Circularity of composites: bringing together experts from across the value chain

On 27 June 2021, SMEs, end-users, manufacturers, research institutions and industry associations discussed the legal, economic, and technological challenges and next steps for the circularity of composites in Europe at an online roundtable event hosted by the European Lightweight Cluster Alliance (ELCA). The main objective was to highlight the opportunities and form a multistakeholder point of view for a circular business model for composite materials in the relevant industries.

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The circularity of composites is becoming one of the most pressing issues for all the stakeholders involved in the manufacturing and application of these materials. To ensure synergy in regulation and practices for circularity, it is important to map out the challenges and state-of-the-art technologies on all levels of the value chain.

The importance of co-operation between different composite stakeholders

The experts gathered at this roundtable discussed the challenges and opportunities for a holistic circular economy business model throughout Europe. The topics for discussion were determined by a survey distributed among the participants that listed questions about the current challenges, trends, and solutions for the circularity of composite materials. Since the participants represented seven different EU countries, each facing dissimilar experiences and expertise, comparisons could be made and overarching challenges were identified.

The list of participants included research institutions and SMEs developing: 1) new ways to reuse composite materials (LAVOISIER COMPOSITES, France); 2) sustainable solutions to replace fossil-based raw material usage and reversible, reprocessable and recyclable cross-linked polymers (SPECIFIC POLYMERS, France); and 3) technologies to upgrade the quality of composites by exploiting novel surface treatments and sizing approaches (Research Lab of Advanced, Composite, Nanomaterials and Nanotechnology (R-NanoLab, School of Chemical Engineering of the National Technical University of Athens, Greece).

HP Composites (Italy), as an end-user, expressed the challenges for part manufacturers to integrate circular materials into their products. Others shared their expertise on the legal, technological, and economic factors of a circular economy business model (Centre Technique Industriel de la Plasturgie et des Composites (IPC), France, European Composites Industry Alliance EuCIA, Belgium/Netherlands, TU Dresden (Institute for Lightweight Engineering and Polymer Technology), Germany, and AMZ Sachsen, Germany). Through this initiative, the ELCA, led by Bax and Company (Spain), aims to raise awareness and contribute to the mutual understanding of stakeholders in the composite industry.

How is the path to a circular economy for materials going so far?

Circular economy for composites seems to be a business model that can only be realised with trial and error. Due to its complex and disruptive nature, many regulations and initiatives were introduced in Europe. Perhaps the most promising one is the Ecodesign for Sustainable Products Regulation (ESPR) included in the European Green Deal of March 2022. The ESPR includes framework legislation, product-specific measures and multiannual working plans for the adoption of ecodesign throughout Europe. It includes the Digital Product Passport (DPP, a process to collect information about a product at all stages of its lifecycle and make the data available as digital information), which can be expected to appear on the market of related industries very soon.

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The European Commission (EC) points out the importance for the tracking of data on sustainability, environmental impact, circularity, and value retention through

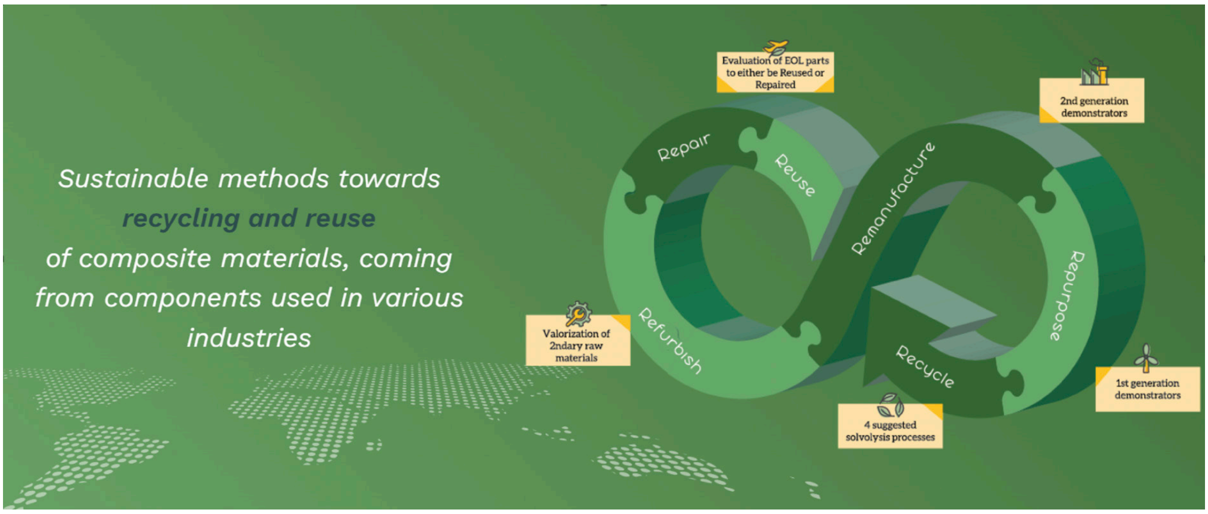

Fig. 1: The R6 strategy as suggested in the EuReComp project

reuse/remanufacturing/recycling. To support recycling strategies, the EC released a 24.7M euro budget for research and innovation projects focusing on innovative dismantling and sorting systems for the reuse and functional recycling of complex composite materials. This will facilitate a higher level of reuse of whole composite products and components and the development of innovative, safe, environment-friendly and commercially attractive recycling processes.

The EC also warned the European Union that several member states have already started to set environmental sustainability requirements on products. This is fragmenting the single market through diverging national rules, which is complicating and increasing the costs of doing business. The roundtable participants all reported having experienced unharmonised legislation and that, in many cases, this complicated their action to improve the circularity of materials. Overall, it was clear that there are still many challenges to overcome, either on a technological, legislative or market implementation level.

Despite the challenges, there are positive examples to be found. TU Dresden (Institute for Lightweight Engineering and Polymer Technology) established a validation centre for new innovative and sustainable lightweighting technologies for the automotive sector. IPC published an ecodesign and recycling guide for composites, and EuCIA developed an Ecocalculator for manufacturers that helps determine the manufacturing technology with the lowest carbon footprint for a given application. The R-NanoLab of the National Technical University of Athens is coordinating the Horizon EU-funded research project EuReComp[1], which proposes an R6 (Reuse, Repair, Refurbish, Remanufacture, Repurpose and Recycling) strategy for end-of-life wind turbine and aircraft parts. As part of the project, an online platform is currently being created to constantly monitor waste streams, providing added-value information about the type of waste, waste condition, state of the materials and forms of recycling.

Technology challenges

The inherent properties of composites make them difficult to recycle, and this is nothing new to most experts. However, circularity issues are not solved by thinking of new ways to recycle alone. At the roundtable, most participants agreed that a more holistic approach to the implementation of technologies, as well as clear priorities for optimising value retention, must be set. The participants seemed to agree on three priorities: 1) ecodesign, 2) the use of biobased and recycled materials, and 3) recycling technologies. However, each of these priorities also involves its own challenges.

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Confusing priorities in circular design strategies

The EC stated that 80% of the circularity results are determined by the product's design. However, clear rules on what ecodesign means for composites are still needed. According to EuCIA, there is still a lack of standardisation, which makes it difficult for manufacturers to prioritise between different actions. LAVOISIER

COMPOSITES underlined that scrap rates are still very high in automotive and aerospace manufacturing facilities, and that companies need to consider what they do with their scrap. For example, composite scrap can be integrated in less demanding parts. According to IPC, the use of adhesives such as foam and wood glue makes the disassembly process difficult, adding that all manufacturers need to rethink the design of their products to consider their end-of-life recyclability. Finally, SPECIFIC POLYMERS stressed that the development of recyclable thermosets shows great promise for the ecodesign of composites in the future. However, due to the lack of reversible thermoset precursors, cost-competitiveness remains a major issue.

Biobased materials: functional drawbacks and expensive, complex production

According to the participants, another key priority for composites circularity is the use of biobased materials. Composite part manufacturer HP Composites reported that the drawbacks of biobased materials prevent their widespread use. These drawbacks include strength prediction under structural loading, long-term performance uncertainties, moisture absorption, lower fire resistance, lower mechanical properties and durability, property variations, temperature and UV radiation sensitivity, limited processing temperatures, more variable cost and properties than traditional composites, and some difficulties in the use of well-known manufacturing processes.

SPECIFIC POLYMERS added that the variability of biobased feedstock leads to uncertainties in material properties. Moreover, solvents and non-sustainable reactants are often required to make biobased materials reactive for the production of thermosets. Finally, the availability of defined suppliers for biobased raw materials is limited. Overall, the complex production of biobased composite materials results in high prices.

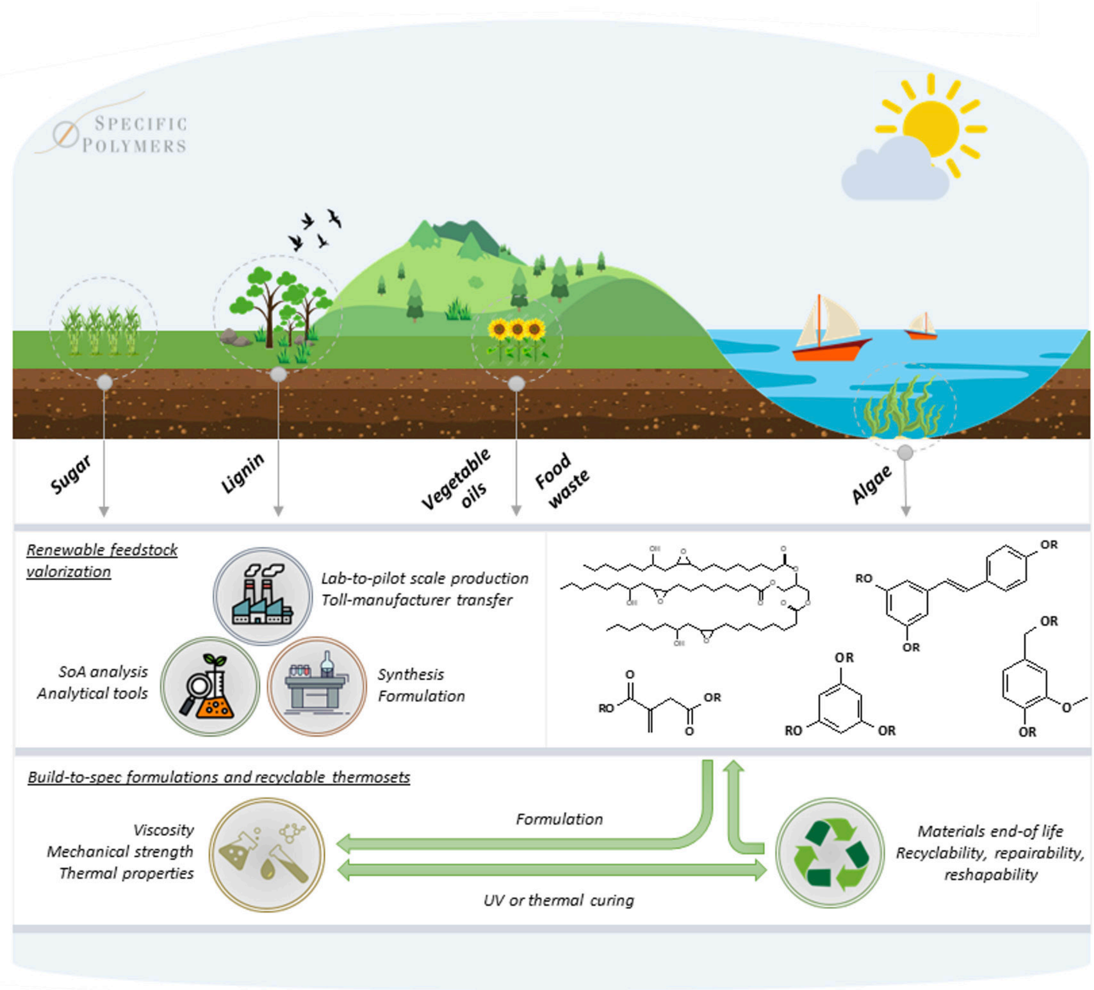

Fig. 2: SPECIFIC POLYMERS' project for the synthesis of biobased materials

High recycling costs and downcycled materials

The use of recycled materials for the development of new composites requires high-quality recyclate, and comparable or preferably lower costs and energy usage in the manufacturing process. Unfortunately, recycling technologies are not always sustainable and may consume more energy than the production of virgin material. For example, pyrolysis and solvolysis use up to 20 times more energy than mechanical recycling routes for carbon fibre-reinforced polymers [2]. Additionally, preventing downcycling, for example by shortening the fibres or changing from a linear to fuzzy fibre alignment, is still technologically challenging. According to R-NanoLab, the quality of reclaimed fibres can be improved by incorporating nanoparticles that provide new functional characteristics or using novel surface treatment techniques. Lastly, since recycled materials often contain impurities or even toxic materials that are difficult to separate, the costs to isolate high-quality secondary materials can run high and affect their market position compared to virgin materials.

Market approaches and legislative challenges

At the moment, implementing circularity practices into the design and production of composite materials is seen more as a challenge than as an opportunity, and many economical and legal barriers need to be overcome.

Information asymmetry and hampering legislation

The information required to set up circularity practices is often unavailable to stakeholders – for example, the information needed to determine the most appropriate trade-offs between performance, cost, and the evaluation of a product's environmental footprint. To access a cost analysis for each technology (composite vs. metal), information about the market volume of the applications and the end-user's planned schedule (technology readiness level (TRL)) are required. At the research level, for the development of innovative molecules or formulations, it is crucial to confirm "freedom-to-operate" and patentability. Therefore, SMEs need to rely on the expertise of lawyers and patent advisors. Additional requirements include REACH compliance and HSE issues (toxicity, transport rules for dangerous materials, people and environmental safety). All these requirements and legislations are slowing down the process for a potential circular business model (SPECIFIC POLYMERS).

On the recycling level, there is a lack of mass recycling structures. Optimal waste management depends on the specifics of each region (in terms of quantities, quality, type of materials, etc.), meaning it could be necessary to consider a combination of recycling solutions that are suitable for each different area. This requires quantifying the composite waste volume at the local scale. According to IPC, these figures are still lacking in most EU countries.

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In general, the information flow about materials seems to get lost between composite stakeholders because composite materials are still not targeted by EoL legislation, as opposed to regular plastics and noble materials (platinum, palladium, etc.) from digital devices, for example.

Finally, regulatory obstacles are impeding the uptake of biobased and recycled materials in major sectors such as automotive and aerospace. The use of recycled materials in private cars and passenger planes is hampered by a number of specific requirements and technical specifications, as well as a strict legal framework.

Lack of financial investments and business initiatives

Upscaling difficulties are another obstacle both at the manufacturing and the recycling level. According to HP Composites, the market for biobased materials is still underdeveloped at the manufacturers' level and only a few supply chains are available, partly due to the high cost of biobased resins/fibres. Furthermore, a continuous supply of recycled materials is required for the effective use of recycled materials in composite manufacturing, but this supply is not available since the composite market is very fragmented throughout Europe.

In regards to the research and development of (circular) new materials, upscaling is necessary to become cost competitive and allow new technologies to reach the market. Unfortunately, public funding is rarely available for upscaling as it tends to focus on research, as underlined by HP Composites and SPECIFIC POLYMERS.

According to AMZ Sachsen, there is a lack of business initiatives for composites circularity in the automotive sector in Germany, as well as a lack of investment and incentives for the integration of biobased, ecodesigned and recycled materials solutions. A report by Accenture and the Wuppertal Institute showed that German companies shy away from precompetitive research and development projects for circular economy and other financing activities due to intellectual property (IP) concerns, lengthy processes and bureaucracy related to public funding. Furthermore, private institutions almost never offer specific loans for circular business

I. Context

models and activities. Participants from other countries, such as IPC and SPECIFIC POLYMERS (France) and HP Composites (Italy), reported that their countries are facing the same issues and that the implementation of a circular business model seems to be challenging throughout Europe. Luckily, some positive examples can be mentioned: in Greece, the Hellenic Foundation for Research and Innovation announced a call for research institutions and SMEs related to composites recycling and fibre reclaiming, with a 15M euro budget, to enhance the business sector and embrace the circularity concept within the community.

The opportunities ahead for a holistic circular business model

The most promising opportunities for the future of composite materials were listed in the survey and the most popular ones were elaborated upon during the 1.5-hour discussion. Most of the participants seemed to agree that the many technologies already available can help the composite materials' circular economy forward. It is up to the market stakeholders to implement these technologies, working together with the expertise of research centres and SMEs providing state-of-the-art technology. The market will also need to be pushed in the right direction by enabling legislation and funding opportunities from policymakers. The most promising solutions that came out of the roundtable are to be found in the next sections.

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100%-recyclable materials

In terms of material development technologies, the end goal for the longer term should be the development of 100%-recyclable materials, meaning the recovery of both fibres and matrix. To this end, further research on the recyclability of thermoset and thermoplastic resins, which are currently the main choice of composite matrix materials, is needed. The recyclability of thermoset resins is still lower than thermoplastic resins, which is why IPC stressed that a switch to thermoplastic materials is inevitable in the future. Thermoplastics show great market potential due to their functionality, mass-production capability, and recyclability. However, an opportunity for thermoset resins lies in vitrimers that, in addition to recyclability, also show self-healing properties. Finally, the social acceptance and further development of nanoparticles should be pursued since they can solve many downcycling issues.

Design for circularity and interchangeability of used parts

Design for circularity practices should be implemented and standardised for the manufacture of parts and products. This means assessing the assembly and accessibility of parts, simplifying common component interfaces and reducing waste during the design phase to enable future circular economy processes. For example, the development of composite parts that integrate their own offcuts or are easily repairable and interchangeable (LAVOISIER COMPOSITES). Also, used materials should become available to be uptaken by other markets. Existing composites still have a high utility for lightweight structures and can be used in new applications, either as such or in processed form after controlled mechanical processing. One example solution for this is a marketplace where you can buy second-hand composite parts and materials that can be refurbished (EuCIA).

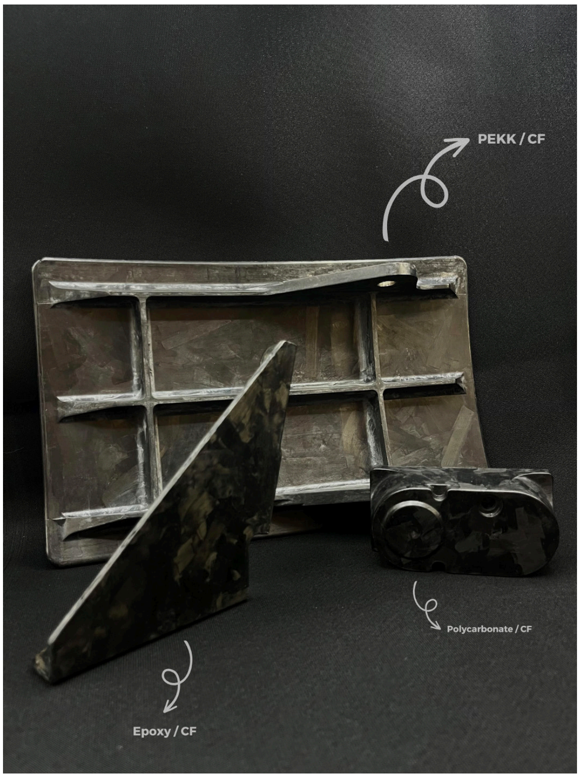

Fig. 3: Structural parts developed from composite waste by LAVOISIER COMPOSITES

Information transfer and harmonised legislation throughout Europe

In addition to the expected Digital Product Passport (DPP), a platform providing information about logistics, standards, regulations, (recycling) technologies, LCA and economic opportunities should be made available to different markets and stakeholders. Also, recyclability should be benchmarked by indexing or labelling the recyclability of products, so that manufacturers can rely on the quality required for their application when buying secondary materials (EuCIA and TU Dresden). Furthermore, a waste management system (including DPP, quality index and proper legislation) with local collection points and a specialised logistics network should be established throughout Europe to improve composite waste collection and sorting quality. Lastly, the competitiveness, attractiveness and acceptance of recycled and biobased vs. virgin composites should be increased through targeted marketing campaigns, legislation about minimal recycled/biobased material percentages to be used by manufacturers and investments in technology upscaling. At the same time, the rules that prevent the use of recycled and biobased materials in certain industries should be revised.

Alignment of stakeholders and a clear time frame for action

The landfilling/incineration of materials that are reaching EoL should be increasingly prevented. Recycling is the latest option to handle these materials. The cement kiln is an example of a recycling technology that can be implemented rapidly on a large scale. According to EuCIA, the downside of this technology is that, compared to more expensive but unfortunately also more energy-intensive, low-TRL, and/or lower-capacity circular economy practices, the material value of composites is lost. For the future composite demand, the market needs to establish eco-design practices, high-quality recyclate-generating (closed loop) recycling technologies, and consider the use of biobased materials, in order to ensure a circular economy business model for next-generation materials/products. To this end, stakeholders from all parts of the value chain need to work together with policymakers to secure a circular and profitable future for composite materials.

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Closing note

With a circular economy under constant development, awareness and actions by stakeholders are becoming increasingly important. The authors would like to thank the roundtable participants and JEC for this collaboration and hope to see a better future to come for composites circularity. The activities of ELCA's circular economy working group aim at coordinating the efforts of stakeholders across the entire composites value chain in order to support the uptake of circularity practices. The objective is to facilitate dialogue between the relevant actors and to foster the creation of collaborative projects and joint initiatives.

Acknowledgements/contributors

- *Dr. Ricardo del Valle, Innovation consultant Bax & Company (ELCA office)*
- *Agathe Bouvet-Marchand, SPECIFIC POLYMERS*
- *Dr. Albert Langkamp, TU Dresden (Institute for Lightweight Engineering and Polymer Technology)*
- *Levin Schilling, TU Dresden (Institute for Lightweight Engineering and Polymer Technology)*
- *Romain Agogue, IPC, Centre Technique Industriel de la Plasturgie et des Composites*
- *Dr. Baptiste Gaumond, LAVOISIER COMPOSITES*
- *Prof. Costas Charitidis, Director, R-NanoLab, NTUA*
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- *Jaap van der Woude, EuCIA*
- *Roberto Frassine, EuCIA*
- *Vincenzo Castorani, HP Composites*
- *Katharina Schoeps, AMZ Sachsen*

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