ManuFUTURE

HLG

Sustainable, Circular and Accountable Manufacturing

Supporting the transition to a Circular Economy

Consultation Document

Contents

Table of Abbreviations:

Abbrev.	Description	Abbrev.	Description
RD&I	Research, Development & Innovation	EFFRA	European Factories of the Future Research Association
HLG	High Level Group	ETP	European Technology Platform
EU	European Union	GBER	General Block Exemption Regulation
E-DIH	European Digital Innovation Hubs	MNC	Multinational Corporation

About ManuFUTURE:

ManuFUTURE is a European Technology Platform (ETP) established in 2003 as “an industry-led stakeholder forum recognized by the European Commission as a key factor in driving innovation, knowledge transfer and European competitiveness”. The mission of ManuFUTURE is to propose, develop and implement a strategy based on Research and Innovation, capable of speeding up in manufacturing industry the rate of industrial transformation to high-value-added-value products, processes, and services, securing high-skills employment and winning a major share of world manufacturing output in the future knowledge-driven economy. As the governing body of the ManuFUTURE Platform, the HLG (High Level Group) sets-up the strategy related to maintaining European leadership in Manufacturing.

1.
Motivation

1. Motivation

Through the European Green Deal[1], Europe has decisively taken the road for transitioning to a climate-neutral, resource-efficient, and competitive economy. Scaling up the circular economy paradigm to the whole European economy will drive the EU industry to a progressive yet irreversible transition to a sustainable economic system while ensuring the long-term competitiveness of the EU.

Manufacturing must play a key role in supporting and guiding this transition affecting many aspects. Products must be designed to improve their durability, reusability, upgradeability, and reparability; they must increasingly rely on recycled materials while ensuring performance and safety; short use phases and premature obsolescence must be avoided, pursuing reuse strategies in alternative sectors or applications.

Traditional business paradigms will also be significantly impacted by this transition, e.g., through product-as-a-service approaches where original equipment manufacturers keep the ownership products during the use phase.

Manufacturing technologies and processes will be challenged by the need to reduce their material and energy footprint, cope with processing secondary materials, and enlarge their scope to cover remanufacturing and recycling processes.

Digital technologies will be the key to this change, enabling the potential to digitalise product information, including solutions such as digital passports.

Excellent science is the key to supporting this endeavour, supporting the development of emergent technologies, the adoption of innovative design approaches for products and services, the assessment of the specific and comprehensive economic viability of circular manufacturing schemes, the exploitation of digital technologies in factories and the manufacturing supply chain, the empowering and valorisation of humans, while establishing a continuous link between fundamental science, applied research, and industry.

[1] Circular Economy Action Plan, For a cleaner and more competitive Europe, European Union, 2020

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3. MANUFUTURE vision for Sustainable, Circular and Accountable Manufacturing

3. ManuFUTURE vision for strengthening the upstream link

A circular economy considers all the actors contributing to the manufacturing chain as inhabitants of a shared ecosystem.

A primary aspect is the role of materials and energy and the impact on the environment coming from their consumption. The use of renewable resources should be addressed, and, at the same time, energy recovery and material recycling and reuse must become essential factors. The research in this area must address solutions to minimise manufacturing costs and environmental impact, namely by reducing the consumption of water, energy and raw materials consumption and shifting to renewable raw materials (e.g., recycled, bio-based, etc.).

Circular flows of the products also need to be considered during their use phase, including repairing, and reusing, in which the interactions with users and retailers increasingly shift their share in the ownership of products and act as service providers by pursuing pay-per-use business schemes. These circular product flows must be coupled with circular data flows along the whole lifecycle.

In this perspective, several manufacturing-related functions, such as maintenance and refurbishing, assume an essential role. Circular approaches must also be applied to components besides whole products. Thus, pursuing their reuse in new products and supporting modified functionalities. The guiding principle is the design of longer lifecycles for products, easing the capability to be repaired, maintained, upgraded, and refurbished with new and enlarged customer services.

Finally, from a technological perspective, research efforts will need to focus on processes, technologies, skills, and facilities devoted to maintaining, repairing, upgrading, remanufacturing and/or recycling products and their components, being another major future challenge for Europe’s manufacturing. Remanufacturing facilities will operate together within closed-loop supply chains to manage the whole lifecycle of products.

New solutions for optimal energy efficiency, recovery, harvesting, and storage are needed to enable Europe's leadership in resource efficiency and sustainability.

3.1 Technological excellence for sustainable manufacturing

3.1.1 Product upgrade, repair and remanufacturing

As the main driver for enhancing sustainability in our society is the reduction of our footprint on the environment, prolonging the life of products is one of the main directions for action.

From the perspective of the manufacturing industry, this entails the need to implement repair and refurbishing approaches for products. In this perspective, manufacturing technologies need to be developed targeting this class of applications:

i. technologies for restoring worn materials, e.g., additive manufacturing technologies, cold spray, etc.).
ii. technologies to assess the state of used products in terms of functionalities and materials.
iii. technologies to support the partial and/or repeated execution of manufacturing processes (see Section 0).
iv. adaptative assembly/disassembly technologies to match repair and re-manufacturing requirements driven by the characteristics of products.
v. technologies to assess the quality and functionality of re-manufactured products.

Capital goods are also crucial in supporting the adoption of these new classes of technologies in the manufacturing industry. Industrial equipment will be needed to implement new technologies and provide the possibility of using existing production technologies according to the requirements of repair and re-manufacturing processes. Furthermore, synergies could be pursued related to industrial equipment for production, repair, and remanufacturing, pushing for the possibility of locating both production and de-production activities in the same factory. Being a major player in the world for capital goods and industrial equipment, Europe must play a prominent role in this transition, leveraging the need to match societal and market requirements with a new leadership in capital goods for the circular economy.

Their design is a fundamental enabler to enhance the repair and remanufacturing of simple and complex products. The feasibility, facility, and economic viability of repairing, re-manufacturing, and upgrading products can be effortlessly hindered by design approaches not considering these aspects in due consideration. Thus, new design principles and approaches must be addressed, exploiting both established (e.g., modularity) and innovative concepts to enhance the prolonging of the lifecycle of products.

Finally, humans and their roles in manufacturing processes and activities will also play a vital role in the transition toward a circular manufacturing scheme. Remanufacturing and repair activities are intrinsically characterised by a high degree of variety and uncertainty. Products to be repaired could belong to different classes and OEMs and be characterised by different damages or degrees of wear. Thus, targeted repair decisions have to be taken. Human operators, supported by advanced tools and methodologies, are often the best option to support these activities due to their capability to take decisions based on the specific situation (possibly with the support of testing and assessing technologies and approaches) and operate accordingly. Furthermore, human operators acting in these environments must be highly qualified. The support and enhancement of human operators in re-manufacturing processes must be thoroughly addressed, taking advantage of a wide range of enabling technologies, e.g., virtual and augmented reality, artificial intelligence, robotics, etc. (see Manufuture initiatives on human-centred manufacturing).

3.1.2 Material collection, sorting, and recycling

Annual waste generation from all economic activities in the EU amounts to about 2.5 billion tonnes, and putting forward waste reduction targets is a significant challenge to address. Specific EU initiatives are being pursued, addressing critical products and sectors, i.e., batteries, packaging, end-of-life vehicles, and hazardous substances in electronic equipment. Furthermore, recycling approaches are being further encouraged as the most effective approach to waste prevention and circularity. High-quality recycling relies on methods and technologies able to sort and separate wastes effectively. Thus, research and innovation initiatives must be targeted to this class of application addressing:

i. technologies to identify materials in used products.
ii. technologies for high-quality sorting and removing contaminants from waste.
iii. technologies for the characterisation of secondary raw materials

3.1.3 Digital approaches to support sustainable and circular manufacturing.

Digitalization is a driving force for a circular economy, as a critical enabler to optimise resource use and operations efficiency within a wide range of industries. Further coordination is needed to accelerate change towards a sustainable circular economy, and digitalisation can help drive this transition. The evolution of digital technologies enables information to travel with a product starting from the design and manufacturing throughout its lifecycle, allowing the collection of essential data to support circular manufacturing approaches and strategies.
The availability of data on the use phase of products has become a significant constraint, pushing targeted initiatives at the European[2] level and, consequently, modern ICT technologies (e.g., IoT, 5/6G, cloud, big data analytics, platforms, etc.) are becoming as important as primary manufacturing ones. Furthermore, the availability of structured and reliable sources of information and data is a primary factor in supporting alternative and innovative business model targeting circularity (see Section 0) and supporting industrial decisions through assessing the economic viability of circular manufacturing schemes (see Section 0).

[2] Digital product passports: enhancing transparency and consumer information in the internal market.

3.2 Mobilise and involve stakeholders

Implementing a circular manufacturing scheme and adopting new models regulating the links and relationships among the actors within the value chain and the customers drives the need for defining principles and rules for the involvement of all the stakeholders. While data collection is a reasonable target, sharing data is a dominant issue. Mechanisms and rules to support the sharing of information while pursuing transparency and trust is the main barrier to the implementation and adoption of circular manufacturing approaches covering the whole lifecycle of products and the whole value chain. Furthermore, standardisation is a crucial factor in enabling repair and remanufacturing and the reuse of components (see Section 0).

In a scenario where data collection and analyses will drive significant investments for the companies, certification initiatives should be launched to support the generation of a clear business value linked to implementing circular economy approaches. Certifications need a complete life-cycle approach. This is a viable option thanks to modern ICT technologies, yet it is hard to realise due to current social, legal and business conditions.

4.
Research and innovation directions supporting the transition to a Circular Economy

4. Research and innovation directions supporting the transition to a Circular Economy

4.1 Modular-functional based design of products

Many complex products commonly used in our society (e.g., cars, instrumental goods, heating and conditioning systems, instrumental goods, and home appliances) rely on basic functionalities. Examples are heating and cooling, power generation, pumping fluids, energy conversion, and many others that, possibly also coupled together, can provide these products with fundamental and ancillary functions.

Nevertheless, devices providing similar functionalities always have different designs, rely on other components, and match different standards and regulations. In a significant portion of the cases, this is due to the specific requirements of a sector or applications in relation to the expected performance, standards, costs, etc. However, in many cases, differences do not depend on concrete and constraining requirements deviations but on customs, trade or commercial barriers, or other non-essential factors that could be eliminated.

This could probably be considered one of the main barriers in the repair and remanufacturing of products and, at the same time, the most binding and rooted since it lies in the design of the products themselves.

As highlighted in Section 0, while pursuing a transition to a circular economy, the reuse of the functions of products is a key strategic objective, more important than the reuse of materials, since it is capable of recovering a higher residual value, covering both the value of materials and one of manufacturing activities and processes that have been exploited to embed functions in it. Thus, the capability of easy reuse and recovering product functions is a fundamental research and innovation area to support the transition to a circular economy scheme.

4.1.1 Modular functional-based design of products

Modularity and componentisation are often considered the holy grail of efficient and structured design approaches and products in many engineering areas, from automotive to software development. Although technical standards and design practices have been pushing towards this direction, modularisation as a design pattern is still scarcely adopted. One of the main reasons for this is that it entails a more complex design and, consequently, a higher cost. Modularity paves the ground for a seamless and more manageable approach to update and repair products or reuse the modules in different designs. The social and regulatory push towards the repair and remanufacturing of products and the reuse of components is thus creating a favourable environment for this approach to become an industry standard and facilitate circularity in industrial, logistics and business processes. In this perspective, modularity can also be exploited to support the design of modular components that provide basic functionalities embedded in complex products. Modularity could also be used to provide components with different characteristics of a given functionality. Thus, components with various capacities associated with a function could be based on a different number of the same module. In contrast, different performances for the same function could be provided through modules with the same interface but belonging to different classes.

Although it may seem a rather theoretical idea, this approach is being pursued in different classes of components and functions.
A first example relates to batteries, where modularity allows the design of scalable solutions for various sectors. Modular battery systems are composed of assembled standard bricks to match the desired requirements[3]. Modularity allows adapting the characteristics of the battery pack (voltage, capacity, etc.) to the specific application through the definition of the number of modules and their connection. Furthermore, modularity also supports the standardisation of the production process and the recycling and repair of the battery packs. Concerning batteries, modularity can be exploited at both the cell level, defining standard cell composing a battery module and pack level, through multiple modules to form a battery pack[4].

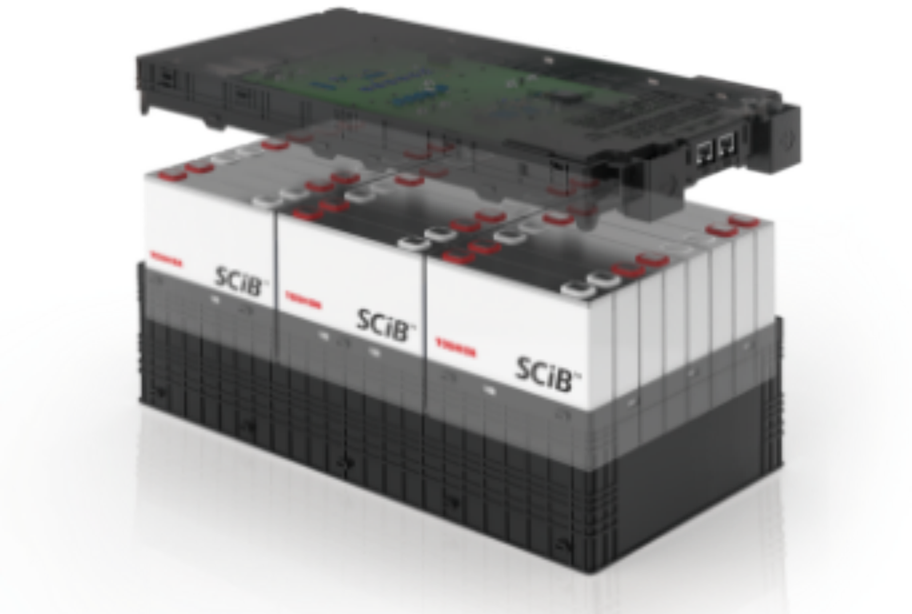

Figure 1. A SCiB™ modular battery pack from Toshiba exploiting modularity at the cell and pack level (courtesy of Toshiba[4])

Modular design approaches are also used in energy conversion to support the scalable design of heat exchangers. Thanks to the modularity, a set of identical modules can be assembled into a heat exchanger whose main dimensions range from one to twelve meters.

[3] https://www.wattalps.com
[4] https://www.global.toshiba/ww/products-solutions/battery/scib.html

Figure 2. A modular heat exchanger produced by Teralba (courtesy of Teralba Industries[5])

4.1.2 Circular paradigms for modular functional-based products

Modularity and componentisation of products and components could also play a significant role in implementing circular economy paradigms in the industry.
The first impacted area is the repair of failed components, where modularity could support the fast and seamless substitution of the failed components without the need for complete substitution of the whole components.
Secondly, also reuse will benefit from modularity. In fact, given that different performance within the same function could be provided by different classes of modules, degraded modules could be substituted in the original products but reused in less demanding areas or applications.

[5] https://teralba.com

4.2 Capital goods for repair and remanufacturing

Many of the significant changes affecting the industry have been driven by advances in technologies and instrumental goods. The transition to a circular economy in manufacturing will also require a new generation of instrumental goods capable of supporting the repair and remanufacturing of products and their components. Besides being a significant enabler for repair and remanufacturing, capital goods also play a strategic role for Europe, being the largest player in the world for industrial equipment. Thus, pushing towards the definition of a new generation of capital goods for circular manufacturing also entails new opportunities for industrial equipment manufacturers. This new generation will require advanced functionalities that are unavailable or difficult to manage in the currently available class of industrial equipment. These are described in the following.

4.2.1 Partial execution of processes

Repair and remanufacturing processes are designed to restore the characteristics of failed or degraded products or components through a specifically designed process. This typically embeds process steps strictly related to repair/remanufacturing (e.g., the addition of material to compensate for the effect of wear) and the repetition of process steps identical to the ones executed in the original manufacturing process. The set of steps to be performed depends on the class of failures or wear affecting the parts and the destination of the repaired parts. Thus, industrial equipment must be capable of executing a process only partially to match the characteristics of a standard manufacturing process (i.e., the process steps to be operated) to the specific part to be remanufactured. Furthermore, the capability of repeating a set of operations or modifying the associated parameters will be a required feature, aiming to address rework operations.

4.2.2 Robust execution of processes

Parts to be repaired or remanufactured are often characterised by very different wear states. They come from possibly different types of users and uses. This entails a potentially high degree of variability that could directly impact remanufacturing processes. To this aim, industrial goods implementing the repair and remanufacturing must be capable of operating with effectiveness and high efficiency in the presence of significant variability of the incoming products, guaranteeing both the quality of the result and the performance of the whole remanufacturing phase.

The correct execution of the processes is also affected by the characteristics of the materials. A possible source of this class of variability stems from the need to add material to worn parts, whose characteristics differ from the original. Furthermore, this issue also arises with respect to the use of secondary materials, i.e., materials obtained from recycling used parts. Also, in these cases, instrumental goods for remanufacturing should be capable of adapting the execution of a process to deviations of the characteristics of materials and parts, taking advantage of the inline characterisation of parts/materials.

4.2.3 Hybrid processes

Repair and remanufacturing processes often require multiple manufacturing technologies, e.g., additive manufacturing to add materials to the worn parts, and subtractive processes to obtain the desired geometry and finishing. Instrumental goods implementing this class of processes must thus be able to operate multiple manufacturing technologies, optimising the routing of parts and reducing non-productive times. Furthermore, within the same class of manufacturing technologies, the possibility to cover a wide range of process parameters must be pursued, with the objective of enhancing the equipment's capability to cope with multiple classes of parts.

4.3 Coupled manufacturing and re-manufacturing plants

The implementation of re-manufacturing activities grounds on the availability of products and components after the use phase and the capability of operating the required manufacturing processes. Original equipment manufacturers (OEMs) are hence the primary candidate to implement this class of processes because they likely retain the link with their customers and, since they are capable of carrying out the manufacturing processes, they would also be able to manage the remanufacturing one.

In this perspective, the coexistence of manufacturing and re-manufacturing activities in the same factory is a viable and possibly convenient option bringing in a set of benefits:

i. mitigate the risk associated with the variability of re-manufacturing flows, guaranteeing the saturation of the plant.
ii. support the integration of forward and reverse supply chains.
iii. ensure the quality of re-manufactured parts.

Nevertheless, pursuing this option and considering the current global architecture of supply and value chains linked to manufacturing (e.g., in the automotive sector) could entail possible drawbacks:

- as re-manufacturing also constitutes a service to customers (see Section 0), the global supply chain will make it difficult to settle it close to the customers, thus neutralising one of the linked strategic benefits.
- re-manufacturing facilities, similarly to manufacturing ones, take advantage of economies of scale. In this perspective, implementing a re-manufacturing scheme for a single class of parts could lead to limited flows and volumes. This is hence pushing towards re-manufacturing business actors coping with products and components from different OEMs

4.4 Support the economic viability of circular manufacturing

The main obstacle to adopting circular manufacturing approaches is its economic viability. Maintenance, repair, remanufacturing, and recycling require the implementation of logistic and manufacturing functions, whose cost could, in many cases, put the economic viability of the circular approach in grave danger.

The assessment of the cost associated with circular manufacturing is influenced and impacted by multiple factors interacting in a complex and multifaceted way:

i. the class of product (e.g., complex assembly, single products)
ii. the value of the product/component.
iii. the amount of material that can be recovered.
iv. the profit margin of the product/component.

All these factors and their interaction must be analysed to identify specific combinations that enable the viable implementation of circular manufacturing paradigms. Furthermore, the economic viability analysis should also consider strategic and robustness-related aspects (see Section 0) by considering the impact of alternative scenarios for the cost of energy, the availability of raw materials, and the stability and reliability of supply chains.

4.5 Business models for circular manufacturing

Reasoning on the economic viability of circular manufacturing paradigms also involves addressing the feasibility and convenience of alternative business models. The transition to circular manufacturing schemes inevitably leads to a closer and long-standing relationship between the manufacturer and the customers and, in many cases, between the manufacturer and its suppliers.

Thus, business models going beyond the simple sale of products are interesting candidates to bring a different point of view. Nevertheless, the impact and economic and logistic and manufacturing implications of these mechanisms are not straightforward to assess. The analysis is strongly influenced by various interacting factors, e.g., the specific class of products, the manufacturing processes operated, the supply and value chain, the destination markets, and the types of customers.

The adoption of alternative business models could raise relevant questions whose solution can undoubtedly impact the design and operation of circular manufacturing schemes:

i. is re-manufacturing a more viable and convenient approach concerning recycling and material recovery?
ii. does a pay-per-use approach entail increased viability of re-manufacturing?
iii. is the manufacturing-as-a-service model a suitable approach for circular manufacturing?

These reasonings need to be further addressed through targeted research initiatives to support the implementation of circular manufacturing approaches.

4.6 Strategic aspects for circular manufacturing

The adoption of a circular manufacturing paradigm must also be analysed in terms of its impact on strategic-related aspects, both at the level of a single company or supply chain, as well as concerning the complex weaving of industrial and economic links in a region.

The first class of considerations refer to the relationship between the manufacturer and its customers. A critical factor in these relations is the capability to provide customers with quick, effective, and possibly personalised responses to their needs during the whole use phase of a product. Circular manufacturing, bringing the repair and remanufacturing activities from the perspective of the original equipment manufacturer, also creates the conditions for providing maintenance and repair services close to the customers, thus reducing response times.
Establishing long-term relationships with customers also increases their loyalty and provides the possibility of implementing up-/cross-selling opportunities coupled with maintenance and repair activities.

Referring to strategic considerations related at the general industrial and economic level, implementing a circular manufacturing paradigm can operate as an alternative supplying source for materials through recovering materials from end-of-life products. This could represent a temporary or stable option to cope with risks and fluctuations affecting the cost of energy, the supply of raw materials and the reliability of supply chains.

Finally, regulations pushing for adopting circular economy schemes to mitigate the environmental impact of industrial activities and products could also establish barriers for competitors not matching the requirements for re-manufacturing, recovery and recycling.

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