AMULET Technology Roadmap

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1. Introduction

The tremendous increase in anthropogenic CO2 emissions arose after the Industrial Revolution until our days are bringing undesired climate changes at a rate steeper than predicted. European Climate Law includes a set of measures targeting net greenhouse gas emissions reductions of at least 55% by 2030, compared to 1990 levels, aiming to make Europe climate neutral by 2050. These changes will involve the radical transformation of multiple value chains, from material development to the product's End-of-Life. In this context, advanced lightweight materials are central in driving the green and digital transition, recognized as critical enablers for nine key Materials Innovation Markets that address societal needs sustainably.

The Advanced Materials & manufacturing United for LightwEighT (AMULET) project (HORIZON 2020) aims to exploit the innovation potential of SMEs through a cross-sectoral, funded knowledge exchange to create new value chains by fostering the penetration of advanced lightweight materials (i.e., polymer-based composites (PBC), metallic alloys and ceramic matrix composites (CMC)) in different fields and sectors: automotive, aerospace and aeronautics, energy, and building.

AMULET's technology roadmap aims to inform decision-makers about the drivers, challenges and innovations related to lightweight materials in four different industrial sectors. This information will provide relevant technological insights about the developments being made in these sectors, allowing the elaboration of better policies as well as providing recommendations on which developments are more suitable to be prioritized.

The technology roadmap was developed using information from four sectoral workshops involving over 50 stakeholders covering various stages of the value chain. This data was completed with detailed bibliographic research.

2. The Automotive sector

The recent EU legislation, including the EU Climate Law, Fit for 55, and the EU Green Deal, underscores the global push to cut CO2 emissions and enhance resource efficiency. In the automotive sector, lightweighting has gained prominence to meet the ambitious target of 60 gCO2/km by 2030. Advanced lightweight materials offer a solution, showing promise in mitigating these additional aspects and even optimizing CO2 emissions for ICEs vehicles.

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Studies indicate that a 10% weight reduction leads to a 14% improvement in electric range and a 6-8% decrease in CO2 emissions and fuel consumption. Transitioning to eco-friendly automotive sectors requires sustainable practices, with lightweight materials to extend range, enhance safety, and improve energy efficiency.

The automotive industry faces challenges in adapting to this transition, necessitating eco-design strategies and adjustments in manufacturing processes to incorporate renewable, bio-based, and recycled materials. Innovations such as thermoplastic materials, embedded sensors for predictive maintenance, and design-for-disassembly contribute to sustainability. Circular strategies like recyclable polymers and bio-based materials facilitate the use of secondary materials.

3. The Aerospace sector

In response to the escalating demand within the aviation industry for advanced lightweight materials, several drivers are at play, including the need for high-performance materials, adherence to fuel efficiency and emissions standards, capacity as well as maintenance cost optimization. Even a minor reduction in an aircraft's weight has the potential to yield reductions in fuel consumption and the associated CO2 emissions.

However, challenges persist, including supply chain vulnerabilities for critical raw materials and energy usage in manufacturing processes. Standardizing testing and certification for new materials in safety-critical components involves significant time and cost, impacting technology adoption.

Despite these challenges, material science is advancing with vigour. Nanotechnology is rapidly advancing, with nanocomposites growing at a 25% annual rate, enhancing aircraft components' durability and functionality. Multifunctional composites improve aircraft efficiency, while advanced modelling tools streamline design optimisation. Substituting thermoset materials with carbon fiber composites reduces structural weight and long-term costs. Graphene-related materials (GRMs) exhibit versatility in constructing lightweight, robust, electrically and thermally conductive structures, with the potential for self- healing and a remarkable 70% weight reduction.

4. The Energy sector

Energy is in the spotlight due to its key role in the transition to a zero CO2 emission society. The electrification of industrial and transport sectors is increasing the demand by an average of 2.4% per year. This concern extends beyond just considering CO2 emissions and encompasses the materials that will be used for the transition.

Wind turbine technology demonstrates this where PBCs constituting 16% of a wind turbine generator's weight have enabled the development of larger and more resilient blades (e.g., GE Haliade X). Nonetheless, the recycling and circularity of these composites present intricate challenges. Consequently, there's a growing trend towards the development of biodegradable materials. Affordable lightweight materials are essential to challenge existing technologies and align with Sustainable Development Goal 7, focusing on "affordable and clean energy."

An efficient value chain, prioritizing both cost and emission reduction, is essential. Streamlining manufacturing through local regulations and optimised transport

networks in Europe is instrumental in addressing this challenge. Expanding beyond energy generation, the effective storage of surplus energy, a critical aspect in the era of renewable energies, is vital.

5. The Building sector

The construction sector is known for its energy-intensive nature, demanding vast amounts of raw materials and natural resources. Additionally, the sector generates considerable waste and often operates inefficiently in terms of energy. In response, the industry is placing a higher emphasis on sustainability, focusing on life cycle assessments, minimising environmental impacts, and using recyclable, energy-efficient products.

However, challenges remain, like recycling difficulties, reliance on distant raw materials, and adapting to climate change. Research suggests solutions such as designing recyclable products, localising material sourcing, and introducing self-healing materials to mitigate greenhouse gas emissions and improve sustainability.

Regulatory requirements for the construction sector are also indispensable, addressing issues from energy inefficiency to safety requirements. The materials cost is comparably high and can be reduced with the use of lightweight materials. The durability and performance of construction materials are important for extending building lifespans and reducing repair and replacement frequency. Lightweight materials offer speed and efficiency in construction, saving labor and transportation costs, and enabling innovative designs.

6. Conclusions

Innovative lightweight materials are paving the way in diversifying innovative advancements globally at a phenomenal pace. These materials are part of the solution to the global challenges offering higher performance during use, lower cost, resource, and energy efficiency considering the end-of-life performance. Global trends toward CO2 reduction and resource efficiency have significantly increased the importance of this topic over the last years.

Advanced lightweight materials are crucial for realising sustainable growth of all four sectors under study: automotive, aviation, energy and building. AMULET’s technology roadmap emphasises the relevance of advanced lightweight materials to contribute to Europe’s competitiveness by increased sustainability standards and provides first-hand information to decision-makers.

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