IPCEI on Circular Advanced Materials for Clean Technologies (IPCEI CAM) – Scope and Objectives

Objectives:

The IPCEI as a whole and all projects need to contribute to a set of interconnected objectives which together form a three-tier system. This structure serves purely as an organizing framework, ensuring clarity and focus across different levels of ambition and scope, without implying any hierarchy of importance. All objectives are equally critical and are simply arranged according to their respective focus areas and strategic roles:

Primary Objectives:

- **Circularity, Recyclability and manufacturability**: Achieving net-zero emissions by 2050 will require tackling both energy-related and non-energy-related GHG emissions, which can be achieved through the transition to a circular economy (CE). The selection, development and engineering of circular, recyclable and manufacturable materials is a critical component towards the development of a circular economy model. The IPCEI aims to bring companies together in the researching and developing circular, recyclable and manufacturable materials and processes and thereby to reach a circular model for such materials in line with the R-strategies (among others Rethink, Refuse, Reduce, Re-use, Repair, Refurbish)[1]. Projects will therefore focus on reducing waste and enhancing material reuse in sectors like energy, mobility, and electronics. Additionally, the IPCEI aims to enable closed-loop systems in advanced materials production and to develop, scale-up and integrate advanced materials in dimensions yet unexplored.
- **Integration of circularity across the entire Value Chain and Innovation Cycle**: The objective is to foster integration of the circularity objectives from secondary material sourcing to recycling, ensuring smooth cooperation across all stages (materials development to end of use and recycling) and to document it. Projects will work on resource optimization and material traceability, enhancing efficiency and reducing costs throughout the innovation cycle from research to market uptake.

Secondary Objectives – Supporting General Objectives:

- **Contribution to the Reduction of EU Dependencies**: The IPCEI aims to reduce reliance on non-EU sources for critical raw materials by developing alternatives within Europe[2]. Projects will focus on boosting (resource) strategic autonomy in critical energy, mobility and electronics, e.g. for batteries, and renewable energy technologies.
- **Energy-efficiency**: The objective is to develop materials and processes that minimise energy consumption during production, usage, and recycling of materials and products. Projects will have to target reductions in energy use in key sectors like energy, mobility and electronics to help meet climate goals.

Secondary Objectives – Advanced Materials-Specific Objectives:

[1] Concrete example (of many that could be named): To illustrate how an IPCEI on Circular Advanced Materials could implement a circular model in line with the R-strategies, consider the development of circular battery materials for electric vehicles in the mobility sector. Electric vehicles currently rely on critical raw materials such as lithium and cobalt, which are mostly imported from non-EU countries. The IPCEI could concentrate on recyclable battery materials that facilitate the recovery and reuse of these CRMs within the EU. For instance, companies could develop new cathode materials that maintain performance and are easily recycled through advanced techniques such as hydrometallurgical processing or direct cathode recycling. This would reduce external dependency and waste. Furthermore, the project could promote battery refurbishment systems, enabling second-life uses in energy storage systems. This would extend battery lifecycles. This closed-loop approach aligns with the objective of the IPCEI on Circular Advanced Materials of minimising waste, advancing resource efficiency, and supporting strategic autonomy.

[2] In line with the recommendation on critical technologies; advanced materials are included in the top 10 (see annex to the recommendation)

- **Data Continuity and Development of Digital Tools**: Computational modelling plays an essential role in materials science and is used in an increasingly predictive manner. The power of modelling techniques continues to grow with the expansion of the capabilities of the computational hardware and the developments in algorithms and software. The expanding development of artificial intelligence (AI) and machine learning (ML) tools could be integrated into IPCEI projects, reflecting their rapidly increasing impact on material design and material innovation. The objective now is to ensure seamless flow of material data across the value chain, based on the FAIR principles (Findability, Accessibility, Interoperability and Reuse). This includes data on design, material stress, application history, and more, thereby enhancing transparency and traceability.
- To facilitate this, **a decentralized digital infrastructure in the form of a data platform** could help and facilitate real-time data sharing and collaboration across industries. The data platform should support academic and industrial collaborations, leverage novel technologies, streamline data exchange, manage and exploit large datasets with advanced digital tools, and integrate AI technologies and machine learning. This will also help to optimize recycling and circular manufacturing processes. This platform should be closely aligned with the Material Commons project[3]. This infrastructure will support the use of advanced digital tools like AI, simulation, and informatics for material development.
- **Safe and Sustainable by Design**: Advanced materials must be designed from the outset to be safer and more sustainable. Projects will focus on integrating lifecycle assessments to minimize environmental and health impacts while replacing harmful or unsustainable materials (e.g. PFAS) with safer and more sustainable alternatives. These alternatives must maintain performance in critical applications like energy, mobility, and electronics. The *Safe and Sustainable by Design Framework*[4] will guide the assessment and ensure regulatory preparedness. To ensure the safety and sustainability of Advanced Materials, harmonized testing methods, standards and guidelines must be used.
- **Contribution to Scale-up or Dissembling**: The IPCEI will focus on scaling up innovative materials to industrial levels, ensuring market readiness. Projects (in the later phases of the value chain) will also address disassembly challenges, making recycling, repurposing, reusing and material reintegration more efficient.
- **Performance-Orientation**: The aim is to improve the functional performance and characterisation of materials, increasing durability, strength, and efficiency while ensuring safety and sustainability. Projects will target high-demand applications in energy, mobility and electronics.

Clear and Concrete Connection to Energy and/or Mobility and/or Electronics Applications: Each project must have a clear and measurable impact on energy and/or mobility and/or electronics sectors. Innovations will focus on improving energy efficiency, sustainability, and performance in these critical industries.

<u>Structure:</u>

<u>Intervention Area #1: The Advanced Materials Value Chain (workstreams):</u>

- Each of these workstreams reflects a critical phase of the value chain, ensuring that "Advanced Materials for Circularity" contributes to a sustainable, closed-loop economy across sectors.

[3] Material commons has the goal - in close collaboration with the Member States - to build up a digital infrastructure for advanced materials for data and computational tools related to advanced materials research and development.

[4] Commission recommendation (EU) 2022/2510 of 8 December 2022 establishing a European assessment framework for 'safe and sustainable by design' chemicals and materials.

- Each project will be embedded in one (or more) workstreams and will be assigned to one or more application areas (or clusters)
- The entirety of the endeavour must ensure a thorough penetration of all phases of the value chain across all application areas/clusters
- Integrate safety and sustainability assessments along the entire life cycle in all work-streams, e.g. along the *Safe and Sustainable by Design* framework.

WS#1: Sustainable Material Sourcing and Processing: Focus on sustainable production and sourcing of secondary materials.

WS#2: Eco-design and Material Innovation: Design advanced materials optimised for circularity and durability, sustainability, and safety – including implementation of machine learning/AI

WS#3: Circular Manufacturing Processes: Implement low-waste, efficient production technologies, remanufacturing, use of secondary raw materials.

WS#4: Material Recycling, Recovery, and End-of-life Management: Develop efficient and sustainable recycling and reprocessing technologies, and create infrastructure for material recovery and reintroduction into the economy.

WS#5: Circularity in Application and Use-phase Optimization: Extend material lifespan and integrate circular use models (repair, reuse, etc.).

<u>Intervention Area #2: Application Areas:</u>

- As of now, the ten Application Areas (AAs) reflect those outlined in the European Commission Communication on Advanced Materials for Industrial Leadership. A focus on the three priority areas energy, mobility and electronics is important for various reason:
  - The AAs from the priority area energy are central to the fight against climate change, with the objective of achieving net-zero emissions by 2050. The expansion of renewable energy sources, like solar and wind power, and the accompanying need for significant advancements in energy storage technologies underline the importance of this sector. Innovations in energy systems and materials are critical to make renewable energy more efficient, scalable, and integrated into the broader grid.
  - The AAs from the priority area mobility play an equally pivotal role as the transportation sector seeks to transition towards low-carbon solutions. Advanced materials are essential for improving vehicle efficiency by reducing weight and enhancing performance without compromising safety. With the rapid growth of electric vehicles (EVs) and the rise of hydrogen fuel cell technology for heavy-duty transport, Europe is positioned to capture a significant share of this emerging market. The development of advanced batteries and the optimization of material use for better energy storage are key to accelerating this transition. In addition, smart and sustainable mobility solutions, including autonomous vehicles and multi-mode transport systems, are leveraging new communication technologies and electronic components to drive efficiency and sustainability in transport.
  - Electronics, while critical on its own, serves as a major enabler for advancements in both energy and mobility sectors. On one hand, the AAs in electronics are key drivers of energy efficiency and circularity, contributing to the reduction of emissions by enhancing the performance of energy systems and electric vehicles. On the other hand, the electronics sector is vital for the production of semiconductors, sensors, and control systems used in energy grids, battery management, autonomous driving systems, and communication networks for smart transport. This value chain approach highlights the essential role of electronics as both an input into energy and mobility applications and a self-standing sector where innovations in advanced materials, such as alternatives to PFAS, can lead to significant environmental and safety improvements. Thus, while electronics hold intrinsic

importance, their broader impact through their integration into energy and mobility solutions underscores their crucial role in achieving sustainability goals across sectors.

- They may be further consolidated or adjusted during the design phase based on the demand and interests of Member States and project proposals collected via national calls, with the thematic focus shaped by Member States' strategic priorities, driven by industrial engagement and willingness.
- It is crucial that, particularly for AAs 3.1 and 3.2, projects maintain a clear emphasis on advanced materials and align with the overall objectives, differentiating themselves from other IPCEIs in related areas (i.e. those on Microelectronics). These projects must especially demonstrate a strong focus on circularity, as well as their integration into the priority areas of energy and mobility.

Priority area #1 - Energy:

AA 1.1 Renewable and low-carbon energy conversion: Advanced materials to improve device durability, corrosion resistance, and conversion efficiency in renewable energy sources (e.g., photovoltaics, wind turbines).

AA 1.2 Energy storage systems: Circular, sustainable materials for batteries, supercapacitors, phase-change materials, and thermochemical technologies.

AA 1.3 Energy distribution and transmission grid: Advanced materials for efficiency, reliability, and protection against corrosion and environmental damage.

AA 1.4 Renewable fuels: Advanced catalysts for the cost-effective production of sustainable, renewable fuels.

Priority Area #2 – Mobility:

AA 2.1 Energy storage and alternative fuels: Advanced batteries and fuel cells for transport modes with improved efficiency, safety, and recyclability.

AA 2.2 Lightweight, high-performance materials: Advanced, durable materials that reduce energy consumption and increase safety in means of transport and infrastructure.

AA 2.3 Durability and protection of transport means and infrastructure: Coatings, paints, and hybrid manufacturing to enhance durability and reduce fuel consumption.

AA 2.4 Circularity and environmental performance: New materials that reduce environmental impact, increase resilience, and support cost-efficient maintenance in transport applications.

Priority Area #3 - Electronics:

AA 3.1 Advanced materials for better energy efficiency and performance: Materials for electronic components with enhanced energy efficiency, durability, and new functionalities (e.g., sensors, power electronics, flexible electronics).

AA 3.2 Advanced materials for sustainable and circular Chip production and advanced packaging technologies: Materials for wafers, substrates, and packaging technologies that enhance efficiency, durability, sustainability and reduce dependency on critical raw materials.

It is essential to emphasize that in-depth discussions during the Design phase—guided by the insights gained from national mapping exercises—will provide a clear understanding of which specific value chains will be addressed within this IPCEI and how they interrelate. This process will likely lead to a reduction or clustering of priority areas. Consequently, considering this and the three broad priority areas mentioned, more than one IPCEI candidate may emerge during the Design phase, depending on the number of value chains and projects identified.