Materials 2030 Roadmap

Draft, June 2022

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List of acronyms

ADC	Analog to digital converter
AI	Artificial Intelligence
AM	Additive Manufacturing
BEV	Battery electric vehicle
BEDA	The Bureau of European Design Associations: BEDA
BIPV	Building integrated photovoltaic
CHADA	Metadata structure (CHADA) for collection data and information related to characterisation methodologies
CRM	Critical Raw Materials
ECP4	The European Composites, Plastics and Polymer Processing Platform
EMCC	European Materials Characterisation Council
EMIRI	The Energy Materials Industrial Research Initiative
EMMC	The European Materials Modelling Council
EMMO	European Materials Modelling Ontology
EoL	End of Lifetime
ERMA	European Raw Materials Alliance
ETCP	Entertainment Technician Certification Program
ETP	European Technology Platform
EU	European Union
EUMAT	European Technology Platform on Advanced Engineering Materials and Technologies
EUMAT-A4M	The Alliance for Materials (A4M) promoted by European Materials Platform (EUMAT)
FCEV	Fuel Cell Electrical Vehicles
FMCG	Fast-moving consumer goods
GDPR	General Data Protection Regulation
GHG	Greenhouse gas emissions
LCA	Lifecycle Environmental Assessment
MANUFUTURE	Assuring the future of a competitive, sustainable and resilient European Manufacturing
MATERPLAT	Advanced Materials and Nanomaterials Spanish Technological Platform
MIM	Material Innovation Market
MODA	Models and Data Framework
NGO	Non Grain Oriented electric steel
RF	Radio Frequency

RFID	Radio Frequency Identification
SUSCHEM	European Technology Platform for Sustainable Chemistry

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Executive summary

Europe is a global leader in advanced materials and associated processes which make up 20% of its industry base and form the root of nearly all value chains through the transformation of raw materials.

As underlined in the Materials 2030 Manifesto[1], published in February 2022, to remain **competitive** and meet **citizens' needs for safer and more sustainable** advanced materials, Europe needs *"a systemic approach to develop the next generation solution-oriented advanced materials which will offer faster, scalable, and efficient responses to the challenges and thus turn them into opportunities for Europe's society, economy, and environment today and in the future".*

Such a systemic approach will drive cross-sectoral industrial innovation by supporting new applications accross all industry sectors. Through selected materials innovation markets sharing **system-critical material applications** (such as lightweight, carbon capture or advanced surfaces), the Materials 2030 Manifesto exemplifies how advanced materials share much more cross-cutting commonalities across all the different markets they serve than apparent at first sight, notably to address four **major materials' challenges**: circularity, zero-pollution, climate contribution, traceability.

The Materials 2030 Manifesto sets out a vision for

"a strong European Materials ecosystem driving the green and digital transition as well as a sustainable inclusive European society through a systemic collaboration of upstream developers, downstream users and citizens and all stakeholders in between".

Building on the vision of the Materials 2030 Manifesto, the goal of the 'Materials 2030 Roadmap' is to pave the way for the engagement of all advanced materials stakeholders through a multidimensional initiative addressing all value chains and innovation markets for transparent, inclusive, and increased innovation power: **The Materials 2030 Initiative for planet, people, and prosperity.**

Currently, Europe lacks a common framework for all Advanced Materials stakeholders to work together. Different initiatives, platforms, research and industry organisations work in their own thematical or organisational silos. By introducing a common framework (the 'Materials commons'), the authors specifically address this lack. The idea is to provide a solution that helps fostering the collaboration based on common grounds between all stakeholders (*e.g.* materials researchers, developers, manufacturers, up takers as, and end users (B2B, B2C)) to create more sustainable products and materials-based technologies in all dimensions, providing meaningfulness, and –ultimately – serving both the people and the planet whilst offering the full possibilities for our society to prosper.

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[1] MATERIALS 2030 MANIFESTO: Systemic Approach of Advanced Materials for Prosperity – A 2030 Perspective; https://ec.europa.eu/info/sites/default/files/research_and_innovation/research_by_area/documents/advanced-materials-2030-manifesto.pdf

The present draft of the Materials 2030 Roadmap has been co-created by the signatories of the Materials 2030 Manifesto[2], the relevant European Technology Platforms EUMAT[3], SUSCHEM[4], MANUFUTURE[5] and the Energy Materials Industrial Initiative (EMIRI[6]).

As a key strategic milestone towards a structured European Materials Initiative, this draft Materials 2030 Roadmap:

- considers **digitalisation of materials development** as major opportunity to accelerate all aspects of materials design and development. It requires new research and development methodologies, merging computational and experimental materials science based on modelling, simulation and high throughput characterisation. Central to success is reliable and easy access to data. It should allow to design novel materials with a speed unattainable in the usual process of discovery and to control material behaviour;
- identifies common manufacturing technologies and looks at the conditions for the processing and **scale up of new materials**, notably process optimisation, decarbonisation, mass customisation, zero defect production, enhanced multi-materials processing and new processing technologies;
- identifies **priority areas** as game changers in the nine innovation markets highlighted in the Materials 2030 Manifesto, addressing the industry and research community challenges with expected benefits to improve EU sovereignty, capacity to reduce environmental footprint, and potential to improve sustainability. These priority areas should form the basis for the development of a novel European strategic materials agenda.
- highlights the importance of an **enabling policy framework** through harmonised criteria for safe and sustainable by design chemicals and materials, evidence based life-cycle assessments, harmonised norms and standards, robust health and safety protocols as well as targeted education and training actions across the value chains;
- argues that strong social foundations are essential for the governance where materials stakeholders, industry, designers, trade unions, workers and civil society are involved in the discussions, pushing for the new materials valorisation. It therefore proposes principles for **inclusive governance** allowing stakeholders to engage in a **new form of cooperation.**

The authors recommend to deploy necessary resources for this initiative and relevant actions towards innovative materials developments, production

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[2] Namely: The Bureau of European Design Associations (BEDA) and their respective, member organisations, Commissariat à l'énergie atomique et aux énergies alternatives (CEA), Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., Iberian Nanotechnology Laboratory (INL), STMicroelectronics, Umicore NV / SA, and Nicole Grobert, Professor, Associate head of Department (Research), Department of Materials, University of Oxford, Chair of the Group of Chief Scientific Advisors (*in her personal capacity*)

[3] EuMaT – European Technology Platform for Advanced Engineering Materials and Technologies; www.eumat.eu/en

[4] SusChem European Technology Platform for Sustainable Chemistry; http://www.suschem.org/

[5] ManuFUTURE European Technology Platform; https://www.manufuture.org/

[6] EMIRI | The Energy Materials Industrial Research Initiative; https://emiri.eu/

technologies, data sharing, and collaboration models on a European level. The integration of the technological approaches and the multitude of stakeholders from different economic sectors to be involved will entail considerable financial and organisational effort. Since the approach is new, as inspiration a **Commons**[7] model may be considered. Indeed, a multitude of organisational questions need to be clarified as well as further stakeholders need to be involved in the design process of the initiative. This will be done in the coming months. The aim is to find the best possible instrument (or instruments) to implement the goals of the initiative in a targeted and efficient way. Whether this is an existing instrument such as a European partnership, alliance or platform, or whether a completely new instrument needs to be developed, remains open for the time being.

This draft roadmap invites all interested stakeholders to support and co-create the new strategic European materials agenda and necessary actions for implementation in the framework of a European Materials Initiative for planet, people, and prosperity (Materials 2030 initiative).

The next planned steps for the further development of the initiative are:

June 2022 | Presentation of the draft roadmap and discussion of possible future initiatives

June 2022 and onwards | Setting up an interim Coordination Group that will:

- coordinate the dissemination of the draft roadmap publicly
- propose an initial overall governance structure and the roles for specific aspects of governance including operations, information/data (from materials and processes), processing, policy, finances, *etc*.
- organise an initial communication link to all onboarded stakeholders and engage, welcome and involve new stakeholders (incl. setting up an engagement / on boarding / joining platform)
- support and coordinate further actions like follow-up conferences/workshops and other activities

July – October 2022 | Reaching out and engaging with further stakeholders to discuss the development of the initiative through a wide and transparent consultation process.

October 2022 | Proposal for a possible instrument to realize the Materials 2030 initiative

2023 | Setting up the operations/activities aimed to create the conditions for 'partners' to enjoy enhanced and efficient transfer & uptake of innovative solutions based on Advanced Materials securing European technological leadership

[7] Commons: https://en.wikipedia.org/wiki/Commons

Part I – Advanced materials – from vision to mission and action

1. Introduction

For the years to come, reaching climate neutrality, circularity, healthy food-systems and sustainability whilst completing the transition to renewable energy sources are among the greatest challenges humanity is facing. With materials and advanced materials being the backbone and source of prosperity of an industrial society, they play a critical and enabling role in the green and digital transition. Sustainable advanced materials are a key driver for innovation, creating new opportunities on multiple dimensions and sectors. The launch of the Green Deal and the Digital strategy by the European Commission will in turn lead to significant changes in materials research due to combination of the rapidly developing digitalisation and the increasing need for sustainable solutions of many aspects in society.

Scientific evidence demonstrates that action on climate change must take an interconnected and systemic approach that involves as many people in a network as possible and integrates components such as technology, society, and institutions. This is exactly where advanced materials can and must deliver solutions.[8,9]

Against this background the Materials 2030 Manifesto[10], published in February 2022, calls *"for a systemic approach to develop the next generation solution-oriented advanced materials which will offer faster, scalable, and efficient responses to the challenges and thus turn them into opportunities for Europe's society, economy, and environment today and in the future*" and recognises *"that 'Blue sky' and applied research both play an integral part in this approach"*.

The vision of the Materials 2030 Manifesto is to enable the EU's twin green and digital transition anchored in good design principles combined with synergies between advanced materials, circularity, digital and industrial technologies. The Manifesto envisages the creation of a multidimensional initiative capturing all value chains, innovation markets and stakeholders for inclusive and increased innovation power securing sovereignty and prosperity in Europe and beyond through **a new Materials for planet, people, and prosperity initiative (Materials 2030 initiative)**. The initiative aims at providing a common framework (the so-called 'Materials Commons') for all stakeholders (*e.g.* as materials researchers, developers, manufacturers, up takers as, and end users (B2B, B2C)) supporting their mutual collaboration on advanced materials in a systemic approach involving

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[8] EC Group of Chief Scientific Advisors: Scientific Opinion – A systemic approach to the energy transition in Europe (June 2021); https://op.europa.eu/en/publication-detail/-/publication/d01f956f-de07-11eb-895a-01aa75ed71a1/language-en

[9] EC Group of Chief Scientific Advisors: Scientific opinion – Adaptation to health effects of climate change in Europe (June 2020); https://op.europa.eu/en/web/eu-law-and-publications/publication-detail/-/publication/e885e150-c258-11ea-b3a4-01aa75ed71a1

[10] Materials 2030 Manifesto (February 2022); https://ec.europa.eu/info/sites/default/files/research_and_innovation/research_by_area/documents/advanced-materials-2030-manifesto.pdf

different innovation markets As a follow up initiative to the Materials 2030 Manifesto the European Technology Platforms (ETP) (EUMAT, SUSCHEM, MANUFUTURE), the Materials Industrial Initiative (EMIRI), and the Materials 2030 Manifesto signatories jointly produced the draft 'Materials 2030 Roadmap'. This Roadmap proposes a way forward to achieve the goals of the Manifesto and **engage stakeholders to support and co-create a new strategic European Materials Agenda and relevant actions for its implementation**.

The draft of this Roadmap presents a set of actions needed for the realisation of the Materials 2030 initiative. They include support activities to accelerate the digitalisation of the development and processing of advanced materials, identifying the most urgent/priority materials innovation markets, policy support and a governance structure for a new advanced materials ecosystem. Furthermore, the roadmap contains the description of the nine Materials Innovation Markets (MIM) introduced in the Materials 2030 Manifesto, their respective challenges and priority areas.

The following chapters will give a brief overview on the importance of the MIMs, the current situation and challenges regarding advanced materials development and prosessing followed by a proposal for future actions. The authors point out, that this is only a first draft of ideas for the realisation of the Materials 2030 initiative. In the coming months, a coordination group will organise the further development of the roadmap and proposals for future actions including the involvement of further interested stakeholders.

For the European advanced materials sector to remain competitive and in the global lead, there is an urgent need to identify the i) 'low hanging fruits' (*i.g.* innovations at high TRL already), ii) long term game changers accelerated by efficient materials research ('technology push') iii) and the needs/requirements of the markets for new solutions or a new product ('market pull').

In this context, the identification of Europe's Materials Innovation Markets that can have a significative positive impact for people, planet, and prosperity (by providing challenge-based solutions) plays a major role in the development of the Materials 2030 initiative. The MIMs represent the 'market pull', using sustainable and collaborative business models, and the likely value chains and markets driven by the long-term needs of Europe's citizens and society at large. They are fuelled by the advanced materials R&I 'technology push' targeting values not volume of future products and services. Both aspects, market pull and technology push, are needed to create products that have a different and much more dynamic logic over traditional approaches, namely value over volume.

In the Materials 2030 Manifesto, nine MIMs in the areas of health, construction, new energies, transport, home & personal care, packaging, textiles, agriculture, and electronic appliance have been selected as a first basis for the creation of the Materials 2030 initiative. Within the last months, in a bottom-up exercise, the authors of the roadmap started a first collection of common materials and processes research that are of vital priority for the nine materials innovation markets.

In order to define the challenges of the MIMs, links with different value chains were established, namely through the Alliance for Materials cooperation (EUMAT-A4M)[11], involving the Spanish Materials Platform (MATERPLAT)[12], Network of Plastics and Composites (ECP4)[13], Construction Platform (ETCP)[14], European Textiles Platform (ETP)[15], European Materials Modelling Council (EMMC)[16], Characterization Council (EMCC)[17], and the EIT Raw Materials (ERMA)[18].

Regarding the involvement of stakeholders, the close collaboration of the ETPs has been a groundbreaking new approach focussing on the wider markets' and value chains' perspective instead of the thematic silos of the different ETPs. This system change serves as the starting point for the broader involvement of further stakeholders.

The detailed information compiled for the nine MIMs can be found in Part II of the roadmap. The current list of MIMs is by any means exhaustive and will be further developed as more stakeholders will join the initiative. It will be critical to 'prioritise', 'review', and 'refresh' the MIMs in a timely manner. (please see also Chapter 3.3).

2. Current situation and challenges for the future

The digital transformation of technologies and services are the basis of Industry 5.0 that superseeds the existing Industry 4.0 paradigm by highlighting research and innovation as drivers for the transition to a sustainable, human-centric and resilient industry. At the same time, sustainable industrial value creation gains increased importance through the use of biological principles, systems and biotechnological processes.

The materials and manufacturing industry is becoming more and more reliant upon knowledge-driven insights and decision making based on a digital ecosystem in which stakeholders are connected, sharing data and knowledge, technologies, human resources, and operations, and organising digital marketplaces that connect manufacturers, suppliers, distributors, recyclers and their consumers. The industrial sector is thus in the process of developing new ontologies.

The combination of digital technologies such as high performance computing, big data management, knowledge engineering based on ontologies and artificial intelligence (AI) revolutionises research and development methodologies that enable this digital transformation by merging computational (modelling, simulation) and experimental materials data (high throughput characterisation).

[11] EuMaT-A4M– Alliance for Materials; http://www.eumat.eu/en/about_a4m
[12] MATERPLAT – Advanced Materials and Nanomaterials Spanish Technological Platform; https://materplat.org/en/
[13] ECP4, The European Composites, Plastics and Polymer Processing Platform; https://www.ecp4.eu/
[14] The European Construction, built environment and energy efficient building Technology Platform (ECTP); https://www.ectp.org/
[15] The European Technology Platform for the Future of Textiles and Clothing (Textile ETP); https://textile-platform.eu/
[16] EMMC ASBL | The European Materials Modelling Council; https://emmc.eu/
[17] The European Materials Characteriasation Council (EMCC); http://characterisation.eu/
[18] The EIT RawMaterials; https://eitrawmaterials.eu

They are supporting the screening of materials properties, materials development, and production processes.

The connection of communities based on developing shared data and knowledge/ontology will accelerate the design of safe and sustainable materials. This approach will help to differentiate the quality of materials designed 'for the planet' in the EU compared to outside Europe.

The availability of fair, shared, combined, and validated data will allow going deeper in the definition of the needs for researchers and industry and will significantly accelerate the development of advanced materials and processing solutions relevant for Europe's innovation markets.

Complementary to advanced materials design and development, industry's twin green and digital transition brings also significant challenges related with the materials processing and scale up (including materials production and utilisation by the different innovation markets), resulting from priorities such as:

- **Low resource utilisation, energy-efficiency and decarbonisation of materials processing**: both the materials and the related processes need to be sustainable and contribute to the green transition. The digital transformation and the advances and convergence of the life, material and production sciences are creating completely new opportunities (such as an enhanced application of materials, structures and principles of living nature).
- Industry-ready processes and technologies for establishment of renewable material sourcing, manufacturing and/or recycling value chains in Europe: sustainable circular economy businesss models call for an integrated approach, providing technologies and solutions for the entire value chain, including de-manufacturing and dismantling, materials recovery and processing, the incorporation of an increased percentage of recycled feedstocks and materials by industry, logistics processes, *etc*.
- **Alternative and lightweight materials processing technologies and solutions:** new and alternative materials will demand for new processing solutions or the adaptation of the existing ones, so this needs to be a joint effort between the materials, production and digital technologies communities.
- **Increased product customisation, guarantee, and labelling**: advanced materials combined with production and digital technologies such as additive manufacturing, advanced robotics, smart sensors and actuators, internet of things, artificial intelligence, *etc*., are critical to build highly flexible, distributed and efficient processes, capable of coping with the growing needs for product customization, while ensuring high productivity and quality guarantee.
- **Support product traceability and lifecycle management:** production and digital technologies will play a key role in supporting the merge of product, materials and process data, along the value chain and during its life cycle.

To address these challenges, advanced production and digital technologies will be deployed to create new processes or significantly improve existing ones. Several of these technologies and solutions also have a cross cutting character, since they adress several or all the innovation markets at the same time. Starting from the Materials 2030 Manifesto, it was possible to identify a first list of **relevant cross cutting R&D challenges related to materials processing and scale up**, that match the previously defined industrial needs and priorities: 1) process optimisation; 2) decarbonisation; 3) mass customisation; 4) zero defect production; 5) circular economy; 6) multi-materials processing; and 7) new materials processes.

Digital, materials and production technologies that are specific to certain market/materials priorities are included in the respective chapters in Part II. A preliminary matrix has been elaborated representing the mapping between those cross cutting R&D challenges in materials and processes and their relevance for the nine innovation markets, are summarised at the end of Part II

The aforementioned aspects are crucial to strengthening Europe's sovereignty in advanced materials. To do this, new forms of inclusive cooperation across the entire value chain will be necessary to overcome the current fragmentation of Europe's R&D&I environment and the ever-increasing complexity of developing new materials and processes. These new forms of synergistic collaboration should bring together: Materials, physical and chemical scientists, life, social and computer scientists, designers, engineers, material producers, converters, recyclers, and users (Business2Business and Business2Clients) and associations representing stakeholder groups from citizens and society jointly, legislators and regulators. Experts from the afore-mentioned sectors will have to work together closely from the early concept stages all the way to product end-of-life scenarios whilst considering the entire process. Boosting interdisciplinary activities to harvest smart and coherent development of advanced materials can tremendously benefit when all forces are aligned. Developing new tools for bringing together Europe's current heterogenous advanced materials ecosystem will be of pivotal importantance.

3. Proposals for future actions

The research community needs a holistic and strategic view to engage, and such engagement includes the need to digitise and deal with data issues. The research community understands market needs and game changers that might differ depending on the sector. Establishing common interest in different markets can help to offer a clear sense of prioritisation. A first attempt to define common priorities for different markets has been identified here both, for materials and processes development.

3.1. Support activities to accelerate digitalisation in product innovation

One of the most important elements for the Materials 2030 initiative is **a Common Digital Ecosystem**, ensuring interoperability between all 'horizontal enabler' technologies and capitalising on commonalities between them. Their integration will be a cornerstone in the digital transformation of the manufacturing industry. Therefore, the partners involved in the draft Materials 2030 Roadmap propose the development of **a materials data base**. The objective is twofold:

1. to design novel materials for given specifications at a speed unattainable in the usual process of discovery where targeted development is difficult and breakthroughs are often unpredictable.
2. **to manage and control material behaviour and data over the materials value chains and along the entire lifetime.** Data obtained in production, laboratory control and use phase ans during End of Life (EoL)-process will be key to increase efficiency and reliability of the material design to minimise the environmental impact through waste, reduction extended lifetimes and to optimise towards circular material flows and materials for the planet.

3.1.1. Management of data

Initial steps in terminology, classification and data documentation for multi-perspective materials modelling and characterisation workflows have been done, establishing the now widely accepted data structures MODA[19] and CHADA[20], respectively. Europe is leading the way in ontology-based data documentation of materials and manufacturing due to the development of the EMMO ontology framework[21].

The **availability, transparency and access to data** are key factors for success; therefore, some important initiatives are added in different European countries such as:

- **Germany:** Platform MaterialDigital PMD[22], NFDI-MatWerk (Nationale Forschungsdateninfrastruktur für Materialwissenschaft & Werkstofftechnik)[23], FAIRmat (FAIR Data Infrastructure for Condensed-Matter Physics and the Chemical Physics of Solids)[24] etc.
- **France:** DIADEM – Discovery Acceleration for the Deployment of Emerging Materials25
- **At European level:** the European Materials Modelling Council (EMMC), European Materials Characterisation Council (EMCC), as an example.

Due to the lack of ontologies able to capture the multiperspective nature of materials science and applications, EMMC and related projects developed a physics, semiotics and mereotopology based top level ontology for applied sciences

[19] Models and Data Framework; https://modeling-languages.com/a-hitchhikers-guide-to-model-driven-engineering-for-data-centric-systems/; https://emmc.info/moda/
[20] Creation of novel metadata structure (CHADA) for collection data and information related to characterisation methodologies; https://cordis.europa.eu/project/id/760827; https://zenodo.org/record/2636609#.Yqgec3ZIDIU
[21] European Materials Modelling Ontology: https://emmc.info/emmo-info/
[22] Platform MaterialDigital PMD: https://www.materialdigital.de/
[23] NFDI-MatWerk Nationale Forschungsdateninfrastruktur für Materialwissenschaft & Werkstofftechnik; https://nfdi-matwerk.de/
[24] FAIRmat FAIR Data Infrastructure for Condensed-Matter Physics and the Chemical Physics of Solids; https://www.fair-di.eu/fairmat/fairmat_/consortium
[25] DIADEM: an exploratory Priority Research Programme and Infrastructure linking materials and AI; https://www.cnrs.fr/en/diadem-exploratory-priority-research-programme-and-infrastructure-linking-materials-and-ai

called EMMO (Elementary Multi-perspective Material Ontology). Industry Commons projects are developing best practices for ontology-based data documentation (OntoCommons[26]) and a data marketplace (DOME 4.0[27]),

The full potential of the effective exploitation of the rich and rapidly growing amount of data in materials science, transformation, use and re-use until the end of life **still needs to be harvested**.

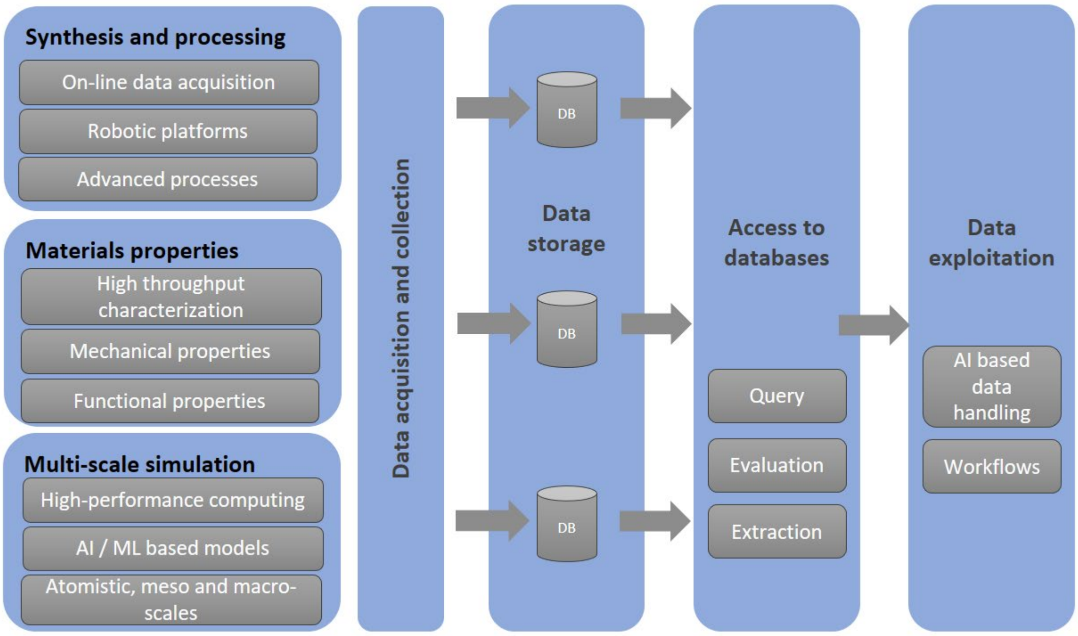

Figure 1: *Efficient pathways for harvesting relevant data originating from synthesis and processing, characterisation, and simulations will need to be created and managed.*

Like any Common European data spaces and infrastructures, the materials data platform should be developed respecting EU rules and values on Data Governance, control and security, openness, interconnection, intellectual property rights, and interoperability. The European data strategy including the Data Governance Act will play an important role in the context of the Materials 2030. The future initiative should be a (common) data space, based on the 'embryonic' data spaces emerged in the manufacturing sector, having a focus on data sharing for circularity in line with the Circular Economy Action Plan, involving organisations from the circular economy (*e.g.* reuse, repair, and remanufacturing, refurbishing and recycling companies to improve circularity and secondary use of the materials).

[26] Ontology-driven Data Documentation for Industry Commons; https://ontocommons.eu/
[27] The Digital Open Marketplace Ecosystem (DOME) 4.0; https://dome40.eu/overview

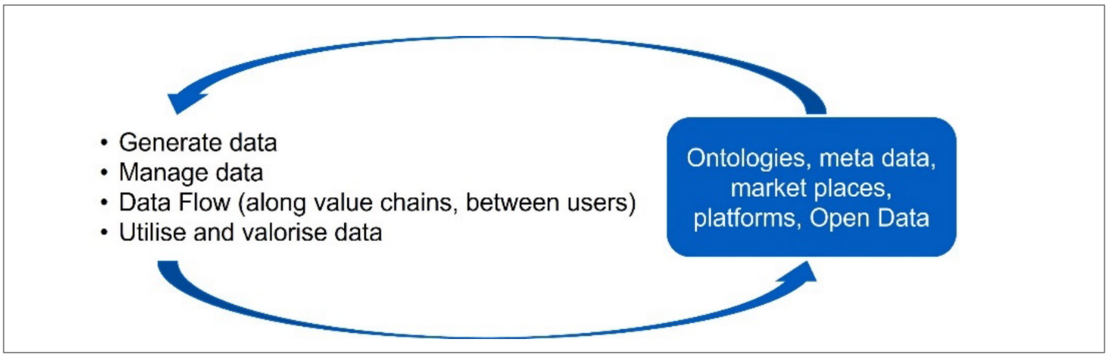

Figure 2*: For data to be useful and accessible for all stakeholders, standards, ontologies etc. will need to be established along the value chain.*

Blockchain technology has great potential to provide transparency and communication in global value chains. The protocol enables trusted data exchange in fragmented supply chains while protecting a company's privacy and sensitive information. Achieving a standard for traceability to origin would enable the proof of origin of materials, therefore fostering recycling practices.

3.1.2. Data-driven development of advanced materials

To achieve the data-driven development of advanced materials, three priorities have been identified that will be elaborated in actions:

1) **Generating new data and knowledge**: Develop digital and innovative methodologies for generating materials data and knowledge, including modelling, characterisation, production and testing technologies
2) **Documenting data and knowledge**: Develop and disseminate a common (standardized) language (ontology) for data exchange and knowledge management
3) **Accessing and interogating data and knowledge**: Provide reliable and easy access to and interrogation of generated data/information/knowledge for all stakeholders

Below, each of the priorities will be further elaborated and specific actions detailed. Together, these actions combine into the development of a digital materials market and Materials Commons uniting digital and materials capacities and competences orchestrated to accelerate the design of advanced materials. Capacities such as data documentation based on ontologies, materials modelling and characterisation, and Machine Learning/AI combine to achieve, *e.g.*, prediction of durability, minimisation of energy consumption, and safe and sustainable-by-design principles.

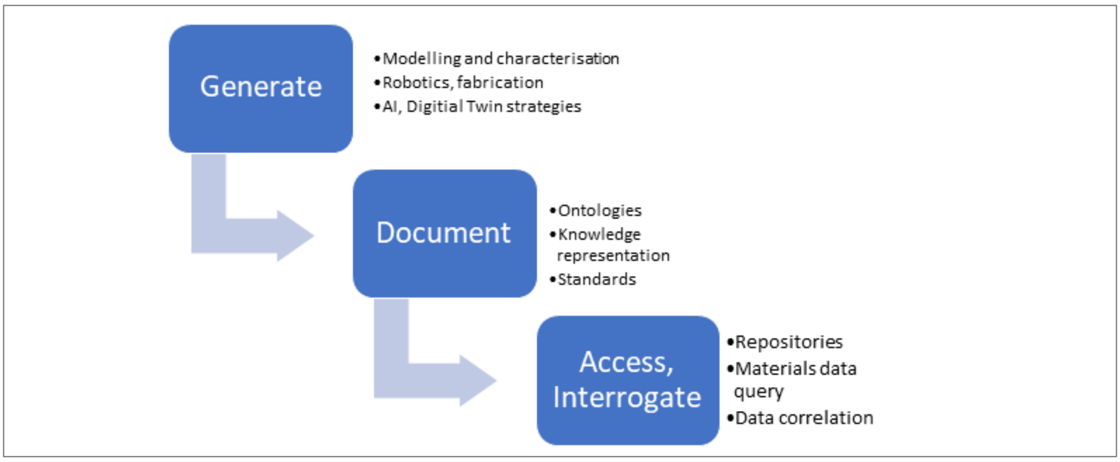

Figure 3: *Three priorities to achieve the data-driven development of advanced materials*

Generating new data and knowledge to process and scale up materials solutions

Advanced materials development requires multiple sources of data and knowledge, based on digital and innovative methodologies, including modelling, characterisation, production, and testing technologies for the advanced materials lifecycle (development, production, use, recycle). Technologies include advanced monitoring tools, robotics, and automatisation to process and scale up materials solutions. Optimisation and harmonisation is required. To address this priority, several actions will be engaged:

1) Optimise and harmonise materials modelling and characterisation, including multi-scale, multi-technique and high performance/high throughput approaches

   Make multiscale materials modelling from electronic to continuum, and data-based (AI/ML) modelling more user-friendly, interoperable, and integrated in workflows to allow automatic and/or high-throughput calculations, based on the MODA structure.

   Coordinate actions towards integration and standardised documentation of multi-scale computational modelling, materials synthesis and characterisation methods and autonomous robotised synthesis. Such multi-technique integration will maximise the potential and value of data, and contribute to a European-wide semantic knowledge base developed in the Industry Commons.

2) Foster and orchestrate enablers such as autonomous robotics platforms and fabrication technologies, high-throughput testing bench, experimentation and characterization

   Coordinate the actions to develop new characterisation test benches and protocols during materials development and fabrication, linking advanced laboratory characterization tools connected with the cloud, including sensors and predictive maintenance of components during use.

   High-throughput characterisation: compositional, structural, mechanical, functional properties and durability, as well as *in situ* or *operando* characterization, will generate large databases. New advanced characterization instruments and protocols are needed, developing the interphase with the cloud, to store and analyse the information, independently of the physical testing.

3) Foster AI-based data handling and workflow optimization as well as Digital Twin strategies:

   Machine learning will be used to develop new approaches and design tools for: a) resources optimisation, b) customisation, c) managing circularity, d) improved performance, and e) durability, which all require specific data and data management.

Documenting data and knowledge

The objective is to develop and disseminate a common (standardised) language (concepts and vocabulary) for data documentation in the applied sciences that supports data exchange and interoperability, and enables communication between different innovation markets (different data space). In order to progress towards this objective, the following five actions are required:

1) Establish **meaningful descriptors** (conceptualisation) to derive insights from abundant data across the entire materials science field and across material value chain.
2) Develop a **common ontology** enlarging the Industry Commons OCES to enable digitalisation of the advanced materials discovery cycle through closed-loop integration of data, metadata, and materials from all parts of the discovery cycle including high-throughput experimentation, and high-performance computing and downstream use of real-life data.
3) Create **materials knowledge representation** along the value chain using semantic technologies.
4) Coordinate the development of **education and training of experts** with semantic, conceptualisation, and domain knowledge. Develop the role of benefit advisors who will enable a broader community of non-experts to participate in the materials discovery process.
5) Accelerate the **development of safe and sustainable-by-design chemicals and materials** through standards, certification schemes, ecolabels, EU sovereignty & Autonomy, risk & lifecycle assessment, and safety.

Accessing and interrogating data and knowledge

In order to provide easy access and tools to interrogate generated data to all stakeholders the following actions are called for:

1) Create standardised, secure, and reliable repositories for curated materials data comprising the entire materials life cycle / value chain (including LCA data)

   As mentioned above, the repositories will combine materials manufacturing data from highly digitalised processes, with materials properties and durability, from testing and multiscale simulation data, under a governance that will allow openness and confidentiality.

Standardised interfaces between all horizontal enablers will be elaborated.

2) Develop and disseminate validated methods for materials data acquisition, storage, query, evaluation, and transfer into information/knowledge of added value (acquisition, validation, handling, and exploitation of data / data mining)

Develop **methodologies for gathering, processing, and managing data by using AI massive data fluxes**. Specific AI tools need to be developed to improve the management of the heterogeneous experimental, simulation and manufacturing data to be used also for Digital Twins of processes.

Develop innovative **digital (twin) strategies**, to support efficiently the mining of materials information during service life until EoL, combining novel characterisation and modelling or virtual and physical tracking and monitoring to support the establishment of efficient management strategies.

Create data and knowledge exploration systems (such as knowledge graphs and exploratory search systems) based on the common ontologies, enabling all stakeholders to interrogate knowledge about materials along and across value chains and markets.

Assist companies to participate in this emerging ecosystem via the **materials data marketplace** and bring their internal systems fully up to date with forward-looking **technology platforms that are open and connected**.

Validate heterogeneous data processing and data correlation tools to transform the data into new, experimentally testable hypotheses that will suggest new directions for materials development.

Develop a common market place to connect all distributed data spaces.

3.2. Support activities for new materials processing and scale up

Advanced materials are enablers in areas that at first sight seem only remotely connected. While different MIM require some specific materials properties, there are also broad communalities: a need for advanced materials and processing technologies that have a wide range of applications and challenges in different markets (tables with these cross cutting needs are presented in Part II). Good data sharing, good information flow, and proper governance can help to tap the enormous potential of such materials and processing technologies in different MIM.

Especially because materials developers need to make substantive investments to process and scale up new materials and new processing technologies, identifying and harvesting synergies from communalities is one of the important benefits of good governance within the Materials 2030 initiative to facilitate cross fertilisation of developments made for several applications, as shown bellow:

Cross-cutting Challenges (with some illustrative examples)
• **Process optimization** (higher speed; flexibility; resources savings (energy, water, consumables) • **Decarbonization** (electrification; renewable sources; CO2 capture, storage, conversion, use) • **Mass customization** (consumer integration; highly flexible, reconfigurable processes) • **Zero Defect Production** (in-line product and process monitoring and feedback to control) • **Circular Economy** (rapid assembly, repairing, de & re-manufacturing and recycling) • **Multi-materials Processing** (multimaterials 3D-printing; joining/assembling & de-assembling) • **New Materials Processing** (flexible, transparent polymer/resins; bio based and nano materials)

For the strategic collaboration between advanced materials development and uptake, it is critical to involve the respective stakeholders, projects and initiatives, going well beyond the initial development stage, into their utilisation by the industrial sectors. The following are only a few example areas where such collaboration is more challenging compared to the current situation:

- Development of digital twins of production processes, to support new materials development.
- Collection of data related to materials, products and production processes, for example, to support materials traceability and LCA.
- Use and incorporation of recycled materials in products.

The following actions intent to reinforce and enlarge the collaboration that was already started under the Materials 2030 Manifesto and pave the way to overcome these challenges:

1) Strengthen the strategic collaboration between materials, digital and production technologies ETPs, targeting namely joint roadmapping activities.
2) Include the development/adaptation of respective digital and production technologies in advanced materials R&D projects, to increase the TRLs and reduce time-to-market of the complete solution (link to 'value chain').
3) Give higher priority to join materials and processing ready for recycling, *e.g.,* use secondary materials and highly efficient disassembly, dismantling processes to reinforce circular economy.
4) Develop 'channels' (formats, protocols, information, communication systems, *etc*.) to support data (information/knowledge) exchange/sharing between materials development, digital and production technologies development and user companies (materials producers and their customers). (link to 'Data')
5) Promote collaboration between materials developers with relevant digital and production technologies initiatives through transparent mechanisms including existing funding initiatives - (link to 'Governance') related to materials, production and digital technologies, namely the new Partnerships (Co-Programmed and Institutional) under Horizon Europe and other EU co-funded initiatives and ERA-NET (such as Processes4Planet[28]; Made in Europe[29]; Photonics[30]; AI, Data, Robotics[31]; Circular Bio-based Europe[32];

[28] Processes4Planet | SPIRE; https://www.aspire2050.eu/
[29] Made in Europe - State of Play | EFFRA; https://www.effra.eu/made-in-europe-state-play
[30] Photonics PPP | Photonics21; https://www.photonics21.org/about-us/photonics-ppp/
[31] European Partnership on Artificial Intelligence, Data and Robotics; https://ai-data-robotics-partnership.eu/
[32] Circular Bio-based Europe Joint Undertaking; https://www.cbe.europa.eu/

European Metrology[33]; Key Digital Technologies[34]; EIT Manufacturing[35]; M-era.net[36]; Manu.net[37] and PARC[38]).

3.3. Identification of most urgent/priority Materials Innovation Markets

The analysis of the nine MIMs showed that the creation of robust connections between digital data needs, computational, and experimental tools together with the identification of priority application areas where innovative advanced materials are urgently needed is pivotal for achieving Europe's strategic objectives, due to the complex nature of European advanced materials landscape.

Using these priority areas for research and demonstration proposals will at the same time deliver the most urgently needed innovative materials and further improve the materials development tools and capabilities. Identifying these priority areas is the primary purpose of the MIMs. Building these in close cooperation with major representative stakeholders of every advanced materials application sector will be essential.

As a stepping stone towards defining future priority areas, the nine MIMs had been chosen by the Platforms and authors of the roadmap. These MIMs (detailed in Part II of the document) address the challenges of the industry and research communities that need to be overcome in order to enhance Europe's capacity to reduce its environmental footprint, improve sustainability, and reach sovereignty. It has to be underlined, that the current list is by any means exhaustive and can be expanded further in the future.

Communalities have been identified between the priorities of the different Materials innovation markets as represented in the next table:

Cross-cutting Challenges (with some illustrative examples)
• **Bio-based, biodegradable or recyclable materials** (Shift from fossil-based to bio-based) • **Embedded electronics and post Si-electronics** (e-textiles, medical devices, wearables) • **Materials for Advanced Coatings and Textured surfaces** (multifunctional, durable) • **Advanced materials for Additive Manufacturing (AM)** (e.g. light weight, microelectronics) • **Sensors and multifunctional materials** (sensor based maintenance and diagnostics) • **Materials for circularity and re-use** (sensors tracking, recycling, reuse of secondary materials) • **Fiber based materials** (fiber reinforced light weight and multifunctional composites)

The challenges within the nine markets are manifold and need to undergo a second step to define 'priority areas'. These priority areas will form the initial basis for the development of a novel European strategic materials agenda. This prioritisation could, for example, focus on both 'quick wins' and long-term research topics that

[33] EURAMET - The European Association of National Metrology Institutes; https://www.euramet.org/research-innovation/

[34] Key Digital Technologies: new partnership to help speed up transition to green and digital Europe | Shaping Europe's digital future; https://digital-strategy.ec.europa.eu/en/news/key-digital-technologies-new-partnership-help-speed-transition-green-and-digital-europe

[35] EIT Manufacturing - European manufacturers together; https://www.eitmanufacturing.eu

[36] M.ERA-Net - ERA-NET for research and innovation on materials and battery technologies; https://m-era.net

[37] European Manunet programme, a partnership of several regions dedicated to promoting smart manufacturing; https://manunet.net/

[38] European Partnership for the Assessment of Risks from Chemicals (PARC); https://www.anses.fr/en/content/european-partnership-assessment-risks-chemicals-parc

will need specific attention due to their complexity. Therefore, one of the next steps in the further development of the Materials 2030 Roadmap is to develop the respective tools for the final selection of future MIMs and priority areas

Existing and future technology areas will need support across the development pipeline to fully leverage current research and development investments and infrastructure. Education and workforce training programs for advanced materials will be critical to encourage strong industry involvement and to maintain a workforce fit for strengthening the MIMs.

3.4. Policy support

Establishing political support measures in Europe for its advanced materials production and related digital technologies will be critical for strengthening Europe's global leadership now and in future. The Materials 2030 Roadmap aims to trigger and aid the debate on the further development of the policy framework for Europe's advanced materials ecosystem to promote exchange between discovery-driven research on the one hand and start-ups and established industry on the other hand. Important actions needs to be considered:

1) Establish measures for safe and sustainable-by-design through secure predictable and stable regulatory environment for the Safe and Sustainable by Design (SSbD) Framework

   Resilient European innovation environments and future perspectives along the value chain require safe and sustainable-by-design criteria for chemicals and materials. Existing criteria must be harmonised and supported through the creation of clear, transparent, and efficient labelling and other pillars of the certifications schemes.

   Develop transparent, clear, feasible rules based on scientific evidence for lifecycle assessment along the value chain in materials circularity

   Efficient scientific evidence-based life cycle assessment is of pivotal importance to compare results and sustainability objectively. The new approach needs to be based on materials circular models instead of linear ones.

2) Harmonise norms and standards to enhance Europe's global competitiveness

   Harmonised norms and standards are a strategic instrument for European companies to exploit their know-how and established technologies more efficiently making them globally more competitive. Standardisation should be an integral part of any strategy to promote future technologies, and it should be considered for funding programs towards sustainable technologies and processes.

3) Ensure robust health and safety protocols are followed to protect Europe's citizens and the environment

   Health and safety measures for handling materials (raw materials, additives, formulations, etc.) covering the design stage all the way to end-user product must be established to protect people, i.e., workers, users, end-users, and the environment. Europe's 'safe and sustainable' guidelines for the assessment of risk must combine the evaluation of hazard and exposure in conjunction with lifecycle assessment for sustainability impacts.

4) Foster education and training across the value chains

Concrete and targeted education and training are critical to align views and to develop a common understanding and application of dedicated methodologies for the development, manufacturing, characterisation, and application of advanced materials.

3.5. Governance for the advanced materials ecosystem (Materials 2030 initiative)

A cohesive governance framework is essential to secure an efficient organisation of the roll-out of the 'Materials for people, planet, and prosperity' (Materials 2030) initiative that can drive the twin-digital and green transition and Europe's resilience, contribute to the Strategic Development Goals (SDG) and to the European Research Area (ERA), and enable an inclusive, meaningful, and increased innovation power, that will secure sovereignty and prosperity in Europe.

The vision of the Materials 2030 Roadmap is to enable a safe and trusted space that provides reliable connections between all involved stakeholders (materials researchers, developers, manufacturers, up takers in various innovation markets, and end users).

In Europe, several activities have been initiated that bring together different stakeholders working in the field of materials development, to design the roadmap of materials research. The materials ecosystem brings together a large number of stakeholders and disciplines. This complexity is also reflected in the Horizon Europe structure, since materials research topic is distributed in several Clusters, Pillars and R&I Partnerships. Therefore, a governance framework needs to be created that reflects the systemic approach of the Materials 2030 Manifesto objectives, ensures flexibility of implementation, adjusts to changing policy, societal and/or market needs and guarantees an efficient cooperation, both inside the materials ecosystem as well as between different initiatives.

3.5.1. Overarching principles

The appropriate **governance system** must ensure fair, transparent, proportionate, and non-discriminatory access to, sharing and use of information[39], and provide the **efficient organisation** of the various needed activities to reach the objectives.

The **stakeholders' participation and access** should be characterised by being open, inclusive, co-creative, accountable, and mutually beneficial. The governance system shall provide the rules for an efficient evaluation of the achieved performance, creating trust among participants that the Eco-System is reaching its objectives. Based on a set of core principles (Proximity, Attribution, Traceability,

[39] In the proposal for a European Data Governance, a data holder is defined as "a legal person or data subject who, in accordance with applicable Union or national law, has the right to grant access to or to share certain personal or non-personal data under its control".

Holism, and Stability = PATHS)[40], the governance system must ensure information is collected on a set of key dimensions where impact is desired.

Implementation of initiative will require new protocols and testing instruments that need to be developed to upgrade materials performance to work in a specific environment, addressing citizens preferences or comfort (*e.g.* visual, odour, pleasant). Collection and assessment of guidelines for testing protocols to produce future standards, certifications, and ecolabels will be highly beneficial at EU Level. The following design principles, complemented by the common indicators chosen to capture the added value of European partnerships in Horizon Europe[41], can serve as a guiding principle to establish a cohesive governance framework:

1. **Additionality and directionality**: create a leverage effect from the EU intervention (additionality) and implementing actions towards the achievement of impacts that cannot be created by other European or national actions alone (directionality).
2. **Transparency and openness:** be open by serving the interests of all relevant stakeholders beyond a narrow composition of core partners, promote the participation of newcomers and ensure a broad communication and dissemination.
3. **Coherence and synergies**: exploit synergies with other initiatives and act in the broader landscape of R&I and sectoral policies.
4. **Policy direction**: lay the ground for new policies in support to the EU materials ecosystem determining the strategic priorities in terms of materials development to secure Europe's technological sovereignty.
5. **Respect of EU rules and values**: make sure that information spaces comply with the applicable EU legal frameworks on personal data protection and security, fundamental rights, environmental protection, competition law, and other rules relevant for the provision.

[40] Bruno, N. and Kadunc, M. 2019. Impact Pathways: Tracking and communicating the impact of the European Framework Programme for research and innovation. Fteval Journal. May 2019, Vol. 47, pp. 62-71. DOI: 10.22163/fteval.2019.330
https://repository.fteval.at/416/1/Journal_47_10.22163_fteval.2019.330.pdf

[41] European Commission, Directorate-General for Research and Innovation, Performance of European Partnerships: Biennial Monitoring Report (BMR) 2022 on partnerships in Horizon Europe, 2022; https://data.europa.eu/doi/10.2777/144363

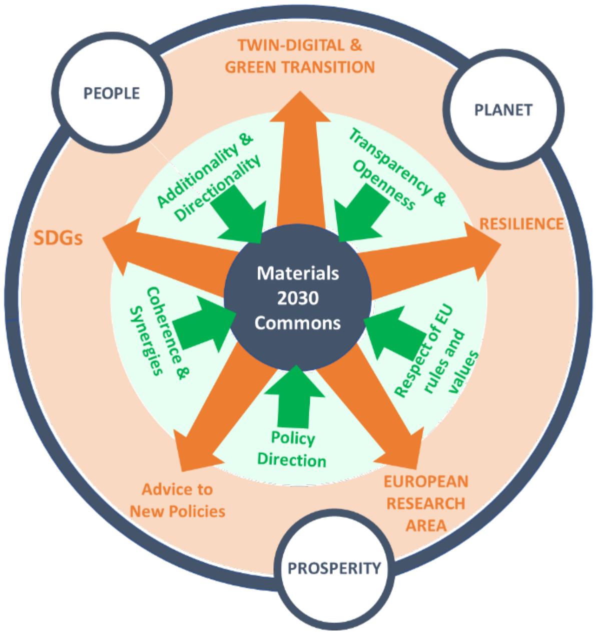

Figure 4: *Materials for Planet, People and Prosperity: principles and strategic challenges*

3.5.2. Implementation

Setting up the Materials for Planet, People and Prosperity Materials 2030 initiative is all about setting up a collaborative framework between the European Commission, member states and R&I stakeholders to achieve defined key strategic objectives, maximize impacts of materials research and to implement a research and innovation program delivering on global challenges and industrial modernization in alignment with the European strategic priorities. Building the initiative is therefore a joint effort which closely resembles the mechanisms put forward by European Partnerships to bring R&I closely to policy needs, develop close synergies with other initiatives, bring together and connect a broad range of R&I actors to work towards a common goal and turn research into socio-economic result. Capitatising from the experience of existing initiatives such as the European Partnerships, Platforms or Alliances, their good practices, lessons learnt and existing base of knowledge (e.g. ERA-LEARN[42]), will be decisive for this joint effort.

To take up coherent and systematic approach to governance arrangements there is a first step needed to establish a **working team** to lead the setting up of four important governance building blocks[43]:

1. **Design the governance structure, bodies, and features**: define management structure, including executive, governing and technical boards/committees and identify the initiative functionalities. The governance structure will be divided in three interlinked dimensions:

[42] ERA-LEARN; https://www.era-learn.eu/

[43] Building blocks defined in alignment with the advice and guidance provided by the ERA-LEARN Platform (Strengthening partnership programmes in Europe): https://www.era-learn.eu/support-for-partnerships/governance-administration-legal-base. Horizon 2020, CSA. Data base of Partnership initiatives, their calls, funded projects and provide studies and analyses on thematic clustering, internationalization, alignment, *etc*.

- The governance system of the **Materials 2030 initiative**
- The governance regulating the **operations** and;
- The governance of the **information/data** (from materials and processes).

2. **Financial rules**: fix the principles for financial commitments and contributions.
3. **Responsible Research and Innovation (RRI):** define the means of absorbing principles of RRI in all activities and interactions of the Materials for Planet, People and Prosperity (incl. open science, equality, and non-discrimination, IPR and GDPR, open innovation, ethics, inclusiveness, and public engagement)
4. **Monitoring and assessment tools**: establish the framework for impact assessment and for monitoring the performance of the initiative and its tools.

Figure 5: *The interlinked objectives to establish a Governance of the Materials 2030 initiative.*

Transversally to the above-mentioned building blocks, a fully open Materials 2030 initiative requires every effort to facilitate stakeholders' engagement, connection, and operations. These features will be facilitated by a platform where three important building blocks are needed:

1. **Engagement platform**: a marketing platform that will articulate and orchestrate the concepts to the various stakeholders (the society, research, industry, and institutions) to create awareness, curiosity and interest for being engaged.
2. **Onboarding/landing platform** which will enroll interested stakeholders.
3. **Pilot Operations and activities platform** addressing the different steps to facilitate the development and scale up of materials research.

Building blocks of the Materials4PPP governance framework		
General Materials4PPP Structure	**Operational Procedures**	**Information Sharing**

▪ Set up of **Governing Bodies** (e.g. Governing/ Executive Board; other overseeing, decision bodies, securing General Data Protection and execution, data curation, integrity, etc.).
▪ Establishment of **formalities** (e.g. statutes, privileges, legal aspects)
▪ Organization of **work programs, funded research, missions etc.** in accordance with societal needs (rules and roles for R&D&I at EC and member states level)
▪ …
	▪ **On-boarding** of stakeholders to Materials4PPP
	▪ **Participation/engagement and utilization** of content.
	▪ Organizing various **operational activities**, e.g.:
	  ▪ Establishing Working Groups
	  ▪ Marketing/dissemination
	  ▪ Collaborative Roadmapping
	  ▪ Evaluation of Impact
	▪ **Research Management**
	▪ …
		▪ **Providing/exchanging information/ data** (e.g. with other initiatives)
		▪ Access to **search & extract information**
		▪ **Documentation** of generated knowledge and available information
		▪ Enable **knowledge transfer**
		▪ Renumeration to data providers (the utilization of ledger technologies and tokens ought to secure that each provider benefits from other utilizations)
		▪ …

Financial Rules Principles for financial commitments and contributions	**Responsible Research and Innovation** Open science, equality and non-discrimination, IPR and GDPR, open innovation, ethics, inclusiveness and public engagement	**Monitoring and Assessment Tools** Impact and performance assessment and monitoring

Table 1: *The building blocks of the Materials 2030 governance framework*

4. Conclusions

As outlined before, the future of advanced materials development and processing faces a lot of challenges while new technologies and digitalisation solutions offer also new approaches for inclusive and increased innovation power securing sovereignty and prosperity in Europe and beyond. The authors of the draft roadmap proposed pragmatic future actions to realise a multidimensional initiative capturing all value chains, innovation markets and stakeholders for inclusive and increased innovation, named the Materials for planet, people, and prosperity (Materials 2030) initiative.

The authors recommend to deploy necessary resources for this initiative and relevant actions towards innovative materials developments, production technologies, data sharing, and collaboration models on a European level. The integration of the technological approaches and the multitude of stakeholders from different economic sectors to be involved will entail considerable financial and organisational effort. Since the approach is new, a multitude of organisational questions need to be clarified as well as further stakeholders need to be involved in the design process of the initiative. This will be done in the coming months. The aim is to find the best possible instrument (or instruments) that helps to implement the goals of the initiative in a targeted and efficient way. Whether this is an existing instrument such as a European partnership, alliance or platform, or whether a completely new instrument needs to be developed, remains open for the time being.

5. Next steps

The next planned steps for the further development of the initiative are:

June 2022 | Presentation of the draft roadmap and discussion of possible future initiatives

June 2022 and onwards | Setting up an interim Coordination Group that will:

- coordinate the dissemination of the draft roadmap publicly
- propose an initial overall governance structure and the roles for specific aspects of governance including operations, information/data (from materials and processes), processing, policy, finances, *etc*.
- organise an initial communication link to all onboarded stakeholders and engage, welcome and involve new stakeholders (incl. setting up an engagement / on boarding / joining platform)
- support and coordinate further actions like follow-up conferences/workshops and other activities

July – October 2022 | Reaching out and engaging with further stakeholders to discuss the development of the initiative through a wide and transparent consultation process.

October 2022 | Proposal for a possible instrument to realize the Materials 2030 initiative

2023 | Setting up the operations/activities aimed to create the conditions for 'partners' to enjoy enhanced and efficient transfer & uptake of innovative solutions based on Advanced Materials securing European technological leadership

Part II – The Material's Priorities Research Areas

1. The Materials Innovation Markets

The **Materials Innovation Markets (MIM)** represent the **'market pull'** to address the societal needs and citizen challenges sustainably, in the longer-term . They represent the **value chains and markets** we are likely to have by 2030, using sustainable and collaborative business models. They are driven by R&I in advanced materials as a '**technology push**' to target value, instead of volumes, for future products and services.

The **Materials Innovation Market** chapter of the Materials 2030 Roadmap describes firstly the societal needs and citizen challenges to achieve the objectives of the Green Deal and other policies that demand both a change in materials portfolios and the creation of new value chains. The industrial pull has been analyzed for **9 selected materials innovation markets**: health, construction, new energies, transport, home & personal care, packaging, textiles, agriculture, and electronic appliance.

The **market dimension**, the **materials challenges,** the **research priorities for each market and the expected benefits** have been described. The potential to improve EU sovereignty, their capacity to reduce environmental footprint, and their potential to improve sustainability have also been explained. Additionally, highlights of **the expected socio-economic benefits, the EU industrial innovation capabilities** and **future outlooks** have been presented**.**

The methodology used to identify the priority areas consisted of collecting expert opinions by leading European Technological Platforms, establishing meetings to select and highlight priorities based on expected benefits:

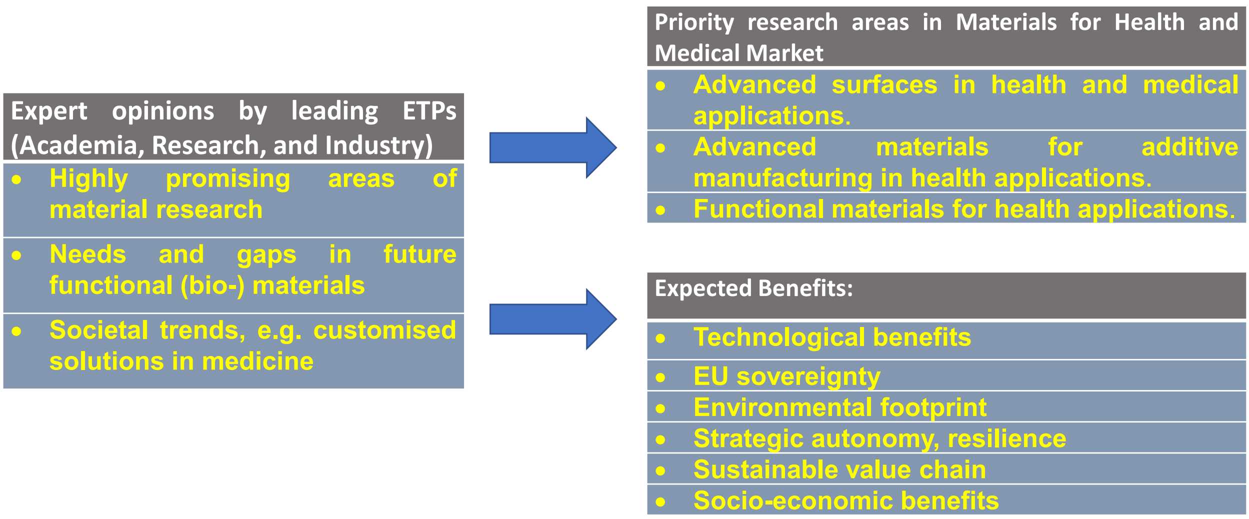

Figure 6: *Methodology to identify priority areas*

The following is a summary of the priorities identified for each Materials Innovation:

MIM1.- Materials for health and medical Market

- Advanced surfaces in health and medical applications.
- Advanced materials for additive manufacturing in health applications.
- Functional materials for health applications

MIM2.- Materials for sustainable construction Market

- Materials for improved energy efficiency
- Materials with and for an increased sustainability and circularity
- Materials with improved product and overall life carbon footprints
- Materials with new functionalities / Smart materials

MIM3.- Materials for New Energies Market

- Advanced materials for renewable and low-GHG-emission energy production technologies
- Advanced materials for energy storage.
- Advanced materials for sustainable transformation of energy-intensive industrial processes

MIM4.- Materials for Sustainable Transport Market

- Zero-emission vehicles
    - Solid-state batteries for BEVs
    - Cost-competitive hydrogen fuel cell systems for FCEVs and direct hydrogen combustion for aviation and maritime transportation.
    - E-motors
- Light weighting for more efficient vehicles and aircrafts.
- **Power electronics** (e.g. silicon carbide and gallium nitride) and smart devices for electrification, connectivity, and control

MIM5.- Materials for Home & Personal care Market

- Alternative **active and non-active ingredients** based on natural and sustainable platforms
- Materials and **design for circularity** and re-use
- Renewable materials and **biotechnology production** methods
- **Multi-functional surfaces,** coatings, sensor functions

MIM6.- Materials for Sustainable Packaging Market

- **New renewable and recyclable materials** and for specific applications biodegradable and compostable materials
- **Smart solutions** to monitor product quality and enlarge shelf-life.
- **Substitution** of Carcinogenic, Mutagenic and Reprotoxic (CMR) and Substances of Very High Concern (SVHC) from packaging formulations (e.g. catalysts, additives, plasticizers).
- Design for circularity, so design for reducing, re-using and recycling.

MIM7.- Materials for Sustainable Agriculture Market

- **Development of efficient sensors** for measuring the maturity of agricultural products and carbon farming
- Development of sustainable and efficient biotechnology-based and/or biodegradable polymers in agriculture and soil preservation
- Development of advanced surfaces and filters for water and air purification

MIM8.- Materials for sustainable textiles Market

- Advanced **biobased and renewable fibres** and textiles for functional and technical applications
- Sustainable and resource efficient **multifunctional textile surface engineering** including biobased chemistry for consumer products and technical applications.
- **Smart E-textiles** for **smart wearables and large-area surfaces** and their efficient integration, manufacturing, and recycling

MIM9.- Materials for electronics appliance Market

- Advanced **multifunctional materials for environmental protection**, heat dissipation, RF transparent and miniaturization
- Advanced **coatings and substrates for electronics** (e.g. flexible electronics, post silicon electronics, fiber optic applications).
- **CRM avoidance**, **replacement, or recycling in electronic devices**. Materials for Electronic appliances designed for reuse and circularity.

2. The context

The System Change Compas[44] report highlights the role of circular based materials in support of economical ecosystems in their delivery of social needs. The report includes some recommendations to increase materials durability, recycling, energy and resources efficiency, to reduce material waste with circular practices, involving

[44] System-Change-Compass-full-report_final.pdf (systemiq.earth)

consumer sector and facilitating the access to secondary materials to mitigate up to 40% of GHG emissions by 2050.

Energy efficiency and materials durability should be further developed. 20% of world total energy consumption (103 EJ) goes to overcome friction. 18-40% of that can be saved by applying new advanced friction and wear protective materials and lubricants, and that would correspond to 8.7% of the global energy use and 1.4% of the global Gross National Production (GNP). The biggest saving potential is in transportation (9.1 EJ/a) and energy industry (8.1 EJ/a).[45,46] Materials development should combine modelling and characterization of the tribological properties, to find sustainable materials solutions to be implemented both in processes and products.

One of the population trends is to increase rural-urban migration that will lead cities to grow rapidly, but massive cities are not comfortable. A way to revert this trend is to translate technology into the agriculture sector (e.g. IT-controlled sensors in farms), improving young people interest to work and live in rural areas. Better public transport infrastructures and hybrid public-private connectivity, will facilitate transport from smaller villages to cities. Super block construction (an area of urban land bounded by arterial roads that is the size of multiple typically sized city blocks), are great concepts to improve quality of life within cities. Teleworking can also reduce mobility needs. All these trends will contribute to reduce the noise and air pollution driving towards a more sustainable mobility.

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[45] Holmberg, Kenneth; and Erdemir, Ali (2017). "Influence of tribology on global energy consumption," *Friction*, 5, pp. 263–284

[46] Holmberg, Kenneth; and Erdemir, Ali (2019). "The impact of tribology on energy use and CO_2 emission globally and in combustion engine and electric cars," *Tribology International*, 135, pp. 389–396

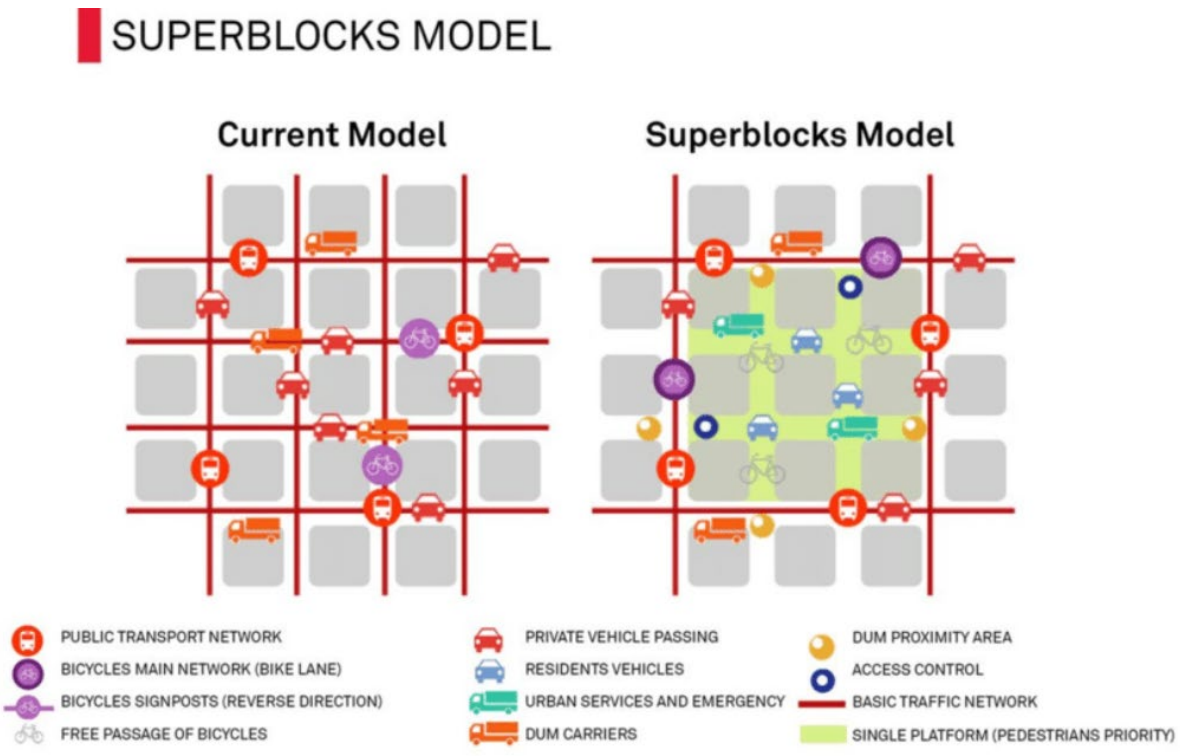

Figure 7: *Super block construction to improve the quality of life*[47]

International dimensions of transition in the EU. While pointing to the deep interdependence of global supply chains, the consequences of the EU's green and digital transition for trade partners and supply chains, e.g. in textiles markets the tendency points to a 'complex, globally interconnected ecosystem' but this could have implications of a EU transition (e.g. fast fashion produced in low-income countries) with its detrimental social and environmental impact. In the case of clean energies sector, Europe has been pioneer in developing materials for renewable energies, but in some cases (e.g. PV), China dominates in processing clean energy materials. This trend should revert to reduce impact on logistics, increase EU jobs and improve EU resilience.

In addition to the EU's environmental footprint, which is especially high for resource extraction, the main burden often lies outside EU, in the extracting countries. A transition towards material use reduction in the EU can have benefits, reducing negative impact of energy-intensive industries and securing raw materials supply[48]. Research by the International Resource Panel[49] shows that natural resource extraction and processing account for more than 90% of global biodiversity loss and water stress, half of global greenhouse gas emissions and one third of air pollution health impacts. The 2022 IPCC highlights that 25-75% absolute reduction of raw material use is indispensable for meeting the climate change targets. It is vital to avoid raw materials overconsumption, which means

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[47] Current and superblock model, which provides an area within the... | Download Scientific Diagram (researchgate.net)
[48] Energy-intensive industries (europa.eu)
[49] Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future (resourcepanel.org)

consuming less and recycling more, needing to apply supply and demand side measures. The individual behavioural change is insufficient for climate change mitigation unless it is embedded in structural and cultural change. Demand-side mitigation efforts could reduce global greenhouse gas emissions in some sectors by up to 70% by 2050.

Although the techniques for a circular economy are well-documented, they are not yet widely implemented. From 1970 to 2017, the annual global extraction of materials tripled, and it continues to grow, posing a major global risk[50]. Industries in the EU have started the shift but still accounts for 20% of the EU's greenhouse gas emissions. It remains too 'linear', and dependent on a throughput of new materials extracted, traded, and processed into goods, and finally disposed of as waste or emissions. Only 12% of the materials used come from recycling." An additional effort is needed in the reuse of recycled secondary materials.

In the McKinsey report 'Securing Europe's future beyond energy' [51], highlights EU leadership in the next materials generation (nanomaterials, nanosensors, new construction materials, green materials, self-healing materials, personalization, new materials, tissue engineering) and the future cleantech (renewables, nuclear fusion, nuclear small modular reactors, recycling, carbon capture and storage, smart grids, long duration energy storage, electric vehicles, cleantech investing, carbon accounting and consulting). In the case of materials, the combined revenue of Europe's top three players is double that of the top three US companies, but only one European nanomaterials company is in the global top ten. Similarly, European companies account for 95% of the value of luxury brands globally, but Europe lags on wearable devices.

In modern Europe, there is a risk of customer acceptance for new technology. But despite all criticism about technology, citizens still share a wide-spread feeling and the expectation that developments in technology will play an important role in solving the urgent societal problems of today. In a recent survey by BOSCH[52], more than 50% of participants agreed that "Technological progress makes the world a better place". Still, the market-share of new technologies is highly dependent on societal adoption and willingness to support the transition. It is necessary to highlight the societal benefits from the innovations to ensure society cooperates in this materials revolution.

Socio-economic benefits are, by common definition, benefits offered to a community, from health and wellbeing through societal trust in technology, up to growth, stable jobs, and strong social networks. Europe's citizens are particularly interested in environmental impacts and sustainability. Advanced materials as enablers of the nine identified priority Innovation Markets provide such a collective value.

Consumers and citizens are aware more than ever of the environmental impact of advanced materials and technologies. End users would like to know if the products they use will be produced sustainably and have a low environmental impact (e.g., energy efficiency, durability, recycling aspects, sustainable packaging, microplastics release toxicity). They actively purchase more sustainable products.

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[50] European Green Deal, 2019
[51] Addressing Europe's corporate and technology gap | McKinsey
[52] Bosch Tech Compass 2022 | Bosch Global

In all nine Innovation Markets, advanced materials based on natural, renewable materials or recycled materials and produced by sustainable production methods have been identified, which at the same time have a large positive societal impact and benefits for society at large.

Digital solutions, such as authentication techniques (e.g., track and trace, chemical marking) combined with detailed information provided (sensors, tags…) on digital databases (digital product passport) could be of help to customers and consumers, for example to inform them of where to dispose and how to recycle products. This increases trust and acceptance by the end user. Advanced Materials made in Europe could be argued to provide consumers with further added value, which will help to push economic growth and increase number of jobs.

The Socio-economic value will be created in each step of the manufacturing process, from sourcing of raw materials and manufacturing of components to final assembly and installation.

3. Materials for Health and Medical Market

3.1. The Innovation Market size and trends

Healthcare in the European Union means improving and protecting the health and well-being of citizens of all ages. Our recent experience of the COVID pandemic placed a heavy burden on the health system. We must improve our capacity to react more quickly, as well as improve diagnosis and treatments for all unmet medical needs. In this market, biocompatible materials are the most important feature.

Beyond today's demands, the challenges of the healthcare system are growing, as a consequence of our aging society. The global medical materials market size[53] is projected to reach € 26.1 billion by 2025 from € 14.4 billion in 2020, at a CAGR (compound annual growth rate) of 13.0% during the forecast period. Pointing to a sub-segment of this market, Ireland-based Research and Markets assumes that the market for medical device additive manufacturing[54] will grow at an estimated CAGR of 16.2% over the next few years, and reach a total value of € 4.04 billion by 2027.

3.2. Materials challenges and priority areas

The growing demand for medical engineered materials is due to increasing healthcare investments and growing demand for improvement in healthcare establishments. Based on observation of publicly available information, statements from governmental bodies, technical conferences and from the growing number of companies active in this field, a wide range of experts (including EUMAT Working Group on Health) agrees on the following trends:

- **New strains of diseases** are driving demand for engineered materials for medical devices (e.g. prostheses adapted to the different growth stages of the human body). There is a high demand for antibacterial surfaces because

[53] Medical Engineered Materials Market Global Forecast to 2025 | MarketsandMarkets
[54] Five pieces of medical equipment that can be made with 3D printing (nsmedicaldevices.com)

of the increasing resistance to antibiotics of some bacteria. Surfaces with anti-viral and anti-fungi action are requested, and bacterial detection to monitor the spreading of bacteria in different environments, for instance, air, water, emergency room, operating room, etc.

- **Rising ageing population** demands advanced materials technologies and devices with new challenges for regenerative medicine, tissue healing, prostheses, and diagnostic devices.
- **The customization of medical engineered materials** to suit the need of a particular device (e.g. biodegradability, recyclability, radio-opacity, and antimicrobial properties) is creating high growth market opportunities.
- **The use of specific materials** in the medical industry has increased manifold in the last decade. Focus should be paid to smart materials capable of providing specific responses to certain condition of the body (inflammatory, infection…) and that in turn, comprise sustainable alternatives to traditionally used materials.

New materials will play an essential role as enablers for future health technologies to prevent, diagnose, monitor, treat and cure diseases. This includes digital technologies in health, in our response to today's health threats and even more so in the future. There is an urgent need to collect clinical data to support the use of medical devices by providing intelligence to the devices. The use of Artificial Intelligence (AI) will be a useful tool to improve materials, processes, and design of future medical devices.

New materials challenges are needed for medical products and devices for testing the effectiveness of medical treatments (such as implants, prosthetics, diagnostics, organoids, etc.), for personal protection equipment (PPE) and delivery systems. Based on our analysis of technologies, market needs and stakeholders, we have come to three truly ground-breaking priority topics in Research, Development, and Innovation. The health market is highly regulated, and medical devices need to meet the Medical Device Regulation (MDR), 2017/745.

The European Materials Platform (EUMAT), through its working group on materials for health, and the European Sustainable Chemicals Platform (SUSCHEM) have identified the following priorities:

- Advanced surfaces in health and medical applications.
- Advanced materials for additive manufacturing in health applications.
- Functional materials for health applications.

(a) **Advanced surfaces for health and medical applications** with improved functionality and biocompatibility, increased performance, sensing and durability, include:

- surface nanostructuring and functionalization to increase materials added value;
- surface texturing to improve cellular growth and tissue anchorage, with stimuli-response adhesion properties for tissue recovery in mild conditions;

- surfaces with antimicrobials, anti-inflamatory, antifouling, anticorrosive, anticoagulating or healing properties;
- surfaces with drug delivery function, which can also be stimuli-responsive;
- surfaces able to reduce friction and wear without the risk of delamination or debris release;
- surfaces able to prevent ageing, corrosion, or tribo-corrosion failures.

Through surface treatments and coatings, new materials properties can be achieved. Biologically inspired materials can support tissue growth and healing.

(b) **Additive manufacturing (AM) can be used in a variety of medical applications**. Among these are personalised implants and prosthetics, membranes and scaffolds, and the use of 3D models in preoperative surgical planning. 3D or 4D printing allows the generation of functional materials, providing sensitivity to stimuli or bioprinting. Combining with cell culture technologies and tissue engineering, it has the potential to repair or replace damaged tissues, to develop organoids to understand diseases and test medical treatments to predict patient response to them, and even to build artificial human organs in the future. Currently, the typical materials used in medical AM mostly are bio inks, new forms of plastics, including biodegradable and high-temperature polymers (such as PEKK, PEEK and Nylon 6.6, Nylon 6, etc.) and metals (such as stainless steel, Ti (Ti40), Ti6AlV4 and Ti6AlV4 ELI, magnesium, etc) with recent developments in reinforced thermoplastics, photopolymers, and metal alloys. Today, significant strides are being taken toward the development of biomaterials such as advanced polymers[55], metals and ceramics fit for implantation in humans. In this sector bioinert and biocompatible materials are required. Biodegradability is a key feature to pay attention to, depending on the need for implants to be permanent or not. The combination of materials with different biodegradation properties can be employed to adapt implants to the needs of early-age patients whose anatomy is undergoing growth.

AM has significant potential for personalized and customized solutions to meet a patient's 'individual conditions and needs'. In medicine, there is a background in digitalization of medical imaging that enables the reconstruction of 3D models from patients' anatomy. The value chain for medical devices is complex, comprising multiple actors from different sectors (namely, software, process developers, metal and plastic industries, and hospitals).

Promising areas of materials research and innovation in medical AM include a combination of additive manufacturing and tissue engineering, bioprinting embedded sensors in 3D-printed medical devices, drug delivery elements in functionally graded implants (either chemically or structural or porosity graded). These allow combining, for example, wear-resistant sections, maximum-strength sections and tissue-supporting sections in the same implant.

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[55] PEEK and PEKK set for most profitable segment in thermoplastics AM » (3dprintingmedia.network)

(c) **Functional materials** are mandatory for the development of the medical devices of the future. The basis is material science and biology. The future comprises regenerative medicine, cell therapy, nanomedicine, rehabilitation, and several other technologies at the interface of materials science, biology, and biomechanics among other areas. The functionality of biological structures (joints, muscles, nerves) or even complex solutions with function and structure integration, such as pro-angiogenesis solutions with tissue healing effects can be enabled. Other applications for functional materials are wearable devices for biomedical applications, advanced monitoring of heart rate and heart activity using flexible electronics, new sensors for monitoring temperature, oxygen saturation, blood pressure, activity level and calories burned, and integration into a universal sensor front end with multiple sensors for monitoring these parameters. Finally, materials adapted to new sterilization techniques such as X-Ray need to be developed to avoid the use of ethylene oxide.

Europe is a strong player in this sector at a scientific level, but getting developments to market is very challenging for companies due to the cost involved in product certification, the lack of suitable standards and suitable collaborations between low TRL players, industry, and clinicians. The development of efficient TRL multistage consortia, a relevant supply chain, appropriate standards and the training of notified bodies will be the basis of success.

3.3. Expected benefits

The future of healthcare will be based on quick and personalized diagnosis, more and more ambulatory interventions, personalised treatments, and a wide range of regenerative medicine. Our recent experience with the pandemic has demonstrated that, with a good knowledge base, a strong industry, and pragmatic behaviour of the authorities, the 'valley of death' in product development can be rapidly closed and that Europe is able to save thousands of lives. But our weaknesses have also been revealed: Europe has a strong knowledge-based capacity in material science, biochemistry, and biology, insufficiently promoted to be translated into industrial solutions. However, it clearly appears that Europe needs to:

- Promote the qualification, predicting and enhancing availability and lifetime of materials to support processes and design of medical devices.
- Develop multi-functional materials to target the above-mentioned applications: regenerative medicine, cell therapy, tissue engineering, drug delivery, sensing, and the combinations of several of these features into single products.
- Incorporate material science at all the stages of medical devices development to reach their full potential. There is a strong dependence on materials, processes, and design in the development of a medical device.
- Foster the presence of the entire supply chain in our development programs. The bottom-up approach is not enough to enhance the European potential in materials and medical devices. Communication between clinicians, medical doctors, industry, and researchers is key to ensure that materials and products are developed with the right key performance indicators they need to cut down access time to the market.

- Incorporate more top-down approaches coming from surgeons, nurses, hospitals, and industry in our research programs.
- Promote authorities' awareness and facilitate access to and training of notified bodies to advance to high TRL levels with the development of adapted standards and regulations.

Such an approach should lead to wider availability of qualified materials and processes to develop new generations of medical devices (for diagnosis or implants) and shorter and cost-effective qualifications to achieve a European leadership in Medical Devices.

EU sovereignty

Europe is strong in high-end diagnostic devices and other higher-value products but in consumptive materials depends on imports, mostly from China, as demonstrated during the COVID pandemic. Additive manufacturing has been used during the COVID period to produce tailored devices and could be more promoted in the future to increase EU sovereignty. EU has a lot of scientific know-how, but we have a gap in terms of transferring this know-how to the market in the shape of new materials, prostheses, and devices. SMEs have difficulties increasing the TRL, to achieve scale-up, don´t have the capital to invest and the documentation is very time-consuming. As mentioned, Europe has a relevant high-performing health industry (manufacturer of diagnostics and medical devices). Advanced materials as enablers may contribute to keep a leading role for this highly profitable EU industry.

Environmental footprint

Single-use articles should be improved since one of the consequences of the current COVID-19 pandemic has been a dramatic waste increase. There is no circular solution for handling waste from medical applications. Medical waste management can be classified as waste containing infectious materials (e.g. waste from hospitals and laboratories). Trends in the use of disposables have increased the use of plastics, generating more waste. There is a need to limit single-use instruments to urgent cases only and to develop procedures to recycle single-use devices or to re-sterilise them so that they can be reused, ensuring the avoidance of infections, instead of being handled by incineration. Manufacturers have started to recycle plastics, but its wastage is still a major challenge in the engineering materials market. Decontamination combined with recycling or alternatively microbial degradation should be further developed.

To improve the **environmental footprint of production processes** (eg. additive manufacturing), biomaterials and materials from renewable or natural sources could be developed, minimizing the quantity of materials used through intelligent product design. Also, there is a need to develop new separation and recycling technologies, and to increase the content of recycled materials in production processes. Not only materials, but also the processes have the potential to reduce their footprint through closed-loop recycling of materials and powders used for example in additive manufacturing, and by optimising the energy efficiency of production plants.

The medical industry strives to reduce its environmental footprint by developing safe and sustainable-by-design products that might reduce the environmental impact. **Sustainability should be firstly driven by increasing product shelf**

life to avoid frequent medical interventions (e.g. implants). The prediction of the product lifetime at laboratory stage should be close to real-life conditions. Early evaluation of the lifecycle assessment should be a screening tool for new materials and processes.

Strategic autonomy and resilience

The 2015 KET report on 3D-PRINTED MEDICAL DEVICES (Contract nr. EASME/COSME/2015/026) stipulates that Europe has all the necessary assets and key players to take on large production volumes in individualized medical AM products. A Pan-European approach to value chains and regulations in medical AM devices is necessary.

Sustainable value chain

New materials will play an essential role as enablers for future health technologies (to prevent, diagnose, monitor, treat and cure diseases); this includes using digital technologies in healthcare, in our response to today's health threats and even more so in the future. We want to unlock the full potential of advanced materials for health, new tools and technology, and notably digital medicine by developing health technologies, mitigating health risks, protecting populations, and promoting good health and well-being. It is important to:

- Redress our healthcare industry through innovation in materials, processes, and designs in strategic areas such as diagnostic, orthopaedics, medicines, organ regeneration and replacement towards fully sustainable value chains.
- Including the entire value chain from early stages of research and development to obtain improved transformation of research to product.
- Incorporating the needs coming from surgeons, hospitals, and industry in our research programs.

3.4. Expected socio-economic benefits

- Well-being, prevention and treatment of diseases, and **life expectancy** will be strongly impacted by advanced tailored implants, bioprinting organs, and engineered biomimetic tissues or organs. In vitro living systems or micro physiological systems, fluidic tools, and miniaturized neural drug delivery systems will strongly and positively influence the quality of life of the universal customer, the patient.
- Increasing the **lifetime of a durable implant** helps avoid patient pain and costly hospital interventions. 3D printing technology will play a greater role in the integration, customization, miniaturization, and the production of lab-on-chip devices for real-time diagnosis.
- Advanced materials, **preferably based on natural and renewable materials** and produced by sustainable production methods in an open and transparent manner, will open new avenues of low-footprint medical technology. The use of lifecycle environmental tools and control of toxicity and ecotoxicity will help design safe and 'sustainable-by-design' medical products.

3.5. EU industrial innovation capacities and future outlooks

In Europe there are very relevant industrial players: a) In medical devices, such as implants: Zimmer, Medtronic, Stryker, Microdent; b) In mobile for hospital: Stryker, Steris; c) In medical devices for diagnostics: Roche, Novartis; d) in Robots for surgery, for example, GE, B. Braun and Intuitive Surgical; e) In actives surfaces (e.g. Heraus for antibiotics surfaces, Rescoll,) and research institutions (BRTA, Fraunhofer, Politecnico di Torino, Dechema, CNR, IMDEA, CSIC, University of Salerno, Politecnico Milan, Cidetec, Inmat, Vito, Tekniker).

The EU has a huge potential in research and industry innovation (eg. personalized medicine), which needs to be further developed on the Pan European scale through synergies across EU national and regional programmes such as: EU4Health, Digital Europe Programme, European Regional Development Fund (ERDF), HealthTech4EU. **The barriers** to overcome are the following:

- **Healthcare social security systems** are increasing the price pressure across all nodes of the value chain, reducing the profit margins, leaving fewer opportunities for small and middle-sized players to survive and decreasing the interest of big players in less profitable devices, leaving rare pathologies without solutions.
- The **new regulation 'MDR'** is very demanding, particularly the clinical evidence needed to support the devices. Such demands will increase the market entry barriers resulting in a risk that a significant percentage of companies (around 15-20%) may partially abandon their product portfolio without renewing it. In addition, several companies have decided to stop their activities in the medical device market due to the new regulation. Some middle and big players have concentrated their effort on innovation in expected highly profitable projects to compensate for the cost increase or just stopped some basic research programs due to the need to focus on them. On the other hand, the number of surviving start-ups that bring innovation to the health care market is becoming more similar to the pharmaceutical market, where only highly profitable projects receive support in the long run.

4. Materials for Sustainable Construction Market

4.1. The Innovation Market size and trends

The **construction sector (**data ECTP) lays the foundation for the basic needs of EU citizens, spending around 90% on buildings and infrastructure that connects them. In Europe, it is one of the largest employers, with 14.8 million jobs and a turnover of € 101.1 billion, representing 9% of the Gross Domestic Product (GDP). The sector involves 3.3 million companies, of which there are 2.7 million SMEs, 95% with less than 20 workers. The construction industry is of fundamental importance to the EU economy. 5% of European workers are directly employed in the construction sector. 1.8% of GDP is invested annually in infrastructures.

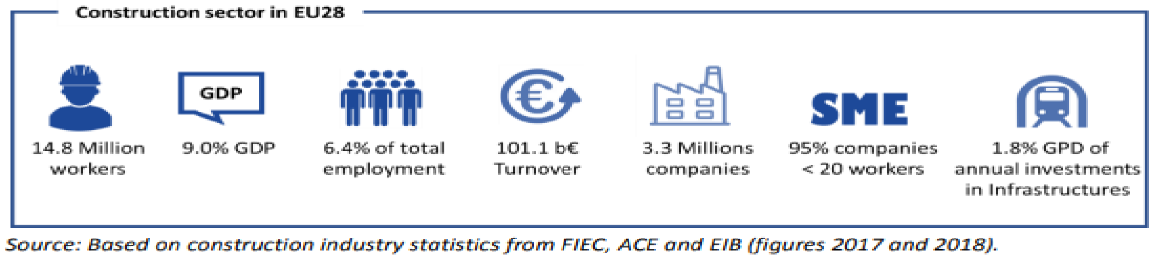

Figure 8: *Construction Sector in EU28*[56]

According to the EU-funded iBRoad project – The Building Renovation Roadmap, 97% of the EU's building stock (which amounts to **over 30 billion m²) is not considered energy efficient, and 75-85 %** of this stock will still be **in use in 2050**. **The ambition** of ECTP is to reach at mid-term a **4-5% renovation rate** in Europe by 2027, with 0.5% growth rate/year to achieve rapid growth in replacing particularly inefficient and **carbon-intensive buildings through developing appropriate innovation partnerships and business models.** Furthermore, other infrastructures (eg. bridges, roads, railways, ports) are not sufficiently efficient, durable, and safe that claim for urgent investment in maintenance, repair, and adaptation to future needs in transport mobility. Infrastructures for new renewable energy sources, such as offshore windmills that need to be durable, working in severe operating environments.

The European market for building energy efficient products and services is estimated to rise to **€80 billion by 2023. Smart building technologies** such as Building Integrated PV, advanced insulation, smart lighting, advanced glazing, and façade systems etc. The global spending on smart building technologies is expected to steadily grow till €116,8 billion by 2030[57]. The share of advanced materials (insulation, new advanced glasses, thermal energy storage, lighting...) is high and growing more than 5%/year. Building Thermal Insulation Market size is valued at €21,16 billion in 2021 and is anticipated to progress at over 5.7% CAGR from 2022 to 2028, with Europe being the largest market.[58] Strict regulations & policies formulated to reduce greenhouse gas emissions by legal bodies along with rapidly changing climate conditions across the globe will augment industry demand. The energy-efficient building market has been segmented by components into ventilation systems, lighting technology, energy management and controls, and by customers into industrial, commercial, and residential markets. The European construction market is affected by following trends:

- **Population growth:** It is forecasted that Europe will have 21 million inhabitants more in 2030 compared to 2010.[59] Building sector will need to recycle materials waste, use secondary materials, and develop more energy-efficient solutions.

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[56] Construction sector in EU28. http://www.ectp.org/
[57] Data provided by EMIRI, 2022
[58] Building Thermal Insulation Market Size, 2028 Forecast Report (gminsights.com)
[59] EUROSTAT statistics

- **Increasing rural-urban** migration is ongoing and will lead cities to grow rapidly. Solutions to revert this tendency will be welcome. Hybrid private-public transport, connected with smart lights and energy-efficient devices, will be needed.
- Some trends are found to show migration to bigger cities (mobility) or bigger farms (agriculture). To retain people in rural area requires better infrastructure, mobility and connectivity.
- Construction industry sees increasing adoption of materials innovation (e.g. PV integration and energy harvesting, wood transformation to natural materials market).
- According to existing infrastructure, there will be a huge need for (energetic) renovation of residential and commercial housing (e.g. smart windows, panels with phase change materials).

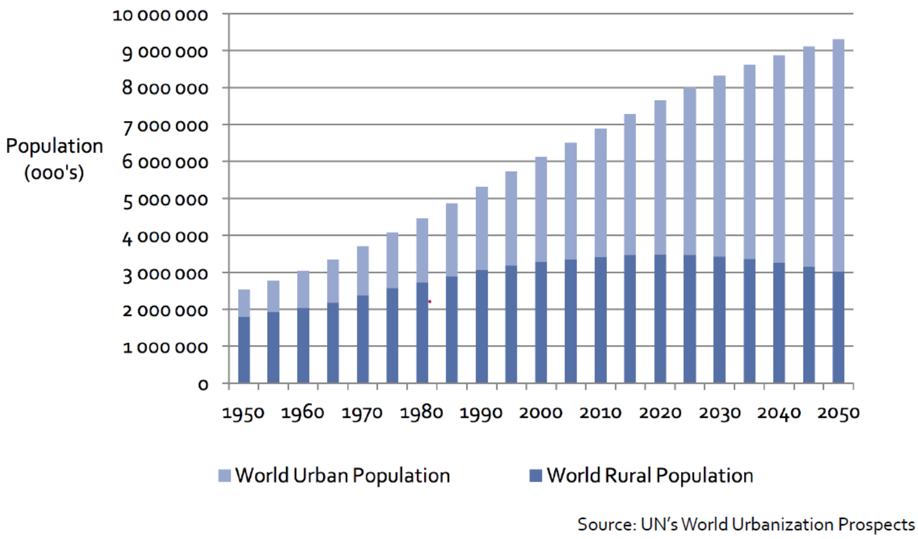

Figure 9: *World Population Prospects*[58]

4.2. The Materials challenges and priority Areas

Based on an initial discussion among the four contributing ETPs (EMIRI, EUMAT, SusChem and ETCP), there are four material applications to define the materials challenges and priorities **for Sustainable Construction**, including non-exhaustive needs for materials development:

1.- Materials for improved energy efficiency

- **Lightweight construction and design for hybrid structures** (e.g. Composites, light metal joints and coatings, aggregate or aerated autoclave concrete, high performance concrete to reduce volume and maintenance cost).
- **Lightweight composite foams** or non-structural foam concrete.
- **Thermal insulation materials & infrastructures** (e.g. energy-efficient massive concrete structures, use of phase change materials, controlling temperature evolution by curing, cooling (hot weather) or heating (cold weather) of concrete raw materials to target a given temperature, and high performance aerogel insulation materials.

- **Advanced materials for thermal energy storage** and for district heating and cooling applications.
- **Multifunctional lightweight materials** (including functionalization by nanotechnology).
- New generation of non inboundable/non-reactive additives (e.g. Blowing agents).
- Cool materials and passive cooling systems (such as ventilated and permeable roof) to decrease the energy demand of building and increase the indoor comfort during hot seasons.

2.- Materials with and for an increased sustainability and circularity

- **Sustainable construction materials (e.g.** Green and ecofriendly concrete, composite eco-design, biomaterials for resins and binders such as bioconcrete, demineralization with self-healing properties, ecofriendly ceramic bricks and tiles, fibers and additives, recycled materials, maximizing the use of waste in concrete or enhanced use of geopolymers).
- **Safe and sustainable by design additives (e.g. additives for circularity,** waste recycling as alternative to mining, sustainable and non-harmful additives for lighter materials, faster assessment of waste materials).
- **Asphalt concrete** using reclaimed asphalt pavement (RAP), slags, bauxite, lignin etc.
- **New recyclable materials and recycling processes** (e.g. new materials from industrial **symbiosis practices** with other industries, new construction and demolition waste materials/new circular construction materials, recyclability for flame retarded systems, **new recyclable** paints, lubricants, inks, toners, and coatings.
- Development of single-materials solutions.

3.- Materials with improved product and overall low carbon footprints

- New materials and additives from renewable/local sources.
- Process simulation and automatization.
- **Electrification of production process** for construction materials (e.g. Cement, ceramic, tiles).
- New materials for 3DP/Additive manufacturing.
- Low carbon foot-print and high-performance concrete (e.g. precast concrete to increase the rate of industrialized production).
- Alternative and sustainable binders **for low carbon footprint (**e.g. new alternative routes for cements as clay cements or optimizing mineral additions from different sources, low clinker cement)**.**
- Wood, cellulose, and lignin derived materials.
- **Pre-fabrication and modular** construction (e.g. Composites, ceramics, metallic structures).
- Increase materials for construction durability to maximize lifespan time.

- Sustainable colourant materials (photonic pigments) to substitute currently used inorganic and organic pigments.
- Optimization of materials formulation and manufacturing or processing conditions, using machine-learning and artificial intelligence-based techniques.

4.- Materials with new functionalities / Smart materials

- **Corrosion protection** green coatings, additives, or encapsulated inhibitors.
- **New materials for increased comfort** (e.g. Odour and thermohydrometric control).
- Advanced materials for lighting technologies (e.g. LED, OLED).
- Advanced materials for electrochromic active dynamic glazing.
- Develop transparent oxide-based electronics **to glass windows.**
- Materials and metamaterials for noise reduction.
- Fire resistance and thermal insulation materials.
- Smart fiber-reinforced concrete & composite materials.
- Antislippery materials for safety floorings.

Other materials applications of interest to construction markets that have been addressed in other markets:

- Advanced **surfaces and filters for water** and air purification. See **agriculture** market.
- Advanced **textiles and fabrics** (2D/3D woven with integrated functionalities; air cleaning, sensing, light emitting). See **textile market.**
- Flexible, conformable, and mobile platforms. See **electronics** market.
- Energy harvesting for powering smart interfaces. See **electronics** market.
- Embedded Photovoltaic (BIPV) in windows and roofs. See energy market.
- Concentrate Solar thermal (CSP) in energy-efficient buildings. See energy market.
- Cross-cutting aspects in horizontal section.

All four priorities need to be developed and supported as they contribute to the transition of the construction industry to a more sustainable one.

4.3. Expected benefits

EU sovereignty

It is noteworthy to mention that 40% of the worldwide top-30 contractors are from the EU. Net positive Energy Buildings and infrastructures can be developed using smart technologies in the design phase of façades, buildings, bridges, or marine infrastructures, with the potential to reduce Europe's overall energy consumption by up to 10%. The Building Market Report Summaries reports the most active countries in Buildings.

By Geography	• North America (U.S. and Canada) • Europe (UK, Germany, France, Italy, Spain, Russia, and Rest of Europe) • Asia Pacific (Japan, China, India, Australia, Southeast-Asia, and Rest of Asia-Pacific) • Latin America (Mexico, Brazil, and Rest of Latin America) • Middle-East & Africa (South Africa, G.C.C., and Rest of Middle East & Africa)

Even though the construction industry relies mainly on regional supply chains, e.g. for cement, EU consumption is mostly satisfied by EU production. However, sand and gravel are the most extracted materials worldwide. In the light of increasing demand for infrastructure by other regions, this creates supply chain problems globally, which increasingly affect the EU also. Successful development and implementation of circular practices into the sector would contribute to technology and material sovereignty.

Environmental footprint

The built environment is responsible for a significant share of our consumption of energy and resources: 50% of all extracted materials, 30% of water consumption, 40% of energy consumption and 36% of Green House Emissions (GHG) in the use phase. At the same time, the embodied carbon in the built environment has been estimated to be 10-12 % of total carbon emissions in several member states. Construction and deconstruction/demolition waste are one of the heaviest and most voluminous (25%-30%) waste streams generated by the EU. Around 75% of the buildings are energy-inefficient due to a number of shortcomings, including lack of maintenance and insufficient investment, defective construction, either through an inappropriate choice of materials or due to a lack of professional expertise, change of use, outdatedness of the building, and others. Europe's energy-inefficient building stock is huge and, with the current rate of renovation of around 1% of buildings each year, it would take a century to upgrade the building stock to modern, near-zero energy levels. There is a crucial need of innovation to improve the situation and deploy energy-efficient and low-carbon materials solutions in the built environment, to avoid an ever-increasing inefficient buildings stock in the next decades.

Advanced materials have an impact on certain stages of the value creation: directly, by using as construction materials and their effect on indoor environmental quality and pollution. Indirectly, by their impact on energy consumption during their manufacture and transportation to construction sites and during the use phase. Buildings represent the largest sinks of materials. It is of fundamental importance to first make this pool transparent and to use it in a circular manner.

Sustainable value chain

Besides energy aspects in the EU, construction and demolition activities include a wide range of materials such as excavation materials, construction, and maintenance materials (concrete, bricks, wood, glass, metal, plastics). Construction and demolition waste (CDW) accounts for more than a third of all waste generated in the EU. Therefore, it is a priority waste stream to deal with[60]. Finding solutions to increase energy efficiency and circularity of materials would have a high impact on the sustainability of the construction value chain in the EU.

4.4. Expected socio-economic benefits

Zero-Energy Buildings (ZEB) and Plus Energy Buildings (PEB) with novel energy and insulation materials will need to be further developed for achieving EU policy goals. Both residential and commercial applications are emerging as areas offering strong growth potential. There is a need of better designed, energy efficient and healthy buildings for citizens to enjoy a citizen-friendly built environment with low energy cost.

4.5. EU industrial innovation capacities and future outlooks

Energy-Efficient Building Market Report summaries detailed information by Top Players such as Cleantech Group, Siemens Building Technologies, Johnson Controls, Ameresco, Serious Energy. The presence of a deep chemical, materials and construction value chain with a well-developed building industry and the advanced expertise in Europe's world-leading RTOs and Open innovation Test Beds bodes well for the EU. As do members of EUMAT and ECTP Materials working group (IMEC, Fraunhofer, Juelich, CEA, FZ, Nobatek, Tekniker, Torroja-CSIC, Acciona, Heidelberg Cement, CEMOSA, INDRA, Univ. Politecnica delle Marche, UNIBO, IETCC-CSIC, Ouzo, Univ. Univ. Stuttgart, VTT, Stam, EMI, Tecnalia, Stress, CEFIC, VITO, ITC, Metabuilding labs). All these provide a key competitive advantage to Europe.

Advances in digital technologies are seizing opportunities in all aspects of construction value creation. Building Information Modelling (BIM) systems are increasingly used not only for design aspects but for all segments of a circular construction industry. Europe has a moderate position in that technology field but needs to develop further.

5. Materials for New Energies Market

5.1. The Innovation Market size and trends

The energy sector today is the source of around 75% of greenhouse gas emissions. It holds the key to averting the worst effects of climate change, perhaps the greatest challenge humankind has faced. As highlighted by the International Energy Agency in the Net Zero by 2050 report[61], reducing global carbon dioxide (CO_2) emissions to net zero by 2050 is consistent with efforts to limit the long-term increase in average global temperatures to 1.5°C. This requires a complete transformation of how we produce, transport, and consume energy. Reaching net zero by 2050 requires rapid deployment of available technologies as well as

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[60] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives
[61] Net Zero by 2050 – Analysis - IEA

widespread use of technologies that are not on the market yet. Major materials innovation efforts must occur over this decade to bring these new technologies to market intime. Industries producing key materials (steel, refinery products, fertilisers and cement) and chemicals emit around 500 million tonnes of CO_2 a year, 14% of the EU total.[62] The implementation of energy efficient Renewable energy is a fundamental pillar to reach a Sustainable industry, Construction and transport sectors.[63]

By 2050, it is expected that the energy sector is dominated by renewables, materials representing between 50-70% of the energy market turnover. In the net zero pathway, global energy demand in 2050 should be around 8% smaller than today, serving an economy growth more than twice, and a population with 2 billion more people. In 2050, the energy sector will be largely based on renewable energy. 66% of total energy supply in 2050 will be from wind, solar, bioenergy, geothermal and hydro energy, solar accounting for 20% of energy supplies. Solar PV capacity will increase 20-fold, and wind power 11-fold. Fossil fuels will fall from almost 80% to slightly over 20% of the total energy supply. Fossil fuels will be mixed with alternative fuels or used in goods where the carbon is embodied in the product such as plastics, in facilities fitted with CCUS, and in sectors where low-emissions technology options are scarce. The next generation of nuclear reactors, will need to operate at higher temperature to produce heat for industrial use without GHG emission. Electricity will account for almost 50% of total energy consumption, playing a key role across all sectors – from transport and buildings to industry –to reduce emissions such as green hydrogen. Electricity generation will increase over 2,5 times, with almost 90% of electricity generation coming from renewable sources, with wind and solar PV together accounting for nearly 70%. The remainder will be nuclear origin, with a similar installed capacity, now (data from National Climate and Energy Plans) prepared by EU member states (2019-20). Cutting industry emissions by 95% by 2050 involves major efforts to build new infrastructure. After rapid innovation progress deployment between now and 2030 to bring new clean technologies to market. Every month from 2030 onwards, ten heavy industrial plants will be equipped with CCUS, 3 new hydrogen-based industrial plants will be built, and 2GW of electrolyser capacity will be added at industrial sites and several nuclear new builds of third generation are already planned.

Hydrogen Production. The EU production capacity via electrolysis is expected to be about 11GW by 2030. Considering a capital cost of an electrolyser at 276 €/kW, and that electrolysis stack cost can be about 45% of the capital cost of an electrolyser, and that more than 50% of the stack cost is due to active materials, we estimate the cumulative market in EU for advanced materials for Polymer Electrolyte Membrane (PEM) electrolysis to be at €759 Million. Adding other advanced materials (plates, diffusion, layers, sealants) that can also cover the non-PEM technologies, it is possible to reach a cumulative market for advanced materials of € 5-7 Billion range. Over 2030-40 period, capacity in EU could grow about 71GW for PEM electrolysis at 230 €/kW, and adding non-PEM technologies,

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[62] According to ETS greenhouse gas inventories, 2019.
[63] European Commission, Directorate-General for Research and Innovation, ERA industrial technology roadmap for low-carbon technologies in energy-intensive industries, 2022, https://data.europa.eu/doi/10.2777/92567

materials market in EU can reach €27,6 billion range. Recently, the RePower EU document indicated that the EU has just multiplied by 4 its target for 2030, corresponding to 160 GW of installed electrolysers. In addition, nuclear energy can be used to make hydrogen electrolytically, and in the future high-temperature reactors are likely to be usable to make it thermochemically. Existing nuclear plants can indeed produce high quality steam at lower costs than natural gas boilers, which can be electrolyzed (using the high- capacity factor electricity production of nuclear power plants) and split into pure hydrogen and oxygen. A single current 1 GW nuclear reactor can produce about 150,000 tonnes of hydrogen each year, with an achievable target cost of 1 €/kg of hydrogen within one decade. This is called yellow or pink hydrogen.

Gas Market. As highlighted by ArcelorMittal, the backbone for H_2 (including re-using existing lines) for transport should reach 40.000km by 2040. The complete infrastructure to transport hydrogen will reach 12.500km by 2040 with an estimated investment between € 43-81 billion[64]. It is not clear to which level the materials of the old pipes can be used and the development of computational models and characterization techniques capable of identifying potential problems will be key to find suitable materials solutions where needed. REPowerEU diversifies the EU's gas supplies as the first action to increase EU energy independence. Biomethane is recognized as a sustainable alternative to natural gas. The document proposes a EU target to produce 35 billion cubic meters (bcm) of biomethane by 2030, which compares to 18bcm of biogas produced in 2020. The document calls for Member States' CAP strategic plans "to channel funding to biomethane produced from sustainable biomass sources, including agricultural wastes and residues. Contaminants like siloxanes in biomethane, and corrosion and high temperature resistance of the burners are key challenges in this market. The EU wholesale gas prices have increased 14-fold since December 2020. Russia's aggression in Ukraine has greatly exacerbated the situation; prices have more than tripled over the past two weeks alone. They now stand at 270 €/MWh, vs 19 €/MWh in December 2020. Mixture of gas with hydrogen could be a solution, but again compatibility with materials (eg. Hydrogen enfragilization resistance) needs to be further studied.

EU solar energy market by 2030 (Solar Power Europe)[65] would become 672GW corresponding to 40% renewables target. Current EU prices for residential instalment cost are ca 1,2€/Wp. Materials represent more than 60% of the total cost of a Photovoltaic (PV) module. At EU level, the overall PV market increase rate will be about 60GW per year. In 2030, 20% of the PV 'consumed' will be dedicated to this market which needs adapted products to be installed 'everywhere'. Cost will be around 0,3 €/W, assuming 80% bill of the materials. The innovation market of advanced materials for 'Customized modules for dedicated applications' is therefore estimated at € 3 billion in 2030 and €11 billion in 2050 (with 60% market share). Today, in Europe, 3% of the electricity consumed comes from solar power. In 2030, 15% will come from PV and it will increase up to 30-40% in 2050. With the expected growth in PV electricity in the energy system, the share of Concentrated Solar Power (CSP) electricity in global electricity production will also increase to allow for grid stability (IEA 2020: World

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[64] https://www.ehb.eu/files/downloads/ehb-report-220428-17h00-interactive-1.pdf
[65] Solar-Powering EU Energy Independence - SolarPower Europe

Energy Outlook 2020). To be able to increase the share of renewable energy in the overall electricity mix to 44% worldwide in 2040, 3 kWh of CSP electricity will be required for every 100 kWh of PV electricity. With an even higher share of renewable energies of 67%, there would be 9 kWh of CSP electricity for every 100 kWh of PV electricity. To achieve this, the output of CSP power plants installed today would have to be increased 30-fold – to about 180 GW. A study by Teske confirms this fundamental relationship and predicts a sharp increase in the expansion of CSP in the period from 2030-40.[66]

Wind energy market. By 2030, the EU will need 451GW of wind power up from 180 GW in 2021. Total installed cost in 2017 for onshore turbines is 1300€/kW, and for offshore 4200€/kW. The wind turbine represents 64 % of this cost, being the material cost roughly 23%. Global wind capacity increased by 14% annually, on average, from 2010 to 2020, reaching 743 GW in 2020.[67] The EU's electricity system will be more than double by 2050. It will grow to 6,800 TWh up from 3,000 TWh today. Wind energy will be 50% of the EU's electricity mix by 2050. Some of the materials challenges in wind, should take into account the use of renewable lubricants, with increased lifetime and energy efficiency of the transmission, the development anti-ice and antifriction blade coatings, the scale up of composite production and the increase of corrosion resistance of windmill components especially for offshore windmills.

Permanent Magnetic markets. Europe used 16 kt of rare earths in 2020, and most of them were used to manufacture permanent magnets (NdFeB). The market size is today around €6.5 billion, but it is still increasing due to the massive electrification of the automotive industry, with a market of 1-2 billion euros. If new magnet composition is successfully developed by 2030 (Nd1Fe12 phases, NdFeMo, high entropy alloys) this PM magnet could be widely applied, also in offshore wind energy and in industry (defence, robotization), representing a market of €2 billion in Europe. Moreover, it may also reach international markets, rising then up to € 8 billion.

5.2. Materials challenges and priority areas

The transition of the energy system will rely on reducing the overall energy demand and making the energy supply side climate neutral. Transport and buildings - on the demand side - being addressed by other MIMs, advanced materials priorities for the MIM 'New Energy' focus on the challenges of the global transition to renewables and low GHG emission, (i) to produce and (ii) integrate higher shares of renewable power in the energy system, and (iii) to reduce the carbon footprint of energy-intensive industries. The detail of the Materials for low carbon Energy can be found in EMIRI Roadmap[68]. The priorities can be divided in:

- **Advanced materials for renewable and low-GHG-emission energy production technologies** (Solar PV, CSP, wind, bioenergy, geothermal…) – Surface treatments to enhance solar adsorption, antierosion, anti-ice and anticorrosion protection and thermal barrier coatings will contribute to

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[66] a) Teske Global Outlook 2016 | PDF | Renewable Energy | Solar Power (scribd.com). b) Concentrated Solar Power (CSP) – Analysis - IEA
[67] It's official: The EU Commission wants 30 GW a year of new wind up to 2030 | WindEurope
[68] https://www.emiri.eu; EMIRI-Technology-Roadmap-September-2019-cond-1.pdf

making the energy supply side cleaner, more secure, and more competitive by further boosting cost and performance in a broad portfolio of renewable energy solutions, in line with societal needs and preferences. Reliability, performance and durability of components and systems will be particularly enhanced by developing innovative materials that are able to withstand degradation in operation. This is especially harsh in the case of operating under conditions of high temperature, high pressure, extreme loading, contact with aggressive chemicals and also irradiation environments. Some examples for this priority are: a) nanocomposites and heat transfer fluids; like ionic melts, including nanosalts; b) increased lifetime functional coatings for offshore applications; c) new steels for improved corrosion resistance, d) hydrogen embrittlement resistant steel coatings; e) green steels.

- **Advanced materials for energy storage,** facilitating the integration of renewable energy - Advanced materials for hydrogen generation, conversion and use and advanced batteries. Developments are also needed to allow the energy networks to support energy system integration, including the progressive electrification of demand side sectors (buildings, mobility, industry) and integration with the low-emission energy carriers. Other innovative energy storage solutions (including chemical, mechanical, electrical, and thermal storage) require innovative materials that are a key element of such flexible and reliable energy system. Some examples are: a) post Li battery technologies (e.g. Na, K, ion), b) biobased carbon and non-scarce metal compounds for higher energy supercapacitors, c) Silicon and Carbon based chemistries for LiBs anodes, d) Functional metal foams for electrocatalysis (e.g. hydrogen production), d) new electrolytes, including solid state electrolytes based on green chemistry, e) tools to enhance battery second life and components recycling, f) proton and anion exchange membrane fuel cells, g) liquid organic hydrogen carriers.

- **Advanced materials for sustainable transformation of energy-intensive industrial processes** - new technologies and new sustainable processes, such as Carbon Capture, Storage and Utilization (CCSU) or the electrification of energy-intensive processes, will enable industry to reduce energy and resource consumption, decarbonize production processes, and protect the environment. Innovation also needs to be accompanied by the large-scale construction/revamping of the infrastructure the technologies will need. This includes new pipelines to transport of gas hydrogen between ports and industrial zones. Affordability of these technologies and infrastructures will however heavily depend on the development of innovative, long-life and performant materials operating under harsh conditions. Some examples are: a) porous materials for carbon dioxide capture and conversion into added value chemicals; b) electrocatalytic and catalyst materials free of critical raw materials; c) clean synthesis routes of porous materials (e.g. metallic foams) based on green chemicals; d) thermo-electric elements and materials for heat transfer for the conversion of (lost) heat energy to electricity.

Common interest with other markets

- Batteries for electromobility. See transport
- Power electronics interesting also for wind applications. See transport.

5.3. Expected benefits

EU sovereignty and strategic autonomy

While Europe was pioneer in Photovoltaic development, nowadays, China is dominating the low-cost PV market. Europe needs to recover their position, pushed by the huge EU-demand of PV panels and due to logistic problems of supply from Asiatic countries. Dramatically raising the share of renewables in total energy production will obviously improve Europe's energy supply security. However, the energy transition requires substantial quantities of critical raw materials minerals (CRM): the total market size of critical minerals like copper, cobalt, manganese, and various rare earth metals could grow almost sevenfold between 2020 and 2030 in the net zero pathway. In order not to undermine our energy security, important innovation actions are required to minimise EU dependency on CRM. Substitution of CRM when possible and a more circular economy will make Europe less dependent on external imports, boosting its resilience. Importantly, circularity and reduced dependence on critical minerals is not only enhanced by developing recycling and reuse technologies that start with the conception of the component and end with its dismantling, but also by increasing as much as possible the component lifetime. This requires the development of degradation resistant materials, which is especially critical in the case of harsh operating conditions. The market size for rare earths is today around €6.5 billion, but downstream leverage is enormous. Thus, massive downstream market value and many jobs are at risk, since 98% of these magnets are manufactured in China. Recycling used magnets and processing rare earths oxides in Europe will increase our sovereignty (we could refer to the rare earth crisis of 2011).

Carbon capture, storage, and utilization (CCSU), solar micro-refineries that capture CO_2 to produce e-fuels, e-cracking to produce hydrocarbons, advanced recycling of plastic waste to feedstock (pyrolysis oil) and other advanced manufacturing technologies will enable to effectively decarbonize Europe's chemical value chains. The EU has a high interest to have a competitive low carbon, safe and circular chemical industry in Europe for domestic use and to capture global market share. The future proof production of chemicals will depend on capturing the carbon from the vent stacks of the manufacturing installations and converting the CO_2 back to feedstock materials. Combining this with full electrification based on renewable energy and nuclear will result in a net zero chemical industry with a much lower dependence on imported fossil-based feedstock. The costs of wind energy will continue to decline significantly over the next 30 years thanks to rising turbine size and capacity factors and optimised ways of installing and operating wind farms. Developments in materials (copper, fiberglass and iron), accounts for a big share of the 30% of reduction achieved from 2015-17.[69]

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[69]Wind turbine cost reduction: A detailed bottom-up analysis of innovation drivers; A. Elia, M. Taylor, B. Ó Gallachóir, F. Rogan; Energy Policy **147,** 111912 (2020)

A Clean Hydrogen Alliance will be established to accelerate the decarbonisation of industry and maintain industrial leadership, followed by Alliances on Low-Carbon Industries and on Industrial Clouds and Platforms and raw materials.[70] Increase of resilience can benefit EU sovereignty. This can be achieved reducing friction and energy consumption, increasing the energy efficiency, and improving wear resistance. Measures on the demand side, can be highlighted, e.g. a) using smart devices with energy harvesting capabilities, b) hybridization (eg. between wind and solar energy), combining with storage facilities and c) energy symbiosis.

Environmental footprint

Sustainable-by-design advanced materials and technologies will enable the switch to decarbonisation of the energy and all major emitting industrial sectors. The pressing need to tackle several sustainability challenges, notably climate change and environmental impacts, creates opportunities supporting economies, industries and the environment while also reducing dependencies by shortening and diversifying supply chains. The technologies covered in the priority areas will enable industry to reduce energy and resource consumption, decarbonise production processes, and protect the environment. The huge volumes of materials used in batteries, solar panels, wind blades, e-motors, etc. will soon require switching from linear to fully circular production and consumption to reduce the billions of tonnes of waste that go to landfill every year. Environmental advantages of **green hydrogen** production over pink (from nuclear) or blue hydrogen production (produced from fossil fuels with later carbon capture) are a clearly lower environmental footprint. Economical & consumer advantages of green or pink hydrogen will be driven by decarbonization trends and rising price of fossil fuels (green or pink hydrogen production could be cheaper than blue hydrogen by the early 2030s). Higher efficiency of solar panels, capable of generating more energy per square meter and thus requiring less overall area, will result in a lower LCOE, reduced carbon footprint, and improve EU energy sovereignty for electricity generation, with a reduced usage of critical raw materials. CSP requires almost no CRM either for power generation or for storage which is provided in simple molten salts. Nuclear also requires almost no CRM and can provide high quantity of electricity and, in the future, hydrogen and heat, at capacity factors higher than 90%.

Sustainable value chain

The EU industrial strategy aims at reinforcing Europe's industrial leadership and increased autonomy in key strategic value chains with security of supply in raw materials, achieved through breakthrough technologies in areas of industrial alliances, dynamic industrial innovation ecosystems and advanced solutions for substitution, resource and energy efficiency, effective reuse and recycling and clean primary production of raw materials, including critical raw materials and leadership in circular economy. This strategy is supporting the Energy sector, with Industrial Alliances in place on Batteries, Hydrogen and Energy-Intensive Industries. Building also on the European Raw Materials Alliance, access to primary and secondary raw materials and the development of Europe's own value chain, when possible, in critical raw materials, will remain a vital prerequisite for both

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https://doi.org/10.1016/j.enpol.2020.111912.

[70] Energy-intensive industries (europa.eu)

Europe’s strategic security and a successful transition to a climate-neutral and circular economy.

5.4. Expected socio-economic benefits

- The EU Commission published the REPowerEU: Joint European action for more affordable, secure, and sustainable energy.[71] This Communication aims to support the EU’s energy independence by accelerating the deployment of renewables and ensuring the affordability and security of energy supply.
- Developments of new materials **for solar applications**, enabling the development of upcoming technologies (e.g. high-efficiency crystalline silicon, post silicon solutions, flexible **photovoltaics** (**PV)**, tandem, BIPV) will reduce the ecological footprint and increase the recyclability of module components. The use of surfaces already artificialized (industry, buildings) is a tremendous opportunity to install PV modules and can deliver a range of social and economic benefits to local communities, increasing autonomy & empowerment. The synergy between agriculture and photovoltaic to enhance food production and at the same time produce electricity represents a win-win situation. CSP can store large amounts of energy (GWh) very cost-effectively and dispatch it reliably and can be used to store high temperature heat (>400°C) in industries.
- The **costs of wind energy** will decline thanks to rising turbine size and capacity factors, reducing friction and optimising wind farms control and operation, using sensors for advanced maintenance. New **permanent magnets** will encompass sustainable windmills.
- Current requirements on the **gas composition of CO_2 and H_2** for the safety of the transport and storage infrastructure, with high impact on CO_2 capture cost will require new materials for energy intensive industries.

5.5. EU industrial innovation capacities and future outlooks

EU can build on a strong industrial basis of advanced materials players (Umicore, Heraeus, Johnson Matthey, Agfa, Bekaert, Solvay, Imerys, Anglo American,..) as well as start-ups. There is however a strong global competition in electrolysis technology with USA and Asia in the lead. EU-based players further down the value chain (producers and users of electrolysers McPhy, Siemens, ITM Power, Linde, NEL, Hydrogenics / Cummins) are eager for EU technologies manufactured at scale and reducing EU's vulnerabilities and dependencies (in frame of EU's open strategic autonomy). EU-based research organizations have strong activities in the field of electrolysis technologies and can be a strong lever to fast-track technology development in the EU.

Lower dependence on natural gas and naphtha, will have a positive impact on climate change and carbon footprint reduction potential of hundreds of millions

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[71] Communication from the Commission to the European Parliament , the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions - REPowerEU Plan, COM/2022/230 final; https://eur-lex.europa.eu/

of tons. The availability of low carbon chemicals and advanced materials will enable a more sustainable society through application across the 9 markets ranging from personal care ingredients to solutions for LED lighting, EV batteries, energy efficient buildings and electronics. The EU counts with many of the largest and stronger steel and pipe manufacturers (ArcelorMittal, Salzgitter, ThyssenKrupp, Dillingen, Europipe, Corinth Pipe Works, Acerinox, Sidenor). The challenges are to assess the embrittlement and determine the boundaries in terms of material requirements, gas composition and applied pressure. Lower dependence on natural gas and naphtha, with a positive impact on climate change with a scope of carbon footprint reduction potential of hundreds of millions of tons.

In Solar energy (PV, CSP) we can rely on several companies and start-ups. For PV, there is a strong competition in China, Asia, coming also from US and India but companies like Wacker, Oxford PV, Enel, Meyer Burger are well positioned. EU-based research organizations also have strong activities in the field of high-performance cells and can be a strong lever to fast-track industrialization in EU (CEA, TNO, HZB, IPVF, Fraunhofer ISE, Tekniker, Leitat, IREC, etc). Barriers to entry are high (CAPEX intensive). For CSP, European industry is the clear leader in this technology and our companies[72] (Belgian, German, Spanish or Danish) install CSP plants of any technology all over the world. European Research Centres[73] are also at the forefront of the technology.

In **Permanent magnets**, EU can build on a strong industrial basis of permanent magnet players (Vac, Magneti, Silmet…) as well as start-ups (Magree Source, Caremag, REEFine, Neo Performance Materials…). European capacity is today at 1kt/year and could rise quickly in 2027 to 7 kt/year. There is a strong global competition in permanent magnets with China/Japan and with USA (which supports the Mountain Pass project). European RTO and academics have activities in the field of permanent magnets and can be a strong lever to fast-track SSBs development in the EU.

Strong industrial capabilities in advanced materials for the Energy Innovation market are present in Europe, with an important number of industrial and technological research stakeholders. China's still lead low cost processing of clean energy metals, and it is leading the supply of the world's critical minerals for the green revolution, being Europe concentrated in of value added materials and processes. Further developing a strong industrial competitive edge in these sectors of the future will ensure that European companies can respond to the rising demand of advanced manufacturing technologies (additive, subtractive) and ecologically designed products and services around the world. More investment and increased collaborations are needed to reach the ambitious 2030 and 2050 goals.

Materials development might be accelerated using digital technologies and advanced modelling and characterization tools to support their scale up and adoption in industrial value-chains and strategic innovation markets.

[72] https://estelasolar.org/members-directory
[73] a) https://www.eera-csp.eu; b) https://www.emiri.eu

6. Materials for Sustainable Transport Market

6.1. The Innovation Market size and trends

Transitioning towards sustainable transport will require improving vehicle efficiency and adopting zero/low carbon vehicle and fuel technologies. Innovation can accelerate the transition by cutting costs, promoting technology learning, reducing materials weight, and improving performance of both conventional and zero-emission vehicles (alternative fuels, hybrid, battery, or fuel cell electric).

Competitive transport systems are vital for Europe's ability to compete in the world, for economic growth, job creation and for people's everyday quality of life. Over the past 60 years, EU transport has progressed substantially and continues to make a significant contribution to European prosperity and employment. The industry now employs around 10 million people, accounting for 4.5% of total employment in the EU and creating also 4.5% of gross domestic product (GDP). Smooth transport connections are also vital to the EU's economy in terms of its exports — shipping carries 90 % of the EU's foreign trade. Many European companies are world leaders in infrastructure, logistics and the manufacture of transport equipment. EU households today spend 13.5 % of their income on transport-related goods and services, such as season rail tickets and holiday or business flights, making transport the second-largest item in their household budgets after house-related expenditure.

Advanced batteries for electrical vehicles (EVs): By 2030, a cumulative market for mobility-oriented advanced batteries of close to 11000 GWh is expected globally, of which EU represents about 30% (3250 GWh). Several gigafactories (with today's technology) are planned in Europe (e.g. Tesla in Germany), and technological progress is moving fast. With an advanced battery cell price estimated at about 69 €/kWh in 2030, the low-range estimation of this cumulative market for mobility-oriented advanced batteries cells is at €759 billion globally and about €230 billion for the EU by 2030, of which ~70% will be dedicated to advanced materials. Advanced materials for battery assembly and fire protection could represent an additional market projected to be worth €184 billion by 2030.

Cost Competitive hydrogen fuel cells systems for EVs (FCEVS). Transport modes such as trucks, buses, maritime and locomotive applications, may particularly benefit from fuel cell rather than pure electric, battery-based drivetrains. Airbus has announced airplanes powered by hydrogen combustion by 2035. Toyota Motor and Hyundai Motors plan to heavily increase the production of FCEVs. The Japanese government and industry are promoting hydrogen electrification strategies, reflected by ambitious targets of 800,000 cumulative FCEV sales and 1,000 refuelling stations by 2030.[74] FCEV costs are anticipated to fall while increasing production. Raising the popularity of mid-and heavy-duty applications (in buses and trucks), is essential to create sufficiently high demand. Main materials challenges are the development of energy-efficient coating solutions, the reduction of critical raw materials (CRM), the increase of the stack lifetime, avoiding hydrogen embrittlement phenomena and improving corrosion and ageing resistance, the elimination of the use of PFAS, the control of the

[74] Eastasiaforum.org, 2022

integrity of materials under pressurized systems including advanced gasket solutions.

E-Motors. Due to the massive electrification of the automotive industry and the wide use of permanent magnet motors (>95% of share in automotive), there is a tendency to rise from 5 kt/year to 70 kt/year by 2030. New permanent magnets (recycled, with reduced rare earth content and with optimized microstructure) could represent 50% of the automotive market share, equivalent up to 1-2 billion euros. There are high opportunities for advanced materials and for additive manufacturing of soft magnetic components in electric motors. In 2030, total demand of NGO electric steel in Europe is forecast to be 2.3 Mt (covering applications in industry, mobility, and power generation), equivalent to a market size of ca. €4 billion. Beyond already available materials (i.e. soft magnetic composites), up to 3% of that amount could be additively manufactured with new materials by that time.

Light weighting for more efficient vehicles. Growth in the need for improved safety and enhanced performance of the vehicle and stringent regulations for fuel economy and automotive emission is driving the growth of the global automotive lightweight materials market. This global market is expected to exceed €115-230 billion by 2030. Based on region, Europe, followed by North America, held the major share in 2020, garnering more than one-third of the global market. The market across this region is also anticipated to register the fastest CAGR of 8.0% from 2021 to 2030. This is due to the rising adoption of automotive lightweight materials and growing need for fuel efficient automotive solutions.

Light weighting for more efficient aircraft. The estimation of the market demand for light weighting materials in the aeronautical field can be based on the Airbus Global Market Forecast 2021 – 2040 report. According to this report, forecasts for the next 20 years will mean a shift from fleet growth to the accelerated retirement of older, less fuel-efficient aircrafts, resulting in a need for about 39.000 new-build passenger and freight aircrafts, 15.250 of these for replacement. The demand for new aircraft will include around 29.700 small aircraft, as well as about 5.300 in the medium aircraft category. In the large segment, a need for some 4000 deliveries is expected by 2040. Considering the typical amount of light-weighting materials in the aircraft structures for each aircraft category (small, medium, and long-range, typically 10, 20 and 30 tons/aircraft), it is possible to assume that approx. 500.000 tons of lightweight materials for aeronautical structures will be produced. Additionally, the new aeronautic propulsion systems to be developed (i.e. hybrid-electric and hydrogen-based), will demand new materials and production processes beyond the limits of the current technology at both ends: cryogenic and very high temperature. The development of these materials and process technology, rather than a quantitative issue, is an enabler for the development of new propulsion technologies.

Smart and sustainable mobility. Sustainability in transportation, logistics and individual mobility involves additional aspects besides CO_2 and energy. Liveable cities, green habitats, and citizen-friendly living areas of the future require a re-thinking of multi-mode mobility with less ownership of cars, fewer parking areas, and environmentally-friendly personal autonomy. Smart Cities will in future provide full information and mobility services: offering optimal multi-mode transport for citizens, extensive public transport including autonomous vehicles, transport-on-demand, shared vehicles, optimized logistics (delivery, collection etc.) – also in rural areas. Public acceptance of autonomous vehicles is growing. [75] [[76] A pre-condition for this scenario is availability of 5G or 6G communication between infrastructure, vehicles, controllers, and users. Equally, safe (semi-) autonomous vehicles need fast, comprehensive, affordable sensors all around. Advanced sensors and communication materials will pave the way for the broad introduction of smart mobility. Major benefits of sustainability, footprint, but also advanced mobility opportunities for sensitive groups (disabled or ill, children and old-age citizens) can be expected[77].

Power Electronics. Materials are fundamental to the field of power electronics, which relies on semiconductor devices (diodes and transistors) and other electrical components (resistors, capacitors, inductors, and transformers) to control the flow of electrical power. Power electronics researchers are constantly driven to improve the efficiency, power density, and reliability of power electronics converters through advances in materials, devices, components, and converter integration technologies. To achieve these objectives, new wideband gap materials, silicon carbide and gallium nitride, are of particular importance.

6.2. Materials challenges and priority areas

Main challenges and opportunities:

1- Zero-emission vehicles

Advanced batteries for electrical vehicles (BEVs) (including solid state batteries)

- higher energy density allowing more range for EVs or smaller EVs for fixed range.
- lower environmental footprint in their production, reduced usage and their sustainable substitution of critical raw materials, improved safety profile, better recyclability.
- for the consumer, more affordable EVs (smaller, lighter, and longer life batteries for same range), faster recharging, improved safety profile.

Cost Competitive hydrogen fuel cells systems for EVs (FCEVS)

- Reach FC cost targets (by reducing precious metal use, by downsizing the fuel cell stack, using high-efficient coatings…).
- Reduce hydrogen storage tank costs.
- Development of new catalysts.

Road, waterborne and aeronautic propulsion using compressed and liquid hydrogen as a direct combustion fuel

- Zero emissions when using green hydrogen.
- Very high gravimetric energy density (about 3x vs. fossil liquid fuel). Reduction of fuel drag weight.

[75] Statista.com/infografik/27564 (2022)
[76] NACTO (2019) Autonomous Urbanisation. Nacto.org/publication/bau2
[77] AutoRich (publicly funded project) report 04-2022; www.h-ka.de/ivi/projekte/autorich/broschuere.pdf

Smart E-Motors

- Reducing the rare earth content in magnets to reduce the environmental impact of mining and Europe dependency on other regions of the world.
- New, printable magnetic materials for use in electric machines would give the EU a competitive advantage over the rest of the world.
- Lighter and higher efficient drives for e-Mobility and industrial applications.
- reduced environmental footprint compared to conventional manufacturing.

The EU has a strong industrial and academic foundation in advanced materials for permanent magnets, in additive manufacturing of cutting-edge components and in the design & production of electric drives.

2.- Light-weighting for more efficient land vehicles, ships and aircrafts

- Develop materials with better durability, reduction of energy consumption and better lifecycle performances (circularity and environmental impact).
- Develop technologies (materials, processing, joining) to enable multimaterials and multifunctionality.
- Improved production processes (higher turnover rate), through implementation of process surrogate models and digital twins.
- High precision non-destructive inspection techniques for zero defects components.
- Advanced material models and simulation tools to extend the usage range of the current critical materials and shorten the development and certification cycle of new materials and processes (e.g. advanced 3D printing, low weight cryogenic and ultra-high temperature materials, nanotechnology, etc.)

3.- Power Electronics

Breakthrough technologies in the field are enabled by innovative developments of covalent and ionic semiconducting materials, particularly new wideband gap materials such as silicon carbide and gallium nitride. The advancement made in the crystal growth of gallium nitride (GaN) on silicon has led to a large number of research activities on GaN-based power electronics converters. Besides that, ionic-based rectifiers and exploiting multicomponent-based oxides should also be addressed.

Priority areas are tentatively consolidated under the 3 following areas:

1. Zero-emission vehicles
    - Solid-state batteries for BEVs.
    - Cost-competitive hydrogen fuel cell systems for FCEVs and direct hydrogen combustion for aviation and maritime transportation.
    - E-motors.

2. **Light weighting for more efficient vehicles and aircrafts**. This has a strong impact on the energy consumption for any propulsion source and is also an enabler for the implementation of new zero-emissions technologies.
3. **Power electronics** (e.g. silicon carbide and gallium nitride) and smart devices for transportation electrification, connectivity, smart mobility and control.

Common interest with other markets

- Sensors, lidar, power electronics and smart devices for transportation electrification, Smart City connectivity, vehicle and traffic control, and advanced communication between infrastructure, vehicles, controllers, and users. See electronic appliance market.

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6.3. Expected benefits

EU sovereignty

With the Ukrainian war, Europe is exposed to dependency on Russian Al, Ni, Pd, Pt.[78] Supply diversification and use of secondary materials is needed. ISO/TC 298 oversees establishing international normalization in rare earth, mining, concentration, separation, and conversion. The discussions are currently led by China and will require stronger European input.

Environmental footprint

Passenger and freight transport continues to rely on motor vehicles, which produce the most greenhouse gas emissions. Promoting other, more environmentally friendly transport modes is a keyway to reduce these environmental impacts and boosting public transport and rail freight. The transition to a transport sector with reduced environmental impact needs to be based on three legs: energy-efficient and fossil-free vehicles, a higher proportion of renewable fuels for operating the vehicles, and a more transport-efficient society. Smart City functions, which create massive synergies and savings by information-based organisation of transportation and mobility, reducing traffic volume per se. Lightweight materials, also play an important role. For every 45,4kg weight reduction, fuel efficiency increases by 1-2%. Naval transport has a great impact on global emissions[79] and there is a high potential for reduction by using hydrogen-fueled maritime transport. Hybrid propulsion systems are under study where co-generation is the main technical development. The Fuel Cells (FC) are used in combination with a gas or steam turbine to use the FC heat produced during use.

Sustainable value chain

Some materials challenges that can improve sustainability are: a) to increase energy efficiency in transport reduction friction and increasing materials durability, b) to move to electrical vehicles including batteries with higher durability and autonomy, c) to move to fast charging fuel cell technologies, improving infrastructure deployment, d) to move towards, automatic/start stop with novel

[78] Source: IHS Market, 2021, Europe is intended as EU27 plus EFTA countries and UK
[79] https://www.eea.europa.eu/highlights/eu-maritime-transport-first-environmental

materials for automatic transmissions, e) improving maintenance, including sensors and aftertreatment systems, f) alternative fuels, with low friction and high durable materials, g) reduce particle emissions from engines, brake and tyres and use self-healing materials.

Different **sustainable transport drivers related to materials improvement** are highlighted: a) positive economic and social impact of road rehabilitation (reducing wear and noise and climate resilient road), b) improve co-creation in inter-ministerial and interagency multi-level collaboration, c) Towards low-sulphur fuels, d) Integrating urban electric mobility solutions, infrastructures and Environment's Electric Mobility Programme, e) Maritime autonomous surface ship, f) Integrated planning at the local level: UN-Habitat-supported g) Sustainable Urban Mobility.[80] CO_2 capture, storage and conversion technologies will also facilitate reduction in carbon footprint.

6.4. Expected socio-economic benefits

- Lightweight advanced materials are the drivers for innovation and progression in the next generation of more sustainable transportation with lower environmental footprint. Competitive transport systems are vital for Europe's ability to compete in the world, for economic growth, job creation and for people's everyday quality of life.
- The benefits of digitalization and efficiency in transportation via intramodality, connectivity and hybrid private-public transport, include reduced noise and air pollution, thus driving towards a more Sustainable mobility

6.5. EU industrial innovation capacities and future outlooks

There are Major industrial players in Europe (ArcelorMittal, BASF, Covestro, Lyondellbasell, Solvay, Thyssenkrupp, Evonik, Hydro Aluminium, Fiat & Chrysler, CRF, BMW, Ford, Volkswagen, Mercedes Benz, Leonardo, BOSCH, Balzers Oerlikon, SKF, Leonardo, Airbus, CAF, BatteryPLAT, CIE Automotive, Unilever, Repsol, Northvolt, Verkor, BASF, ACC, AVL, EDP, ABEE, Unilever, Arkema, ITP, Armor, Aspilsan...) and a wide range of R&D stakeholders (EARTO, Tekniker, CIDETEC, CIC Energigune, ITE, Fraunhofer, VTT, TNO, CEA, Aalto Univ., AIT, others).

The future outlook involves:

- Increased sensoring, connectivity and intramodality
- Lightweight materials, to reduce fuel consumption
- Additive manufacturing for spare parts
- Alternative fuels and lubricants, energy efficiency and durability
- Fuel cells, batteries and charging infrastructures

[80] Transportation Report 2021_FullReport_Digital.pdf (un.org)

- Monitoring and reducing emissions (catalyst, engine component design)
- Predictive sensoring and predictive maintenance.

7. Materials for Home & Personal care Market

7.1. The Innovation market size and trends

Home and personal care covers not only everyday tools and household products (e.g. cosmetics), but also cleaning products that help people to stay healthy, control allergies, provide anti-bacterial surfaces or even medical home appliances. The European home care market size was valued at € 76.8 billion[81] in 2019 and is expected to grow at a compound annual growth rate (CAGR) of 7.6% from 2020 to 2027. The growing geriatric population in the region, coupled with the rising incidence of chronic diseases is the key factor driving the market for home care in the region.

A major issue faced by manufacturers during the COVID-19 situation was the disruptions caused to supply chains, especially for cosmetics, during lockdown. As a result, manufacturers and exporters were facing high competition. Furthermore, the on-premises sales through supermarkets suffered lockdowns and the closure of retail stores, as individuals had been practicing social distancing measures and avoiding gatherings and outings. However, the sales through online retail channels majorly supported the market penetration. For example, in the United Kingdom, the e-commerce shares in retail rose from 17.3% to 20.3% in 2020 according to the Organisation for Economic Co-operation and Development (OCED). A movement from Business to Business to Business to Customer with more personalized products will be a major driver in the future.

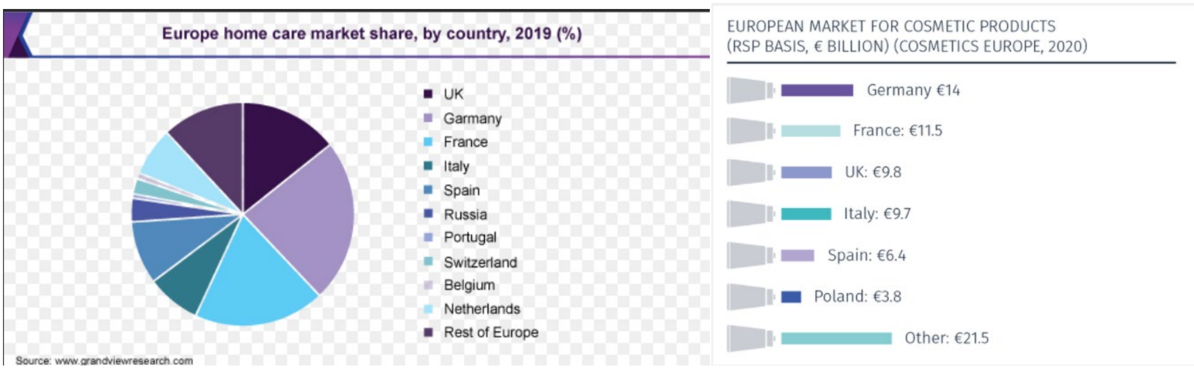

Figure 10: *Innovation market of home care and cosmetic products by country[79]*

The European cosmetics and personal care market is the largest market for cosmetic products in the world. The largest national markets for cosmetics and

[81] Europe Home Care Market Size: Industry Report, 2020-2027; grandviewresearch.com

personal care products within Europe are Germany (€14 billion), France (€11.5 billion), the UK (€9.8 billion), Italy (€9.7 billion), Spain (€6.4 billion) and Poland (€3.8 billion).[82] Furthermore, the global cosmetic chemicals market valued at €13,5 billion in 2019 projected to reach €22,17 billion by 2027, CAGR of 6.5%[83]. The focus on sustainability has encouraged the actors of the value chain to put more attention on their products and manufacturing processes. All major players have placed sustainability as key part of their agenda, and small and medium enterprises penetrating the market with specific sustainable solutions. A trend in this regard is the sourcing of raw materials, the production of active and non-active ingredients and their final formulation with fulfilling the complete LCA. The demand of sustainable solutions as well the trend of personalized products leads to one of the major challenges of whole value chain: transparency. A transparent presentation over the value chain is needed to show utilization of new advanced materials and that the final end-product has an environmental impact for the end user.

7.2. Materials challenges and priority areas

Advanced materials as a key innovation driver for the personal and home care market must combine several important aspects, e.g., sustainability, safety and supporting health and wellbeing. Therefore, the development of new advanced materials as the starting point in the value chain is very challenging and in a strong focus of the related industries. Actual activities of the industry are focused on the selected priorities bellow.

1. New developed advanced materials **based on natural and sustainable platforms**, useful as **alternative active and non-active ingredients** need to fulfill already specific regulatory limits and guidelines, which maybe more regulated in the future. To support the development of the final value chains towards sustainable needs and expectations, involved advanced and raw materials are developed by either new **chemical solutions** (e.g., new biosurfactants) or new **feedstock solutions** of known materials (e.g., replacement of fossil carbon by biomass). The development of advanced materials by new chemical solutions is subjected to strong regulatory conditions, such as safety and toxicology aspects, which needs to be taken in consideration. These aspects define final specification or product profiles of the developed advanced materials, which should be met in lab scale and with industrial production processes. This leads to the risk that new advanced materials meet these specifications in lab scale but fail in scale up development and under industrial process conditions. Further the registration of new materials for the personal and home care market requires animal tests for evaluation of toxicity, which describes an ethical dilemma. Industry exerted to reduce animal tests in general, by using only promising candidates. To identify non suitable candidates before conduction of animal tests and expensive scale up development, extensive application test in lab scale must be performed. Here digital simulation approaches could be of help.

2. A second approach is the development of new feedstock solutions to produce already established advanced materials for the personal and home care

[82] https://cosmeticseurope.eu/cosmetics-industry/
[83] https://www.alliedmarketresearch.com/cosmetic-chemicals-market

market by natural and **renewable** raw **materials** and **biotechnology production methods**. Sourcing of these raw materials play a crucial role for the implementation of the green chemistry platform. The transfer from petrochemistry to biobased chemistry, should consider the demand of crop areas for world food supplies. Therefore, the application of new feedstock solutions requires utilization of second generation (waste streams) and third generation (algae) biomass or direct carbon capture from atmosphere.

3. A third approach are the **materials for design and circularity and reuse**. 3D printing or additive manufacturing is a production technology with the capability to create tailored new materials (metals, ceramic, polymers, and composites) and components starting from powder or filaments. The capability to design new materials performance varying the process conditions are very wide. Characterization and modelling tools can be digitized and used to the design of new materials with lower environmental footprint, easy to repair, reuse, or recycle (eg. transforming again to secondary powder and filaments).
4. The fourth approach is the development of **multifunctional surfaces and coatings** that play a decisive role in the function and performance of different components and systems, adding functional properties, such easy to clean, antimicrobial surfaces or specific optical properties. It is required to develop solutions to problems along the entire process chain, combining research and industrial cooperation involving raw material suppliers, coating industries, component supplier, end-users, and recyclers. This will cover the design of a suitable surface nanostructure, coating layer (from single layer up to complex interference systems), transferring knowledge from laboratory to the industrial applications, with comprehensive and application´s-oriented solutions. The possibility to test and model the failure mechanism at laboratory conditions, to predict durability, will make possible to scale up, the best cost-effective solutions along the lifecycle.

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The priority areas as defined by SUSCHEM and EUMAT are the following:

1. Alternative **active and non-active ingredients** based on natural and sustainable platforms
2. Materials and **design for circularity** and re-use
3. Renewable materials and biotechnology **production methods**
4. **Multi-functional surfaces,** coatings, sensor functions

7.3. Expected benefits

EU sovereignty

A specific support implementing innovations in the field of advanced materials for personal and home care markets is on the one hand harmonized standards and norms regarding regulations and registration of advanced materials. This supports and accelerates international cooperation of the raw material producing and processing industry, speed up time to market loops and finally strengthening Europe’s sovereignty.

Environmental footprint

It is self-explanatory that final products (such as cosmetic, cleaning products) of the value chain of personal care will be emitted to the environment after used by customers. To minimize the impact to the environment, the portfolio of ingredients should change from non-biodegradable products to biodegradable products with fast degradation timelines and based on sustainable natural biobased resources. The use of 2nd or 3rd generation biomass has a big potential for environmental-friendly production.

It is therefore a key aspect to design sustainable materials and production processes (e.g., fermentation, environmentally friendly coating processes, 3D printing), and to evaluate the overall LCA along the whole value chain to quantify and reduce the environmental impact to finally achieve sustainability goals for the personal and home care market. As an example, the energy mix to be used in the process needs to be reconsidered to reach sustainability from an economical, availability and environmental footprint criteria. The use of renewable energy or mixtures (e.g. natural gas/hydrogen), in the production energy mix, could further reduce the environmental footprint. Providing sustainable advanced materials by using new feedstock solutions, is also one of the key drivers.

Strategic autonomy

Newly developed feedstock solutions based on biomass will require crop areas, which sometimes are located outside Europe and requires strategic partnerships, logistic and transport solutions. Development of the specific 2nd and 3rd generation solutions utilizing biomass or from direct carbon capture conversion can be implemented in Europe and circumvent complex logistic solutions and strengthening therefore the strategic autonomy. Nevertheless, it requires the right network of scientific and industrial experts. For example, new upstreaming processes for raw materials needs to provide the necessary quantity of raw materials for processing industries. Partnerships need to be established and supported along the whole value chain with risk and cost reducing effects.

Sustainable value chain

Advanced materials developed by new and sustainable chemical processes or new feedstock solution play a crucial role for closing the carbon loop and therefore act as a basis for a sustainable value chain. However, the sustainable effect enhancing multifunctionality and durability during use, being prepared to recycle and reuse, must be secured along the whole value chain. Processing industry must develop and implement sustainable process steps, for example water treatment and reuse. For the future, it will be increasingly important to co-create new products and processes, involving all the value chain stakeholders to understand the implications of new innovations at various levels, including consumer perception. The evaluation of positive social effects at the development phase of the product will help reach consumer confidence and will facilitate the introduction of the product in the market. Carbon footprint calculations and passport card of the product will facilitate information for selecting the recycling pathway.

7.4. Expected socio-economic benefits

The market pull in personal and home care markets is typically driven by business to business market needs but is increasingly moving towards business to customer needs. The functionality of the product comes first in citizens preferences, and end users would like to know if the personal and home care products they use are sustainable and have a low environmental impact. The risk of customer acceptance is in balance with the additional costs of the sustainable solution.

7.5. EU industrial innovation capacities and future outlooks

This sector is pushed by chemical industries. Relevant industrial EU Players include Henkel, L'Oreal, Chanel, Beiersdorf, Unilever, Healthcare at Home, Bayada Home Health Care, Ashfield Health care, Accredo health Group, Heritage independent Living, Mears Group PLC, BASF, EVONIK, AVON, P&G, Palmolive, Sephora, Ives Rocher, Douglas. Research players include BRTA, Leitat, Fraunhofer and many others.

Technologies and technical solutions for new feedstock solutions based on biomass are already developed in the EU. However, the substitution of petrochemistry by biomass from crop areas can only be an intermediate solution. Ongoing developments in this regard are:

- New sources of biomass in the production process of alternative active and non-active ingredients for personal care and home care.
- New biobased feedstock solutions and sustainable processes by utilization of sustainable energy solutions

Existing technologies e.g., fermentation processes act as a starting point. Efforts go towards further development of upstreaming and down streaming processes to access next generation of raw materials like biomass from waste stream or carbon captured from the atmosphere.

Additive manufacturing (AM) can also be a revolution in terms of new materials availability (reducing stocks) to build just in-time tailored components. In AM there is a need for increased precision, improved surface finishing and faster processing speed.

Solutions for coating and surface treatments for the home and personal care market can benefit greatly from developments in Health and Medical Devices (see MIM1); here, the implementation of multifunctional properties (e.g., easy to clean, self-healing, antimicrobial properties), long-life durability and industrial scale-up at competitive prices are the main steps forward. The European Home and Personal Care industry stands ready to meet these challenges.

8. Materials for Sustainable Packaging Market

8.1. The Innovation Market size and trends

The global market size for packaging is around € 889,6 Billion, where Europe accounts for roughly 41%[84,85]. The main base materials for packaging are plastics, paper and cardboard, alumina, and glass. Paper and cardboard are biobased and

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84 "The Future of Global Packaging to 2026" Market Study, Smithers Information Ltd, 2021

85 "2022 and beyond for the packagings industry's CEOs: The priorities of resilience" Mc Kinsey, 2021

have a very high recycling rate (approx. 80%), however this requires substantial amounts of water and heat. The production of alumina and glass requires a lot of energy, but both products can be recycled infinitely requiring less energy for secondary purification and remelting. Plastics have the benefit of lightweight and tunable functionality with a lot of innovation headroom for circularity. In this sustainable packaging overview, we will therefore focus on plastic packaging. The total EU27+3 virgin polymer production (excluding recycling) in 2020 was 55 Mton out of a global plastics production volume of 367 Mton. The 2020 EU 27+3 market demand was 49 Mton of which about 20 Mton (40.5%) was for packaging. Main polymer types for packaging (large to small volume) are LDPE/LLDPE, PP, HDPE, PET, PS, PS-E, PVC, other plastics, PA, PUR and other thermoplastics (see Figure 11 a). Plastics production volume in the EU is flat till 2050, so focus is rather on substitution of existing plastics by more sustainable circular plastics rather than volume growth.

Figure 11: *a)Types of polymers and applications, b) Evolution of post-consumer plastic waste treatment*[86]

The post-consumer plastic waste treatment evolution is depicted in the figure 11b showing a stabilization of energy recovery (@12.4 Mton), a decrease in land fill (@6.9 Mton) and a clear increase in recycling (@10.2 Mton), adding up to a total of 29.5 Mton of collected plastic waste in 2020.

For the EU plastics industry to become Net Zero, it is required that the industry will become more circular (figure 12) and shift from fossil to circular carbon feedstocks. We will assume that packaging will remain about 40% of the EU polymer production. Within the packaging market, 40% is related to food. 30% of all food produced worldwide is lost or wasted along the supply chain, optimized packaging may be one of the solutions to reduce this staggering amount.[87]

The industry value chain players comprise of raw materials producers (for plastics, board, glass, metals, etc.), the packaging manufacturers, the FMCG companies, and the retailers. The whole industry will face a number of challenges over the next years. Overall trends are:

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[86] Plastics - the Facts 2021 (plasticseurope.org), pages 23 and 27.
[87] Wohner, B., Pauer, E., Heinrich, V., & Tacker, M. (2019). Packaging-related food losses and waste: An overview of drivers and issues. Sustainability (Switzerland), 11(1). https://doi.org/10.3390/su11010264

- **Demand for packaging materials** in the EU is going to grow also in the coming years (due to population growth, population ageing, increasing urbanization and reduced family sizes). The strategy of big plastic players is to increase the recycling share in the plastics, adding secondary plastics to new formulations. Also, to invest in biobased packaging.
- Increased **need for packaging recycling** based on the implemented legislation and those to be completed by 2030 (Directive (EU) 94/62/EC) and carbon footprint reduction.
- **Minimization of food waste.** Food waste is a big problem, and packaging protects the content (e.g. food). By improving barrier properties or including sensors to monitor food shelf life it might be possible to reduce the food waste problem.
- Aim to **eradicate single-use plastics** as the major source of littering.
- Legislation concerning the de-materialisation objective of **phasing out unnecessary packaging**, the introduction of recycled and **reusable alternatives** for the transport of goods.

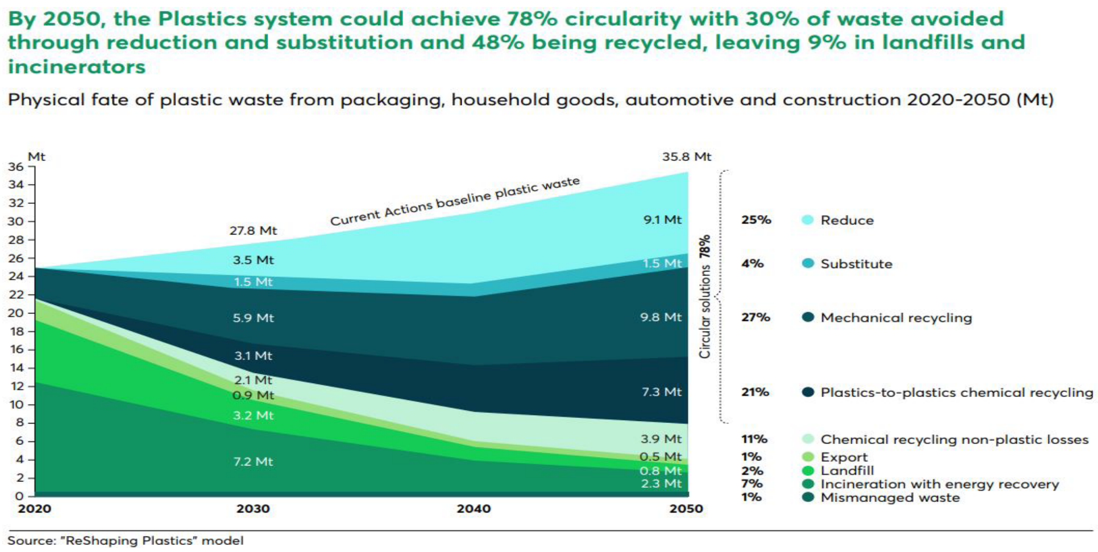

***Figure 12**: Fate of EU plastic waste towards 2050*[88]

8.2. Materials challenges and priority areas

The **innovation potential and challenges** for the EU sustainable packaging industry, based on the selected priority areas are therefore:

- Development **of (mechanical, chemical, and biochemical) recycling technologies** for plastics, bio-based polymers. Note that the shift towards bio-based and CO_2 feedstock will benefit the production of oxygenated polymers such as PET, PLA and PEF compared to polyolefins. For bio-degradable polymers, PHA and PHB, volume demand is expected to grow.

[88]SYSTEMIQ (2022): ReShaping Plastics: Pathways to a Circular, Climate Neutral Plastics System in Europe. ReShapingPlastics-v1.9.pdf (systemiq.earth)

- Development of **smart solutions** such as barrier coatings (including biobased ones) able to protect the content of the packaging (e.g. food, personal care) and extend lifetime. The lifecycle environmental assessment indicate that carbon footprint of the packaging is negligible when compared with the content. Increasing the shelf-life of products will reduce the environmental impact. (Results from Biosmart EU Project[89]).

For sustainable packaging we recognize four key principles: a) Apply Reduce/Re-use/Recycle (RRR) principles, b) Design for safety, c) Design for product protection and d) Design for circularity.

Based on the above four key principles for sustainable packaging, the following four innovation areas have been jointly identified by EUMAT, ECP4 (Network of Plastic and Composites) and SUSCHEM:

1. **New renewable and recyclable materials** and for specific applications biodegradable and compostable materials.
2. **Smart solutions** (barrier coatings, antimicrobial or antifungal coatings, sensors, smart electronic interfaces to communicate and for tracking purposes) to monitor product quality and enlarge shelf-life.
3. **Substitution** of Carcinogenic, Mutagenic and Reprotoxic (CMR) and Substances of Very High Concern (SVHC) from packaging formulations (e.g. catalysts, additives, plasticizers).
4. **Design for circularity,** which leads to **design for reducing**, re-using and recycling. This can be at material and product level (physical design) or at molecular level (chemical design).

8.3. Expected benefits

EU sovereignty

Less dependence on feedstocks (oil and gas) from outside the EU due to electrification, recycling, biobased and CO_2-based polymers that can be converted into low emission packaging.

Environmental footprint

- Reduced GHG emissions over the **product life cycle for plastic packaging,** including losses in (chemical) recycling by switching to waste/recyclate, bio-feedstocks and CO_2 as a feedstock. Estimated maximum achievable CO_2 emission reduction for the EU polymer production for packaging assuming a flat market of 20 Mton/yr and conversion to 100% circular feedstock towards 2050 is approximately 70 Mton/yr.
- **Reduce formation and leakage of microplastics** into the environment by closed loop recycling and using bio-degradable polymers for those applications where leakage cannot be avoided. Innovative technologies can be licensed or sold outside the EU to support the growth of regions with low emission production technologies. The total **CO_2 emission reduction**

[89] Bio-based smart packaging tackles food waste | BIOSMART Project | Results in brief | H2020 | CORDIS | European Commission (europa.eu); https://cordis.europa.eu/article/id/436351-bio-based-smart-packaging-tackles-food-waste?WT.mc_id=exp

potential for the global polymer production for packaging (500 Mton/yr) by 2050 will approximately be **1.8 Gton/yr.**

- **Loss of fish or meat** due to inappropriate packaging (e.g. failing sealing or barrier properties might have a detrimental effect on carbon footprint.
- The **phasing out of CMR and SVHC** will contribute to intrinsically safe packaging materials that are easier to recycle and prevent leakage of these substances into the environment.
- The development of innovative **smart packaging solutions** will reduce food waste and reduce damage of high-value packed products and associated GHG emissions.
- **Packaging designed for circularity** will reduce the quantity of bio-feedstocks and CO_2 feedstock (and related energy) as it enables more efficient and high-value recycling loops.

Strategic autonomy

Currently, both packaging and future developments in material technology including sensors have a huge potential to monitor and minimize food waste[90,91,92], protect valuable products and to contribute to food safety and security, increasing EU autonomy (See next figure). Protective packaging (e.g. including antimicrobial, antifungal properties, UV, humidity, or oxygen barriers) will increase the content shelf-life, reducing orders of magnitude the footprint. The EU has a strong R,D&I ecosystem and strong industrial base for a global leadership position.

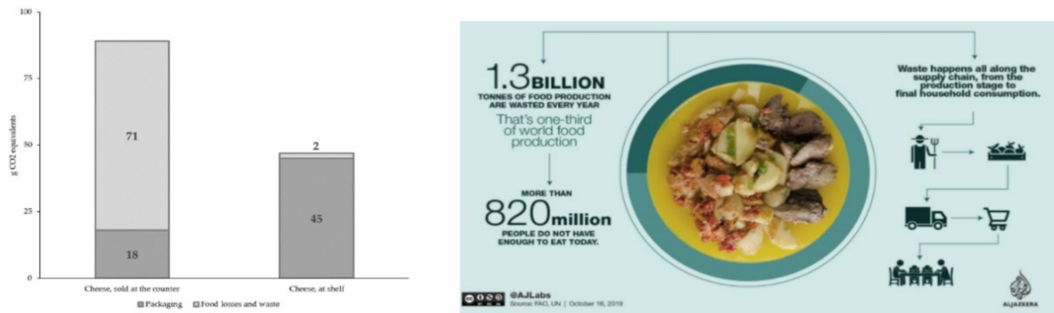

Figure 13: *a) Carbon footprint of 2 cheese packaging (150 g cheese)* **[93]** *b) Food waste impact*[94]

Sustainable value chain

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[90] Kowalska, A. The issue of food losses and waste and its determinants. Logforum 2017, 13, 7–18.
[91] Mena, C.; Adenso-Diaz, B.; Yurt, O. The causes of food waste in the supplier–retailer interface: evidences from the UK and Spain. Resour. Conserv. Recycl. 2011, 55, 648–658.
[92] Manalili, N.M.; Dorado, M.A.; van Otterdijk, R. Appropriate Food Packaging Solutions for Developing Countries; Food and Agriculture Organization of the United Nations: Rome, Italy, 2014
[93] Denkstatt. Vermeidung von Lebensmittelabfällen durch Verpackung: Kooperationsprojekt mit Partnern aus den Bereichen Rohstoffherstellung, Verpackungsproduktion, Handel, Verpackungsverwertung und Forschung; Denkstatt: Vienna, Austria, 2014.
[94] Source FAO, UN / October 16, 2019.

- **Sourcing bio-feedstocks** (agriculture, waste, and forestry) from the EU will generate more control over an environmental and social sustainable value chain.
- **Increasing durability of the packaging** will make transportation more sustainable and reduce the added value waste.
- Development of innovative **smart packaging solutions** will allow monitoring of the humidity during transport, or the gas released from the packaging content (e.g. Oxygen, CO_2, amine).
- **Lifecycle environmental assessment** of the raw material, production process, use and recycling of the packaging will allow control and minimization of the environmental impact across the value chain.
- **Phasing out unnecessary packaging,** increase recycling and introduction of reusable alternatives.

8.4. Expected socio-economic benefits

In the areas of **plastic recycling, biobased packaging** can reduce CO_2 and environmental footprint etc. Use of advanced materials and technology in packaging, improving barrier properties to increase content shelf-life will help to tackle the urgent societal challenges and fulfil the expectations of the citizens. Price, availability, and lack of performance are the main barriers for introduction of biobased solutions and further developments are needed. Recycled plastics are more and more accepted by citizens.

In Europe, **88 million tons of food are wasted each year**, equivalent to 20 % of the food produced in Europe. More than 50% of what is lost is in the food chain. This represents 304 million tons CO_2 eq. (6% of the total Green House Gas Emissions). The Development of smart packaging is a very important part of the solution. Sensor-equipped packaging has the potential of seriously reducing this unacceptable loss of precious food resources. Biobased, sustainable and high durable packaging has a crucial role to minimize waste. Bio-degradable packaging can facilitate food waste handling and their use for composting or energy generation.

8.5. EU industrial innovation capacities and future outlooks

The main industries in the plastics materials and packaging value chain are GEA, WIPAK, BASF, Propagroup, Evonik, Unilever, Febrero Rocher, Avantium, Novamont, Corbion,TECSENSE, NatureWorks, Borealis, Veolia, etc. There are also many Knowledge research institutes and Universities in Europe such as ITENE, AIMPLAS, Tekniker, RISE, LILLE, Univ. Friburgo, Univ. Reading, Cidetec, TNO, Fraunhofer, CEA, IPC and many others.

EU industrial capabilities in packaging are huge with an important number of industrial and technological research stakeholders, but investment is also needed to enhance the cooperation from different stakeholders, to reach the ambitious 2030 and 2050 goals. New plastic developments need huge time and money investment (figure 4), to find the right solutions considering the lifecycle impact of the value chain of the product**.**

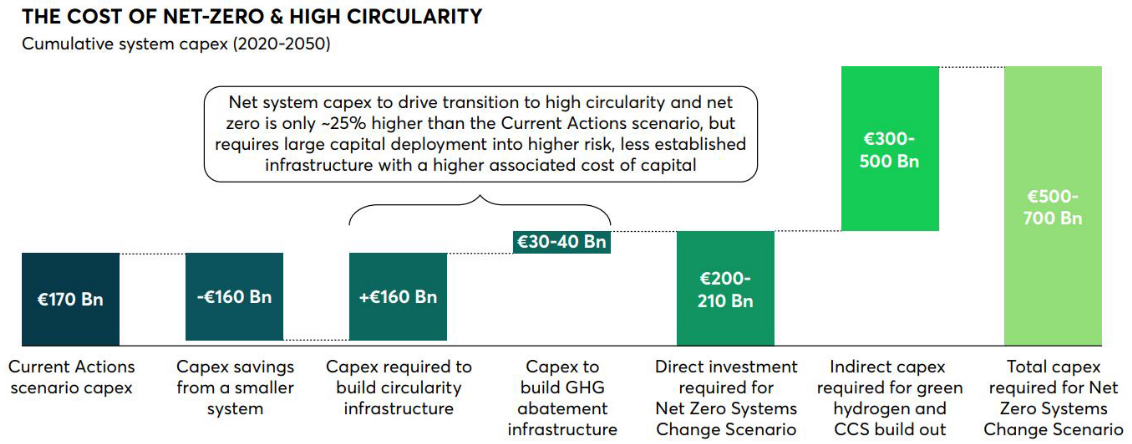

Figure 14: *Costs of net zero and high circularity scenario for the EU plastics industry (taken from 'Reshaping Plastics' model of SYSTEMIQ (2022)*[95]

The global bioplastics industry is on course to increase its production capacity by 300,000 tonnes over the next five years, according to the annual European Bioplastics' market data update, but this will pale in comparison to global primary plastic production. The data presented at the 14th European Bioplastics Conference in Berlin, revealed that the global bioplastics production capacity is set to increase from around 2.1 million tonnes in 2019 to 2.4 million tonnes in 2024, with bio-based versions of polymers such as polypropylene (PP) and natural polymers such as polyhydroxyalkanoates (PHAs) driving the predicted growth.[96]

Furthermore, upon closer analysis, about 40 to 70% - depending how they are classified - are like fossil-based plastics (Polyethyleneterephthalate (PET), polyethylene (PE), Polyurethane (PUR), Polyamide (PA) incurring the same end-of-life (EoL) issues except for bio-CO_2 emissions for EoL scenarios. This leaves about 1 to 1.5 million tons of new biobased plastics (including starch blends) that are targeted at addressing both the feedstock and the EoL challenge. These relatively new alternatives are, Polyethylenefuranoate (PEF), Polylactate (PLA), Polybutyleneadipateterephthalate (PBAT), Polybutylenesuccinate (PBS), Polyhydroxyalkanoate (PHA), Starch blends and others (e.g. proteins).

The plastic sector plans to grow in the next years, with the strategy to promote recycling and to combine primary and secondary plastics, to create more sustainable packaging. For the EU, the growth of these biobased polymers offers a huge opportunity to establish a new sustainable bio-feedstock (forestry, bio-waste) based European value chain and associated green jobs.

[95] Infographic-v4.4 - Standalone version (plasticseurope.org)
[96] Industry predicts bioplastics market growth | Resource Magazine

9. Materials for Sustainable Agriculture Market

9.1. The Innovation market size and trends

Agriculture represents a near €7,36 trillion industry globally, according to the World Bank[97], so the application of advanced technology in this sector has potentially profound implications: for the planet, for people and for investors. A recent report from FAO[98] has estimated that the global value added generated by agriculture, forestry and fishing grew by 73 % in real terms between 2000 and 2019, reaching €3,22 trillion in 2018 representing an increase of €1,38 trillion compared with 2000. In Europe, this increase was estimated to be a 19% in the same period. The value added of the agro sector (incl. livestock and plant breeding, fishery and forestry) in the EU27 was €219 billion and is expected to grow by an average annual growth rate of 1% in the period between 2021 and 2030.[99]

The food supply chain in the EU involves around 11 million farms, more than 300,000 processing companies and 2.8 million retailers, creating around 44 million jobs in the EU[100]. The majority of the 15 million holdings and companies in the food chain are SMEs. Specifically, 70% of farms in the EU are smaller than 5 h.a. (smallholders). In this heterogeneous context, economic, social, and environmental sustainability of intensive agricultural farms are indispensable requirements that society and agricultural policies are currently demanding with the final goal of increasing productivity but keeping the sustainability in the sector[101]. Additionally, the social demand from customers for environmentally friendly production[102] requires the deployment of technologies to produce high-quality products under sustainable environmental standards. The biggest drivers of food demand are population and income, and both are on the rise. By 2050, the world population will be 9.1 billion, up from 7.4 billion in 2016. According to the UN, the best agricultural companies must increase food production by 70 % compared to 2007 levels to meet the needs of the larger population. It's estimated that global growth will boost food demand by 20,500 trillion calories by 2050—a potential opportunity for investors to make a positive difference.

Agriculture does not only cover livestock and plant manufacturing to fulfil needs for food production. Forestry is gaining a lot more attention as a sustainable raw material for e.g. construction, and as an input material for cellulose and lignin-based materials. Growing demands for these materials lead to an intensification of forestry and are contradictory to other targets of the Green Deal, such as biodiversity. These conflicting targets need to carefully be balanced by politics.

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[97] World Bank news. Agriculture Overview: Development news, research, data | World Bank
[98] FAO. 2021. World Food and Agriculture – Statistical Yearbook 2021. Rome. https://doi.org/10.4060/cb4477en
[99] IHS Consultants, Economic Sector Review and Forecast, 2022
[100] a)European Commission, DG Agriculture and Rural Development, Unit Farm Economics , "The Food Supply Chain", 2017; b) Ensuring global food supply and food security | European Commission (europa.eu)
[101] European Innovation Partnership Agriculture and Innovation (EIP-AGRI), "The permanent subgroup on Innovation for agricultural productivity and sustainability", 2015.
[102] European Commission, "Environment. Sustainable Food", 2016, http://ec.europa.eu/environment/eussd/food.htm [accessed: 25/07/2018]

Ensuring the quality of European inland and marine waters directly and indirectly ensures the quality of food production and European fisheries. Measures for keeping waters clean have a direct impact on the biotopes living in them.

Also, agriculture is a major outlet for plastics globally and in the EU, representing 4.4% (equal to 2.36 Mt p.a. in 2021[103] of total consumption in the EU 27+3 countries). Materials have a huge impact on the protection of seeds, fruits and other products during manufacturing, as well as in the food delivery chain starting from agriculture, however this impact is, in most cases, more indirect. e.g. foils help keep and increase the quality of soil and also contributes to food-waste prevention.

The most commonly used nitrogen fertilizers are based on nitric acid or urea. These fertilizers produce nitrous oxide (N_2O), a GHG almost 300 times more potent than CO_2 over a 100-year period. More than half of human made N_2O emissions come from fertilizers in agriculture.[104] Use of mineral fertilizers (global use estimated at 198.2 Mt in year 2020/21, almost 10 Mt (5.2%) higher than in 2019/20)[105] needed for increasing crop production, presents some issues caused by their volatilization and leaching processes, leading to a 30% to 50% loss of the applied fertilizer, with the concomitant contamination of soil and water. It is necessary to promote the use of enhanced efficiency fertilizers (EEFs), which should display an adequate biodegradability, non-toxicity, water-solubility, swell ability, and ease of chemical modification. Additionally, problems derived from reduced availability of fertilizers have been observed. Thus, biostimulants can substitute chemicals, enhancing fertilizer efficiency. Regarding seed coating, the European Seed Coating market is estimated to grow at a CAGR of 8.1% during the forecast period 2020-2025.[106] Euroseeds, the European Seed Association, control through standards, the quality assurance of the seed treatment and the treated seeds (ESTA).[107]

Excluding aquatic plants, total world fisheries and aquaculture production showed a 41 % growth in the 2000–2019 period, reaching 178 million tonnes in 2019. This represents an overall expansion of 52 million tonnes compared to 2000 [32].

9.2. Materials Challenges and Priority Areas

Within the **priority areas,** preselected by SUSCHEM and EUMAT, the main challenges have been found in:

- **Development of efficient sensors** for measuring the maturity of agricultural products and carbon farming
- Development of **sustainable and efficient biotechnology-based and/or biodegradable polymers** in agriculture and soil preservation

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[103] Plastics Europe 2022 "Facts & Figures"
[104] Tackling climate change," European Commission, Archived December 3, 2021. Archive URL: https://archive.ph/vKMzc.
[105] International Fertilizers Association (IFA). Public Summary. Medium-Term Fertilizer Outlook 2021 – 2025. Avalaible at https://www.statista.com/statistics/438930/fertilizer-demand-globally-by-nutrient/#statisticContainer.
[106] Europe Seed Coating Materials Market - Growth, Trends, Covid-19 Impact, And Forecasts (2022 - 2027). Mordor Intelligence.
[107] ESTA Standard. European Seed Treatment Assurance. Quality Assurance System for Seed Treatment and Treated Seed. Available at https://euroseeds.eu/esta-the-european-seed-treatment-assurance-industry-scheme/.

- **Development of advanced surfaces and filters** for water and air purification

Sensors for measuring the maturity of agricultural products and carbon farming

Sensors for measuring the maturity of agricultural products

One of the major objectives of the agro-food industry is to develop traceable methods to certify final product quality. This requirement is not easily achieved with time-consuming post-production analytical laboratory methods. Furthermore, several trends have enhanced these needs: (a) consumers demand higher quality control; (b) production rates have increased; (c) the consumer demands products with longer shelf-life, making it less adequate to hold the products waiting for laboratory results.

In this context, photonic measurement principles such as Infrared or Raman spectroscopy are very well positioned as key technologies. Sensitive spectroscopic optical sensors based on infrared absorption or Raman scattering derive the fundamental knowledge from proper analysis of active infrared and Raman vibrational modes of targeting molecules from food maturity monitoring. It allows for the selection of the spectral bands in which this information is enclosed. Multivariant data analysis is used in parallel to this knowledge, providing an efficient procedure to extract this information from within a complex rough spectrum, helping also to identify additional spectral bands relevant to conclude a robust prediction model. Both aspects require appropriate sensor design in which light sources and light detectors have sensitivity over the selected spectral bands, also playing a fundamental role.

Sensors for carbon farming

Carbon farming refers to sequestering and storing carbon and/or reducing greenhouse gas emissions at farm level. It offers significant but uncertain mitigation potential in the EU, can deliver co-benefits to farmers and society, but also carries risks that need to be managed. Open questions need to be resolved to scale up carbon farming in a way that delivers robust climate mitigation and European Union Green Deal objectives.[108] One of the central challenges of Carbon Farming is measurement, monitoring, reporting and verification (MRV). The direct measurements on farm level can also be achieved by sensors.

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[108] Published papers of the EU Commission on CAP; EUROPEAN COMMISSION, DG Climate, COWI report 2020. "Carbon farming -Making agriculture fit for 2030", (ENVI). Completed 11/2021, PE 695.482

Biotechnology-based and/or biodegradable polymers in agriculture and soil preservation

Different natural and synthetic polymeric materials are known,[109] although biopolymers (mainly polysaccharides)[110] constitute a more sustainable alternative, as they can be derived from biomass, in many cases also by using less-contaminant enzymatic or biotechnological procedures. An example includes chitosan-based fertilizers obtained from chitin (the second most abundant polymer in nature, found in exoskeletons of insects and crustaceans), which can be formulated in many ways.[111] The upgrade of this waste material to its application as biofertilizer can be envisioned as a sustainable virtuous circle. Herein, biocatalysis can certainly contribute to their valorization. During their storage, seeds need to be protected from environmental conditions that are favourable for germination (moisture, light and temperature). Various chemical substances are used in the form of slurries to coat seeds before drying, but this method can produce rough surfaces and leaching of chemicals which are toxic to the environment and harmful to humans. Another alternative, the use of microplastics for seed coating, causes severe soil contamination.[112] Hydrogels made by copolymerization of synthetic acrylic monomers with polysaccharides (i.e., starch, cellulose, chitosan, agarose, carrageenan, etc.) can be used, but biodegradable super absorbent hydrogels wholly derived from the above-mentioned polysaccharides are a more sustainable alternative.[113,114,115] Biotechnology can assist the generation and upgrading of such biopolymers for agricultural challenges.

Advanced surfaces and filters for water and air purification

Air Filtration. Microbial agents such as viruses, bacteria and fungi can remain in the air for a long time and be easily transmitted to a susceptible host through inhalation. Accumulation of dust, moisture in Heating, Ventilation and Air Conditioning (HVAC) systems and poor filter maintenance produces a favourable

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[109] Sikder, A.; Pearce, A.K.; Parkinson, S.J.; Napier, R.; O'Reilly, R.K. Recent Trends in Advanced Polymer Materials in Agriculture Related Applications. ACS Appl. Polymer Mat. 2021, 3, 1203-1217

[110] Chiaregato, C.G.; França, D.; Messa, L.L.; dos Santos Pereira, T.; Faez, R. A review of advances over 20 years on polysaccharide based polymers applied as enhanced efficiency fertilizers. Carbohydr. Polym. 2022, 279.

[111] Prajapati, D.; Pal, A.; Dimkpa, C.; Harish; Singh, U.; Devi, K.A.; Choudhary, J.L.; Saharan, V. Chitosan nanomaterials: A prelim of next-generation fertilizers; existing and future prospects. Carbohydr Polym 2022, https://doi.org/10.1016/j.carbpol.2022.119356.

[112] Europe Seed Coating Materials Market - Growth, Trends, Covid-19 Impact, And Forecasts (2022 - 2027). Mordor Intelligence

[113] Elshafie, H.S.; Camele, I. Applications of absorbent polymers for sustainable plant protection and crop yield. Sustainability 2021, 13.

[114] Pirzada, T.; de Farias, B.V.; Mathew, R.; Guenther, R.H.; Byrd, M.V.; Sit, T.L.; Pal, L.; Opperman, C.H.; Khan, S.A. Recent advances in biodegradable matrices for active ingredient release in crop protection: Towards attaining sustainability in agriculture. Curr. Opin. Colloid Interface Sci. 2020, 48, 121-136.

[115] Karamchandani, B.M.; Chakraborty, S.; Dalvi, S.G.; Satpute, S.K. Chitosan and its derivatives: Promising biomaterial in averting fungal diseases of sugarcane and other crops. J. Basic Microbiol. 2022, 10.1002/jobm.202100613.

environment for microbial proliferation [116]. In addition, modern high efficiency particulate air filters (HEPA) only limit viral and bacterial transmission, but they cannot completely inhibit the growth of bacteria, fungi or inactivate viruses present on the surface or in the filter porous structure. These conditions can lead to a decrease in air quality and an increase in respiratory diseases resulting in a potential risk for human health. Air quality directly influences occupant health, comfort, and productivity.

Advanced purification of water. The need to develop anti-biopollutant filtration systems involves also different applications, not only for ventilation but also the treatment of water. Potable water is an essential requisite for a healthy life and water treatments such as purification and filtration is fundamental. However, waterborne diseases remain a serious cause of death in the world and are a significant economic constraint in many subsistence economies and can be transmitted to agricultural quality. [117] .Several bacteria and viruses such as adenovirus, rotavirus, norovirus, hepatitis A, are presented in surface waters and in underground sources [118,119]. The use of chlorine in traditional procedures for water disinfection can led to the production of harmful by-products in addition to bad odour or taste. A second approach using UV methods does not form dangerous by-products, but it is not effective on some types of viruses, such as adenovirus [120]. Activated carbon membranes are also widely used as a valuable absorbent material thanks to its peculiar nanostructure, high porosity, and large specific surface. However, activated carbon filters have no intrinsic antimicrobial effect and they are not able to neutralize waterborne microorganisms.

Materials and coating solutions are needed to overcome these challenges. For example, filters coated by nanoparticles or metallic nanocluster/silica composites layers are promising solutions in preventing bacteria, fungi, mould, and virus proliferation. These coatings can be for example, deposited by sputtering or sol-gel coatings (immersion/spraying) with clean, industrially feasible processes, able to coat the filter without altering its performances. The challenge is also that the filters and membranes should be efficient after heating, allowing the filter to be reused after thermal regeneration. Technological innovation to save water is also important both in industry and agriculture. Improved membranes will be useful for water recycling and reuse.

9.3. Expected benefits

EU Sovereignty

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[116] Möritz, M.; Peters, H.; Nipko, B.; Rüden, H. Capability of Air Filters to Retain Airborne Bacteria and Molds in Heating, Ventilating and Air-Conditioning (HVAC) Systems. International journal of hygiene and environmental health 2001, 203 (5–6), 401–409

[117] European Commission, "A strategic approach to EU agricultural research & innovation, 2016

[118] Hamza, I. A.; Jurzik, L.; Stang, A.; Sure, K.; Überla, K.; Wilhelm, M. Detection of Human Viruses in Rivers of a Densly-Populated Area in Germany Using a Virus Adsorption Elution Method Optimized for PCR Analyses. *Water Research* **2009**, *43* (10), 2657–2668

[119] Abbaszadegan, M.; Lechevallier, M.; Gerba, C. Occurrence of Viruses in US Groundwaters. *Journal-American Water Works Association* **2003**, *95* (9), 107–120.

[120] Yates, M. V.; Malley, J.; Rochelle, P.; Hoffman, R. Effect of Adenovirus Resistance on UV Disinfection Requirements: A Report on the State of Adenovirus Science. *Journal - American Water Works Association* **2006**, *98* (6), 93–106. https://doi.org/10.1002/j.1551-8833.2006.tb07686.x

In December 2021 the Commission adopted the Communication on Sustainable Carbon Cycles, as announced in the Farm to Fork Strategy. The Communication sets out short to medium-term actions aiming to address current challenges in carbon farming to upscale the green business model that rewards land managers for taking up practices leading to carbon sequestration, combined with strong benefits for biodiversity. These include driving forward the standardization of monitoring, reporting and verification methodologies to provide a clear and reliable framework for carbon farming.

The consumption of paper is being reduced, since computers are improving readability, reducing significantly the need to print paper. The use of natural wood from forests is increasing in the Construction market. Transformation of wood in panels with higher strength and resistance to humidity is an important challenge. This demand should balance while keeping forests healthy and boosting biodiversity and innovation in wood panels transformation.

Europe loses an unexpected amount of water. It has been estimated that the water saving potential in Europe stands at 40%[121]. Proper filters and control of water spills will help to keep clean water resources, which also protects fish and also the forest. Technological innovation to clean and recycle water using antimicrobial membranes will have a direct impact in agriculture, food chain, fishery and industry.

Environmental footprint

Biological pollution or bio-pollution generally is the contamination of aquatic and terrestrial environments by living organisms known as bio-pollutants. Bio-pollutants include bacteria, viruses, molds, mildew, dust, mites, and pollen. Obviously, the degree of the impact of these contaminants on human health differs between healthy and sick individuals. Bio-pollutants could be considered as triggers for allergic reactions and infectious disease. Biopollution may affect both the individual organism and the entire community up to the ecosystem. Currently filtration systems applied to air, water or other fluids can almost completely overcome the problem of bio-pollution contamination, assuring the quality of filtered media after the passage through filter. However, the low maintenance and attention of the filtration system itself creates a suitable environment for biofilm formation on the surface and consequentially proliferation of microorganisms. Well established serious illnesses such as Legionnaires' Disease and more widespread health issues such as allergy can occur in part due to poor air quality and exposure to indoor pollutants (particularly those associated with building dampness and mold).

Other airborne illnesses such as the common cold or influenza to even more acute respiratory illnesses, like the Severe Acute Respiratory Syndrome (SARS) and COVID-19, caused by the coronavirus SARS-CoV-2, can be transmitted more rapidly through the air due to elevated indoor pollutant levels as well as other indoor environmental conditions. These aspects potentially affect a large number of buildings, vehicles or airplane occupants and are associated with significant costs due to health-care expenses.

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[121] Water Scarcity & Droughts in the European Union - Environment - European Commission (europa.eu)

The **greenhouse production** will allow for control of food maturity, production of improved and consistent crop yields, shorter supply chains, reduced transportation to consumers, efficient use of fertilizers or no use of pesticides, water conservation through efficient irrigation methods and recycling of water and nutrients. Global population growth, climate change, water, and land scarcity, and shifting consumer preferences are driving the need to revamp food systems at every stage, from seed to table. The pulses (edible seeds of plants in the legume family) are rich in proteins and have a high potential for innovative agriculture/the food market in the EU.

With recent projections of sectoral greenhouse gas (GHG) emissions, agricultural and land use in the EU emerges as a potentially dominant sector with a share of total emissions increasing towards 2050 (European Commission, 2018). For the years 2040 to 2050, Agriculture and Transport sectors will cover 20-30% of emissions each, with Land Use and Land-Use Change and Forestry (LULUCF) being a significant net sink. In other words, biogenic carbon will make up most of the carbon fluxing through the European economy by the second half of the century. The central challenge of Measurement, Monitoring, Reporting and Verification (MRV) refers how participants' climate actions and GHG emissions are reliably measured (reliable, affordable monitoring). The monitoring part of MRV poses a particular challenge for carbon farming. Monitoring can be achieved by direct measurement, modelling, combined modelling and measurement, and on-site measurement of carbon stored e.g., in trees or soil and of GHG gases emitted. Direct measurement can monitor GHG impact with considerable accuracy but can be prohibitively expensive. Carbon Farming is highly relevant for: a) the Green Deal, b) the objectives of carbon sequestering 2030, and c) the program Farm to Fork and d) the CAP (Common Agricultural policy). There is great potential, acceptance and support in society for Digital Farming. The popular expectation is that with integrated sensors, Digital Farming will contribute to mastering the grand challenges, in particular CO_2 footprint.

Strategic autonomy

Serious concerns about how we will produce food to supply the increasing world population.[122] The scenario is more complex if the climate change challenge is considered. Thus, it is mandatory to renovate agriculture systems, by controlling the delivery of agrochemicals to deal with soil degradation, water pollution, climate change, and plant protection against pathogens and diseases. Likewise, value generation from marginal land appears as an important complement as well. 2019 European Commission study: estimation of 179 million hectares of available agricultural land in the EU, and 75% of them (134 million) are fertilized with mineral fertilizers.[123]

Sustainable value chain

The sensors for measuring the maturity of agricultural products would provide significant sustainability benefits such as: (a) optimization of fertigation parameters to maximize yield while respecting food quality and safety criteria, (b)

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[122] World population prospects 2019. United Nations, Department of Economic and Social Affairs, vol. 141.

[123] Fertilisers in the EU, Prices, trade and use," European Commission. Archived September 14, 2021. Archive URL: https://archive.md/gXedC

reduction of waste generation ensuring water consumption to a minimum, which increases sustainability, (c) reduction of economic losses linked to quality controls. In this context, the inclusion of sensor devices for agricultural products maturity monitoring would be a key action to improve the data management infrastructure.

9.4. Expected socio-economic benefits

Related to **employment impact**, the food sector is the largest employment sector in the EU providing 44 million jobs[124] and a €164 billion turnover, with sizeable disparities in different regions. The deployment of (photonic and other) sensor devices for food maturity control and food quality & safety monitoring in the agroindustry, linked to a food traceability system, will increase consumer trust and will make rural economy grow thanks to an increase in product quality, efficiency, productivity, and costs savings.

Agriculture is recently projected to produce 20-30% of **sectoral greenhouse gas** (GHG). Novel low-cost sensors and data acquisition systems can solve the central challenge of Measurement, Monitoring, Reporting and Verification (MRV): direct measurement can monitor GHG impact with considerable accuracy, but can be prohibitively expensive. Affordable sensors will allow for effective Carbon Farming which is highly relevant for a) the Green Deal, b) the objectives of carbon sequestering 2030, c) the programme Farm to Fork and d) the CAP (Common Agricultural policy). Digital Farming will contribute to mastering the grand challenges, in particular CO_2 footprint, while guaranteeing safe and sustainable food for Europe

Advanced membranes for water and air filtration with antimicrobial, antiviral properties and advanced sensors to control quality are necessary for healthier lives and a cleaner planet.

9.5. EU industrial innovation capacities and future Outlooks

The main industrial players in this sector are SMEs, but there are also some bigger industrial companies including ACCIONA Agua, BEFESA, Advanta Seeds, Cargill, ADM, Bayer, BASF, Fertiberia, Evonik and Libelium. There are also many research institutes and Universities dealing with this market (Tekniker, Azti, Univ. Reading, Leitat, INL, UPC).

The development of sensor systems for agriculture and Digital Farming, such as new photonic sensors, will involve industrial technological development in different fields such as (i) new materials to manufacture low-cost detectors; (ii) flexible and low-power electronics to develop more compact equipment with greater autonomy; and (iii) new embedded systems for the management of the measurements and their interconnectivity with a data management platform. Biobased and/or biodegradable polymers based on sustainable protocols that can protect the soil cultivation will provide a better competitive position in Europe, transforming the excellent scientific knowledge into new marketable products. The development of antimicrobial solutions for membranes, filters for air and water

[124] Fawell et al., Br Med Bull. 68 (2003) 199-208

treatments with higher durability while preventing environmental contamination is required to achieve cost efficient solutions to improve air and water quality .

The EU has a huge capacity to be world leading in this sector, in sustainable agriculture as well as precision and digital farming with high productivity and food security.

10. Materials for sustainable textiles Market

10.1. The Innovation Market size and Trends

The end markets for fibres and textiles are undergoing significant changes and are expected to see a massive shift in terms of types of products, materials used and their volumes in the coming years. Textiles and clothing are a diverse sector that plays an important role in the European manufacturing industry, employing 1.7 million people and generating a turnover of €166 billion. While low added value commodity products have been outsourced, high added value products are still largely made in Europe, with broadly stable added value and steadily growing exports. The sector is undergoing a radical transformation to maintain its competitiveness within this move towards products with higher value added, and gaining a significantly improved sustainability profile.

The textile manufacturing value chain is a complex, globally interconnected ecosystem with over 150,000 manufacturing companies in the EU alone, almost all of which are SMEs. Starting from fossil or biobased fibres, the industry processes this raw material in subsequent processing and production steps via filaments and yarns into fabrics, which are typically dyed and finished in many highly specialised processes and finally converted and assembled into final products for the clothing and fashion, interior and many technical end markets.

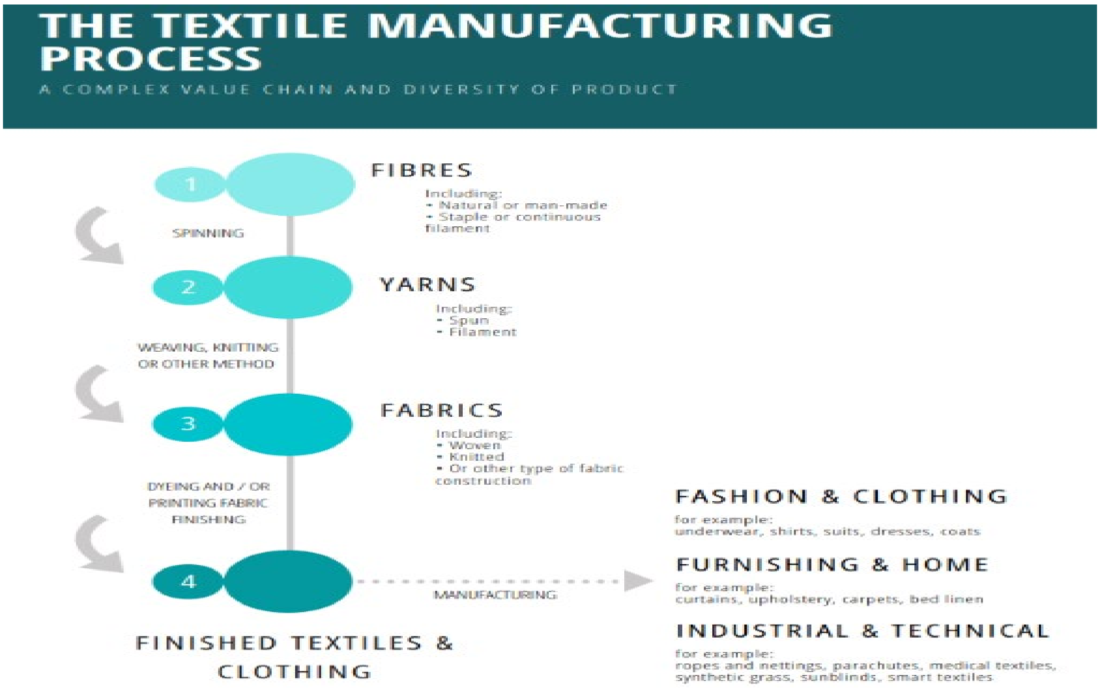


Figure 15: *The textile value chain*[125]

The EU textile and clothing industry has shifted its focus to high added value products for the most demanding consumer and industrial end markets such as premium and luxury fashion and interiors, medical textiles and nonwovens, high quality workwear and personal protective equipment and materials and components for the transport, construction, environmental protection, agriculture, and fishery markets. EU producers not only serve EU end markets with their innovative products but also export an increasing share of EU production to global markets. The annual export value of the EU textile and clothing industry is more than €50 billion.

Electronic textiles (e-textiles), i.e. filaments, fabrics and textile end products that have electronics and interconnections integrated into them, are seeing rapid growth in the current decade, driven by many added value niche markets across healthcare, sports and gaming, personal protection and smart interiors. Market analysts believe next generation wearables will provide significant opportunities to newcomers and well-established textile companies for creating value. Europe has a good starting basis thanks to a strong technical position of the textiles industry.

10.2. Materials challenges and priority Areas

The EU textile industry strives for sustainable fibres and fabrics with additional functionalities and superior performance in novel application areas at affordable costs. The path to this combined target lies in the following technical innovation and processes:

Innovation trends and new industry paradigms

- High performance fibres and textiles for high added-value technical applications
- E-textiles for smart wearables and interiors
- Renewable and biobased fibres to replace fossil-based materials
- Ecodesign and Circular Economy approaches covering the entire value chain from design to product development, manufacturing, distribution, use, care, maintenance and repair, disassembly, and recycling
- Design and processing for longevity and low fibre release of textile products
- Design, processes, and related chemistry for safe and sustainable functional textile products
- Resource-efficiency and decarbonisation of textile processing and manufacturing.

Three priority areas have been selected by the ETP (European Textiles Platform), SUSCHEM and EUMAT:

[125] https://euratex.eu/facts-and-key-figures/

Advanced biobased and renewable fibres and textiles for functional and technical applications. Focus on low-cost and low-impact high performance fibres and textiles from renewable sources for technical end markets. It needs effective circularity enabling technologies for technical textiles, nonwovens and fibre-reinforced composites, biopolymer or natural fibre based high performance fibres, textiles, nonwovens and composites, industry-ready processes and technologies for establishment of complete renewable material sourcing, manufacturing and recycling, EU value chains with focus on biobased and renewable fibre feedstocks, rapid assembly, de- and re-manufacturing of complex technical textile, multilayer or hybrid material products.

1. Sustainable and resource efficient multifunctional textile surface engineering including biobased chemistry for consumer products and technical applications. Priority developments must include a) innovative processes and technologies for targeted (multi)functionalisation of fibres and textiles, sustainable and durable high-performance textile chemistry, efficient low resource utilisation processes and technologies, innovative coating and lamination processes and technologies and efficient re- and de-functionalisation.
2. **Smart E-textiles for smart wearables and large-area surfaces and their efficient integration, manufacturing, and recycling.** Important drivers for the growth of the smart textiles market include implementation of advanced technologies in fibres and surfaces, miniaturization of electronic components and the integration of low-cost Smart Wireless Sensor Networks. Innovation efforts need to focus on strategically building up this new manufacturing value chain, mastering all key components, building a strong R&D and technology base and develop the technical, especially digital, skills of the work force.

10.3. Expected benefits

EU Sovereignty

Europe's textile sector, its technology providers and research community are world-leading. The most technologically advanced textile products are being manufactured in Europe and new manufacturing value chains such as technical textiles were developed in Europe first, in the 1990's and early 2000's. While the global textile industry is somewhat dependent on European manufacturing technology and advanced material know-how, Europe is heavily dependent on imported raw material supply in both synthetic and natural fibres (close to 90% non-EU origin) and to a significant extent on textile processing chemistry. These external dependencies can be reduced by creating competitive EU-based sources of sustainable textile fibres and green chemistry. Focus should be on **fashion that is produced in the EU.** Currently, fast fashion that is mainly produced in low-income countries is consumed in Europe.

Environmental footprint

Today approximately 70% of all global textile fibre-based products are made of fossil-based feedstocks. While collection and re-use rates of end of (first) life clothing is relatively significant (20-30% depending on EU country), ultimately the vast majority of European post-use textile waste is still incinerated or landfilled (in the EU or elsewhere in the world). While not all synthetic fibres are likely to be replaced in the short term for performance or cost reasons, significant research and technology advances are needed to enable future large-scale replacement of virgin fossil-based fibres by biobased or renewable materials, preferably from EU agricultural, forestry and waste resources.

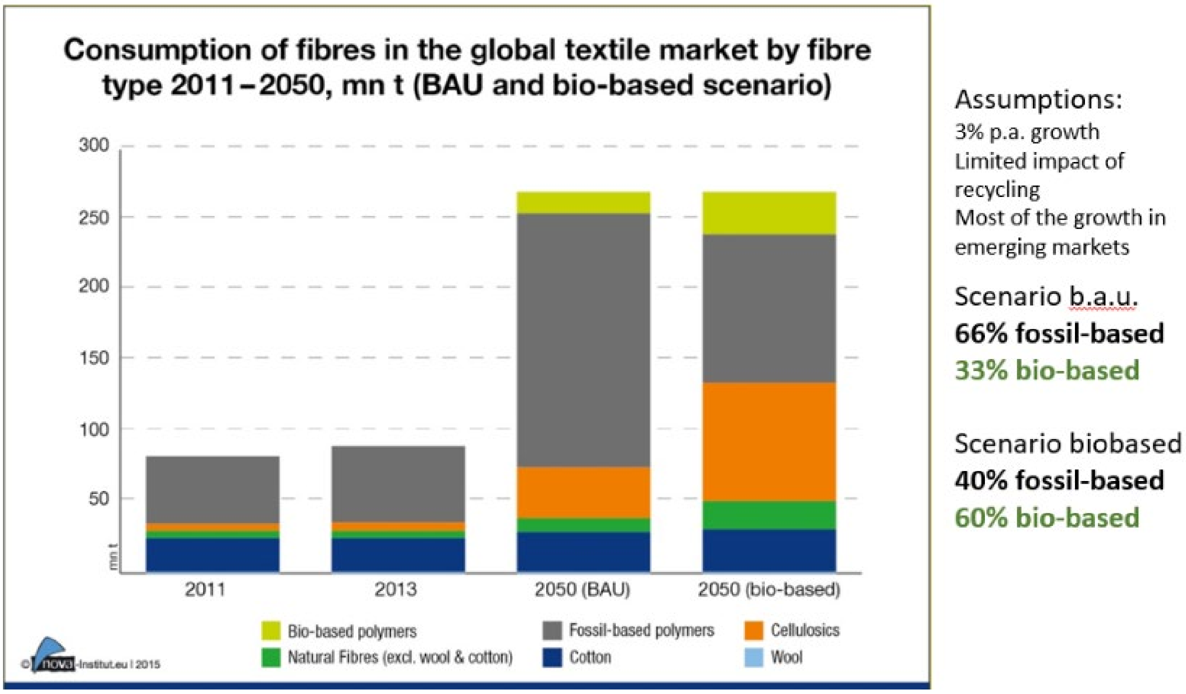


Figure 16: *Long-term scenarios of global textile fibre consumption* [126]

One major problem of the European textile industry is the lack of willingness at all customer levels to pay higher prices for today‘s more pricy sustainable products. Detailed data on impact of all major textiles and processes is needed, and cost-efficient innovation in the production of renewable fibres is paramount. To reach a much higher level of circularity and renewable resource use, **the following innovations need to be prioritised**:

- Low-cost, low-resource, and low-impact high performance durable fibres and textiles from renewable sources for technical end markets.
- Effective circularity enabling technologies for technical textiles, non-wovens and fibre-reinforced composites, e.g. biopolymer or natural fibre based high performance fibres.
- Industry-ready processes and technologies for establishment of complete renewable material sourcing, manufacturing, and recycling value chains in Europe with focus on abundant biobased and renewable fibre feedstocks.
- Rapid assembly, de- / re-manufacturing of complex technical textile, multilayer, or hybrid products

[126] Source Nova Institute, 2015. http://bio-based.eu/ibib/

- Reduction of hazardous chemical processing for crucial technical functionalities of textiles.
- Intelligent textiles with sensing capability and ability to interact with the environment
- Efficient re- and de-functionalisation.

Strategic autonomy

While the EU textile industry is world-leading in many specific high-end areas, commodity textile chemistry like dyestuffs, inks, conventional finishes, and auxiliaries has been mostly transferred to Asia. Lack of EU supplies of some of these mission-critical chemicals has created disruptions in EU supply chains. The EU textile and clothing industry imports a large share of its raw material supply, both synthetic fibres (mostly polyester) and natural fibres (mostly cotton and wool). A way out of these dependencies is the rapid deployment of sustainable value chains with EU-based sources.

The key challenges to achieve, preserve, and enhance Europe's strategic autonomy in textiles are:

- Preservation of the strategic textile manufacturing value chain in Europe and development of new high added value manufacturing chains for future products such as smart textiles.
- Digitalisation of materials and products manufacturing value chains, business models at home in the EU to enable fully circular local and regional on-demand manufacturing, repairing and recycling operations.
- Micro-factories and urban manufacturing for rapid prototyping, customised short runs, or high added value niche products.
- Reinforcement of the European functional and technical textile ecosystem including suppliers of innovative processing technology and performance chemistry.
- Reinforcement of the European manufacturing industry, silicon and post-silicon interfaces, flexible electronics and chipsets aiding the development of Internet of Things and Internet of Bodies in Europe.
- Assurance of European autonomy in functional and technical textiles for strategic sectors such as defence, personal protection, and healthcare.
- Focus on fashion that is produced in EU, prioritising these over those produced in low-cost countries.

Sustainable value chain

Functional textiles: Many functionalities of advanced textiles are realised through mechanical or chemical engineering of textile surfaces, often tailored for specific customers or niche markets. These innovations are typically realised in close collaboration with developers of processing technologies and performance chemistry to guarantee the highest level of functionality, reliability, and durability. Stricter environmental and health regulations have removed or threaten to soon remove many traditional chemical finishing processes from the market. Europe needs to strive to be a global leader in the replacement and substitution of such hazardous processes by safer and biobased or renewable alternatives. The energy and water consumption of finishing processes should be reduced, and water/air pollution risk minimised.

A new supply chain for Smart Textiles. Smart E-textiles, smart wearables and interiors provide the opportunity to develop a new world-leading manufacturing value chain based on Europe's engineering, multidisciplinary innovation, and high-quality manufacturing skills. E-fabric solutions are becoming relevant, for instance, in energy harvesting & thermo-electricity, wireless key board fabrics, sensors for direction and speed of motion of a person, biosensors in healthcare as well as in fashion fabrics.

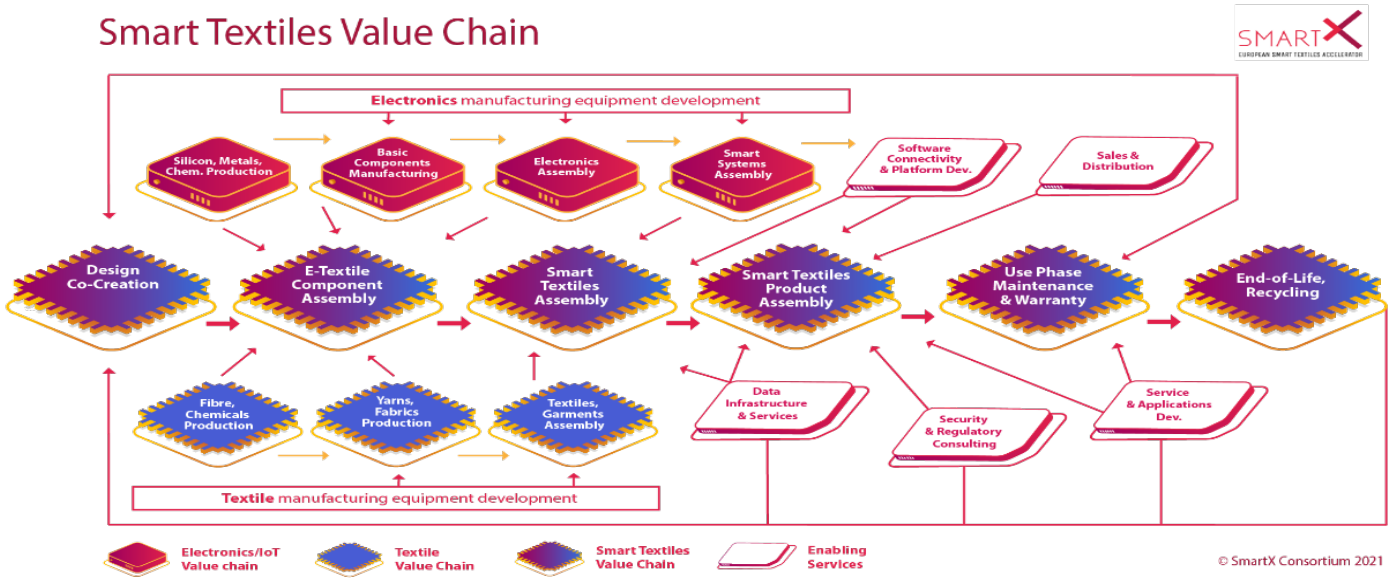


Figure 17: *The emerging Smart Textiles Value Chains*[127]

10.4. Expected socio-economic benefits

Consumers have increased **awareness of the environmental impact of textile production** and consumption and actively seek more sustainable purchases. The same is true for **public procurers in textile end markets** such as work wear and protective clothing for public services, hospital textiles, supplies for defence and security.

Today, more **sustainable textile and fibre product alternatives** come at higher prices; technological and non-technological innovation is needed to drive down costs of sustainable and circular textiles, while accompanying regulations should incentivise consumption of more sustainable alternatives while disincentivising less sustainable products.

[127] Source: SmartX project, 2021, https://www.smartx-europe.eu/introducing-the-full-smart-textiles-value-chain-map/

The pathway to ensure the success and impact of the new **green textile technologies** should be via an open channel with society, for a living 'community building' process via wider dissemination of the research and industrial roadmaps, technology transfer and upskilling initiatives, leading to broad acceptance and trust by the public.

10.5. EU industrial innovation capacities and future outlooks

Europe is an undisputed world leader in textile innovation, both in high end fashion and luxury (LVMH, Kering, Hermès, Marzotto, Armani, Ferragamo, Prada, Ermenegildo Zegna, Hugo Boss…) and in technical textiles and nonwovens (Sioen, TDV-Klopman, TenCate, Schoeller, Porcher, Serge Ferrari, Getzner, Freudenberg, Ahlstrom, Sandler…) and has important global players in man-made fibres (Lenzing, Radici, Aquafil, Sinterama…) and sportswear (Adidas, Puma, Decathlon). The sector is dominated by SMEs, many of which are so-called hidden global champions in their respective niches. In addition, European textile machine manufacturers (such as Rieter, Saurer, Picanol, Karl Mayer, Groz Beckert, Lindauer Dornier, Andritz, Van de Wiele, Lectra…) dominate the world market. In textile performance chemistry especially for niche technical markets and biochemistry (enzymes), innovation is still mostly driven by European suppliers or EU-based development divisions of multinational companies (eg. BASF, Dupont, Novozymes, Dyestar, Archroma, CHT Beitlich, Zschimmer & Schwarz…). Europe's textile research infrastructure is rich with world-renowned institutions such as DITF, ITA-RWTH Aachen, CITEVE/CeNTI, AITEX, Centexbel, Hohenstein, STFI, IFTH, CETI, Centrocot, TU Dresden, ENSAIT, University Boras, UPC, Ghent University or University of Minho.

As far as commodity textiles and critical value chains in global markets are concerned, there are promising EU industry strategies to reduce external material dependencies: a) by increasing EU man-made cellulosic fibre production (from forest-based and waste feedstocks), b) by chemical recycling of synthetic fibres and c) significant growth of EU natural fibre crops, especially hemp.

EU industry has given up on cheap, commodity products made in low-added-value labour-intensive workplaces from which nobody in Europe can live decently. The industry has refocussed on smaller volume higher-added-value premium/luxury and highly functional/technical niche products. Exports of EU-made textile products to the rest of the world have doubled to almost €60 bn in the last 15 years. This tendency will also continue in the future.

Industrial innovation in fibres and textiles will be the driving force and enabler for many **cross-sectoral developments** in different end markets:

- IM 'Healthcare' (filaments and fabrics for medical use, coatings for wound treatment, sensors)
- IM 'Construction' (light-weight structures, fibre-reinforced concrete, flexible membranes…)
- IM 'Energy' (fibre-reinforced materials for wind, flexible photovoltaics, and biogas membranes)
- IM 'Transportation' (light-weight fibre-based, smart textile structural and functional parts)

- IM 'Sustainable Packaging' (biobased and/or biodegradable flexible packaging)
- IM 'Sustainable Agriculture' (Agrotextiles, biodegradable growth support materials)
- IM 'Electronics' (E-textiles; sensors, smart wearables and interiors)

11. Materials for electronics appliance Market

11.1. The Innovation Market Size and Trends

Europe's Consumer Electronics Market size crossed € 230 billion in 2020 and is anticipated to exhibit a CAGR of 8% from 2021 to 2027. According to other sources, 2022 consumer electronics revenue totalled more than € 0,92 trillion worldwide and € 188,6 billion in Europe (Statista, most recent update Nov 2021). The market growth is owing to a low population growth and a high penetration rate in most product categories.[128] Concerning production of European consumer electronics merchandise in 2022, most revenue is generated in China (Statista: € 74,52 billion in 2021); annual growth rate (CAGR 2022-2025) of 9.28%. In the Electronics segment, the number of users is expected to amount to 469.4million users by 2025. User penetration will be 46.0% in 2022 and is expected to hit 55.3% by 2025. The average revenue per user (ARPU) is expected to amount to 441,7€.[129]

Semiconductor market size

Semiconductor sales reached € 552 billion in 2022 (Deloitte). Towards 2030, the global semiconductor market might further grow far beyond €910 billion.[130] Today, the EU just accounts for 10% of worldwide semiconductor sales; by means of the Chip Initiative, Europe wants to double this share (20%) (EU Commission). The innovation market for **advanced materials** is therefore estimated to grow towards €63,7 billion[131]. By 2030 deposition of materials (plating, precursors, sputtering targets) will represent an opportunity of more than €9,1 billion and non-silicon advanced substrates will represent a €4,55 billion opportunity.

As far as the electronic market is concerned, besides the traditional silicon-based market, a new growth market is impacting today's technology, where the key targets concern the use of sensing devices with ultra-low power consumption, together with the exploitation of eco-sustainable materials, exploiting green technologies and the use of recyclable materials which will create a positive impact in reducing the so-called electronic high-tech trash. Here, flexible and conformable electronics is a vital issue to be considered in the future, where sensing and the electronics required to control, transfer and store information is critical. Indeed, flexible electronics has been one of the world's fastest growing technologies, with

[128] European Market size, February 2022
[129] https://www.statista.com/outlook/dmo/ecommerce/electronics/eurpe#revenue, 2022
[130] https://www.mckinsey.com/industries/semiconductors/our-insights/the-semiconductor-decade-a-trillion-dollar-industry
[131] https://www.semi.org/en/blogs/business-markets/iss-2022-semiconductor-industry-outlook-and-prospects-for-reaching-%241-trillion-by-2030

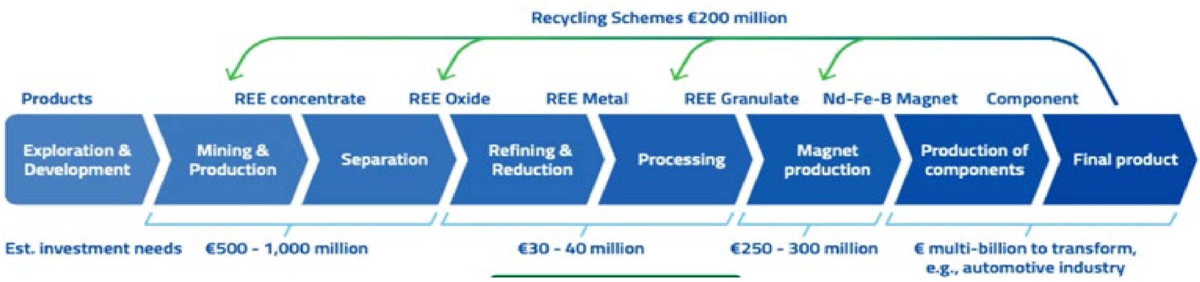
a market valued at €21,74 billion in 2019 and projected to reach €39,08 billion by 2027 (CAGR of 7.4 % from 2020 to 2027)[132].

Global Roll Out of 5G

Collective global investments in R&D and CAPEX by firms that are active in the 5G value chain will be in the range of €216,2 billion annually (IHS market). Enhanced mobile broadband, massive internet of things and mission critical services. The potential in 5G communications is already driving an accelerated demand. Expectations are high for increased mobile speed, largely due to the insatiable appetite for video content. Some of the key applications driving this growth are:

- Advanced Materials for new 5G/6G connectivity
- IoT and Innovative Technologies for Sensors
- Advanced Materials and Substrates (e.g. Silicon Carbide and Gallium Nitride)
- Advanced Materials for the Housing and Structural Frames of Electronics
- Advanced materials for next-generation fibre-optic components (e.g. connectors and transceivers)

Sensors, lidar, power electronics and smart devices for Transportation electrification, connectivity, and control. Global expenditure for sensors (all types) will rise by more than €184 billion in 2022-2026, with a CAGR of 16,5% (Research and Market report, Jan. 2022). The use and the dependability of electric sensors, wiring, harnesses, and connectors will be essential for autonomous vehicle deployment and life-saving safety features, with advanced materials being scoped for all the new cameras, radar, LIDAR, sensors [and redundant safety]. Interior vehicle safety sensor communication and vehicle-to-vehicle communication will require redundant safety features to remain continuously reliable. Investment dimensions for recycling scale up requires € multi billion investment.[133]



[132] Humbare R, Wankhede S and Kumar V 2020 Flexible Electronics Market By Component (Flexible Display [OLED, E-paper, and LCD], Flexible Battery, Flexible Sensor [Bio Sensors, CMOS Hybrid Sensors, Photo Detectors, Piezo Resistive, and Others], Flexible Memory, and Flexible Photovoltaics) and Appli 219
[133] Source EIT Raw Materials.

Figure 18: *Investment Dimensions for recycling*[126]

11.2. Materials challenges and priority areas:

Main Materials challenges

Advanced materials are needed for the new 5G network infrastructure.5G networks require new levels of RF transparent and heat dissipating materials. Signal transmission and thermal management will be critical. 5G transmitters call for robust, low-loss materials to minimize radio frequency interference in the mmWave spectrum.

Advanced Materials for Electronic Structural Components

Electronic component housings and electric structural components are integral to the quality, reliability, and function of their end-use applications. As the electronic devices market demands continue to trend towards light weighting and miniaturization at low cost, innovative light materials are needed in critical applications such as housings, structural frames of sensors, camera and speaker modules, switches, connectors, microphone membranes and other components in some of today's most advanced electronics, enabling improved performance with increased design flexibility, and superior mechanical properties.

Innovative Technologies for Sensors

With the push from market innovations such as the Internet of Things (IoT), mobile and wearable devices, 5G and high-speed communications and other smart electronics, design trends for sensors continue to shift. These innovations demand an abundance of sensor advancements such as sensor function fusion and integration, increased sensitivity, a reduced power consumption, continued miniaturization, and overall system cost reduction. This selection of unique improvements requires an equally versatile portfolio of specialty materials to deliver such well-rounded proficiency. Some relevant technologies are advanced printing technologies for sensors fabrication and subtractive technologies to design the electronics of the future.

Sustainable conformable and flexible electronics

The challenges concerned flexible/stretchable sensors will be to maintain the integrity of material properties and at the same time to meet the requirement of quality printing. Printing is at a mature stage in development making it suitable for a varied range of applications. The design to production time is reduced, and the direct deposition tool minimizes the material wastage. Additive manufacturing techniques are adopted to fabricate flexible/stretchable tactile sensors with tailored geometries to improve their performance in sensing systems conforming to unstructured surfaces.

However, there is need for further development of materials (inks) and additive manufacturing technologies if these sensors are to be mass-produced for large scale mainstream consumer-related applications with emphasis on recyclability. A desirable feature of flexible electronic systems for various smart surfaces, ranging from healthcare to automotive markets, is **the combination of multiple sensor arrays**, e.g. signal conditioning and processing circuitry, memory, energy harvesting and wireless transmission of information. The challenges regarding ultra-low power sensing is connected to device and systems integration at nanoscale. Flexible and transparent electronics, manufactured using natural and sustainable materials, are of importance for the smart functionalisation of the interior of e.g. vehicles geared with smart-monitoring of passengers and cargo in the car cabin; vehicle user interface (HMI - Human Machine Interface); safety and comfort of passengers.

An important element to consider is taking advantage of eco-sustainable materials to provide solutions for tomorrow's **challenges at a micro and nano scale for smart dynamic sensors.** This, in turn, can build the transition towards the next-generation of hyper-trends, applied research needs to be carried out on multifunctional materials for sensing and electronics, chip-less integrated systems, ultra-low power sensing electronic systems, among others.

Our objective is to address the challenges of our collective future, where the aim is to preserve the European quality of life and living standards by integrating the people's voice in our work; the spirit of co-creation and citizen involvement has gained more and more importance in our democratic community, where circularity, and a sustainable supply chain should be included in new developments. Here, flexible, and conformable electronics is a vital issue to be considered in the future, where sensing and the electronics required to control, transfer and store information is critical. Thus, the focus should be centred in:

- Materials for **ultralow power sensors**, transductor, and actuators for advanced industry applications.
- **Smart sensors for advanced packaging,** for cooling and thermal distribution management.
- Wearable, **flexible and stretchable smart sensors for** green electronics, including reliability, self-healing, hybrid integration, assembly, and bonding/soldering of heterogeneous components.
- Inks for **functionalization of fibbers and flexible surfaces**, with mechanical properties suitable for printing and/or nano-stamping processes.
- **Thin films produced in vacuum**, printed and/or nano-printed with tailored electrical properties
- Chemical, **optical, temperature and pressure sensors** with specifications ad-hoc to the car cabin.
- **Monolithic integration in flexible substrates** of Complementary Metal Oxide Semiconductor (CMOS) technology based on metal oxide thin film transistors (TFTs), with cutting frequencies of transistors close to 1 GHz and operating voltage below 4 V, with switching speeds below 1 μs, with energy consumption per operation of reading/transmitting data per device <2 fJ.
- **Integrated electronic systems for the control and transmission** of ultra-low energy consumption information in terms of units to be integrated: microcontroller (3.5 mW); sensor set (20 mW); ADC (10 mW); ring oscillators (0.03 mW), RF diodes (1 mW), dial (50 mW), an RFID (10-100 mW), additional transparent peripheral circuits (1 mW).
- Integration of sensors in **multiplex and electronic format** in flexible substrates following matrix approach.

- Materials for next-generation fibre optic applications
- Dependable Optical Fibre Connectors

  As fibre optic connections develop, OEMs must deliver a multitude of variations to meet and exceed market demands**.** Plastics continue to replace metal in several fibre connector components, with high-performance thermoplastics remaining the ideal materials for connector housings, dust caps, fibre ferrules, and fibre optic wire and cables. Optical fibre connector housings are a critical piece for fibre connectors, panels, modules, and adaptors, as they contribute to both the quality and longevity of performance. Solutions for these housing applications must display extremely high tolerance, inherent flame resistance, excellent colourability, UV resistance and exceptional aging resistance.
- High-Performance Optical Transceiver Modules

  Today's advanced optical transceiver modules are used in high-bandwidth data communications applications and must be extremely reliable. Transceiver modules connect the rest of the system to the fibre optic cable through an electrical interface, and consist of lenses and mirrors, module housings or plug housings. Materials for components of optical transceiver modules must exhibit outstanding optical performance for light transmission and high-temperature performance.

Today's electronic components face the challenges of high frequency, high-speed communication where radio frequency signals can easily decay, especially for high moisture absorption materials like polyimide (PI) or Epoxy. Accordingly, Printed Circuit Board (PCB) and Fabricated Printed circuits (FPC) components require low dielectric loss materials as dielectric loss is the most significative factor to signal loss. These high-performance insulating solutions must be capable of insulating but not interfering with high frequency, high speed electrical signals in applications such as communication PCBs and FPCs.

Materials for Electronic appliances designed for reuse and circularity.

Thermosets do not count as recyclable but are commonly used in miniature circuit breakers (MCBs). The same applies for polymer additives (e.g. for flame retardation, fillers). Hence material and/or recycling process innovation for high performance polymers is needed. Upcoming regulations on product design and secondary materials will require MCBs to be recyclable.

CRM avoidance, replacement, or recycling in electronic devices.

- CRM use reduction, CRM substitution. Increase durability of CRM
- CRM reuse, remanufacture, repair
- CRM recycling, downcycling
- Design of electronic appliance for resue and circularity
- Advanced materials/processes that extend the expected lifetime of electronic appliances by including integrated cooling features and advanced joining methods

Some material solutions **to reduce CRM dependency** can be highlighted:

- multifunctional materials electronics for chip-less applications at a nanoscale for solving integration complexity.
- New semiconductors based on 1-D and 2-D materials as alternatives to silicon, increasing electronic mobility by taking advantage of the transport mechanism of 1D and 2D semiconductors.
- To develop new and low-cost electronics compatible with flexible electronics

The priority areas defined by the EUMAT working group in materials for electronics and EMIRI are as follows:

- Advanced multifunctional materials for environmental protection, heat dissipation, RF transparent and miniaturization in electronic market (e.g. 5G network, wearable devices, sensors, semiconductor).
- Advanced coatings and substrates for electronics (e.g. flexible electronics, post silicon electronics, fibre optic applications).
- CRM avoidance, replacement, or recycling in electronic devices. Materials for Electronic appliances designed for reuse and circularity.

11.3. Expected benefits

The expected benefits with regards to EU Sovereignty, environmental footprint, strategic autonomy, and sustainable value chain include:

- Enabling sovereign access to semiconductor materials within Europe.
- Environmental advantage due to sustainable use of (recycled) materials to produce electronic materials and due to reduction of production waste
- Activities will contribute to sustainable value chains in the EU, based on sustainable and responsible metal sourcing, which contributes towards the strategic autonomy for EU in view of EU's chip production ambitions.

EU Sovereignty

This combined with the effects of a rapidly growing semiconductor industry facilitated by the European Chip Act will enable the EU to reach its ambition of doubling its current market share to 20% by 2030.

In relation to dielectric material solutions for printed circuit boards (PCB) and flexible printed circuits (FPC), upcoming regulations (e.g. EU Green deal, circular economy action plan) on product design and secondary materials will require recyclability (eg. MCBs) and permanents magnets which are required in high-growth applications such as electric vehicles.

Environmental footprint

Digital technologies will contribute to decarbonization in the (chemical) value chains, resilience & climate neutrality. Electronics market will facilitate the digitalization that facilitates distance cooperation without transporting persons and goods, reducing energy consumption and thus, carbon footprint.

Strategic autonomy

Improved recycling technologies will sustain competitiveness in markets with already stricter regulations and reduce geopolitical supply risks (e.g. from China). EU studies on strategic autonomy can be considered. Smart materials have the ability to be sensorised, connected, interactive with surfaces capable of responding to external stimuli by varying one or more of their properties and/or incorporating sensors, lighting or electronics. Advanced materials and processes will contribute to extend the expected lifetime of electronic appliances for example, developing and scaling up smart thin films (e.g. batteries, fuel cells, CSP, PV) or by including integrated cooling features and advanced joining methods. Additive manufacturing for low carbon energy systems will require hybrid manufacturing processes and strategies to reduce post processing steps/activities, with localized production systems ('factory in a container'), to minimize infrastructure, transport, and associated CO_2 emissions. There is a positive effect of increasing durability (e.g. for Cu), the longer the lifetime, the lower the raw material dependence. This will reduce demand and delay recycling.

Sustainable value chain

5G is the engine of the modern society. Enabling the IOT and its massive data flows requires billions of sensors, cameras, antennas, and other electronic devices that need to be designed and assembled. In addition, all these devices need to be protected from the environment, to guarantee their lifetime and repairing possibilities, so advanced assembly and disassembly materials will play a key role. Sustainable (Green) polymer material innovation, combined with sustainable design guidelines to facilitate ease of disassembly, repair, and remanufacture.

11.4. Expected socio-economic benefits

The increasing digitalisation and decoupling of economic growth from resource consumption will change the way people live, work, are entertained and travel, as well as how governments and businesses interact among themselves and with the world. These market drivers are increasing the demand for smarter, lower cost, sustainable and more power efficient electronic devices which can sustain and enable applications such as electric vehicles, energy management and 5G/6G.

11.5. EU industrial & innovation capacities and future outlooks

Industrial and innovation capacities can be built on the strong semiconductor value chain in Europe, covering advanced materials, equipment providers and electronic components (Umicore, BASF, SOITEC, Air Liquide, Merck, Osram Opto Semiconductors GmbH, NXP semiconductors NV, ASML, Zeiss, Besi, EVG, Applied Materials, Obducat, Robert Bosch GmbH, STMicroelectronics NV, Infineon, Philips, Siemens GmbH). These EU strengths are also complemented with world-class research R&D capabilities and organisations (IMEC, Leti, Fraunhofer, INL, BRTA and others) and associations (AENEAS, EMIRI, EUMAT, EARTO…) which support the European semiconductor industry. These leads to possibilities in terms of:

- Technical advantage around improving performance of the semiconductor devices, improved energy efficiency and enabling new applications.

- Economical advantage due to cost-effective material solutions.
- Reduction of energy consumption, thanks to heat management, weight reduction and miniaturization.
- Energy harvesting.

12. Overview of preliminary mapping exercise: Cross cutting challenges

Advanced materials are enablers in areas that at first sight seem only remotely connected. While different Materials Innovation Markets (MIMs) require some specific materials properties, there are also broad communalities: a need for advanced materials and technologies that have a wide range of applications and challenges in different markets. As shown above, good data sharing, information flow, and proper governance can help to tap the enormous potential of such materials in different Innovation Markets. Furthermore, processing technologies and solutions to scale up new materials, dealing with different applications and challenges are equally important. In the following, a first overview about cross cutting horizontal applications of advanced materials in the MIMs and materials processing and scale up R&D challenges will be presented.

12.1. Preliminar Mapping: Horizontal applications of advanced materials in the MIMs

The following list does not claim to be exhaustive but presents a selective overview of horizontal applications of advanced materials across the MIMs. The table is a summary of the topics contained in the nine MIMs and holds only the keywords. Materials **cross cutting common interest** in different markets have been identified in order to increase the synergies and impact in materials development.

Advanced Materials and Technologies	Applications in the Materials Innovation Markets
Bio-based, degradable materials	**Health Care:** biocompatible, degradable materials, waste management **Sustainable Construction:** biodegradable fluids (eg. concrete) **New Energies:** biodegradable fluids (eg. windmills) **Sustainable Transport:** bio-degradable fluids (cooling, lubricants) **Home & Personal Care:** New bio-based chemical solutions and feedstocks **Sustainable Packaging:** Shift from fossil-based to bio-based polymers **Sustainable Agriculture –** bio-degradable polymers **Sustainable Textile-** bio-based renewable fibres **Electronics appliances:** Biodegradable housing for electronical devices
Embedded electronics and post-silicon electronic materials	**Health Care:** electronics embedded in monitoring or diagnostic´s devices **Sustainable Construction:** integrated photovoltaics and sensors **New Energies:** high-efficiency energy production, transformation, storage, and control **Sustainable Transport:** Power electronics for connectivity and control; ionic semiconductors, GaN technology **Home & Personal Care:** embedded electronics in smart mobiles for home care control, patches with electronic control of drug delivery **Sustainable Packaging:** embedded sensors e.g. food quality monitoring **Sustainable Agriculture:** Embedded sensors to control food maturity

Advanced Materials and Technologies	Applications in the Materials Innovation Markets
	Sustainable Textile: E-Textiles and wearables, medical textiles **Electronics appliances:** GaN microelectronics; multi-sensor arrays;
Materials for Advanced Coatings and Textured surfaces	**Health Care:** anti-microbial surfaces; textured surfaces; low-wear, low-friction devices for implants **Sustainable Construction:** smart and green construction materials **New Energies:** surface technologies for solar and storage **Sustainable Transport:** light materials low-friction and wear surfaces **Home & Personal Care:** multi-functional surfaces and coatings **Sustainable Packaging:** smart barrier coatings, antimicrobial coatings **Sustainable Agriculture:** Agrotextiles, plastics with antimicrobial properties for smart cultivation. **Sustainable Textile:** textile surface engineering with functional properties **Electronics appliances:** Electronics coatings and surfaces
Advanced materials for Additive Manufacturing (AM)	**Health Care:** AM with advanced polymers and metallic alloys (e.g. Ti) **Sustainable Construction:** large-scale AM; including light metals and wood-based-materials **New Energies:** 3D printing of batteries. **Sustainable Transport:** light weight components and structures by AM **Home & Personal Care:** tailored materials including polymers **Sustainable Packaging:** AM with advanced polymers, 3D printing of labels for packaging tracking **Sustainable Agriculture:** 3D printing of monitoring devices, sensors. **Sustainable Textile:** 3D printing of textiles **Electronics appliances:** printing/AM. - microelectronics
Sensors and multifunctional materials	**Health Care:** integrated biosensors for diseases diagnostic **Sustainable Construction:** Energy harvesting, air cleaning, sensing **New Energies:** Sensors to monitor health status of the lubricants in wind applications **Sustainable Transport:** Multi-materials in vehicles and aircraft; sensor-based maintenance **Home & Personal Care:** multi-functional surfaces and sensind **Sustainable Packaging:** smart plastics incorporating multifunctional barrier coatings and sensors. **Sustainable Agriculture:** sensors and sensor networks for maturity monitoring; Carbon farming **Sustainable Textile:** integrated sensors, E-Textiles **Electronics appliances:** multi-sensors, multifunctionality in wearables
Materials for circularity and re-use	**Health Care:** cleaning treatments for medical waste to avoid incineration. **Sustainable Construction:** sustainable materials, e.g. wood-based materials, biobased materials **New Energies:** CO_2 capture, conversion, and use (CCSU), battery & blades recycling, biobased, recycled and reused materials from windmills **Sustainable Transport:** sensor to separate waste before recycling/repair **Home & Personal Care:** Switch from non-degradables to bio-degradable materials **Sustainable Packaging:** design for circularity; biodegradables, recyclables **Sustainable Agriculture:** bio-degradable growth support materials **Sustainable Textile:** recyclable wovens and non-wovens **Electronics appliances:** electronic materials in re-use /circularity design
Advanced fibre materials	**Health Care:** wearables and sensors; coated fabrics for wound treatment **Sustainable Construction:** textiles (2D,3D) with integrated functionalities. Fibre-reinforced concrete**.** **New Energies:** Advanced recyclable composites for wind blade **Sustainable Transport:** fibre-based lightweight materials

Advanced Materials and Technologies	Applications in the Materials Innovation Markets
	Home & Personal Care: fibre materials for cleaning and antislip floorings **Sustainable Packaging:** fibre-based flexible packaging **Sustainable Agriculture:** Agrotextiles **Sustainable Textile:** large-scale industrial innovation in fibres **Electronics appliances:** light electronic devices.

Table 2: *Advanced Materials and Technologies in the nine MIMs*

12.2. Preliminiary Mapping: Materials processing and scale up R&D challenges

The following matrix represents a preliminary mapping between the most relevant **materials processing and scale up cross cutting R&D challenges** (with an illustrative list of sub topics) and their relevance for the **9 innovation markets or materials priorities**. The challenges that are specific to certain market/materials priorities are indicated in the respective sections.

Cross Cutting R&D Challenges	Relevance for Innovation Markets and/or Materials Priorities
Process optimization • Higher speed; flexibility • Resources savings (energy, water, consumables, etc.) • Separation process optimization	**Health Care** (processes for biocompatible functional surfaces) **Sustainable Construction** (production ready to install functional modules) **New Energies** (big size functional components for energy applications) **Sustainable Transport** (optimized processes for light materials production) **Home & Personal Care** (processes for functional coatings) **Sustainable Packaging** (protective coatings and sensors) **Sustainable Agriculture** (advanced sensors production to control food maturity) **Sustainable Textile:** µ-factories, urban manufacturing, water saving processses) **Electronics appliance** (mass application of monolithic integration of flexible substrates)
Decarbonization • Energy savings • Electrification • Renewable sources • Hydrogen economy and hydrogen production with low-carbon footprint • CO2 capture, storage, conversion, use	**Health Market** (detoxification processes for medical waste recycling) **Sustainable Construction** (integration of renewables, hydrogen-gas mixtures) **New Energies** (scale up, hybridization, cleaning) **Sustainable Transport** (production process adapted to secondary materials) **Home & Personal Care** (recycling processes) **Sustainable Packaging** (barrier coatings and sensors for content protection) **Sustainable Agriculture** (sensors for CO_2 farming) **Sustainable Textile** (recycling processes) **Electronics appliance** (eg. multifunctional materials production processes)
Mass customization • Consumer/customer integration • Highly flexible, reconfigurable	**Health Care** (personalized devices, prostheses) **Sustainable Construction** (eg natural biomimetic materials processing) **New Energies:** PV integration processes in devices **Sustainable Transport** (eg. additive manufacturing for production of spare parts) **Home & Personal Care** (tailored B2C products)

Cross Cutting R&D Challenges	Relevance for Innovation Markets and/or Materials Priorities
engineering and production processes • Supply-chain management	**Sustainable Packaging** (monitoring of the food packaging by the retailers, consumers) **Sustainable Agriculture** (monitoring of the maturity of agricultural products) **Sustainable Textile**: Tailored textiles processes **Electronics appliance:** Wearable devices; post-Si electronics
Zero Defect Production • In-line product and process monitoring and feedback to control • New, more accurate and intelligent sensing devices • Simulation of failure mechanisms at laboratory scale, accelerated tests and feedback to the process • Process and Product tracking	**Health Care** (Medical applications with enhanced quality and durability) **Sustainable Construction** (eg. processing of energy efficient and active materials) **New Energies** (eg. zero defect production processes to scale up materials) **Sustainable Transport** (eg. zero defects in materials manufacturing processes) **Home & Personal Care** (bio based production process improvement) **Sustainable Packaging** (zero defect control packaging industry using sensors) **Sustainable Agriculture** (bio based production processes, clean air and water) **Sustainable Textile** (bio based textiles production control) **Electronics appliance** (high-output zero defect microelectronics technologies)
Circular Economy • Rapid assembly, de-assembling, repairing, de & re-manufacturing recycling of materials, multilayer or hybrid material, including re- & de-functionalisation • Waste valorisation processes with emphasis on complex materials mixtures (eg. construction, electronic) • Eco-design along the value chain • Use of secondary materials	**Health Care** (detoxification processes for medical waste recycling) **Sustainable Construction** (sensors to analyse and classify construction waste) **New Energies** (recycling composites for windmills blades) **Sustainable Transport** (production involving secondary materials, on siter repairing) **Home & Personal Care** (Eco-design) **Sustainable Packaging** (de-coating processes) **Sustainable Agriculture** (water and air smart filtering) **Sustainable Textile (**low-footprint high performance durable fibres and textiles from renewable sources; Industry-ready processes for complete renewable material sourcing, manufacturing, and recycling) **Electronics appliance**: electronics 'designed for re-use"
Multi-materials processing • Design of the material and related properties • Production, joining/assembling & de-assembling • Multimaterials 3D-printing	**Health Care** (personalised and customised protheses; bioprinting, joining) **Sustainable Construction** (additive manufacturing with multimaterials) **New Energies** (improve energy efficiency and durability of windmills) **Sustainable Transport** (multimaterials processing, joining technologies) **Home & Personal Care** (multilayer coatings, and decoating processes) **Sustainable Packaging** (multilayer coatings, and decoating processes) **Sustainable Agriculture** (barrier coatings for cultivation protection) **Sustainable Textile** (Smart textiles and multi-functional fabrics) **Electronics appliance** (Printing circuits and sensors; advanced coatings for electronics)

Cross Cutting R&D Challenges	Relevance for Innovation Markets and/or Materials Priorities
New materials processing • Materials working under extreme conditions, mainly relevant to health, energy, transport, electronics, construction, etc • Flexible, transparent polymer/resins • Bio based, biodegradable and nano materials as feedstock (Bio- and waste-based) for materials manufacturing	**Health:** regenerative medicine (cell therapy, nanomedicine), technologies at the cross borders of materials science, biology, and biomechanics) **Sustainable Construction** (additive manufacturing technologies) **New Energies** (improvement of materials working at extreme conditions) **Sustainable Transport** (additive manufacturing and near net shape processing **Home & Personal Care**; Sustainable Packaging; Sustainable Agriculture (biotechnology and nanomaterials processes and scale up) **Sustainable Textile** (Advanced bio-based processes for textiles) **Electronics appliance** (nanofabricacion, wearables and sensors; post-silicon electronics)

Table 3: *Cross Cutting R&D Challenges in the nine MIMs*

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