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Release 2

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RELEASE 2

GEAR-UP: Data, Traceability and Skills for Circular Manufacturing

In our previous update, we looked at how recycled metals, simulation and design tools are helping circular additive manufacturing become a practical reality. In this second update, we widen the view: circular polymers and textiles, the digital technologies that connect data and ensure traceability, and the skills the industry will need to make it all work.

Circular Polymers and Textiles

Advanced Composites for High-Performance Applications

Circularity in GEAR-UP extends beyond metals. CelluCircle and COLFEED4Print are developing composite materials from recycled textiles and plastics reinforced with carbon fibres, nanocellulose (ultra-fine fibres derived from cellulose), and titanium dioxide nanoparticles. Extensive mechanical and environmental testing of 3D-printed specimens ensures suitability for demanding applications, including components for electric mobility and advanced consumer products.

If these recycled composites reach industrial-grade performance, automotive and electric-vehicle component manufacturers, sports and outdoor equipment brands, consumer electronics/robotics producers along with the additive manufacturing sector itself would benefit the most from this material. Indeed, these components are frequently exposed to wear, damage, and replacement, making both cost efficiency and material performance important considerations.

Growing demand for more sustainable products is driving manufacturers to look for materials that combine mechanical durability with economic viability and improved end-of-life options. The ability to collect, recycle, and reprocess these materials into new components, and to properly combine them with inorganic particles or fibres, could reduce waste generation and support more circular production systems for durable, functional materials and components. In additive manufacturing, this approach also creates opportunities for sustainable, high-performance feedstocks that can be used by filament producers and 3D printing service providers as alternatives to conventional virgin polymer-based materials.

Compared to conventional plastics or fibres, what makes these recycled composites a meaningful alternative is their potential to provide comparable mechanical performance with a lower carbon footprint, while remaining suitable for collection and recycling at the end of their service life. This can help integrate component replacement into a more circular material system and reduce waste generation.

Figure 5: Printed drill bits.

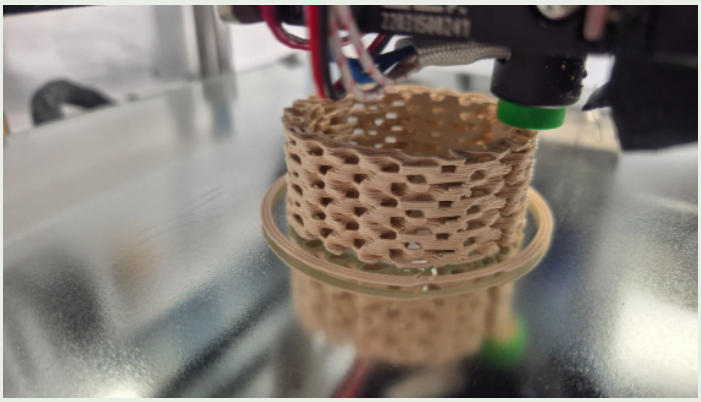

Figure 6: Printing process of a photocatalytic, TiO2 filter (a filter that uses light to help break down pollutants).

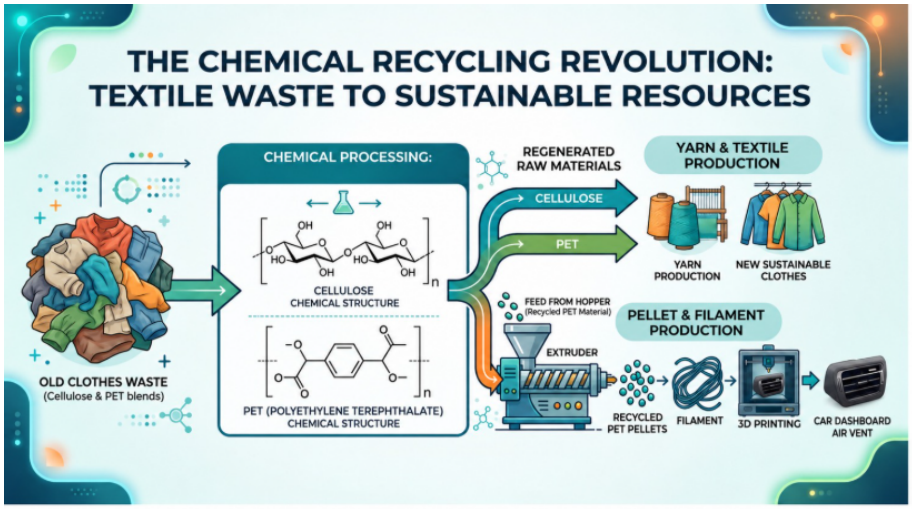

Figure 7: The chemical recycling revolution

> *"We do not want recycling to be the final chapter of a textile's life. Our goal is to keep the story going, where a worn part becomes a new filament, the filament becomes a new part, and the material finds its way back into the loop again and again."*
>
> **— Varvara Apostolopoulou-Kalkavoura**,, CelluCircle

Digital Technologies Enabling Circularity

Interoperable Data Models and AI for Environmental Assessment

GEAR-UP isn't just about new materials: it's also about making the manufacturing process smarter. Fraunhofer SCAI is building the digital backbone that helps companies manage and understand complex data from 3D printing with recycled metals and polymers. These tools connect data from different stages of the manufacturing process, so that information about materials, printing conditions and the performance of the final parts can be linked, understood and reused.

At the core of this work are two main tools: the VMAP Standard, which organises simulation and measurement data in a consistent way, and SIMS (Semantic Information Management System), which turns this data into a "knowledge graph" (a map of how pieces of information relate to each other) that engineers can easily explore.

In practice, information about material composition, printing conditions, and part performance is linked and searchable — reducing guesswork and making it easier to reuse knowledge across teams and projects.

This digital approach helps engineers handle one of the biggest challenges of circular manufacturing: variability in recycled materials. Recycled metals or polymers can differ slightly from batch to batch, and traditional process sheets aren't enough to capture this. By using SIMS, engineers can identify suitable starting parameters for each batch based on available data, helping to reduce costly trial-and-error.

GEAR-UP is also integrating AI-driven environmental assessment. As part of SINTEF's work, the project uses Life Cycle Assessment (LCA, a method to estimate the environmental impact of a product over its whole life) tools and AI-assisted literature analysis to estimate the environmental impact of different materials and manufacturing processes. Later, data from real industrial demonstrations will be used to train AI models that can predict how choices in materials and processes affect sustainability outcomes.

Why it matters: with these digital tools, companies can adopt recycled materials more confidently, optimise production processes, and make smarter, faster decisions — all while reducing waste and environmental impact.

Recent developments: Fraunhofer SCAI is building ontologies that help connect datasets belonging to the same product or manufacturing process and recognise when different terms refer to the same concept. This gives SIMS a common structure for organising and understanding heterogeneous engineering data.

The ontology provides the structure and meaning that allows SIMS to understand the relationships between different types of engineering data, rather than simply storing them.

Fraunhofer SCAI is also developing the ontology as a reusable, standards-aligned asset rather than as a system designed only for SIMS. It builds on established reference ontologies such as EMMO (European Materials Modelling Ontology) and DOAM (Domain Ontology for Additive Manufacturing) and connects to the VMAP Standard for simulation and measurement data. This helps ensure that the knowledge and relationships created in GEAR-UP remain interoperable and can be used beyond a single software tool.

Predictive Modelling and Traceability

Simulations for Recycled Materials & Digital Product Passports

Aerobase is developing predictive models and simulations tailored to recycled metals and polymers, accounting for variations in composition and behaviour under additive manufacturing conditions. These tools help engineers optimise designs, anticipate defects, and reduce trial-and-error in production. Technovative Solutions, a UK-based digital solution incubator focused on circular economy and net-zero challenges, and DigiProdPass, a UK sustainability-focused technology provider, are jointly contributing to traceability by developing a Digital Product Passport framework integrating ontologies, knowledge graphs, and blockchain technologies. The system will be applied across GEAR-UP use cases to ensure full transparency of materials, manufacturing processes, and lifecycle data.

Technovative Solutions and DigiProdPass have progressed the GEAR-UP Digital Product Passport (DPP) framework and circularity platform, providing an ontology-based (built on shared vocabularies that define what data means) and blockchain-enabled (using a secure, tamper-resistant way of recording data) environment for managing product and lifecycle information.

The implemented workflow supports the collection and mapping of product data from different sources, the generation and publication of the DPP, controlled access, retrieval via QR code, and export as a PDF or as a machine-readable file (JSON-LD) that other software can use.

A common DPP data-collection template has been established for the GEAR-UP use cases. Initial data collection and preliminary testing have started with Use Case 3 (composite additive manufacturing with recycled polymers, carbon fibres and titanium dioxide). The available data have already been used to generate a sample DPP, to test the passport structure and the generation workflow. The next phase will focus on integration with the wider GEAR-UP platform, followed by full use-case demonstration and end-user validation.

Illustrative Digital Product Passport interface showing how product, material and lifecycle information can be digitally accessed and traced within a circular manufacturing environment. Data shown are illustrative.

Key risk this work addresses

The key risk this work addresses is fragmented and inconsistent product and lifecycle information, which can limit traceability and confidence in recycled materials. The DPP framework addresses this by organising information from different sources in a single, consistent structure (a common semantic model, where every piece of data has a shared, clear meaning) and providing controlled access and integrity verification (checks that the data has not been altered).

How it supports the adoption of recycled materials

By making information on material composition, recycled content, manufacturing history, quality and environmental performance structured and traceable, the DPP complements predictive modelling (the simulations described above) and helps manufacturers make better-informed decisions when using variable recycled feedstocks (recycled materials whose properties differ from batch to batch).

TECHNOVATIVE SOLUTIONS

"In terms of lifecycle management, better traceability can help with more accurate second-life assessments, predictive maintenance planning, and performance optimisation."

— **Dr Fahim Chowdhury**,Technovative Solutions Ltd (TVS)

Building the Skills for Circular Manufacturing

Technological innovation alone is not enough to unlock the potential of circular manufacturing. The sector also needs a workforce equipped with the right knowledge and competencies. GEAR-UP adopts a human-centric approach that places people at the heart of the transition, ensuring engineers, technicians and manufacturing professionals acquire the skills needed to understand, adopt and get the most out of these technologies.

Identifying tomorrow's skills. Before developing its training programme, GEAR-UP carried out a comprehensive skills assessment — combining a literature review, a dedicated skill gaps analysis, cross-project analysis and targeted surveys and workshops with partners and industrial stakeholders — to understand which competencies will be most critical for the future of circular manufacturing. The analysis pointed to a multidisciplinary skillset: eco-design, Life Cycle Assessment (LCA), material recovery, digital engineering, process monitoring and sustainable product development, alongside growing needs in AI, digitalisation, sustainability compliance and simulation.

From skill gaps to priority areas. The analysis identified specific gaps where the sector needs to reach a new level of competence, and the consortium is now developing skills-update pathways to close them:

- **Material Modelling for Recycled Materials** – The increasing use of recycled materials requires robust modelling approaches to understand material behaviour, account for composition variability and improve the accuracy of engineering simulations.
- **Simulation-Driven AM with Recycled Materials** – Accurate simulation of additive manufacturing processes requires understanding process physics, thermal and thermo-mechanical behaviour, and the integration of simulation results into process optimisation and decision-making.
- **Simulation integration & semantics organisation** – As tools and data multiply across the project, teams need shared ways to organise and connect this information.
- **Additive Manufacturing Standards, Qualification Frameworks & Certification** – The successful adoption of additive manufacturing depends on confidence in materials, processes and data. Standards, qualification frameworks and certification provide the foundation for ensuring quality, compliance and trust across the AM value chain.
- **In-process Monitoring & Process Stability in Additive Manufacturing** – The increasing availability of process data in additive manufacturing is enabling real-time monitoring, improved process control, enhanced quality assurance and more reliable qualification and certification practices.
- **Design & process optimisation for circular manufacturing** – The transition to circular manufacturing requires new approaches to product design and process optimisation that maximise resource efficiency, minimise waste and support sustainable value creation across the manufacturing lifecycle.

- **Life Cycle Assessment & circular economy** – A shared understanding of lifecycle thinking is what ties all these competencies together.

These skills-update pathways are being designed in close connection with GEAR-UP's industrial use cases, so participants will be able to link the theory behind these emerging solutions to how they are actually applied in real industrial environments.

Latest training updates: Partners are finalising the first phase of the course outline and learning material development. All materials will undergo a peer-review process to ensure quality, consistency and alignment before moving into the next stage of development.

Through this integrated approach — combining research, industrial validation and tailored education — GEAR-UP is contributing to a skilled workforce ready to drive Europe's transition towards a more digital, resilient and circular manufacturing sector.

> *"What made this work truly valuable wasn't just the desk research. It was the opportunity to work directly with partners, understanding where they face challenges while drawing on their expertise to co-design training content that reflects real industrial needs."*
>
> **— Antonella Gagliardi**, EIT Manufacturing South

Looking Ahead

By combining advanced materials research, digital technologies, and industrial demonstration, GEAR-UP is helping demonstrate how circular manufacturing can become a practical reality. Through the collaboration of research organisations, technology developers, and industrial partners, the project is contributing to a more sustainable, transparent, and resource-efficient European manufacturing ecosystem.

Future updates will continue to share progress and insights as GEAR-UP advances its work on circular additive manufacturing.