy. The categorisation is as follows:

- Agriculture & Food

[5] Technology Readiness Levels (TRL) serve as a system for evaluating the development stage of a specific technology. Every technology project undergoes assessment according to the criteria established for each level, resulting in the assignment of a TRL score that reflects the project's advancement. The scale comprises nine levels, with TRL 1 indicating the earliest stage of development and TRL 9 representing the most advanced stage.

[6] Annex I contains the full list of the EIC taxonomy with primary and secondary categories. In the current report JRC used the version of the taxonomy made available by EIC in December 2023. Both level categories are occasionally referred to throughout this report as areas or domains.

- Built Environment
- Energy
- Environmental Tech
- Health
- Space
- Mobility
- Advanced Manufacturing
- Information & Communication Technologies
- Hardware & Semiconductors
- Advanced Materials

On top of this categorisation, and as mentioned earlier, this report offers a methodological update to the work published last year (Farinha, Vesnic-Alujevic, Alvarenga, & Polvora, 2023) by introducing several improvements that keep systematic track of signals in different fields, and provide concrete examples of potential applications connected to them.

In the current report, the authors have:

- reviewed 186 reports and articles, ranging from general sources to sector-specific and specialised ones. Last year a total of 170 reports and articles were reviewed.
- captured 489 signals[7], of which 86 were short-listed and 34 selected for this report. Last year 106 signals were captured in the final list for the report.
- created an internal database of signals, to be continuously supplemented via new literature review and horizon scanning exercises.
- connected signals with EIC portfolios and other EC initiatives that, together with the primary and secondary categories of the EIC taxonomy, provide multiple possibilities for analysis and insights.
- drawn conclusions that aim to support the EIC's funding prioritisation and additionally, provide reflections on EIC portfolio setting.

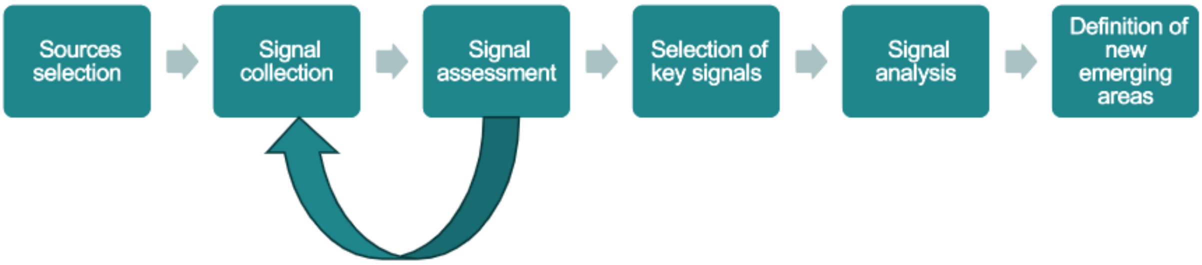
In the context of the FUTURINNOV project, two additional literature review reports are programmed. For this work, the authors will continue to use the best publicly available data, augmenting and curating the JRC internal database and following the iterative customised methodology developed for this purpose.

[7] Number of signals inserted in the database up until the date of the decision on the final key signals.

2 Methodology

The methodology used in this study is a six-step iterative process outlined in Figure 1. Each of the six steps has the potential to be reiterated. However, the step in the process which was iterated the most was that going from signal collection to signal assessment. For instance, when the assessment of signals revealed too little novelty or relevance to one of the criteria listed in Section 2.1, the authors then revisited the sources to collect more.

Figure 1. Simplified diagram of the flow and methodology for literature review



Source: Authors.

2.1 Signal collection

The literature review process started by gathering reports to scan for signals which were selected on the following basis, with no quantified weight attributed to any filter nor any special order:

— relevance to the EIC's three strategic domains: Digital & Industry, Green and Health;

— relevance to the mission of the EIC and fitting within at least one of the 11 primary categories of the new EIC taxonomy;

— contribution to the EU's key strategic areas and technologies mentioned in the Strategic Technologies for Europe Platform (STEP)[8], hereafter referred to as "STEP" and in the Commission Recommendation on Critical Technology Areas for the EU's economic security[9], hereafter referred to as "10 critical technology areas";

[8] The Strategic Technologies for Europe Platform (STEP) is the common European action to support EU industry and boost investments in critical technologies in Europe. STEP will leverage and steer resources across 11 EU funding programmes to 3 target investments areas in the EU and in people who can implement those technologies into the economy, namely: digital technologies and deep-tech innovation; clean and resource efficient technologies; and biotechnologies. https://commission.europa.eu/strategy-and-policy/eu-budget/strategic-technologies-europe-platform_en

[9] Commission Recommendation of 3 October 2023 on critical technology areas for the EU's economic security for further risk assessment with Member States. https://defence-industry-space.ec.europa.eu/commission-recommendation-03-october-2023-critical-technology-areas-eus-economic-security-further_en

— relevance to EIC funding mechanisms, namely Pathfinder, Transition and Accelerator[10], taking into account information on the TRL or an initial qualitative assessment of its maturity;

— technologies that show novelty or contain novel aspects which may enable or accelerate the development of other emerging technologies or innovations.

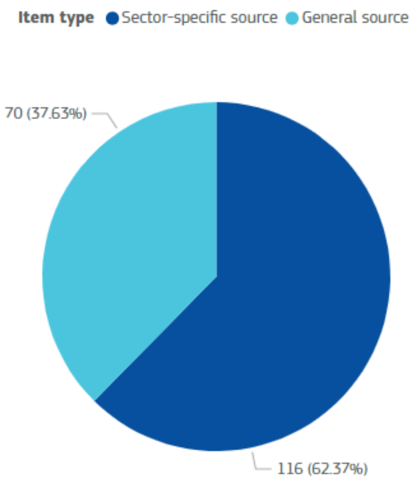
Preference was given to sources that provided the following:

— diversified geographic scope, perspectives, and authors, including but not limited to international organisations or forums, scientific organisations and public agencies.

— newer content, with emphasis on sources published in 2022, 2023, and 2024, and none published before 2019.

From the 186 third-party reports selected for further review, 489 signals were collected. Most (116) of the sources selected were classified as 'sector-specific', published with a focus on a single domain or industry, with the others being classified as 'general', with overall views on signals from a wide range of areas. A chart of all sources in the internal database of signals is shown in Figure 2.

Figure 2. The diversity and number of sources found in the signals radar.



Source: Authors.

It is worth noting that many of the types of reports employed in similar past work conducted by the JRC for the EIC have become too generic for the purpose of this project. For this report, novelties were surfaced better when investigating journal articles and scientific studies. This raises the need to go beyond the numerous generic tech foresight reports that are published nowadays by a significant number of organisations, which risk inflating hype-ness, a phenomenon that certain technologies go through. The authors acknowledge this risk and make clear that their aim is to surface specific breakthrough applications that are perhaps not known by most policy makers.

[10] For more information on the specificities of each mechanism, check: https://eic.ec.europa.eu/eic-funding-opportunities_en

2.2 Signal assessment

Once a signal was identified, it was entered into an internal database built specifically for this project. This database is also referred to as 'radar' or 'signals radar' throughout this report. The maturity of each signal was evaluated. In the signals radar, a signal was assigned 'novel' status when it was referenced in a recent academic article or patent. The signal was assigned 'emerging' status when it was referenced in publications and reports but still facing technology development challenges. The signal was assigned 'close-to-market' when examples of pilots or demonstrations were available. In essence, a signal was categorised based on R&I developments.

Each signal was assigned to a single primary category and multiple relevant secondary categories of the EIC taxonomy. Exceptionally some signals were assigned to more than one primary category if the technology or innovation could be applied significantly across more than one field. Each signal was also assigned to a specific EIC Programme Manager (PM) portfolio[11] and related EIC macro area[12].

To perform an initial assessment of the signals, the JRC and EIC were keen to have a relatively balanced number and mixture of signals across the primary categories, the EIC portfolios and the EIC macro areas. This was not always a straightforward exercise, given the qualitative features of the mapping. This was done in collaboration between the JRC and EIC across several iterations.

2.3 Selection of final key signals

From the radar's 489 signals the authors shortlisted 86 key signals and subsequently selected a final list of 34 key signals. These key signals (also referred to as 'final' or 'selected') are detailed in section 3. For the purposes of assessing the impact and uncertainty of signals, a qualitative review process was designed and deployed (Figure 3). JRC reviewers assessed the relevant signals and assigned each an impact and an uncertainty rating from 1-5, with 1 being the least potentially impactful or uncertain and 5 being the most potentially impactful or uncertain.

The impact rating refers to the potential impact that this signal could have in this area of technological development in the EU, based on a JRC assessment of key policy files, highlighted previously in the context of STEP or the 10 critical technology areas, but also other policy priorities linked with higher level ambitions of the current College of the European Commission, such as the 'European Green Deal', a 'Europe fit for the digital age', or an 'European economy that works for the people'[13]. The uncertainty rating refers to the signal's precociousness or wildness.

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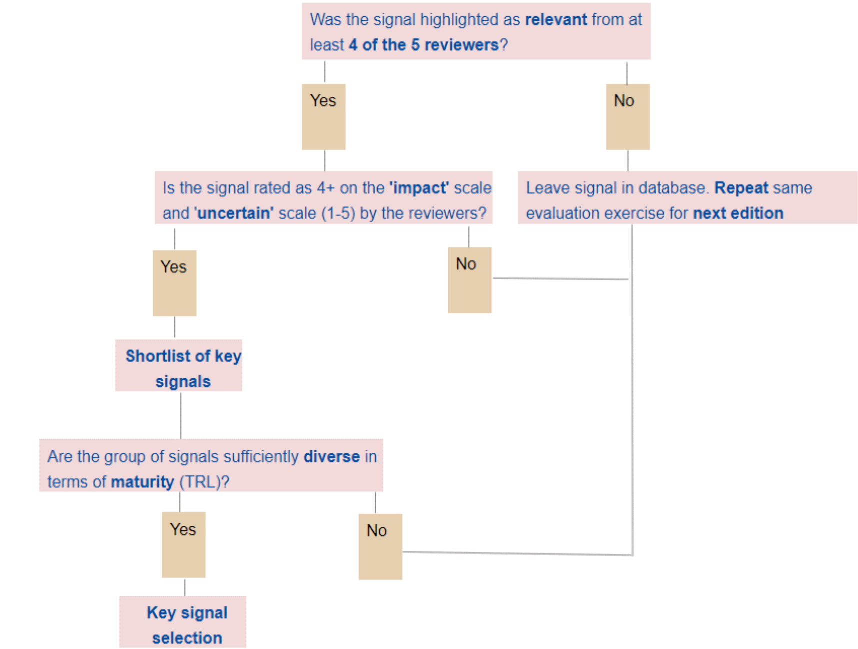
[11] The 10 EIC PM Portfolios considered for this report are: Advance Materials; Agriculture & Food; Architecture, Engineering and Construction, Energy Systems; Health and Biotechnology; Medical Technologies and Medical Devices; Quantum Technologies; Renewable Fuels and Chemicals; Responsible and Sustainable Electronics and Space. The EIC PM portfolio names used throughout this report are a simplification of the official denomination, agreed with the EIC Strategic Intelligence Team.

[12] The 3 EIC Macro-areas considered for this report are: Digital & Industry, Green and Health.

[13] [Priorities 2019-2024 - European Commission (europa.eu)]

Figure 3. Decision tree and process flow for the selection of key signals for literature review



Source: Authors.

It was imperative to ensure each primary category had a diversity of technologies in terms of technology maturity (see Figures 19, 20 and 21 in section 4). Having diversity of maturity in technologies in the signals radar reflects the fact that the EIC funds technologies spanning all TRLs. For instance, the low TRLs represent breakthrough technology, supported by the EIC via the Pathfinder programme for early-stage deep tech developments. At the other end, higher TRLs represent novelty closer to commercial uptake, which in the EIC is supported by the Accelerator programme, based on their market potential [14].

[14] For more information on the specificities of each mechanism, check: EIC Funding opportunities - European Commission (europa.eu)

3 Selected signals for EIC

The semi-hierarchical architecture of the EIC taxonomy reinforces the authors' understanding of how novelty and innovation cross sectoral, technical, and policy fields and how novelty hotspots can be highlighted in a longitudinal way.

The following subsections depict 34 signals organised by each one of the 11 primary categories of the EIC taxonomy. They also provide a summary cross-analysis showing connections with the secondary categories, the EIC PM portfolios and EU policy initiatives and priorities. In this last point the relation is also stated for each signal; for instance, those closer to the highest risk areas with the 10 critical technology areas are starred and underlined.

Table 1. Summary list of key signals presented in the following pages.

Primary category	Signal number and title	
Health	01	Flexible electronics demand new batteries and new flexible brain-machine interfaces
	02	Spatial omics as a transformative life sciences tool
	03	Xenobots made of human cells become self-assembling and last longer
	04	Nanobot has DNA clutch
	05	Vaccines delivered via ultrasound
	06	Cancer-killing DNA molecules
Mobility	07	Engineered bacteria in sustainable aviation fuel
	08	Lidar on a chip - more efficiency and reliability with shorter size and costs
	09	AI's role in driving sustainability and safety in the mobility sector
Space	10	Lunar 'soil' for farming and roads on the moon
	11	Wireless Power Transfer as a plan B for SmallSats
Agriculture & Food	12	Antimicrobial packaging to reduce food waste and health risks
	13	DNA traceability for food authenticity
	14	Paper sensors to reduce food waste

Primary category	Signal number and title	
Hardware & Semiconductors	15	Nanomagnetic computing could reduce the energy cost of AI
	16	IoT devices that communicate without electronics
	17	Thermal transistors that can handle heat with no moving parts
	18	Rare earths show potential for quantum communications, processors
Advanced Manufacturing	19	Paper-thin solar cells that are easily integrated into other materials
	20	Biofoundries to speed up the bioeconomy
Environmental Tech	21	Biocatalytic membranes for quicker and cleaner chemistry
	22	Fast detection of freshwater contamination with a new type of engineered microbes
	23	Tiny robots suck contaminants from rivers
	24	Exploring solar geoengineering as a piece in a multifaceted climate change mitigation strategy
Energy	25	Multivalent batteries for lower cost chemistries
	26	Accelerating the shift from thermal energy to electrical energy to produce lower emission fuels & chemicals
	27	'Energy kites' for harnessing high-altitude wind energy
	28	Ultra-high density hydrogen storage holds twice as much as liquid H2
Built Environment	29	Material with beetle nanostructure for efficient solar reflectivity
	30	Sustainable transparent wood
Advanced Materials	31	Self-repairing materials and 4D printing for electronics and space applications
	32	Tuning the 'charge density' knob so super-conductors can operate at room temperature
Information & Communication Technologies	33	Ethically-challenged pirate AI models
	34	Emotional cloaking devices for voice interfaces

Source: Authors.

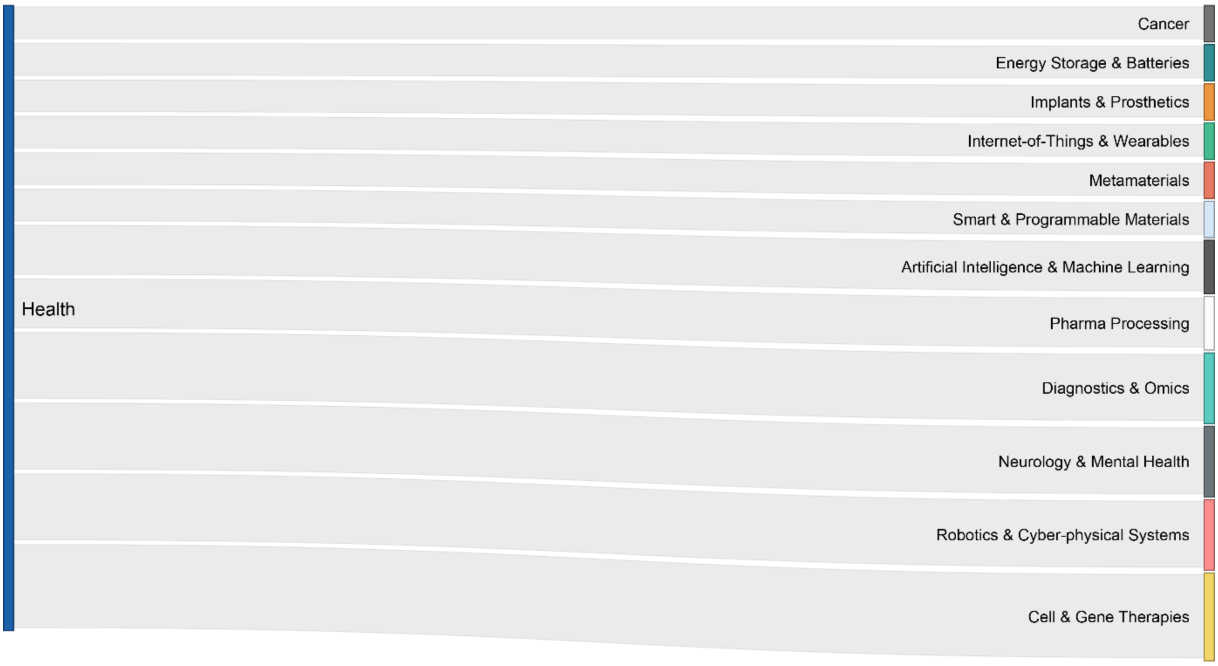
3.1 Health

A notable convergence was observed between health/medical technology and consumer electronics/advanced materials. According to the European Innovation Council Impact Report 2023, neurology is a significant part of the Health domain of funding for European Innovation Council, particularly within the Medical Devices area (European Innovation Council, 2024).

For many years, there has been an increasing trend towards crossover between medical and consumer electronics. Now there is the addition of new, advanced materials coming to this space. These materials allow for new potential applications in neuroscience, medicine, and virtual reality. Figure 4 shows that high number of signals relate to neurotech medical devices and robotics which could signal more opportunities for funding this frontier.

However, there are several gaps to be addressed: development and regulation of neurotechnology, equitable and ethical access, recycling regulation convergence, among others. There are some European Commission initiatives which convene around aspects of this technology including, but not limited to, STEP and the 10 critical technology areas. Many of the signals which fit within the Health category (and often in the secondary category of Cell & Gene Therapies) are connected to synthetic biology, a critical technology according to the EU list: this suggests that the EIC would benefit from a dedicated focus on this topic.

Figure 4. Indication of secondary categories for those signals which have Health as the primary category. The width of the line indicates the number of connections.



Source: Authors.

01

Flexible electronics demand new batteries and new flexible brain-machine interfaces

Flexible batteries are crucial for wearable technologies like medical devices, smartwatches, flexible displays, and textile electronics, offering the ability to bend, twist, and stretch. One of the most promising applications is in health, where these batteries can enable new types of monitoring devices to wirelessly transmit patient data, facilitating remote healthcare. They are also essential for powering emerging textile electronics, which include features like built-in heating and health monitoring.

One notable advancement in the health space is flexible brain-machine interfaces (BMIs). BMIs allow thought-based control of machines by translating brain signals into computer instructions, and current BMIs are already used in epilepsy treatment and neuro-prosthetics. However, they face challenges like scarring and signal drift due to rigid materials, but recent advances in soft, biocompatible circuits promise better integration with brain tissue, enhancing signal accuracy and reducing recalibration needs.

These BMIs can be packed with enough sensors to stimulate millions of brain cells at once, vastly outperforming the scale and timeframe of hard probes. They could be used to deepen understanding of neurological conditions such as dementia and autism. Flexible BMIs are already in FDA-approved trials, hinting at a future of seamless human-AI interaction. However, ethical considerations regarding privacy, data use, and public trust must be addressed alongside technological developments. Potential recycling loops for this type of product should also be addressed.

Source	Top 10 Emerging Technologies of 2023 (World Economic Forum, 2023)	
Underlying technologies or innovations	Flexible brain-machine interfaces / Textile electronics / Flexible batteries	
Technology Maturity	Emerging (TRL 4-6)	
EIC macro-areas	Digital & Industry, Health	
EIC portfolios	Responsible and Sustainable Electronics / Energy Systems / Health and Biotechnology / Advanced Materials	
EIC Taxonomy	Primary	Health / Hardware & Semiconductors
	Secondary	Energy Storage & Batteries / Internet-of-Things & Wearables / Robotics & Cyber-physical Systems / Diagnostics & Omics / Neurology & Mental Health / Implants & Prosthetics / Artificial Intelligence & Machine Learning / Smart & Programmable Materials
EC initiatives	10 Critical Technology Areas	*Biotechnologies: synthetic biology / Advanced materials, manufacturing, and recycling technologies: smart materials / Robotics and autonomous systems: AI-enabled systems
	STEP	Deep and Digital Technologies, Clean Technologies, Biotechnologies

02

Spatial omics as a transformative life sciences tool

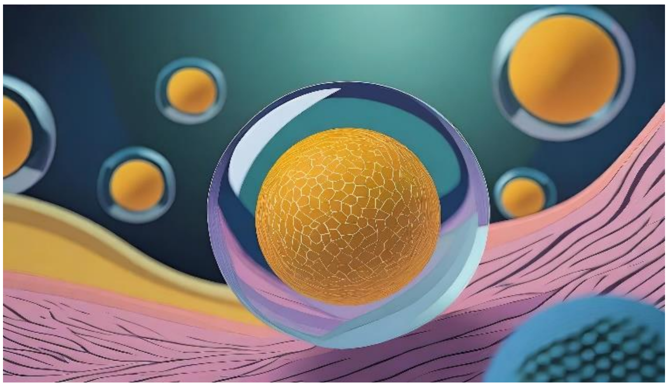
Spatial omics offers detailed insights into cellular structures and biological processes, enhancing therapeutic discovery. It has enabled the identification of neuron populations crucial for spinal cord injury recovery, as seen in treated mice. This technique could be pivotal for personalised cancer treatments and understanding complex diseases like Alzheimer's and rheumatoid arthritis. It also sheds light on the systemic impact of viruses, such as SARS-CoV-2. However, challenges in data handling and the need for broader applications remain.

Since being highlighted in 2021, spatial omics is transitioning from a specialised method to potentially a standard and transformative scientific tool. It could soon deliver on cellular mapping that biotechnologists need to understand the complex landscape of the human body and could help create personalised disease or cancer treatments. It also offers opportunities in other domains such as imaging, mass spectrometry, and bioinformatics. For instance, the advances in image analysis and deep learning could allow for better image data of cells which can improve molecule and sub-cellular structure mapping, providing insights into molecular circuits and mechanisms governing cell biology. Considerable work nonetheless remains before spatial omics can be used to guide the fabrication of targeted drug therapies, which is a big driver for the health field.

Source	Top 10 Emerging Technologies of 2023 (World Economic Forum, 2023)	
Underlying technologies or innovations	Spatial omics	
Technology Maturity	Close-to-market (TRL 7-9)	
EIC macro-areas	Health	
EIC portfolios	Health and Biotechnology	
EIC Taxonomy	Primary	Health
	Secondary	Diagnostics & Omics / Neurology & Mental Health / Cell & Gene Therapies
EC initiatives	10 Critical Technology Area	*Biotechnologies: synthetic biology
	STEP	Biotechnologies

03

Xenobots made of human cells become self-assembling and last longer



Scientists have developed tiny robots made of human cells, known as "anthrobots," that can repair damaged neural tissue. Previous versions of these tiny robots, known as "xenobots", were limited in their medical applications, as they were not derived from human cells and had to be manually shaped.

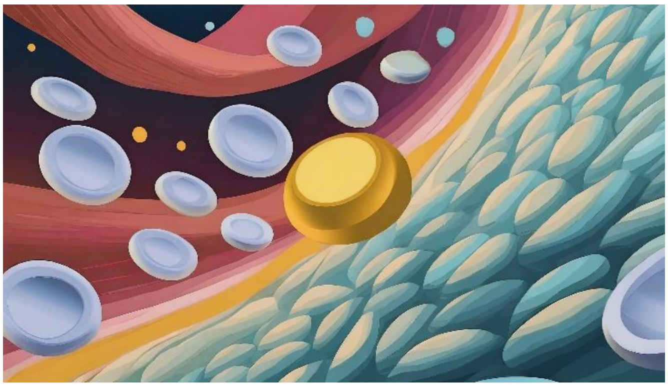
The new self-assembling anthrobots have shown therapeutic potential by successfully repairing neural tissue in laboratory experiments without requiring genetic modification. Previous anthrobots did not survive long but advancements and progressive research accomplished with the help of artificial intelligence simulators have allowed some lifetime extension.

Xenobots are not completely new as they were invented back in 2020, however, this wave bears innovative properties which don't require cells to be manually carved into the desired shape. They can self-assemble which helps side-step lengthy clinical trials or lab experiments. These developments correlate with the expansion of self-repairing materials which can be seen in many different emerging applications today such as sustainable construction and outer-space exploration.

Source	Tiny robots made from human cells heal damaged tissue (Hutson, 2023)	
Underlying technologies or innovations	Anthrobots	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Health	
EIC portfolios	Health and Biotechnology / Medical Technologies and Medical Devices	
EIC Taxonomy	Primary	Health
	Secondary	Diagnostics & Omics / Neurology & Mental Health / Cell & Gene Therapies / Robotics & Cyber-physical Systems / Metamaterials / Artificial Intelligence & Machine Learning
EC initiatives	10 Critical Technology Areas	*Biotechnologies: synthetic biology / *Artificial Intelligence Technologies / Robotics and Autonomous Systems: robots and robot-controlled precision systems, AI-enabled systems
	STEP	Digital technologies and deep tech innovation / Biotechnologies

04

Nanobot has DNA clutch



A tiny robot with a clutch that mimics similar mechanisms found in microorganisms could be used to trigger the internal workings of a cell. The engine consists of a nanoparticle made from gold and iron oxide that rotates in a magnetic field and is surrounded by a spherical gold cage.

The cage is around 200 nanometres across, which is similar in size to a typical virus. A team of researchers have successful attached single strands of DNA to the inside of the cage and to the outside of the nanoparticle motor. When the engine is given a trigger, such as a specific molecule or increased salt levels, the single DNA strands on both surfaces fuse together and the nanoparticle connects to the cage, engaging the clutch.

These nanobots are related to other signals, such as xenobots (signal 03), but with a particular focus on harnessing the power of DNA to create tiny robotic devices. They are also aligned in terms of objective to spatial omics (signal 02), meaning that nanobots could be used for recognising and understanding specific cell targets within a complex mixture of cell types, which could revolutionise targeted therapies, programming immune responses to treat various diseases.

Source	Nanobot uses a DNA clutch to engage its engine (Wilkins, 2024)	
Underlying technologies or innovations	Nanorobots	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Health	
EIC portfolios	Health and Biotechnology / Medical Technologies and Medical Devices	
EIC Taxonomy	Primary	Health
	Secondary	Cell & Gene Therapies / Robotics & Cyber-physical Systems
EC initiatives	10 Critical Technology Areas	*Biotechnologies: synthetic biology / Robotics and Autonomous Systems: robots and robot-controlled precision systems
	STEP	Digital technologies and deep tech innovation / Biotechnologies

05

Vaccines delivered via ultrasound

Researchers at the University of Oxford have developed a needle-free method of delivering vaccines through the skin using ultrasound. By mixing vaccine molecules with tiny proteins, applying the liquid mixture to the skin of mice and exposing it to ultrasound, they found that the vaccine molecules were pushed into the upper layers of the skin, where the bubbles burst and released the vaccine.

This method for vaccine delivery uses cavitation, which is the formation and popping of bubbles in response to a sound wave. It was found to produce more antibodies in mice compared to conventional jabs and did not cause pain or visible damage to the skin. Ultrasound-based vaccine delivery offers a promising path towards painless immunisation, benefiting both needle-phobic individuals and public health efforts.

Though research shows that fewer vaccine molecules may be delivered by the cavitation approach compared to conventional injection, this approach could produce a higher immune response. The researchers theorise this could be due to the immune-rich skin the ultrasonic delivery targets. The result is a more efficient vaccine that could help reduce costs. However, further research is needed to determine the safety and reliability of this new vaccination method for widespread use in humans.

Source	Ultrasound can push vaccines into the body without needles (Padavic-Callaghan, 2023)	
Underlying technologies or innovations	Ultrasound vaccines	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Health	
EIC portfolios	Medical Technologies and Medical Devices	
EIC Taxonomy	Primary	Health
	Secondary	Pharma Processing
EC initiatives	10 Critical Technology Areas	Biotechnologies
	STEP	Biotechnologies

06

Cancer-killing DNA molecules

University of Tokyo researchers have developed artificial oncolytic (cancer-killing) DNA molecules, termed oncolytic hairpins (oHPs), which selectively target and eliminate cancer cells without harming healthy ones. These oHPs activate when encountering miR-21, a microRNA abundant in tumours, forming longer DNA strands that trigger an immune response against cancer cells.

Tested successfully in lab settings on human cervical and breast cancer cells, and melanoma cells in mice, this approach shows promise in eradicating tumours and preventing cancer recurrence. However, as an early-stage discovery, it requires further research to assess efficacy and toxicity. This breakthrough hints at a future where nucleic acid-based drugs could revolutionise treatment for cancer and other challenging diseases, potentially reshaping medical landscapes and reducing their societal impact.

This new ground-breaking technique uses artificial DNA to target and kill cancer cells using the immune system response – similar to a cancer vaccine. This signal fits within the synthetic biology area which is a reoccurring area in the Health primary category and perhaps should be considered by EIC as its own secondary category.

Source	Future of Healthcare - Futurist Analyses on 3 Change Signals (Kuosa, Stucki, Ota, & Sandal, 2023)	
Underlying technologies or innovations	Oncolytic DNA molecules	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Health	
EIC portfolios	Health and Biotechnology	
EIC Taxonomy	Primary	Health
	Secondary	Cancer / Cell & Gene Therapies / Pharma Processing
EC initiatives	10 Critical Technology Areas	*Biotechnologies: synthetic biology
	STEP	Biotechnologies

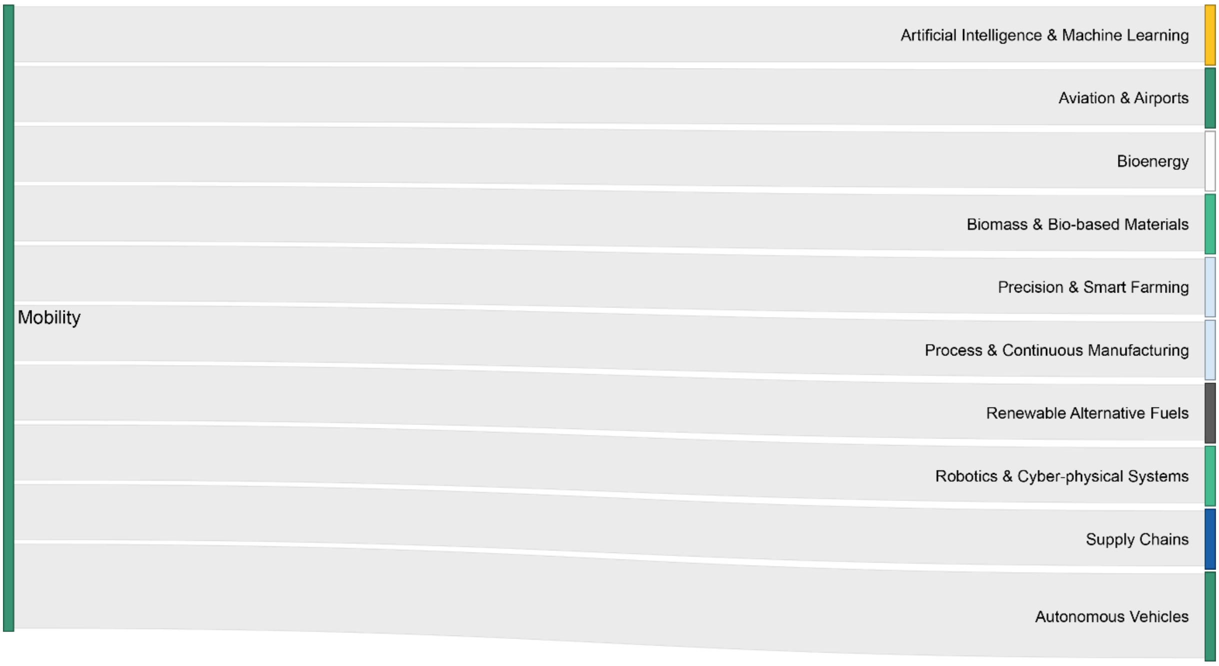
3.2 Mobility

There has been an increasing need to decarbonise heavy transport and associated fuels; nonetheless alternative fuels generally face many technical challenges. The signals collected here may or may not fully address these challenges. What can be said is that novelty (or how 'novelty' is understood in this report) in the Mobility sector is found on the fringes, and that the answer to meeting the challenge to decarbonise transport may be to harness technologies from many areas.

Mobility connected very strongly to secondary levels of categorisation outside its own domain, signalling that some innovation in this area comes from outside this technological domain. This is in contrast to the information found in the latest EIC Impact Report, which shows that last year projects on Mobility generally contributed to the development of that field and did not converge elsewhere.

There is also a notable convergence between artificial intelligence technologies and mobility; in fact, two of the three key signals in the mobility space revolve around AI. The EIC could consider monitoring innovation specifically in the area of Mobility and AI. As semiconductor and artificial intelligence technologies are increasingly vulnerable to economic and security risk, the European Commission initiatives from STEP and 10 critical technology areas connect with the uptake of these two technology signals.

Figure 5. Indication of secondary categories for those signals which have Mobility as the primary category. The width of the line indicates the number of connections.



Source: Authors.

07

Engineered bacteria in sustainable aviation fuel

The aviation industry, needing energy-dense fuels for long flights, lags in decarbonisation. The American Society of Testing and Materials has supported several Sustainable Aviation Fuels (SAFs) over the last two decades. The first was made converting syngas—derived from biomass, waste, or captured CO2 and green hydrogen—into hydrocarbons. Others came from plant oil and animal fat but faced challenges in raw material sourcing and the need for green hydrogen.

Engineered microorganisms offer a potential solution by breaking down non-edible biomass, improving the SAF's energy profile and reducing reliance on traditional raw materials. One of the most recent experiments involved engineering bacteria for production of sustainable polycyclopropanated jet fuel alternatives, with a potential higher energy density than current aerospace fuels.

However, there are several gaps still to be addressed: among which are scalability and business model. For instance, according to Sustainable Aero Lab, in 2023, there was 300 million tons of aviation fuel demand; however only 450,000 tons of *sustainable* aviation fuel supply. That means today's sustainable aviation fuel volume is less than 1% of total consumption.

Source	Top 10 Emerging Technologies of 2023 (World Economic Forum, 2023)	
Underlying technologies or innovations	Sustainable aviation fuel	
Technology Maturity	Emerging (TRL 4-6)	
EIC macro-areas	Green	
EIC portfolios	Renewable Fuels and Chemicals	
EIC Taxonomy	Primary	Mobility
	Secondary	Aviation & Airports / Renewable Alternative Fuels / Bioenergy, Biomass & Biobased Materials
EC initiatives	10 Critical Technology Areas	Energy technologies: hydrogen and new fuels
	STEP	Clean Technologies

08

Lidar on a chip - more efficiency and reliability with shorter size and costs

Lidar (Light Detection and Ranging) is increasingly seen as a crucial sensor for autonomous vehicles, offering distinct advantages over cameras and radars. Its ability to create detailed 3D maps of the environment with high fidelity exceeds what cameras can achieve. Lidar operates in the infrared spectrum, which allows for much better spatial resolution than automotive radar, as its emitted waves can be more tightly focused.

Earlier lidars faced challenges like high costs, integration difficulties, reliability issues, and susceptibility to interference from direct sunlight or other lidars. However, recent developments in chip-scale, solid-state lidars are addressing these issues. These new lidars, built entirely on a photonic integrated circuit using ordinary silicon, have no moving parts and are compact enough to integrate seamlessly into the design of modern cars.

This evolution in lidar technology is expected to drastically reduce costs and simplify integration into vehicles, making it a more feasible option for widespread use in autonomous driving. Furthermore, the potential applications of lidar extend beyond automotive uses, including industrial automation, robotics, mobile devices, precision agriculture, surveying, and gaming.

Source	Lidar on a chip puts self-driving cars in the fast lane (Watts, Poulton, Byrd, & Smolka, 2023)	
Underlying technologies or innovations	Lidar on a chip	
Technology Maturity	Emerging (TRL 4-6)	
EIC macro-areas	Digital & Industry	
EIC portfolios	N/A	
EIC Taxonomy	Primary	Mobility
	Secondary	Autonomous Vehicles / Robotics & Cyber-physical Systems / Precision & Smart Farming
EC initiatives	10 Critical Technology Areas	*Advanced Semiconductor Technologies: photonics technologies / Advanced Sensing Technologies / Advanced Connectivity, Navigation and Digital Technologies
	STEP	Digital technologies and deep tech innovation

09

AI's role in driving sustainability and safety in the mobility sector

Applied AI is revolutionising the mobility sector, particularly in enhancing sustainability and safety. Companies are leveraging AI to simulate countless driving scenarios for autonomous vehicles (AVs), far beyond what is possible manually. This not only streamlines the development process but also significantly cuts costs by identifying and addressing potential safety issues without the need for physical reiterations. In procurement, AI is instrumental in scanning supply chains for environmental and social risks, thus promoting sustainable manufacturing practices critical to consumers, as evidenced by surveys indicating a strong preference for eco-friendly vehicles.

In manufacturing, AI technologies, including vision cameras and radar, are deployed for stringent quality control, ensuring vehicles meet high safety standards while reducing production lead times. Marketing strategies benefit from AI by identifying at-risk customers and enhancing loyalty through personalised incentives. Furthermore, AI integration into vehicle systems offers personalised infotainment recommendations, improving the driving experience.

With the automotive industry's increasing focus on automation, significant investments in AI are anticipated, aiming to address labour shortages and enhance operational efficiency by automating mundane tasks. This holistic application of AI across the mobility ecosystem underscores its potential to drive forward both environmental sustainability and safety in the sector.

Source	What technology trends are shaping the mobility sector? (Kelkar, Moller, & Ziegler, 2024)	
Underlying technologies or innovations	Artificial Intelligence / Autonomous vehicles	
Technology Maturity	Emerging (TRL 4-6)	
EIC macro-areas	Digital & Industry / Green	
EIC portfolios	N/A	
EIC Taxonomy	Primary	Mobility
	Secondary	Autonomous Vehicles / Artificial Intelligence & Machine Learning / Supply Chains / Process & Continuous Manufacturing
EC initiatives	10 Critical Technology Areas	*Artificial Intelligence Technologies / Advanced Sensing Technologies / Advanced Connectivity, Navigation and Digital Technologies
	STEP	Deep and digital technologies

3.3 Space

Recent developments in space systems and technologies warrant some optimism about the innovation coming to the sector. Based on the European Innovation Council Impact Report (European Innovation Council, 2024), EIC-funded projects in the Space domain have generally contributed to technological development in that specific field and are not contributing directly to technical development in other domains. This finding does not follow the historical trend of multiple spill-over effects of benefits on Earth generated from technologies developed for outer space. However, the signal analysis reveals that the intersection of Space and Energy topics in recent innovation is clear. This is also evident in Figure 6 which shows many linkages between the Space and Energy secondary categories.

Additionally, the link between Space and Agriculture & Food technologies appears in this literature review. However, this seems to occur less frequently in the media and in research and could be an insight for EIC to investigate further, regarding the potential to support innovation in both Agriculture & Food and Space domains together.

Finally, the signals surfaced that an upcoming area for EIC to follow may be in the emergence of new materials to handle space-based power. For instance, materials for space-based power transmission and distribution could be a dedicated area for EIC to fund in the future.

Space Technologies & Propulsion Technologies and Biotechnologies (in the agriculture realm) are part of the 10 critical technology areas and STEP. Monitoring the areas of research which hit both these domains could therefore be useful for the EIC.

Figure 6. Indication of secondary categories for those signals which have Space as the primary category. The width of the line indicates the number of connections.

Source: Authors.

10

Lunar 'soil' for farming and roads on the moon

Lunar dust could be melted into paving slabs to create roads on the moon, enabling easier transport across its surface. Using lasers to heat "lunar dust" to 1200°C, the dust is compacted and turned into a black, glassy structure with a compression strength comparable to that of concrete, which could be usable as a road surface.

This is interesting because it could facilitate more space materials use for manufacturing. Moreover, lunar soil is being augmented with new microbes that enhance the availability of phosphorus, an important plant nutrient. These microbes could turn the lunar regolith into bio-friendly substrate, thereby enabling plants to grow in greenhouses on the moon.

Space technologies such as these have the potential to rapidly transform how we do things extraterrestrially but also terrestrially, due to the spill-over potential that they historically bear. This signal may indicate a growing trend observed in the literature where agriculture transforms how the space sector operates in the long term.

Source	We could make roads on the moon by melting lunar dust (O'Callaghan, 2023)	
Underlying technologies or innovations	Laser melting manufacturing / Lunar fertile soil	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Green / Digital and Industry	
EIC portfolios	Space / Agriculture & Food	
EIC Taxonomy	Primary	Space / Agriculture & Food
	Secondary	Missions / Operations & Space Traffic / Soils & Crops Management
EC initiatives	10 Critical Technology Areas	Space and Propulsion Technologies / Advanced Materials, Manufacturing and Recycling Technologies: Digital controlled micro-precision manufacturing and small-scale laser machining/welding
	STEP	Biotechnologies: Agricultural Biotechnologies

11

Wireless power transfer as a plan B for SmallSats

In the commercial sector, there are already technologies capable of wireless sensing and power transmission, ranging from microwatts to kilowatts. For SmallSats, wireless power transfer and detection can serve as alternative solutions in dusty environments where physical connectors might become contaminated, or in situations that necessitate frequent swapping and powering of hardware, including battery changes.

Despite being less efficient compared to conventional wired methods, ongoing research and development in wireless power technology for space applications shows promise for improving the reliability and robustness of power management and distribution systems in SmallSats.

This technology could be helpful in addressing the bigger issue of power in space, a pre-requisite for any future space economy. However, for effective power transmission and distribution in space, this would need to be scaled to the 100MWs and not the 1KWs as the current (novel) technology shows.

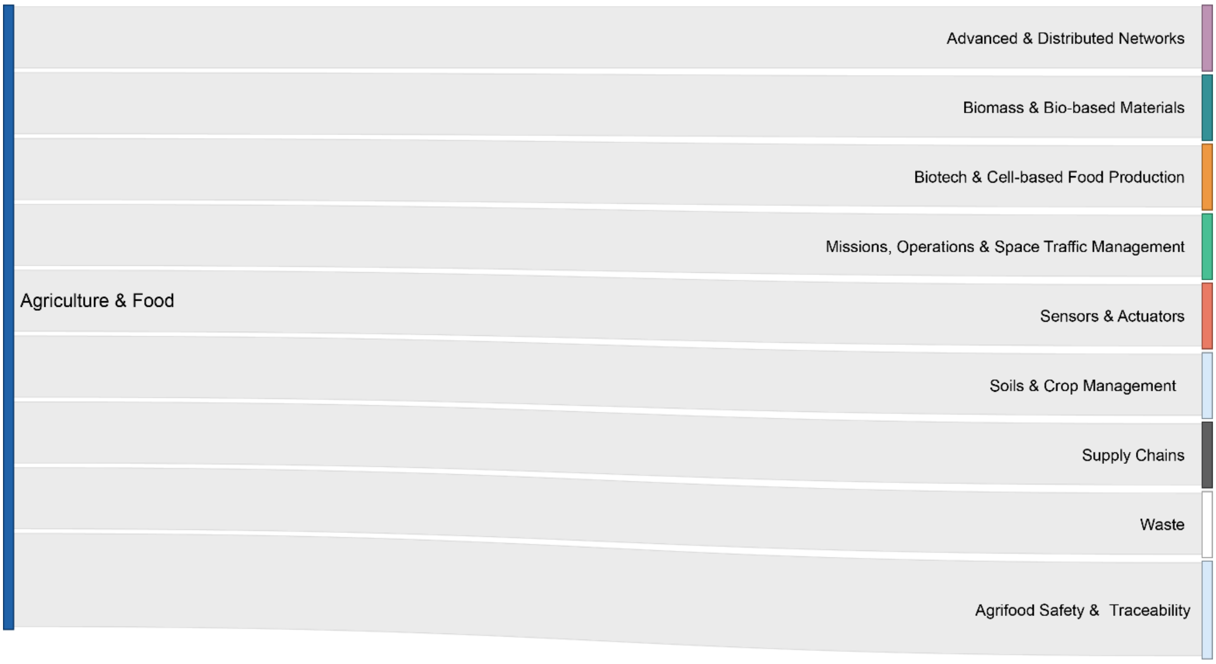
Source	State-of-the-Art Small Spacecraft Technology (NASA, 2023)	
Underlying technologies or innovations	Wireless Power Transfer / SmallSats	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Digital & Industry	
EIC portfolios	Space	
EIC Taxonomy	Primary	Space
	Secondary	Spacecrafts Systems & Technologies / Servicing, Assembly & Manufacturing / Energy Transmission, Distribution & Grid
EC initiatives	10 Critical Technology Areas	Space and Propulsion Technologies: Dedicated space-focused technologies, ranging from component to system level
	STEP	Digital technologies and deep tech innovation

3.4 Agriculture & Food

The secondary categories associated with Agriculture & Food are generally directly connected with the primary category. However, there are also links with the Information and Communication Technologies, Advanced Materials and Space primary categories.

Digitalisation and ICT has been converging with the Agriculture & Food domain for quite some time: for instance the connection with Information and Communication Technologies (secondary area: Advanced and Distributed Networks), picks up on this (European Union, 2023). The new area of connection is Missions, Operations & Space Traffic Management. The recent emergence of connections between Agriculture & Food and Space could be a new insight for the EIC and an area to monitor closely.

Figure 7. Indication of secondary categories for those signals which have Agriculture & Food as the primary category. The width of the line indicates the number of connections.



Source: Authors.

12

Antimicrobial packaging to reduce food waste and health risks

Antimicrobial packaging, a form of active packaging, integrates antimicrobial agents to maintain a microenvironment that inhibits microbial growth in food, thereby prolonging shelf life, avoiding food waste, and improving safety. Key antimicrobial elements used include bacteriocins, metal ions, nanoparticles, organic acids, fungicides, and various chemicals. This technology has gained traction due to consumer preference for foods with fewer preservatives, amidst concerns over the health impacts of certain artificial preservatives like nitrates, benzoates, sulfites, sorbates, and parabens. The direct food contact of these antimicrobial substances is heavily regulated. However, challenges remain in the development and use of natural antimicrobials in packaging. The technology both depends on and encourages multi-disciplinary work between food technology, material science, engineering, and microbiology.

It offers a promising solution to extend the shelf-life of food by doing what packaging does best: protecting against oxidation and bacterial growth. However, in this case, the environmental impact of petrochemical-derived plastics use is also reduced. Antimicrobial packaging is already on the market and US FDA-approved. More recent developments have emphasised the use of natural agents instead of traditional synthetic agents, thereby enhancing the sustainability dimension.

Source	Trends and Technologies Shaping the Food & Drink Industry (Djock, 2022)	
Underlying technologies or innovations	Antimicrobial packaging	
Technology Maturity	Close-to-market (TRL 7-9)	
EIC macro-areas	Health / Green	
EIC portfolios	Agriculture & Food	
EIC Taxonomy	Primary	Agriculture & Food
	Secondary	Biotech & Cell-based Food Production
EC initiatives	10 Critical Technology Areas	Advanced Materials, Manufacturing and Recycling Technologies: Technologies for nanomaterials, smart materials, advanced ceramic materials, stealth materials, safe and sustainable by design materials
	STEP	Clean technologies

13

DNA traceability for food authenticity

DNA traceability is an innovative method for ensuring product integrity and quality throughout the supply chain and compliance with ESG regulations, including food safety, animal welfare, and sustainability.

It involves either extracting DNA from organic products like cotton and meat or adding synthetic DNA to materials, including liquids like fuel, without altering their properties. This DNA is analysed using techniques such as Polymerase Chain Reaction (PCR), DNA sequencing, or DNA barcoding to provide essential information about the product's origin, manufacturing date, and custody chain. This technology offers a more sophisticated and scalable alternative to traditional tracking methods such as RFID and physical barcodes.

The widespread adoption of DNA traceability depends on the advancement of related technologies, such as next-generation sequencing and DNA data storage. Food authenticity via DNA analysis is not uncommon and as stated is usually assessed through targeted real-time PCR methods. However, this approach is limiting because the number of targets that can be tested is small.

However, the recent introduction of Next Generation Sequencing (NGS) into the food sector opens the door to a new approach which allows for accurate detection and differentiation of thousands of different food product species. One can use a single DNA analysis to assess the whole composition of a food product. Moreover, this signal incorporates blockchain technology to further enhance food product traceability and transparency. There is currently no standardisation of this method, however, extensive discussions and draft projects on the topic are being pursued by international standardisation bodies, specifically the International Organization for Standardization (ISO).

Source	Trends and Technologies Shaping the Food & Drink Industry (Djock, 2022)	
Underlying technologies or innovations	DNA Sequencing / Blockchain / DNA data storage	
Technology Maturity	Close-to-market (TRL 7-9)	
EIC macro-areas	Green	
EIC portfolios	Agriculture & Food	
EIC Taxonomy	Primary	Agriculture & Food
	Secondary	Agrifood Safety & Traceability / Supply Chains / Advanced & Distributed Networks
EC initiatives	10 Critical Technology Areas	*Biotechnologies: synthetic biology, new genomic techniques / Advanced Connectivity, Navigation and Digital Technologies: distributed ledger and digital identity technologies
	STEP	Digital technologies and deep tech innovation / Biotechnologies

14

Paper sensors to reduce food waste

These sensors, made with cellulose paper and conductive ink, can detect gases in food spoilage without added moisture. By incorporating the sensors into food packaging, along with near-field communication tags, consumers can use their smartphones to determine the freshness of food. The detection of gases is essential to provide food security.

This technology could potentially replace traditional 'use-by' dates, reducing unnecessary food waste and its contribution to greenhouse gas emissions.

Food waste occurs not only in the commercial setting but also at home. In fact, according to Eurostat, in 2021, household food waste accounted for the most food waste among all economic settings. Paper-based devices could be a faster, cheaper solution compared to the lab techniques which are used today to assess food safety. Thus, paper-based sensors are particularly suitable for deployment in low-resource settings, like domestic households.

Source	Tech Foresight 2040 - Intentional creations (Imperial College London, 2020)	
Underlying technologies or innovations	Paper sensors / Food packaging	
Technology Maturity	Emerging (TRL 4-6)	
EIC macro-areas	Green	
EIC portfolios	Agriculture & Food	
EIC Taxonomy	Primary	Agriculture & Food
	Secondary	Agrifood Safety & Traceability / Sensors & Actuators / Biomass & Bio-based Materials / Waste
EC initiatives	10 Critical Technology Areas	Advanced Materials, Manufacturing and Recycling Technologies: Technologies for nanomaterials, smart materials, advanced ceramic materials, stealth materials, safe and sustainable by design materials / Advanced Sensing Technologies.
	STEP	Digital and deep tech innovation / Clean technologies

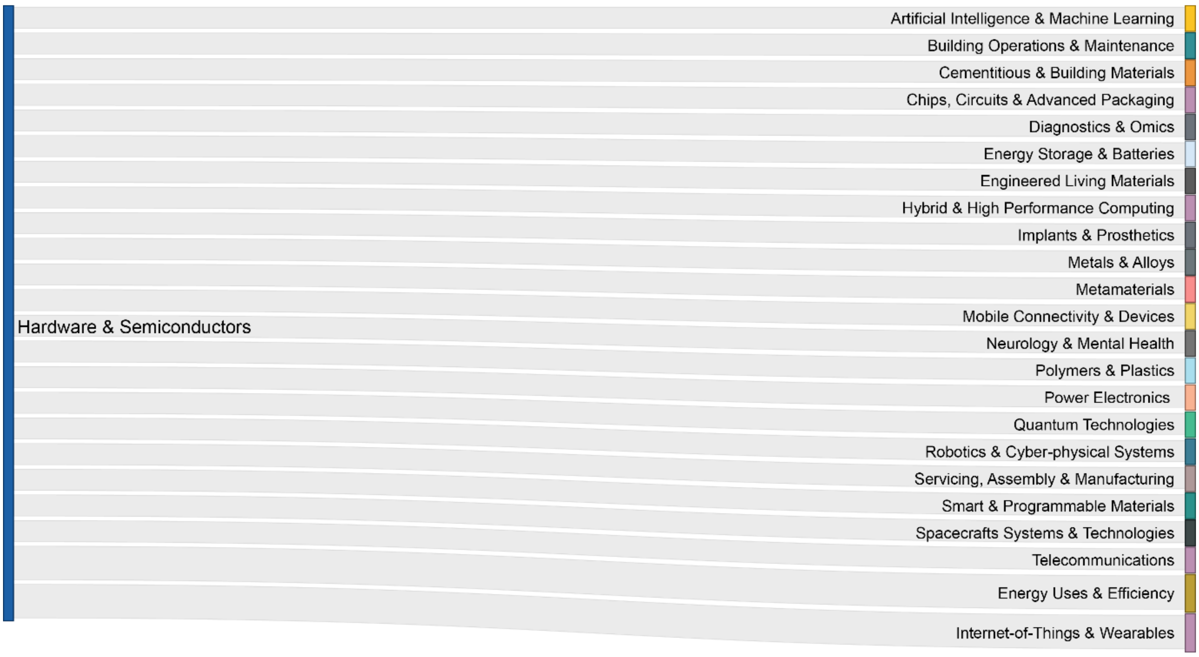
3.5 Hardware & Semiconductors

The primary category which had the most convergences and connections with other areas was Hardware & Semiconductors. Figure 8 displays the connections with secondary levels of Advanced Materials, Space and Health, hinting at the multitude of cross-sector innovation upcoming in this domain.

These selected signals converge most with secondary categories related with Internet-of-Things & Wearables and Energy Uses & Efficiency. There is a probable interest for the EIC to explore this latter area. Energy efficiency is becoming a major focus of many of the electronics hardware and semiconductors technologies, especially in the realm of AI (Bullard, 2024).

There are some European Commission initiatives which are directly concerned with quantum technologies (QT), including but not limited to, STEP and the 10 critical technology areas. When considering the critical technology areas, signals surfaced for this literature review and fitting within Hardware & Semiconductors are more connected to Artificial Intelligence Technologies and Advanced Semiconductor Technologies than QT. According to the latest European Innovation Council Impact Report, QT were most represented in projects in the Hardware & Semiconductors space in Horizon Europe (European Innovation Council, 2024). However, in this literature review QT are present in only one signal. This is not due to the lack of relevance and novelty of this domain, but rather to the fact that it was sufficiently covered by previous publications.

Figure 8. Indication of secondary categories for those signals which have Hardware & Semiconductors as the primary category. The width of the line indicates the number of connections.



Source: Authors.

15

Nanomagnetic computing could reduce the energy cost of AI

Nanomagnetic computing is an emerging field that harnesses the power of magnetic materials at the nanoscale to store and manipulate information. This technology holds the potential to enhance computer system performance and reduce energy consumption.

By using networks of nanoscale magnets, the energy cost of artificial intelligence can be significantly reduced. This is particularly crucial as the demand for AI continues to rise globally, with its energy consumption doubling approximately every 3.5 months. Nanomagnetic computing can offer a promising solution to address this energy challenge.

Source	'Nanomagnetic' computing can provide low-energy AI (Imperial College London, 2022)	
Underlying technologies or innovations	Nanomagnetic computing / Artificial Intelligence	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Digital & Industry / Green	
EIC portfolios	Responsible and Sustainable Electronics	
EIC Taxonomy	Primary	Hardware & Semiconductors
	Secondary	Hybrid & High-Performance Computing
EC initiatives	10 Critical Technology Areas	*Artificial Intelligence Technologies: Cloud and edge computing / Advanced Materials, Manufacturing and Recycling Technologies: Technologies for nanomaterials, smart materials, advanced ceramic materials, stealth materials, safe and sustainable by design materials / Advanced Sensing Technologies.
	STEP	Digital and deep tech innovation / Clean technologies

16

IoT devices that communicate without electronics

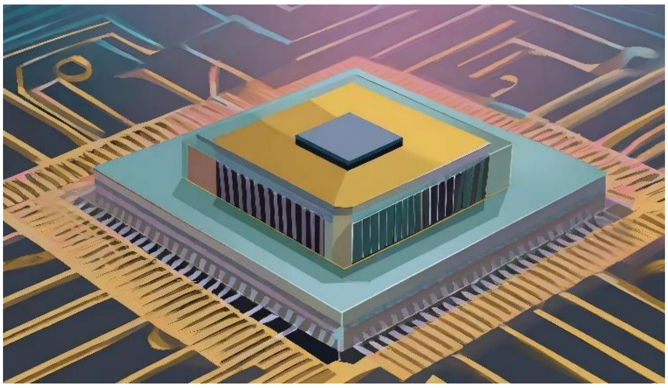
Researchers have built upon work on objects which can wirelessly communicate using WiFi. This invention itself is not particularly new as there were researchers at the University of Washington who achieved this in 2017 with 3D printed plastic objects and a clever use of an anemometer and backscatter gear. However, in 2020, researchers proposed a new practical design called WiFi-IoT to enhance energy-efficient IoT communication within WLANs.

The introduction of an asymmetric physical (PHY) design is a key innovation. In this approach, the access point communicates with multiple IoT devices at a significantly lower sampling rate. By allowing IoT devices to operate efficiently with minimal energy usage, this design addresses the critical need for prolonged battery life in IoT deployments. Applications could include attaching such devices to household supplies such as detergent, with the device automatically re-ordering when they run low.

Source	Coexistence of Wi-Fi and IoT Communications in WLANs (Pirayesh, Sangdeh, & Zeng, 2020)	
Underlying technologies or innovations	Low-energy IoT	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Digital & Industry	
EIC portfolios	Responsible and Sustainable Electronics	
EIC Taxonomy	Primary	Hardware & Semiconductors
	Secondary	Internet-of-Things & Wearables / Mobile Connectivity & Devices / Energy Uses & Efficiency
EC initiatives	10 Critical Technology Areas	Advanced Connectivity, Navigation and Digital Technologies: internet of things and virtual reality
	STEP	Digital and deep tech innovation

17

Thermal transistors that can handle heat with no moving parts



Researchers at the University of California, Los Angeles have developed a solid-state thermal transistor—the first device of its kind that uses electric fields to control the flow of heat through electronics. Their study, which was recently published in *Science*, shows that electric fields can be used to modulate the conductance of a channel with only a small thin film.

Historically, electronics and their GPUs have been cooled down with fluids, fans, or cumbersome moving parts. This can take a long time—typically minutes to hours—and is often not very precise. This new thermal transistor can 'turn on' a thermal switch in which the heat flow can be modulated. This works through a careful blend of chemical bonds and electrically charged distributions within a thin molecular interface. With that single-molecule layer, the molecular motion would be quite slow however speeds up when enhanced with electrons.

These devices have very high switch speeds and were able to reach the maximum change in conductivity at a frequency above 1 megahertz. By leveraging electric fields, the researchers can speed up the switch from millihertz to megahertz frequencies. This speed makes them a promising option for managing heat in electronic devices. This technology is novel in the sense that it draws inspiration from energy and electricity to enhance thermal operations.

Source	Thermal Transistors Handle Heat With No Moving Parts (Rak, 2023)	
Underlying technologies or innovations	Thermal transistors	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Digital & Industry	
EIC portfolios	Responsible and Sustainable Electronics	
EIC Taxonomy	Primary	Hardware & Semiconductors
	Secondary	Chips, Circuits & Advanced Packaging / Energy Uses & Efficiency
EC initiatives	10 Critical Technology Areas	*Advanced Semiconductor Technologies: Microelectronics, including processors, High frequency chips
	STEP	Digital and deep tech innovation

18

Rare earths show potential for quantum communications, processors

While conventional computers use binary bits (1s and 0s), quantum computers use qubits, which can occupy two states simultaneously. As it turns out, crystals containing rare earths make good qubits, since their unique electron configuration can store quantum information for long periods of time. Researchers achieved a breakthrough in this area by showcasing the significance of europium molecular crystals, a rare earth ion, in quantum communications and processors. These crystals owe their success to ultra-narrow optical transitions, allowing them to interact optimally with light. The remarkable thinness of these transitions results in long-lived quantum states, which were harnessed to store a light pulse within the molecular crystals.

This novel material for quantum technologies introduces unprecedented properties and lays the groundwork for innovative computer architectures and quantum memories, where light assumes a pivotal role. This technology is highly relevant for EC initiatives due to the intersection of quantum and advanced materials. Advanced materials, such as rare earth element crystals, are helping to influence the expansion of these critical technologies. These key technology developments could contribute to the EU's economic security.

Source	Ultra-narrow optical linewidths in rare-earth molecular crystals (Serrano, et al., 2022)	
Underlying technologies or innovations	Quantum computing / Quantum communications / Molecular crystals	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Digital & Industry	
EIC portfolios	Quantum Technologies	
EIC Taxonomy	Primary	Hardware & Semiconductors
	Secondary	Quantum Technologies / Telecommunications / Metals & Alloys
EC initiatives	10 Critical Technology Areas	*Quantum technologies / Advanced Materials, Manufacturing and Recycling Technologies
	STEP	Digital technologies and deep tech innovation

3.6 Advanced Manufacturing

Advanced manufacturing technologies are helping to deploy energy system hardware and contributing to cost efficiency to a significant degree within the Energy and Biotechnology space. The EIC could benefit from looking for Advanced Manufacturing innovation particularly in the Health and Energy portfolios. According to the European Innovation Council Impact Report 2023, 'Industrial Biotech & Biomanufacturing' is the most significant part of the funding for the Advanced Manufacturing domain for European Innovation Council (European Innovation Council, 2024), representing a clear link with the Health portfolio. However, there is less evidence from the EIC impact report on Advanced Manufacturing's influence on the Energy portfolio.

There are some European Commission initiatives which converge around aspects of this technology, including but not limited to, STEP and the 10 critical technology areas. Many of the signals which fit within the Advanced Manufacturing category fit within the 'high-risk' biotechnologies area from the EU lists; however, signals related to energy and clean technologies deserve close monitoring, too.

Figure 9. Indication of secondary categories for those signals which have Advanced Manufacturing as the primary category. The width of the line indicates the number of connections.

Source: Authors.

19

Paper-thin solar cells that are easily integrated into other materials

Researchers have developed a scalable fabrication technique to produce ultrathin, light-weight solar cells that can be seamlessly added to any surface. These durable, flexible solar cells, which are much thinner than a human hair, are glued to a strong, lightweight fabric, making them easy to install on a fixed surface. They can provide energy on the go as a wearable power fabric or be transported and rapidly deployed in remote locations for assistance in emergencies.

They are one-hundredth the weight of conventional solar panels, generate 18 times more power-per-kilogram, and are made from semiconducting inks using printing processes that can be scaled in the future to large-area manufacturing. Semi-conducting inks is also a relatively new area which could transverse Advanced Materials and Information and Computing Technologies. This alludes to the significance of this the technology for EC initiatives, but not the extent that it is high-risk.

Source	Paper-thin solar cell can turn any surface into a power source (Zewe, 2022)	
Underlying technologies or innovations	Flexible solar cells	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Green	
EIC portfolios	Energy Systems / Renewable Fuels and Chemicals / Advanced Materials / Architecture, Engineering, and construction	
EIC Taxonomy	Primary	Advanced Manufacturing / Energy / Advanced Materials
	Secondary	Process & Continuous Manufacturing / Solar / Metals & Alloys
EC initiatives	10 Critical Technology Areas	Energy Technologies / Advanced Materials, Manufacturing and Recycling Technologies
	STEP	Clean technologies

20

Biofoundries to speed up the bioeconomy

Biofoundries primarily provide integrated facilities for high-throughput iterative prototyping of biodesigns, prior to any scale-up, such as a pilot-scale fermentation or biomanufacturing. A notable example is the Manchester Synthetic Biology Research Centre for Fine and Speciality Chemicals, where Escherichia coli strains were prototyped for the production of 17 chemically diverse bio-based building blocks in 85 days from scratch.

Biofoundries will help support the complex, interdisciplinary collaborations needed to advance research across the sciences and engineering.

There is not a specific EC technology initiative which links to biofoundries as it's more of a concept or way of manufacturing than a technology, but focus to date has been on the chemical and biotech sectors. Thus, biotechnologies from the 10 critical technology areas and STEP could be included here as relevant initiatives for this signal.

Source	Biodigital Today and Tomorrow (Policy Horizons Canada, 2022)	
Underlying technologies or innovations	Gene editing / Biotechnology / Bio-foundry	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Green, Health	
EIC portfolios	Energy Systems / Renewable Fuels and Chemicals / Agriculture and Food / Health and Biotechnology	
EIC Taxonomy	Primary	Advanced Manufacturing
	Secondary	Industrial Biotech & Biomanufacturing / Biotech & Cell-based Food Production / Renewable Alternative Fuels / Pharma Processing
EC initiatives	10 Critical Technology Areas	*Biotechnologies / Advanced Materials, Manufacturing and Recycling Technologies
	STEP	Biotechnologies

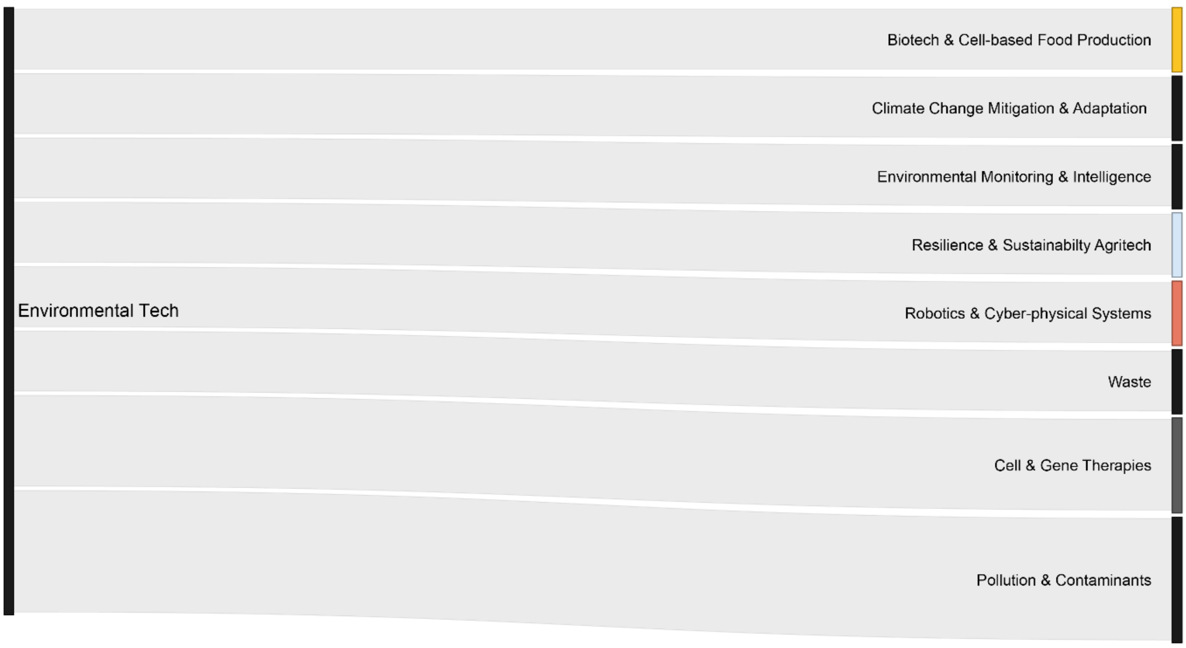
3.7 Environmental Tech

Figure 10 depicts the range of secondary categories linked to the Environmental Tech primary category. For the most part, the environmental tech signals stay within that category. The exception is biotech including, but not limited to, 'Cell & Gene Therapies' which is located within the Health category. This is because newly-engineered enzymes or microbes are being used to 'eat away' at or minimise pollution, constituting a new tech domain. This new frontier can also be seen in the Mobility domain especially within the signal related to engineered bacteria in SAF (signal 07).

The EIC could benefit from looking for Environmental Tech innovation particularly in the biotechnology domain. According to the European Innovation Council Impact Report 2023, projects supported in the Environmental Tech area tend to touch other primaries (more than stay within the primary), supporting the idea that other areas outside the Environmental Tech domain such as Health & Biotechnology could become relevant, or even disruptive, for Environmental Tech innovation (European Innovation Council, 2024).

Many of the signals which fit within the Environmental Tech category apply to several EC initiatives. Two of the four signals fit within the 'high-risk' biotechnologies area from the 10 critical technology areas; nearly all the selected signals fit into clean technologies and biotechnologies area from STEP.

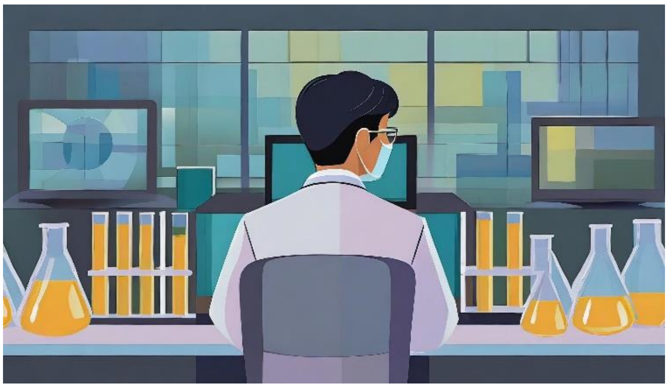
Figure 10. Indication of secondary categories for those signals which have Environmental Tech as the primary category. The width of the line indicates the number of connections.



Source: Authors.

21

Biocatalytic membranes for quicker and cleaner chemistry



Biocatalytic membranes are an emerging type of membrane inspired by the structure and functions of cell membranes. They combine the benefits of enzymes (biological catalysts) with selective barriers, or membranes. They have useful properties such as enhancing reaction efficiency, improving the removal of pollutants, and enabling the re-use of enzymes in some processes. Many use cases are being experimented on right now for carbon capture and utilisation. Enzymes like carbonic anhydrase enhanced CO2 capture efficiency and enzymatic conversion can be used to eventually turn that captured CO2 into useful chemicals.

These biocatalytic membranes are still only at the lab-scale but their 'double whammy' aspect of being able to use them for CO2 capture and conversion make it attractive for EC initiatives and for EIC funding sustainable technologies in the future.

Source	Welcome to the future - UK's 50 Emerging Technologies (Innovate UK, 2023)	
Underlying technologies or innovations	Biocatalytic membranes	
Technology Maturity	Emerging (TRL 4-6)	
EIC macro-areas	Digital & Industry	
EIC portfolios	Health and Biotechnology / Agriculture and Food	
EIC Taxonomy	Primary	Environmental Tech
	Secondary	Biotech & Cell-based Food Production / Cell & Gene Therapies / Pollution & Contaminants / Waste
EC initiatives	10 Critical Technology Areas	Advanced Materials, Manufacturing, and Recycling Technologies/ Biotechnologies
	STEP	Clean technologies, Biotechnologies

22

Fast detection of freshwater contamination with a new type of engineered microbes

Researchers from Rice University have innovated in the field of synthetic biology by developing rapid, sensitive biosensors for monitoring harmful contaminants in freshwater. These living cell-based sensors, using engineered Escherichia coli, employ a novel transcription-independent electron transfer mechanism, significantly enhancing detection speed and accuracy. Initially designed to detect thiosulfate, known to promote excessive microbial growth in water, the system has been adapted to also identify 4-hydroxytamoxifen, an estrogen antagonist. The incorporation of electroconductive nanoparticles into the sensor's encapsulation material has further improved its response time and sensitivity.

This breakthrough is particularly crucial for regions with limited resources, offering a versatile and efficient tool for freshwater monitoring. The biosensors' modular nature allows adaptation for various contaminants, but ongoing refinements are necessary to address issues like natural contaminant concentrations and the environmental safety of using genetically modified organisms.

Source	Engineered microbes report levels of freshwater contamination in real time (Crnković, 2023)	
Underlying technologies or innovations	Synthetic Biology / Biosensors	
Technology Maturity	Emerging (TRL 4-6)	
EIC macro-areas	Health / Green	
EIC portfolios	Health and Biotechnology / Agriculture and Food	
EIC Taxonomy	Primary	Environmental Tech
	Secondary	Environmental Monitoring & Intelligence / Pollution & Contaminants / Cell & Gene Therapies
EC initiatives	10 Critical Technology Areas	*Biotechnologies: synthetic biology
	STEP	Clean technologies, Biotechnologies

23

Tiny robots suck contaminants from rivers

Annual polymer consumption in the G20 countries has tripled since 2001 according to Back to Blue. This includes the phenomenon of microplastics, which are simply the breakdown of large plastic products but are extra-harmful due to their ability to bind with other harmful chemicals before being ingested by marine organisms or even humans. This signal refers to the development of biohybrid robots capable of targeting and degrading microplastics in water bodies. These robots, inspired by the locomotion of jellyfish and propelled by cardiac muscle cells, represent a novel approach to addressing water pollution. This signal also hits upon another trend of biomimicry within the advanced materials and environmental technology space.

The innovation lies in the robots' ability to autonomously navigate water environments, locate microplastics, and enzymatically break them down. This technology holds promise for cleaning up microplastic pollution in oceans and waterways. By leveraging biological components, the biohybrid robots present an environmentally-friendly solution to combat the growing environmental threat posed by microplastics.

Source	Scientists create incredible tiny 'robots' that could suck harmful contaminants from rivers: 'Remarkable removal efficiency' (Funaki, 2024)	
Underlying technologies or innovations	Biohybrid robots	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Green	
EIC portfolios	N/A	
EIC Taxonomy	Primary	Environmental Tech
	Secondary	Pollution & Contaminants / Robotics & Cyber-physical Systems
EC initiatives	10 Critical Technology Areas	*Biotechnologies / Advanced Connectivity, Navigation and Digital Technologies / Robotics and Autonomous Systems
	STEP	Digital technologies and deep tech innovation / Clean technologies, Biotechnologies

24

Exploring solar geoengineering as a piece in a multifaceted climate change mitigation strategy

Harvard's recent study reveals solar geoengineering, involving aerosols to reflect sunlight, could significantly mitigate climate change impacts on agriculture. Collaborating with international research centres, the study found methods like stratospheric aerosol injection and marine sky brightening might cool the Earth's surface to benefit crops like maize and wheat. Key insights include the crucial role of humidity in maintaining crop productivity, challenging previous assumptions about reduced rainfall and yield losses. The research, emphasising a nuanced approach to solar geoengineering alongside emissions reductions, underscores the complexity of combating climate risks.

The study further suggests combining global strategies like carbon removal with local agricultural adaptations to address food security concerns. This holistic perspective highlights the potential of solar geoengineering as part of a multifaceted climate change mitigation strategy, urging policymakers to consider diverse solutions to safeguard against the adverse effects on agriculture.

Source	Model shows solar geoengineering may be surprisingly effective in alleviating impacts of global warming on crops (Burrows, 2021)	
Underlying technologies or innovations	Solar Geoengineering	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Green	
EIC portfolios	Agriculture and Food	
EIC Taxonomy	Primary	Environmental Tech
	Secondary	Climate Change Mitigation & Adaption / Resilience & Sustainability Agritech
EC initiatives	10 Critical Technology Areas	Energy Technologies
	STEP	Clean technologies

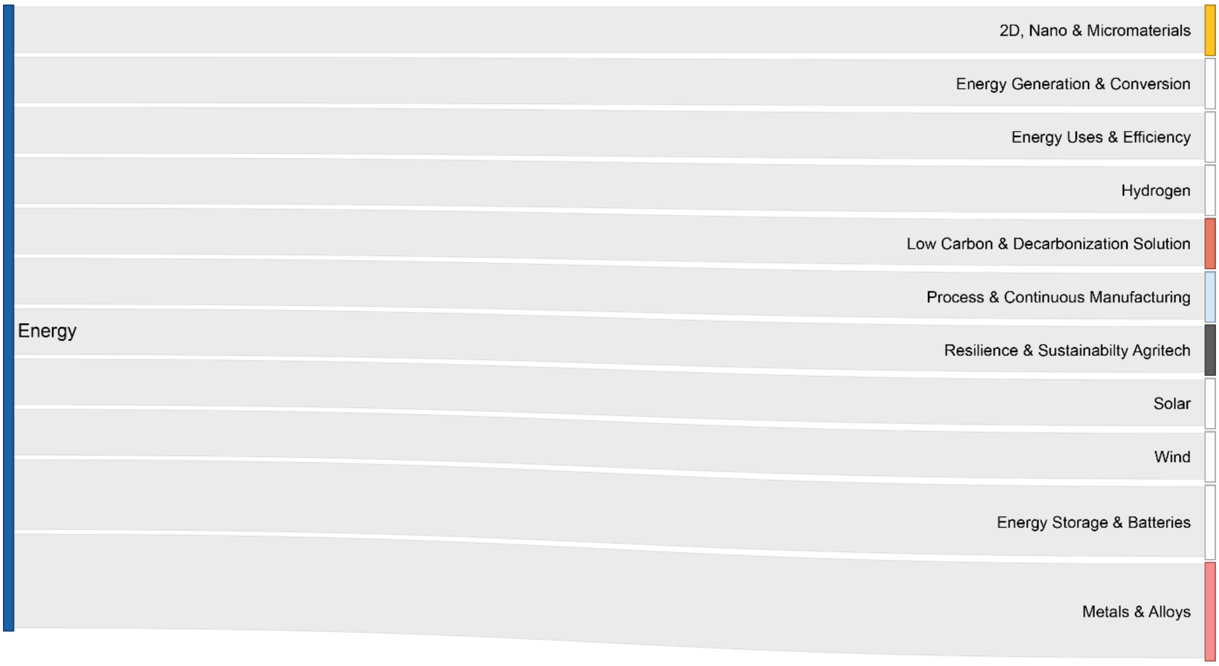
3.8 Energy

The primary category of Energy touches several secondary categories from other domains such as Advanced Materials. Energy is often associated with a specific secondary category within Advanced Materials, called Metals & Alloys.

However, for the most part, the Energy domain refers to signals within its own secondary level, most notably, Energy Storage & Batteries and energy or e-molecules such as Hydrogen, Solar, Nuclear, etc. For batteries, this is nothing new as batteries and energy storage technologies have been the focus of improvement through innovation since the 1980s (Zu & Li, 2011). Nevertheless, it seems from the key signals that even more innovation is possible in this space as new battery tech with abundant source materials and safer performance is being developed. This is also evident in the EIC impact report from 2023, as projects with a relevance to Energy in Horizon Europe were largely situated in the 'Energy Storage & Batteries' domain (European Innovation Council, 2024).

From the signals analysis, it also seems pertinent that the EIC funds alternatives to the manufacturing of traditional e-molecules which are increasingly using electrochemical instead of thermochemical methods. This could benefit many sectors in the EU such as energy, petrochemical, food, and more, which is why the many links with EC initiatives like STEP investments and the 10 critical technology areas are evident.

Figure 11. Indication of secondary categories for those signals which have Energy as the primary category. The width of the line indicates the number of connections.



Source: Authors.

25

Multivalent batteries for lower cost chemistries

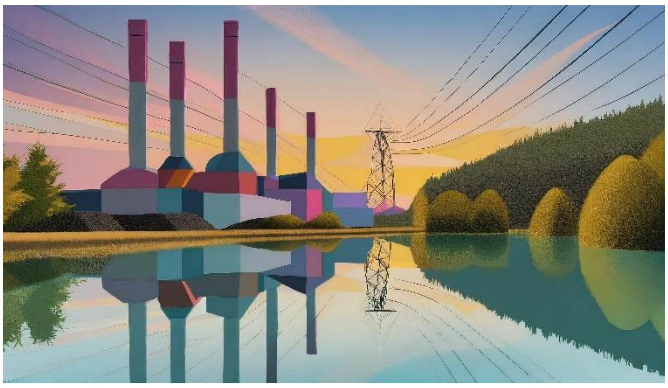
A multivalent battery is a rechargeable battery that uses ions with multiple charge states, such as magnesium or aluminium, during charging and discharging. This allows for higher energy density and lower production costs compared to traditional lithium-ion (Li-ion) batteries. Multivalent batteries also have potential safety advantages. However, they face challenges in terms of ion movement, efficiency, and suitable electrode materials. Despite these challenges, multivalent batteries are being actively researched for their potential to improve energy storage in applications like electric vehicles and grid storage.

Organic materials are becoming a popular choice for post-Li-ion battery technologies and have shown tremendous progress in recent years. Essentially, multivalent is attractive due to its ability to move more electrons back and forth than Li-ion, which allows the multivalent batteries to store and release more energy. This back-and-forth process results in the deposition and stripping of metal atoms on the surface of a battery's anode (negative electrode). A high-performance, long-lasting battery should be able to reversibly deposit and strip a uniform layer of metal for thousands of cycles. Today, most multivalent batteries under investigation by researchers do not perform thousands of cycles, which limits their commercial viability for now.

Source	A new blueprint for designing high-performance batteries (Matz, 2023)	
Underlying technologies or innovations	Lithium-ion batteries	
Technology Maturity	Emerging (TRL 4-6)	
EIC macro-areas	Green	
EIC portfolios	Energy Systems / Advanced Materials	
EIC Taxonomy	Primary	Energy
	Secondary	Energy Storage & Batteries / Metals & Alloys
EC initiatives	10 Critical Technology Areas	Energy Technologies: smart grids and energy storage, batteries
	STEP	Clean technologies

26

Accelerating the shift from thermal energy to electrical energy to produce lower emission fuels & chemicals



Hard-to-abate sectors such as the petrochemical industry have employed various strategies to reduce carbon emissions. The move from thermal energy in ammonia synthesis to electric energy is seen in the chemical industry and is done via new routes today such as electrochemical synthesis of ammonia, plasma technology, or other novel electrochemical synthesis routes (such as hydrogen permeable membranes or electrocatalytic nitrogen reduction). For nitrogen reduction reactions, a catalyst is crucial and new research is ongoing to improve catalysts and catalytic systems to ensure high efficiency and selectivity. This signal also has links to the Agriculture and Food category as ammonia synthesis is a key aspect of food production. This represents a paradigm shift: obtaining carbon neutral fuels from electrochemical processes instead of thermochemical processes.

This shift is not without its challenges, however as cost, scale and materials innovation could inhibit future widespread adoption of these greener technologies. However, if R&D funding from entities like EIC could help build up the offer of alternatives to traditional thermochemical methods, this could apply to a wide range of sectors like energy, petrochemical, food, and more.

Source	Energy Technology Perspectives 2023 (International Energy Agency, 2023)	
Underlying technologies or innovations	Haber-Bosch ammonia production / carbon neutral fuels	
Technology Maturity	Close-to-market (TRL 7-9)	
EIC macro-areas	Green	
EIC portfolios	Energy Systems / Advanced Materials	
EIC Taxonomy	Primary	Energy
	Secondary	Energy Generation & Conversion / Energy Uses & Efficiency / Low Carbon & Decarbonization Solution / Resilience & Sustainability Agritech
EC initiatives	10 Critical Technology Areas	Energy Technologies: Nuclear fusion technologies, reactors and power generation, radiological conversion, enrichment, recycling technologies / Advanced Materials, Manufacturing, and Recycling Technologies
	STEP	Clean technologies

27

'Energy kites' for harnessing high-altitude wind energy

High-altitude wind power, also known as airborne wind energy (AWE) or airborne wind power (AWP), involves using wind turbines or other devices such as 'energy kites' stationed at high altitudes to capture stronger and more consistent winds compared to those at ground level. There are several technology design choices in the kite-based wind generation field, one of which is high-altitude (or low-altitude); in fact, this is one of six choices according to CleanTechnica (Barnard, 2014). Thus, several companies and research groups are actively working on developing airborne wind energy technology with various design choices. Some have conducted successful test flights and are moving towards commercialisation, while others are still in the research and development phase. Overall, while harnessing high-altitude wind for energy is not entirely novel, ongoing advancements in technology and research are making it an increasingly viable option for renewable energy generation.

For the moment, this solution seems most suitable for remote areas which are far from grid with poor solar radiation or with grid connection in sparsely populated areas. However, if the business model and scalability improve, this technology holds immense potential for the renewable energy landscape in EU as it doesn't require massive investment or land use, and the kites' minimal visual impact has a significant advantage for coastal regions.

Source	Emerging climate technologies in the energy supply sector (United Nations Climate Change - Technology Executive Committee, 2023)	
Underlying technologies or innovations	Airborne wind energy generation	
Technology Maturity	Emerging (TRL 4-6)	
EIC macro-areas	Green	
EIC portfolios	Energy Systems	
EIC Taxonomy	Primary	Energy
	Secondary	Wind
EC initiatives	10 Critical Technology Areas	Energy Technologies: Net-zero technologies, including photovoltaics
	STEP	Clean technologies

28

Ultra-high density hydrogen storage holds twice as much as liquid H2

The hydrogen molecule is naturally not very dense, meaning it occupies a large volume even at high pressures. Hydrogen is also a leaky molecule and can be explosive when contained in large quantities; thus, storing hydrogen when it's not immediately needed has always posed a problem. Recently, there have been advancements in storage methods.

One of the newest is a hydrogen storage system which was developed by a team of researchers in South Korea. The system utilises a new material called "pentinitride" to store hydrogen at significantly higher densities compared to conventional storage methods. The novel aspect lies in the material's ability to hold hydrogen at a high density under ambient conditions, bypassing the need for extreme pressures or temperatures. However, the kinetics of hydrogen release from the pentinitride can be slow, and rapid and reversible hydrogen release is essential for real world applications. While still in its infancy, this breakthrough could potentially revolutionise hydrogen storage, making it safer, more efficient, and economically viable for various applications, including fuel cells and energy storage.

Source	Ultra-high density hydrogen storage holds twice as much as liquid H2 (McClure, 2024)	
Underlying technologies or innovations	Liquid hydrogen	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Green	
EIC portfolios	Energy Systems / Advanced Materials	
EIC Taxonomy	Primary	Energy
	Secondary	Hydrogen / Energy Storage & Batteries / 2D, Nano & Micromaterials / Metals & Alloys
EC initiatives	10 Critical Technology Areas	Energy Technologies: Hydrogen and new fuels, Smart grids and energy storage, batteries / Advanced Materials, Manufacturing, and Recycling Technologies
	STEP	Clean technologies

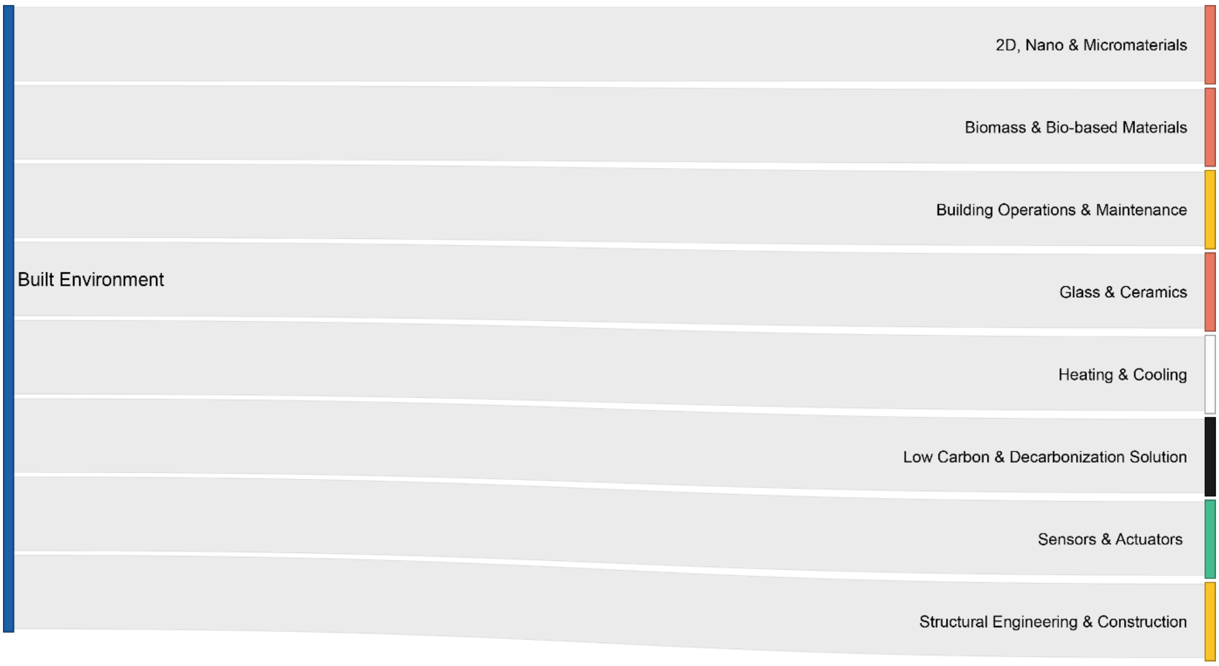
3.9 Built Environment

Signals within the Built Environment primary category connect largely with domains from other areas such as Advanced Materials and Energy. This is likely to be connected with the specificities of the sector as well as the EIC taxonomy itself.

According to the EIC Impact Report from 2023, the EIC challenge calls under the Built Environment domain focus on breakthrough innovations for decarbonised materials. Other sources point out that clean tech investment in Built Environment industries expanded in 2023 (Bullard, 2024), highlighting additional areas where innovation in this sector is heading.

In this sense, and also taking into account the importance given to clean tech, advanced materials and energy by EC initiatives like STEP and the 10 critical technology areas, the EIC should consider broadening the funding topics of this primary category.

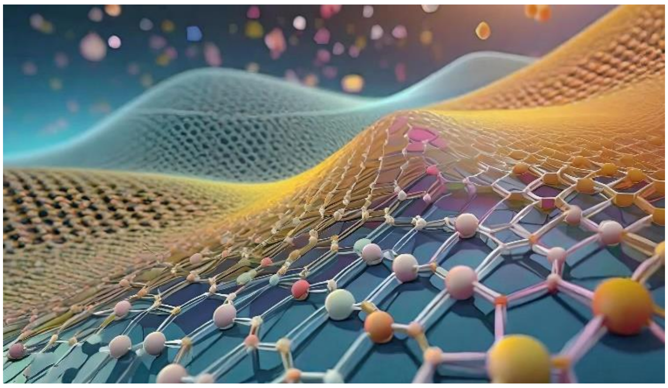
Figure 12. Indication of secondary categories for those signals which have Built Environment as the primary category. The width of the line indicates the number of connections.



Source: Authors.

29

Material with beetle nanostructure for efficient solar reflectivity



Scientists at City University of Hong Kong (CityU) have developed a new cooling ceramic material with a solar reflectivity of 99.6%, which is a record high, along with an infrared thermal emission of 96.5%. The alumina structure is highly porous and inspired by the Cyphochilus beetle.

This is another example where biomimicry has helped inform some of our most novel devices. The nano aluminia structure allows for higher reflectivity which makes the distribution of the sunlight better. The application discussed in the source article is buildings; however, one could also imagine applications in space, textiles, automotive, and solar panels.

Source	Ultra-white ceramic cools buildings with record-high 99.6% reflectivity (Irving, 2023)	
Underlying technologies or innovations	Cooling ceramic	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Green	
EIC portfolios	Advanced Materials / Architecture, Engineering and Construction	
EIC Taxonomy	Primary	Built Environment / Advanced Materials
	Secondary	Building Operations & Maintenance / Glass & Ceramics / 2D, Nano & Micro materials / Heating & Cooling
EC initiatives	10 Critical Technology Areas	Advanced Materials, Manufacturing and Recycling Technologies: Technologies for advanced ceramic materials, stealth materials, safe and sustainable by design materials
	STEP	Clean technologies

30

Sustainable transparent wood

A team at the University of Maryland have furthered this 1992 innovation. They have made a wood which is both thin and robust due to its honeycomb structure and strong wood fibres and outperforms traditional materials like Plexiglass and glass in durability tests. This makes it a promising alternative for use in smartphone screens, light fixtures, and building elements such as colour-changing windows.

Recent efforts focus on enhancing the sustainability of transparent wood. A notable breakthrough involves replacing petroleum-based resin with a bio-based polymer derived from citrus peels. This innovation maintains the material's mechanical and optical properties while improving environmental friendliness.

Researchers have also developed a version of transparent wood with polyvinyl alcohol, reducing heat conductivity fivefold compared to glass, further highlighting its potential in sustainable building design.

Source	Why scientists are making transparent wood (Coleman, 2023)	
Underlying technologies or innovations	Transparent wood	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Green	
EIC portfolios	Architecture, Engineering and Construction	
EIC Taxonomy	Primary	Built Environment
	Secondary	Structural Engineering & Construction / Low Carbon & Decarbonization Solution / Biomass & Bio-based Materials / Sensors & Actuators
EC initiatives	10 Critical Technology Areas	Advanced Materials, Manufacturing and Recycling Technologies: Technologies for advanced ceramic materials, stealth materials, safe and sustainable by design materials
	STEP	Clean technologies

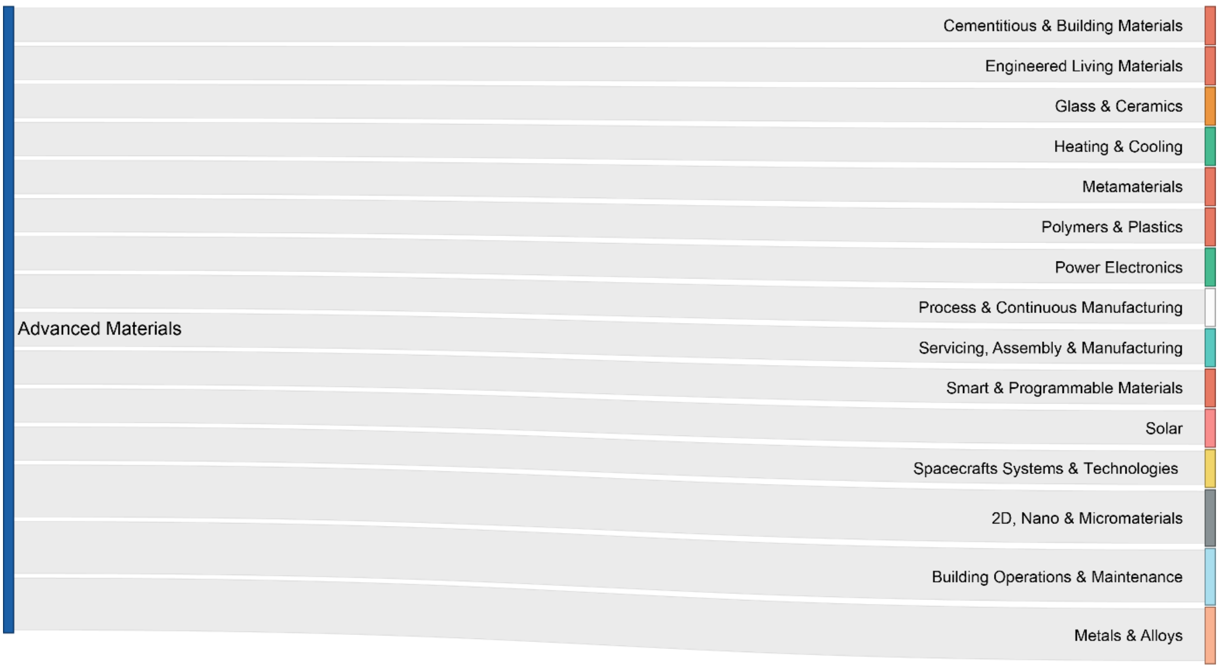
3.10 Advanced Materials

Materials are used throughout many of the breakthrough emerging technologies; therefore, Figure 13 reflects a wide range of secondary categories for this field.

The importance of Advanced Materials is also underlined as one of the 10 critical technology areas. This is because many of the high-risk technology areas are based on special materials and thus hinge on progress being made in the advanced material field. This is a very important domain to monitor for EIC and could even be used as a signpost for innovation and technological progress in other associated areas, particularly within the Energy space, as seen in Figure 13.

The EIC Impact Report from 2023 demonstrates that the secondary categories of '2D, Nano & Micromaterials' and 'Biomass & Bio-based Materials' have been awarded the most projects in Advanced Materials technologies in Horizon Europe (European Innovation Council, 2024). From the signal selection for this literature review, these areas emerge as well; however, most Advanced Materials key signals were largely situated in the 'Metals & Alloys' domain. This demonstrates that this may be a relevant field for future innovation in the Advanced Materials for Energy area.

Figure 13. Indication of secondary categories for those signals which have Advanced Materials as the primary category. The width of the line indicates the number of connections.



Source: Authors.

31

Self-repairing materials and 4D printing for electronics and space applications

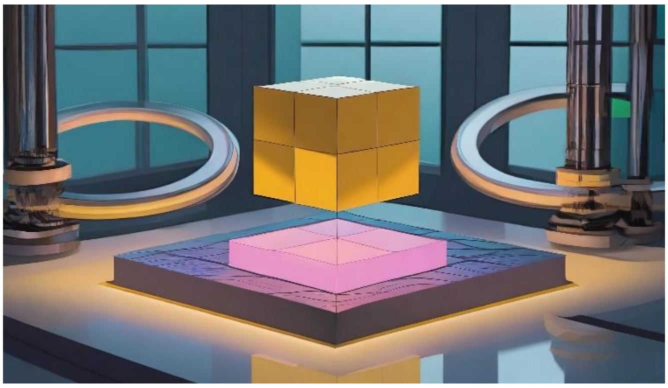
4D printing can be used to create complex and unique structures that would be difficult or impossible to produce using traditional manufacturing methods. Self-healing materials can automatically sense failure or breakdown, halt the process, or stop it from worsening, and then repair the damage as soon as possible. 4D printing is not itself the novelty here but rather the application of self-healing materials which improve these 4D objects. Self-healing materials can be used to make these 4D structures more adaptable, by allowing them to change shape or stiffness in response to changes in temperature or pressure.

This could lead to the development of new applications, such as buildings that are more energy efficient and resilient. For instance, self-healing materials (shape memory polymers) can be used to change shape or expand upon response to various stimuli which can repair damaged parts in buildings or even space satellites. This again signals where 'biomimicry' comes into play for emerging breakthrough innovations. Another way self-healing materials can significantly enhance the performance and durability of 4D printed objects is by introducing microcapsules (which contain a healing agent such as epoxy) into the 4D printing material. Thus, when damage occurs, the healing agent can activate to repair the material.

Source	Trends & Technologies Shaping The Aerospace Industry (Sokutu, 2023)	
Underlying technologies or innovations	Shape Memory Polymers / 4D Printing	
Technology Maturity	Emerging (TRL 4-6)	
EIC macro-areas	Digital & Industry	
EIC portfolios	Space / Advanced Materials / Responsible and Sustainable Electronics	
EIC Taxonomy	Primary	Hardware & Semiconductors / Advanced Materials
	Secondary	Power Electronics / Engineered Living Materials / Polymers & Plastics / Metamaterials / Cementitious & Building Materials / Building Operations & Maintenance / Spacecraft Systems & Technologies / Servicing, Assembly & Manufacturing
EC initiatives	10 Critical Technology Areas	Advanced Materials, Manufacturing and Recycling Technologies: Technologies for advanced ceramic materials, stealth materials, safe and sustainable by design materials / Space & propulsion technologies
	STEP	Clean technologies / Digital technologies and deep tech innovation

32

Tuning the 'charge density' knob so super-conductors can operate at room temperature



Right now, superconductors can operate only at very cold temperatures. So, finding one that could work at room temperature without needing to be kept in a cold chamber could revolutionise power electronics. Scientists have discovered a new link between superconductivity and charge density waves, which could help in the search for room-temperature superconductors. The majority of superconducting materials currently operate at extremely cold temperatures, making them impractical for widespread use. The researchers found that the superconductivity of a material called yttrium barium copper oxide (YBCO) was connected to the density of electrons in the material. By altering the superconductivity, they were able to manipulate the charge density waves.

The EC initiatives most related to this area seem to be in the advanced materials and digital technologies space. The technology may rely on materials which are critical to the EU and therefore recycling loops must be thought about to incorporate into the design of such a technology to be able to keep the critical material in the EU.

Source	A new step in the search for room-temperature superconductors (Shelton, 2022)	
Underlying technologies or innovations	Superconductors	
Technology Maturity	Novel (TRL 1-3)	
EIC macro-areas	Digital & Industry	
EIC portfolios	Advanced Materials / Responsible and Sustainable Electronics	
EIC Taxonomy	Primary	Advanced Materials / Responsible and Sustainable Electronics
	Secondary	Metals & Alloys / 2D, Nano & Micromaterials / Smart & Programmable Materials / Power Electronics
EC initiatives	10 Critical Technology Areas	Advanced Materials, Manufacturing and Recycling Technologies: Technologies for advanced ceramic materials, stealth materials, safe and sustainable by design materials
	STEP	Digital technologies and deep tech innovation

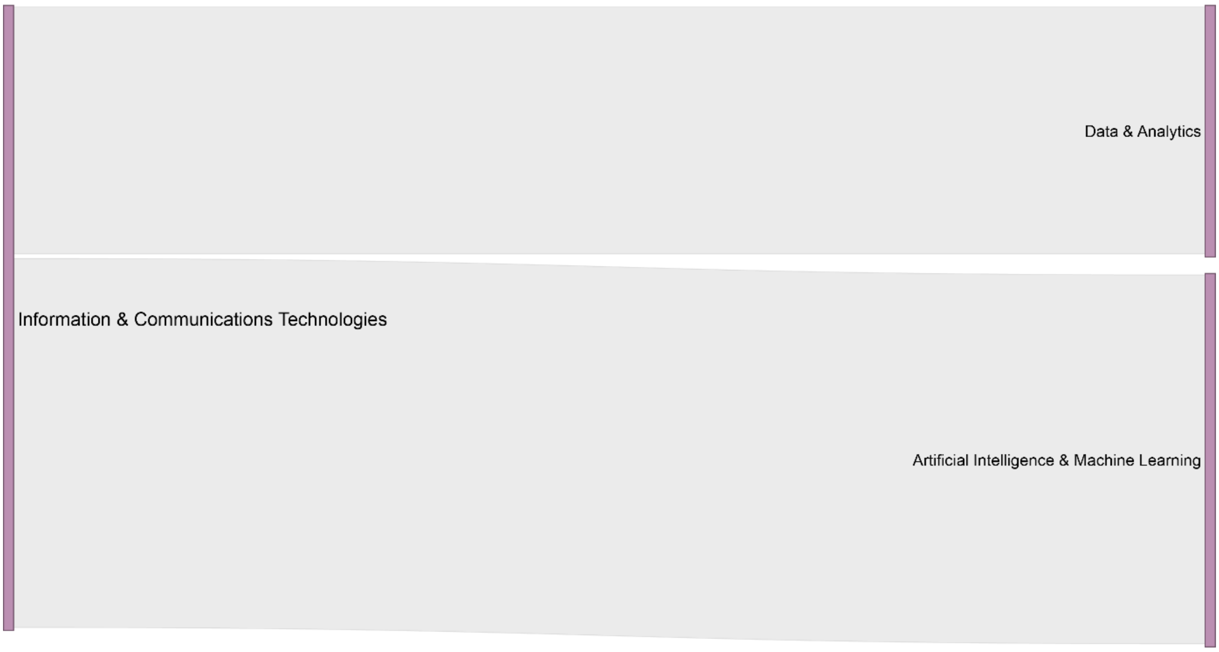
3.11 Information & Communication Technologies

The signals related to Information and Communication Technologies have the least amount of diversity in terms of secondary categories of any of the primary categories. The largest secondary category is within its own domain, related to Artificial Intelligence & Machine Learning. The two selected signals are not representative of the entire Information & Communication domain but they do show that Artificial Intelligence is quickly garnering focus and gaining potential.

In just the final quarter of 2023, Artificial Intelligence was mentioned nearly 40,000 times in public company presentations and earnings calls, according to *Fortune* (Estrada, 2024). This represents a 3 to 4-fold increase from the same quarter only 3 or 4 years ago (Bullard, 2024). The EIC notes the rising profile of Artificial Intelligence in many areas in their impact report, demonstrating that many of the funded projects have technologies which fit in the Artificial Intelligence domain (European Innovation Council, 2024).

These Artificial Intelligence technologies are of course significant to the EU and feature in the 10 critical technology areas.

Figure 14. Indication of secondary categories for those signals which have Information & Communication Technologies as the primary category. The width of the line indicates the number of connections.



Source: Authors.

33

Ethically-challenged pirate AI models

As AI development advances, a consensus on responsible AI regulation and governance measures is emerging. However, this could lead to an underground market for non-compliant AI models, created by and for criminals. These illegal models might be trained on copyrighted or illicit materials or lack safety constraints. For instance, a variant of ChatGPT could potentially instruct users in making weapons or programming ransomware. Criminals could face similar challenges to legitimate organisations in accessing GPUs, data science talent, and large data sets for training. Consequently, they are more likely to modify open-source models or use stolen proprietary models, removing safeguards, or adding new data for training.

This scenario poses a challenge for lawmakers, who must devise effective penalties for creating and using such illegal AI models. The urgency of devising technology and/or legislation which mitigates the effects of these pirate AI models and other frontier models is becoming apparent through various initiatives throughout the world including the establishment of a U.S. Artificial Intelligence Safety Institute Consortium (AISC), established by the National Institute for Standards and Technology (NIST) (Commerce, 2024)

Source	Tech Trends 2024 (Info Tech, 2023)	
Underlying technologies or innovations	Artificial intelligence	
Technology Maturity	Close-to-market (TRL 7-9)	
EIC macro-areas	Digital & Industry	
EIC portfolios	N/A	
EIC Taxonomy	Primary	Information & Communications Technologies
	Secondary	Artificial Intelligence & Machine Learning
EC initiatives	10 Critical Technology Areas	*Artificial Intelligence Technologies
	STEP	Digital technologies and deep tech innovation

34

Emotional cloaking devices for voice interfaces

A huge range of information about an individual can be discerned from their voice. Emotional cloaking devices for voice interfaces refer to techniques or design approaches that allow voice user interfaces (VUIs) to adapt their responses based on the user's emotional state or preferences. While emotional cloaking enhances user experience, it also raises ethical questions around privacy. When interacting with voice-activated devices, emotional cloaking strips out the emotional nuance or other identifying information to increase privacy.

The novelty around these devices – besides their ability to dynamically adapt voice interfaces based on the user's emotional context – is that they also rely on a multidisciplinary approach. The development of emotional cloaking devices will not evolve unless expertise in linguistics, psychology and AI are all consulted.

The current EU AI act limits the use of emotion recognition. However support to technological development could advance its use in non-excluded areas, contributing to better user engagement and understanding.

Source	Tech Foresight 2040 - Intentional creations (Imperial College London, 2020)	
Underlying technologies or innovations	Artificial intelligence / Voice-activated devices	
Technology Maturity	Emerging (TRL 4-6)	
EIC macro-areas	Digital & Industry	
EIC portfolios	Responsible and Sustainable Electronics	
EIC Taxonomy	Primary	Information & Communications Technologies
	Secondary	Artificial Intelligence & Machine Learning / Data & Analytics
EC initiatives	10 Critical Technology Areas	*Artificial Intelligence Technologies
	STEP	Digital technologies and deep tech innovation

4 Analysis and final notes

4.1 Signal distribution

The number of signals is relatively balanced across the primary categories of the EIC taxonomy, as previously illustrated in Table 1.

The authors purposely limited the number of primary categories for each signal in the final selection to ensure a horizontal perspective across most policy and economic areas. There are only 5 key signals which sit in more than one primary category (highlighted in red in Table 2, below).

Table 2. The spread of key signals among the 11 primary categories

Key signals	Health	Mobility	Space	Agriculture & Food	Hardware & Semiconductors	Advanced Manufacturing	Environmental Tech	Energy	Built Environment	Advanced materials	Information & Com. Tech
01. Flexible electronics demand new batteries and BMIs	X				X						
02. Spatial omics as a life sciences tool	X										
03. Xenobots made of human cells become self-assembling	X										
04. Nanobot has DNA clutch	X										
05. Vaccines delivered via ultrasound	X										
06. Cancer-killer DNA molecules	X										
07. Engineered bacteria in sustainable aviation fuel		X									
08. Lidar on chip		X									
09. AI's role in driving sustainability and safety in the mobility sector		X									
10. Lunar 'soil' for farming and roads on the moon			X	X							
11. Wireless Power Transfer as a plan B for SmallSats			X								
12. Antimicrobial packaging to reduce food waste and risks				X							

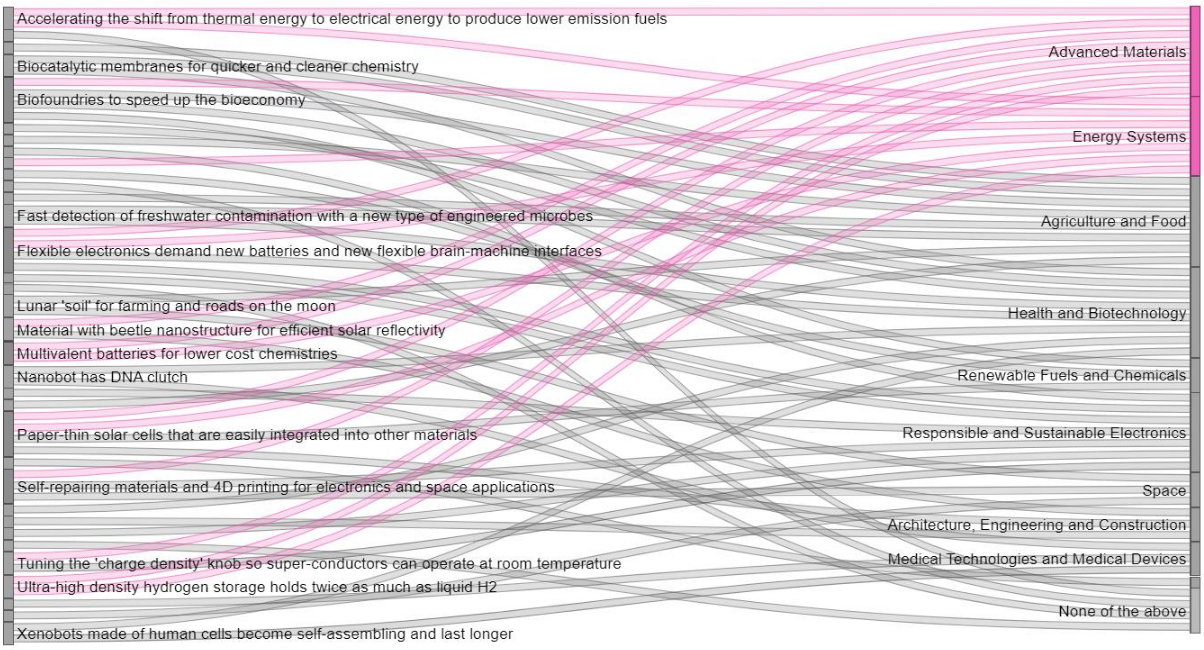
Key signals	Health	Mobility	Space	Agriculture & Food	Hardware & Semiconductors	Advanced Manufacturing	Environmental Tech	Energy	Built Environment	Advanced materials	Information & Com. Tech
13. DNA traceability for food authenticity				X							
14. Paper sensors to reduce food waste				X							
15. Nanomagnetic computing reduce energy cost of AI					X						
16. IoT devices that communicate without electronics					X						
17. Thermal transistors that can handle heat					X						
18. Rare earths show potential for quantum communications					X						
19. Paper-thin solar cells that are easily integrated						X		X		X	
20. Biofoundries to speed up the bioeconomy						X					
21. Biocatalytic membranes for cleaner chemistry							X				
22. Fast detection of freshwater contamination							X				
23. Tiny robots suck contaminants from rivers							X				
24. Exploring solar geoengineering							X				
25. Multivalent batteries for lower cost chemistries								X			
26. Accelerating shift from thermal to electrical energy								X			
27. 'Energy kites' for harnessing high-altitude wind energy								X			
28. Ultra-high density hydrogen storage								X			
29. Material with beetle nanostructure for efficient solar									X	X	
30. Sustainable transparent wood									X		

Key signals	Health	Mobility	Space	Agriculture & Food	Hardware & Semiconductors	Advanced Manufacturing	Environmental Tech	Energy	Built Environment	Advanced materials	Information & Com. Tech
31. Self-repairing materials and 4D printing					X					X	
32. Tuning the 'charge density' knob for superconductors										X	
33. Ethically challenged pirate AI models											X
34. Emotional cloaking devices for voice interfaces											X

Source: Authors.

Additionally, in Figure 15, we can observe how the final selected signals are relatively well dispersed across the EIC portfolios, with some notable crossovers in certain areas like Advanced Materials and Energy Systems (highlighted in colour). All 10 PM EIC portfolios considered for this report are represented in Figure 15, but some signals do not have this connection and are therefore marked 'none of the above'. As remarked in last year's report, both situations - crossovers and no connection - support a reflection on the scope and number of portfolios.

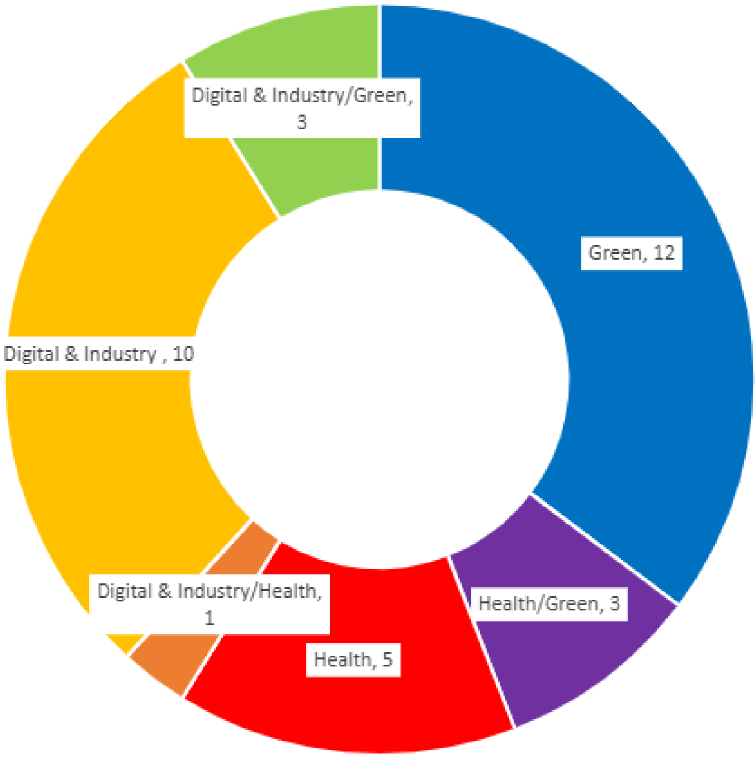
Figure 15. The key signals and the diversity of their connections to EIC PM portfolios.



Source: Authors.

The signals surface insights as to the biggest areas of novelty, cross-cutting areas, and missing categories in the EIC taxonomy. These 34 key signals could serve as inspiration for policy areas or funding priorities for the EIC. Some of the final key signals fit into more than one of the EIC's own macro areas; for instance, 'biofoundries to speed up the bioeconomy' (signal 20) fits into both 'Green' and 'Health.' The biggest area of signals can be found in the 'Green' macro area for EIC as in Figure 16.

Figure 16. Key signals by EIC macro area



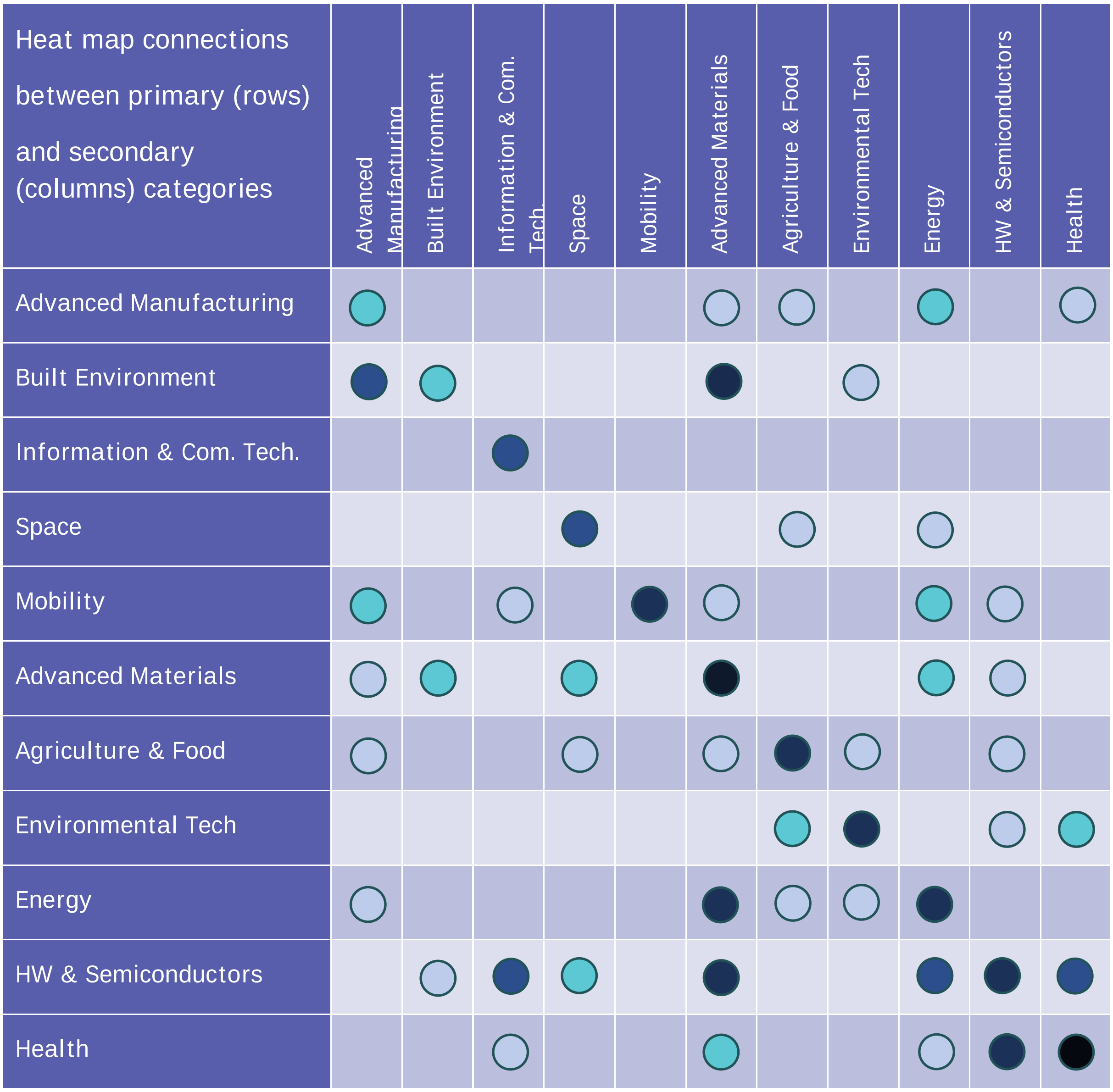
Source: Authors.

In addition to connecting the signals to the 3 EIC macro areas, each signal in the radar has an indication of an underlying technology / innovation. An underlying technology/innovation refers to the specific technology, combination of technologies or innovative developments on which this signal is based. This aspect provides a higher level of detail outside the use of the EIC taxonomy.

As an example, for the signal on multivalent batteries, lithium-ion batteries are indicated as the underlying technology/innovation, as intellectual property related to lithium-ion batteries paved the way for next generations of batteries such as multivalent ones. There are a number of underlying technologies/innovations that support multiple signals, most notably carbon-neutral fuels, Haber-Bosch process, and artificial intelligence.

As the analysis by category has shown, secondary categories are mostly aligned with their associated primary category; however, Environmental Tech, Hardware & Semiconductors, and Advanced Materials have the largest spread of secondary categories outside their own primary domain. On the other side, the Information and Communication Technologies category seems to have the least overlap into other areas but a strong convergence in its own secondary category of Artificial Intelligence and Machine Learning. This sort of analysis provides insights regarding spill-over effects and/or interdependencies between scientific, innovation and business areas. Figure 17 summarises this.

Figure 17 Connection between primary categories (rows) and secondary categories (columns). The darkness of the coloured dots represents the number of times a secondary category appears in signals under each Primary category (the darker the dot, the more times a signal is referenced).



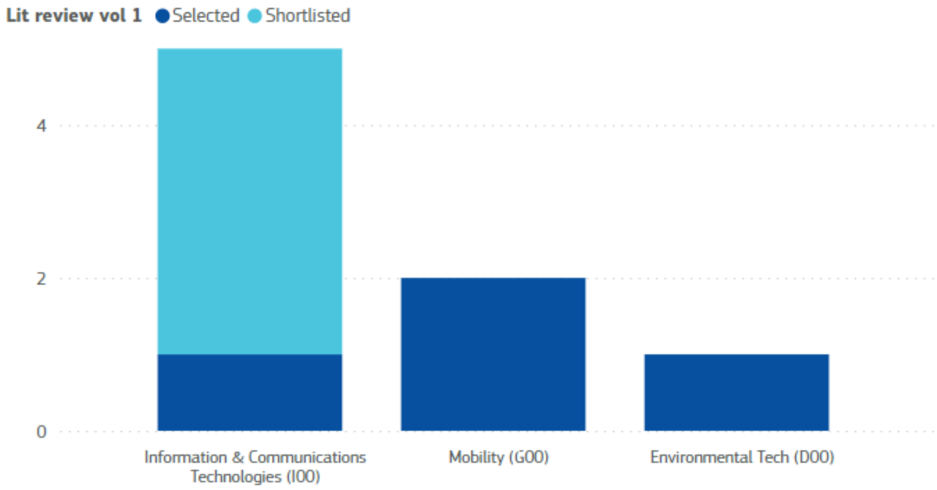
Source: Authors.

Following similar analysis done in previous reports, there were also gaps among the key signals, i.e. signals that did not fit into a specific EIC PM portfolio. For instance, there is no clear portfolio for many of the AI-related signals, particularly those linked to AI within the mobility sector.

As mentioned previously, the authors started with a large set of signals obtained from publications, then narrowed them down to a shortlist of 86, and then selected 34 key signals for the final list. In that sense it was important to include in this report's analysis the broader set of shortlisted signals, as evidence to support conclusions. Figure 19 demonstrates that a similar conclusion can be made from the evaluation of primary categories in the EIC taxonomy that do not map directly to an EIC portfolio. In the 86 shortlisted signals, as well as in the 34 selected key signals, Information & Communication Technologies, Mobility and Environmental Tech were the main primary category for signals that are not linked to at least 1 EIC PM portfolio.

This finding can support the reflection on the need for a dedicated portfolio covering these areas, as we regularly see signals of emerging technologies and breakthrough innovations connected with them. Additionally, and as mentioned before, some of these final key signals are connected with AI, as their titles in Table 3 point out. This may be an additional insight for the EIC that a separate, dedicated portfolio and/or a Primary level category for AI should be considered.

Figure 18 Number of shortlisted and selected signals that are missing a related EIC portfolio



Source: Authors.

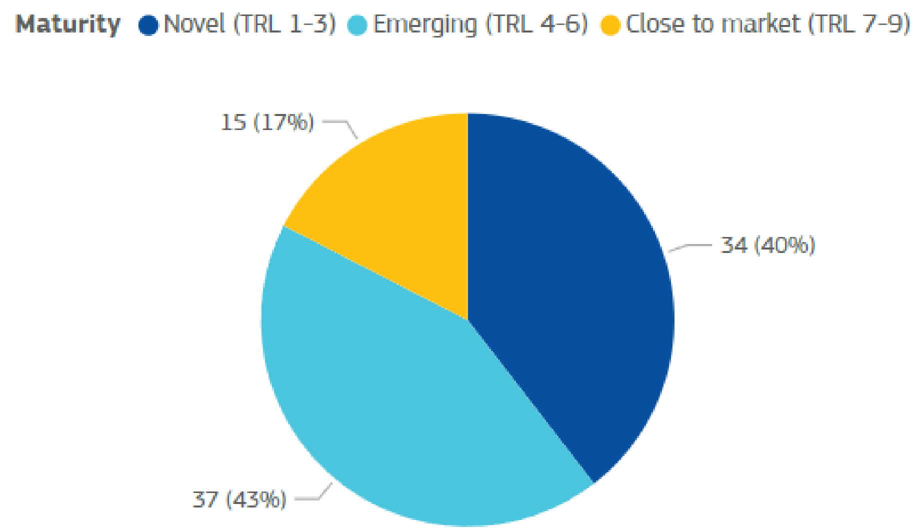
Table 3 . Key signals that are missing a related EIC PM portfolio

Signal number and title		Primary Level Category
08	Lidar on a chip – more efficiency and reliability with shorter size and costs	Mobility
09	AI’s Role in Driving Sustainability and Safety in the Mobility Sector	Mobility
23	Tiny robots suck contaminants from rivers	Environmental Tech
33	Ethically challenged pirate AI models	Information & Communications Technologies

Source: Authors.

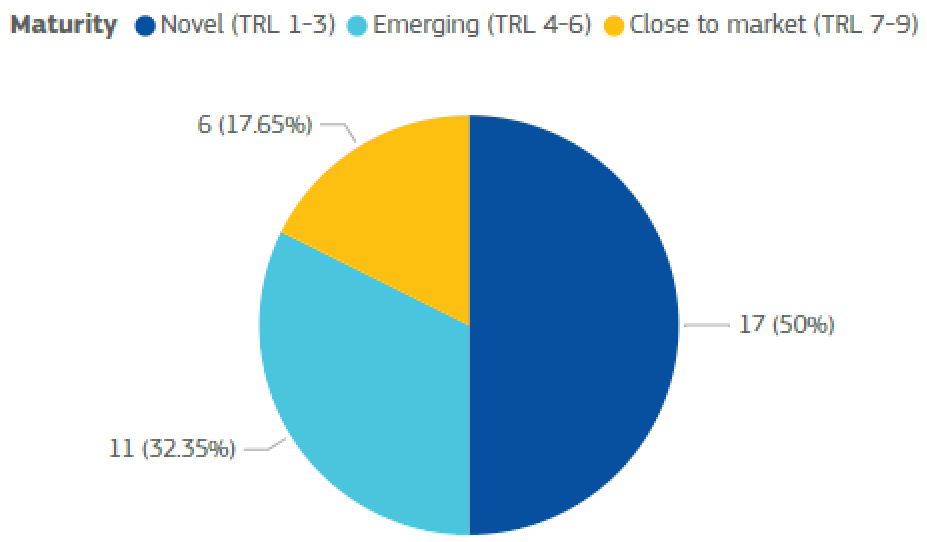
The diversity of technology maturity of the shortlisted (86) and the selected (34) signals is depicted in Figure 19 and Figure 20 (see next page), respectively.

Figure 19. Technology maturity diversity within the 86 shortlisted signals.



Source: Authors.

Figure 20. Technology maturity diversity within the 34 key signals



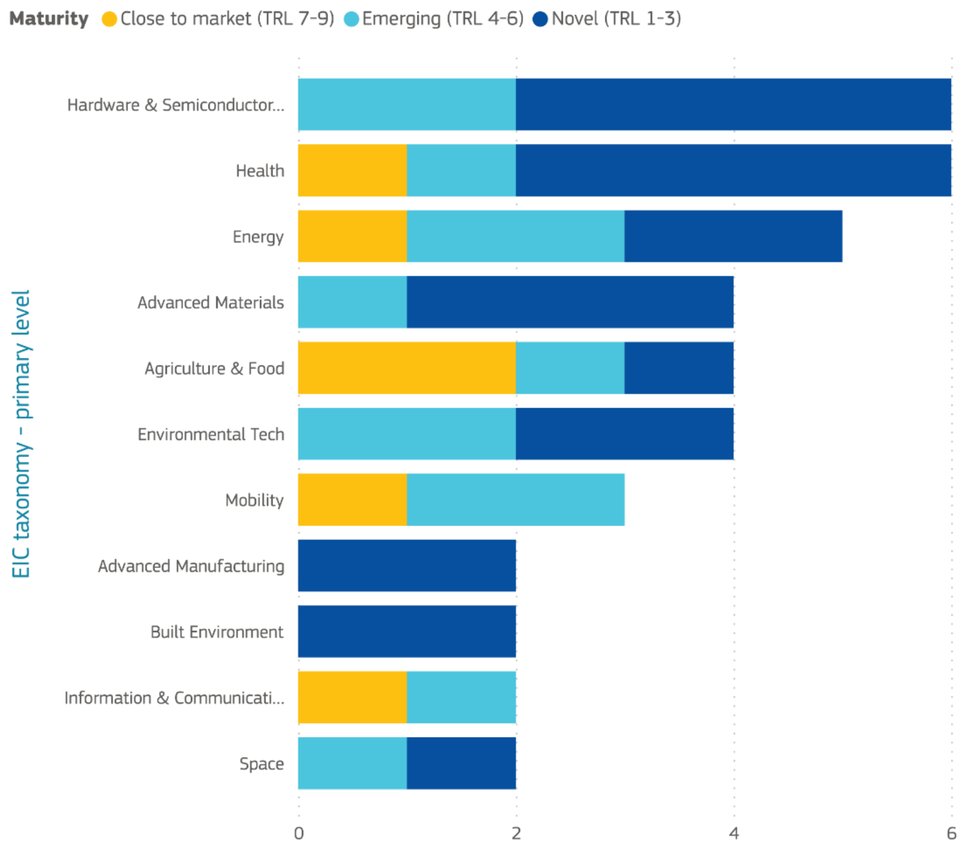
Source: Authors.

It should be emphasised that according to the authors' understanding, and the framework chosen for this report, novelty can appear at any TRL, even in signals which are categorised as 'close-to-market'. Innovation is not only connected with the maturity of the technology(ies) used, but also with many other aspects. Therefore, it is relevant for policymakers and the EIC that all 3 groups of TRLs are covered by this work.

For the key signals, a majority are determined as 'novel' followed by 'emerging' and 'close-to-market.' The key signals show slightly more novelty in these TRLs 1-3, as can be observed by comparing Figures 19 and 20. This was the result of the application of the decision tree depicted in Figure 3.

Figure 21 breaks down this topic, by showing that the early-stage key signals come predominantly from the Health, Hardware and Semiconductors, and Advanced Materials domains.

Figure 21. Technology maturity diversity by primary category within the key signals.



Source: Authors.

The signals which were not selected (according to the decision tree framework in Figure 3) will be continuously monitored via the signals radar which has been created especially for this project. Each volume of this literature review will go through a similar review process to evaluate the signals and shortlist them based on a structured method like the one detailed in Figure 3, all the while adding new signals into the radar.

Key signals were surfaced based not only on novel aspects but on their potential for novelty, based on their intersection with fringes of other domains. For instance, 'flexible batteries in brain machine interfaces (BMI)', part of signal 01, was selected not only because BMI is frequently mentioned in recent publications and media and therefore relevant for a shortlist of emerging technology, but also because an innovation in a different domain (in this case Energy Storage & Batteries) has enhanced the innovativeness of this technology.

Spill-over effects and trade-offs lurk beneath the surfaces. Often, technologies and their systems are treated as separate domains, divided into different policy streams. However, if one can garner any insight from this report, it is that innovation policy — or specifically public funding of innovation and the underlying prioritisation policy - must contain an overarching strategy, which connects technologies on a multi-faceted level.

4.2 Connections with key EU policy initiatives

It is crucial for the EU to be abreast of major technological trends to become a global leader, especially from a strategic autonomy point of view. With high levels of technological research, development, and market uptake needed, this may require not only betting on specific technologies, but also a series of combinations of different technologies with different maturity levels and with different applications.

Part of the EIC's role is to identify emerging deep tech that can help the EU to address and secure this requirement. Numerous signals identified in this report are relevant for EIC in this context and were selected with these criteria in mind, connecting to major policy initiatives as previously mentioned. Of note and primarily considered throughout this report are:

— the Strategic Technologies for Europe Platform (STEP)[15] to support the development in the EU territory of critical technologies and the strengthening of manufacturing value chains, plus shortages of labour and skills that are critical for these technologies (Ragonnaud & Mileusnic, 2024),

— the list of 10 critical technology areas[16] likely to be a focal point for economic risk, from which four are additionally listed as priority technology areas (Advanced Semiconductors Technologies, Artificial Intelligence Technologies, Quantum Technologies, Biotechnologies)[17], which present the most sensitive and immediate risks on technology security, all put forward by the EC.

This report marked and assessed several signals in STEP target investment areas, surfaced in its three priority areas: deep and digital technologies, clean technologies, and biotechnologies (European Commission, 2024). Signals such as lidar on chip (08), nanomagnetic computing (15) and thermal transistors (17) are extra high-risk technologies, demarcated by an asterisk and underlined in Sections 3.1 – 3.11. Figure 22 (next page) illustrates the connections observed in the 34 key signals with both the 3 STEP categories and the 11 EIC primary categories.

Furthermore, this report also highlights signals in connection with the list of 10 critical technology areas[18], and the list of four priority technology areas (Advanced Semiconductors Technologies, Artificial Intelligence Technologies, Quantum Technologies, Biotechnologies)[19,]. For instance, in the biotechnologies space, synthetic biology was identified as an example of sub-area of a critical technology for the EU's economic security, with five of the six key signals listed in the Health primary category focused on synthetic biology technologies. The amount of signals related to synthetic biology and its increasing importance in EC initiatives should be considered by the EIC as a focus area for the Health portfolio. Figure 23 illustrates the connections observed in the 34 key signals with the 10 critical technology areas and the 11 EIC primary categories.

[15] https://commission.europa.eu/strategy-and-policy/eu-budget/strategic-technologies-europe-platform_en

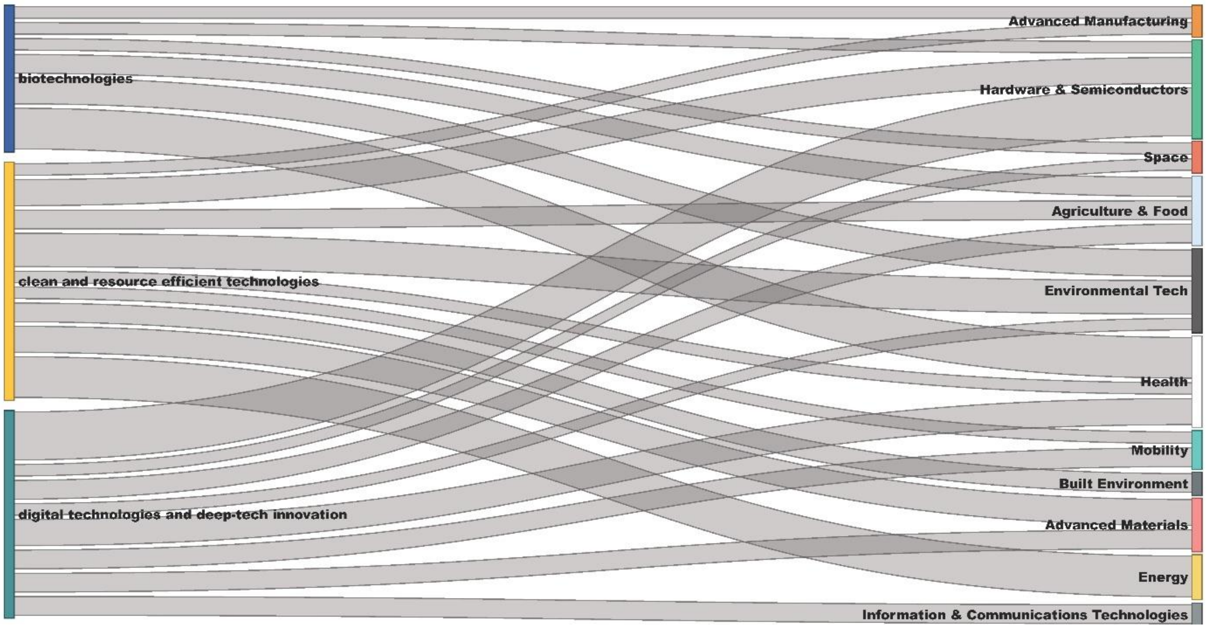
[16] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L_202302113

[17] https://defence-industry-space.ec.europa.eu/system/files/2023-10/C_2023_6689_1_EN_ACT_part1_v8.pdf

[18] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L_202302113

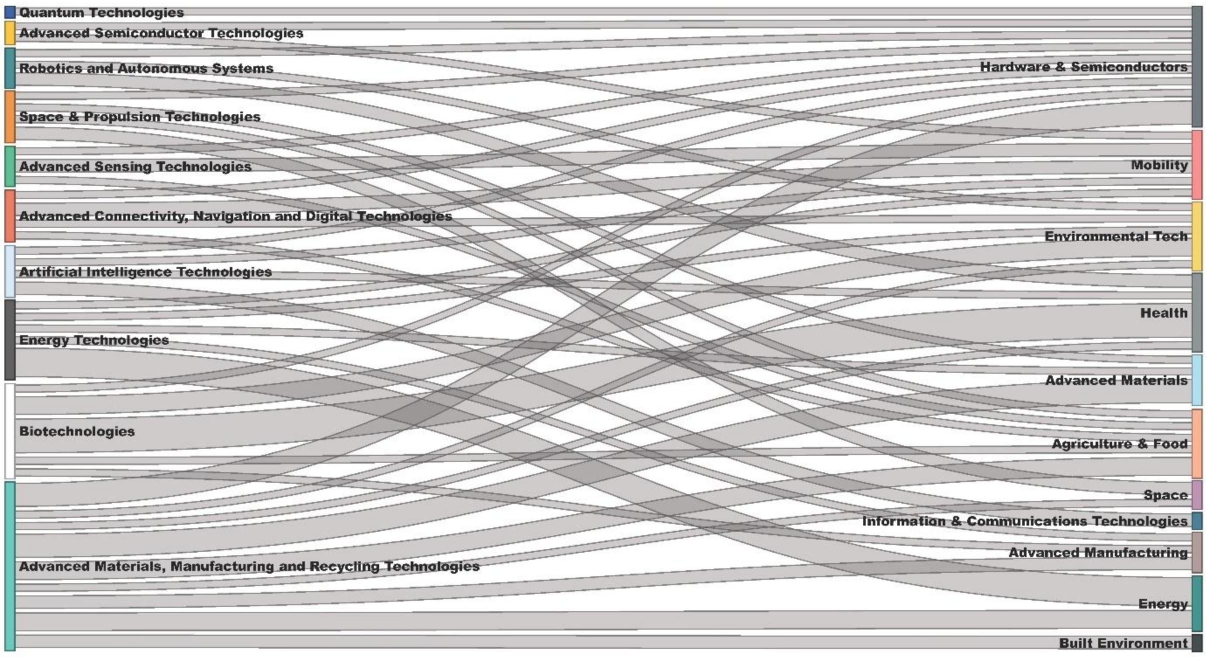
[19] https://defence-industry-space.ec.europa.eu/system/files/2023-10/C_2023_6689_1_EN_ACT_part1_v8.pdf

Figure 22. Signals found in STEP categories (left) and connections with the 11 primary categories of the EIC's Taxonomy (right). The width of the line indicates the number of connections.



Source: Authors.

Figure 23. Signals found in the 10 critical technology areas (left) and connections with the 11 primary categories of the EIC's Taxonomy (right). The width of the line indicates the number of connections.



Source: Authors.

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List of abbreviations and definitions

Abbreviations	Definitions
°C	Degrees Celcius
3D	Three Dimensional
4D	Four Dimensional
AI	Artificial Intelligence
Avs	Autonomous Vehicles
AWE	Airborne Wind Energy
AWP	Airborne Wind Power
BMIs	Brain-Machine Interfaces
CO2	Carbon Dioxide
DNA	Deoxyribonucleic Acid
EC	European Commission
EIC	European Innovation Council
EISMEA	European Innovation Council and SMEs Executive Agency
ESG	Environmental, social and governance
EU	European Union
FDA	Unites States Food and Drug Administration
FUTURINNOV	FUTURe-oriented detection and assessment of emerging technologies and breakthrough INNOVation
GPU	Graphics Processing Unit
IoT	Internet of Things
ISO	International Organization for Standardization
JRC	Joint Research Centre
KWs	Kilowatts
Lidar	Light Detection and Ranging
Li-ion	Lithium ion
MWs	Megawatts
NGS	Next Generation Sequencing
oHPs	Oncolytic Hairpins
PCR	Polymerase Chain Reaction
PHY	Physical Layer
R&D	Research and Development
RFID	Radio-Frequency Identification
RNA	Ribonucleic Acid
SAFs	Sustainable Aviation Fuels
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
STEP	Strategic Technologies for Europe Platform

Abbreviations	Definitions
TRL	Technology Readiness Level
VUCA	Volatilty, Uncertainty, Complexity and Ambiguity
VUIs	Voice User Interfaces
WiFi	Wireless Fidelity
WLANs	Wireless Local-Area Networks
YBCO	Yttrium Barium Copper Oxide

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Annexes

Annex 1. List of EIC primary level categorisation of taxonomy and their corresponding secondary level categories as of December 2023.

Primary level	Secondary level
Health	Diagnostics & Omics
	Disease Modelling
	Pharma Processing
	Drug Delivery
	Cell & Gene Therapies
	Surgeries & Peri-Operative
	Medical Imaging
	Implants & Prosthetics
	Infectious Diseases & Vaccines
	Cancer
	Cardiovascular
	Neurology & Mental Health
	Women & Reproductive Health
	Other Diseases
	Healthcare Systems & Emergency Preparedness
Mobility	Automotive & Roads
	Rail & Rapid Transit
	Aviation & Airports
	Maritime & Ports
	Multimodality & Networks

Primary level	Secondary level
	Freight & Logistics
	Mass Transit & Public Transport
	Autonomous Vehicles
	Personal Mobility
	Electric Vehicles (EVs) & Electrification
Space	Spacecraft Systems & Technologies
	Launchers, Propulsion & In-space mobility
	Servicing, Assembly & Manufacturing
	Missions, Operations & Space Traffic Management
	Communications & Space-based Connectivity
	Earth Observation & Meteorology
	Space Debris & Space Situational Awareness
Agriculture & Food	Soil & Crops Management
	Forestry
	Animal-based Agriculture
	Fisheries & Aquaculture
	Plant-based Agriculture & Horticulture
	Biotech & Cell-based Food Production
	Agrifood Safety & Traceability
	Precision & Smart Farming
	Resilience & Sustainability Agritech
	Quantum Technologies

Primary level	Secondary level
Hardware & Semiconductors	Hybrid & High-Performance Computing
	Chips, Circuits & Advanced Packaging
	Sensors & Actuators
	Power Electronics
	Memories & Data Storage
	Photonics, Optics & Displays
	Robotics & Cyber-physical Systems
	Internet-of-Things & Wearables
Advanced Manufacturing	Industrial Biotech & Biomanufacturing
	Digital Fabrication & Prototyping
	Modelling & Digital Twins
	Process & Continuous Manufacturing
	Discrete Manufacturing & Packaging
	Supply Chains
	Machinery & Automation
	Instrumentation & Metrology
	Standards & Interoperability Systems
	Quality Control & Security
Environmental Tech	Climate Change Mitigation & Adaptation
	Critical Raw Materials Alternatives
	Low Carbon & Decarbonization Solutions
	Circular Economy

Primary level	Secondary level
	Environmental Monitoring & Intelligence
	Pollution & Contaminants
	Waste
	Natural Resources & Biodiversity
	Water Management & Resilience
Energy	Solar
	Wind
	Hydro
	Ocean Energies
	Geothermal
	Bioenergy
	Nuclear
	Hydrogen
	Renewable Alternative Fuels
	Energy Generation & Conversion
	Energy Transmission, Distribution & Grids
	Energy Storage & Batteries
	Heating & Cooling
	Energy Uses & Efficiency
Built Environment	Cities & Territorial Planning
	Digital Design & Simulation
	Structural Engineering & Construction

Primary level	Secondary level
	Development, & Real Estate
	Building Operations & Maintenance
	Heritage & Renovation
	Public Infrastructures & Resilience Measures
	Acessibility & Inclusive Spaces
Advanced Materials	2D, Nano & Micromaterials
	Metamaterials
	Smart & Responsive Materials
	Engineered Living Materials
	Biomass & Bio-based Materials
	Polymers & Plastics
	Composites
	Metals & Alloys
	Glass & Ceramics
	Fibers, Textiles & Fabrics
	Cementitious & Building Materials
Information & Communication Technologies	Software & Services
	Advanced & Distributed Networks
	Cloud & Edge Architectures
	Artificial Intelligence & Machine Learning
	Data & Analytics
	Digital Identities

Primary level	Secondary level
	Telecommunications
	Mobile Connectivity & Devices
	Navigation Systems
	Mobile Connectivity & Devices
	Navigation Systems
	Cryptography, Cybersecurity & Privacy
	VR, AR & XR
	Interactive & Non-linear Media

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