PRIORITY 3: Maximizing material closed loops by recycling consumer products, buildings and infrastructure

The shift towards increased material-efficiency in manufacturing will highlight the demand for more complex and diverse material compositions in various applications from consumer products to buildings and infrastructure. The trend is leveraged by the circular economy, which is expected to trigger research and development focusing on strategies related to service economy, eco-design, industrial symbiosis and waste prevention. The circular economy will also provide a significant momentum for the optimisation, redesign, and regeneration over the whole product lifecycle from extraction, utilization, and management of resources to materials design, production and processing, to the manufacturing, usage and end-of-life (EOL) phases. Actions are needed to increase knowledge and develop tools for analysing best available alternatives concerning product quality, energy consumption, environmental loads from reuse and recycling, including the cleaning and separation processes. From the very outset of the product design phase, innovations need to address both recycling and extended life-span of materials for abiotic and biotic raw materials.

Key research and innovation areas

3.1 Increasing collection, sorting, separation & detection efficiencies

3.2 Recycling technologies adapted to complex, durable, miniaturized & material-efficient products

3.3 Developing and integrating assessment methodologies for balancing recycling costs and benefits

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3.1 Increasing collection by efficient sorting, separation and detection

Rationale

Recycling is an option to obtain materials from processed goods and a means to enhance resource efficiency that, in turn, relieves the pressure of extracting and harvesting of resources from nature. However, complete recycling of products, parts and components with a view to recovering pure raw materials and their original performance and value is environmentally, economically and technically neither achievable nor feasible. Often, the original functionalities and the value of alloying elements or fibers cannot be recovered in the recycling process, particularly in low concentration levels. Impurities, undesired elements, for example heavy metals, or degraded molecules, such as polymers and paper, remaining after the processes of sorting, separation and detection will determine the performance of the recovered materials in their new application. Innovative solutions in these recycling streams are essential to improve the value and the market opportunities of recycled materials. In addition, shifts related to ownership of products, in which product manufacturers retain equipment and devices with economically valuable raw material content, could provide opportunities for achieving higher collection efficiencies and dramatically change product design and longevity.

State of play

Europe has already become the leading continent in the recycling of base metals, paper, packaging and several other post-consumer wastes. The **EU wood processing industries and the pulp and paper sector** have a well-known tradition of using residues as a secondary raw material or as bioenergy source for their industrial processes, having products being up to 100% manufactured from recovered fibers and wood. A good example and still evolving case is the paper fiber loop: the sector attained a recycling rate of 71.5% in 2015[1] and keeps efforts to raising these levels through progress in the paper collection, sorting, and in recycling and de-inking technologies.

The **construction and demolition waste (C&DW)** is one of the heaviest and most voluminous waste flow generated in the EU, accounting for around 25% to 30% of all wastes. It includes concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil. The potential to raise its levels of recycling and material recovery is estimated at a range between less than 10% to over 90%, with an average value of 54%[2]. A market for secondary aggregates derived from C&DW is in place and the technology for the separation and recovery is well established, readily accessible and in general inexpensive.

Similar goals need to be achieved for the recycling of **critical raw materials**, where significant deficits still exist, with low recycling rates for most technology metals, in many cases even being below 5%.

Expected achievements by 2030

By 2030, product-centric perspective and a product lifecycle (PLC) approach will have replaced the current material-centric perspective and its corresponding waste hierarchy principles. That will allow for a coherent and consistent integration of recycling as a useful strategy for waste management in

[1] http://www.cepi.org/system/files/public/documents/publications/recycling/2016/FinalMonitoringReport2015.pdf
[2] http://ec.europa.eu/environment/waste/construction_demolition.htm

support of a more circular economy. Substantial increases of the recycling rates and of the quality of recycled materials will have been attained, thanks to mainstreaming of EOL management into the product's value chain as well as increased knowledge sharing on product composition, design and architecture alongside the value chain. Mining, harvesting and industrial processing have minimized residues and wastes and now feed these into other added-value uses. Innovative and comprehensive solutions will have contributed to raising the rates of recycling and recovery of C&DW to well above 70% in the EU[3].

Expected achievements by 2050

Optimized C&DW reutilization, significant improvements in recycling rates of critical and technology metals and composite materials and enhanced extraction from secondary sources in all member states will have expanded the overall availability of resources for the European economy, hence giving a crucial contribution to maintaining EU's independence from the external supplies of raw materials. Multilateral, international cooperation of dedicated networks and logistic platforms will have been operating and maintaining the viability of collection, recovery, recycling and transport of waste and materials. A vital industrial symbiosis has emerged underpinning EU-based businesses.

Research and Innovation Activities by 2030

(the number of activities to be reduced)

The abiotic and biotic sector

A. Develop new product-centric process technologies for separation, fractionation or extraction with improved selectivity for various components in recycling stock which enables utilization in value-added applications inside and outside the production chain.
B. Develop flexible disassembly, sorting and separation technologies that can deal in a cost-effective manner with increasing levels of impurities within recovered materials as well as various processing incompatibilities.
C. Develop treatment technologies to input-specific combinations that allow for obtaining high yields and purities from complex products, e.g. alloys and composites with low concentrations of various valuable materials.
D. Develop technologies to extend the use of residual products and waste as feedstock in building materials production (pre-treatments of wastes, quality control of waste and final products manufactured with waste).
E. Improve treatment technology for C&DW comprising pre-treatments and/or in deep characterization of waste, quality control of waste and final products containing waste
F. Explore waste and recycling technologies that provide effective sinks for (eco-)toxic substances and materials in order to avoid reuse in a circular economy
G. Develop innovative technologies for the value-added use of separated and extracted components from wastewater treatment.
H. Research the potential of disruptive technologies and innovation and their impact on product's EOL phase.

[3] Target laid by the EU Waste Framework Directive for 2020 http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0098

I. Develop integrated processes and systems to recover and reuse mineral resources utilized in pulp and paper making, e.g. fillers and pigments in a cross-sectorial symbiotic approach.
J. Develop tools and systems for monitoring (standardisation of information), simulation and predictions of optimal handling and mixture of reuse, recycling, energy utilization and renewal of biotic materials (e.g. wood, and fibres from forestry and/or recycling regimes including necessary cleaning technology, logistics etc.).
K. Develop new logistic concepts and manufacturing technologies for improved utilization of C&DW.
L. Develop new certification and traceability methods for construction products in order to have a better control of demolition waste.

The abiotic sector

M. Create efficient sorting, pre-treatment and metallurgy processing of complex multi-metallic and material EOL products, including functional surfaces, e.g. liquid-crystal-displays (LCDs), photovoltaic, etc. and the interface optimization, addressing interdependencies of the steps by using a systems approach.
N. Explore methods and technologies for the recycling of critical and, technology and toxic metals in general, e.g. gallium, indium germanium, rare earth elements, tantalum, arsenic, tungsten, and vanadium to assure that in the future, secondary critical and technology materials can be recovered at a quality level.
O. Investigate methods and technologies that enable recycling of, e.g. cobalt, copper, lithium, palladium, platinum, rare earth elements, rhenium, scandium, silver, tantalum, titanium, tin and other minerals which recycling rates are near to zero, from various applications.
P. Recover gallium and germanium from fly-ashes on an economic scale.
Q. Recover indium from gasses and ashes of tin and copper ore concentration and future recycling of display applications on an economic scale to increase the yield.
R. Development of energy-efficient collection, cleaning, sorting and refining technologies.
S. Deploy technical means for tracking and tracing of material flows, e.g. by tagging relevant products and components such as mobile phones, circuit boards, batteries, etc with radio-frequency identification (RFID) chips or other types of tags.

The biotic sector

T. Develop systems for turning recycled, solid wood products into fibers and other high-value products. Progress further on paper collection systems and sorting technologies for enhanced quality of paper for recycling for the different paper grades.
U. Develop agile sorting systems using new sensors for detection and robotics technologies for paper, wood waste and forest residues to separate according to different types of fibers, inks and fillers, contaminants and soil residues and resulting in higher sorting accuracy and velocity.
V. Improve separation and cleaning technologies (using physical chemistry and/or industrial biotechnology) for a further closure of water cycles and to reduce the amount of effluent.
W. Create radical innovations for the removal of inks and fillers from a paper by utilizing easy-to-remove new inks and adopted printing technologies as well as by breakthroughs in de-inking technology.

X. Research the treatment and pre-treatment of recycling stock, including enzymatic processes, for pulp and paper for recycling and other wood-based products.
Y. Develop ways to strengthen fibres so that they become more resistant to recycling loops
Z. Develop further improvement for the collection of residues from harvesting operations and processing (paper, construction materials, waste wood, forest residues, etc.) with priority for separate collection and quality assortment classifications.
AA. Develop non-destructive wood property measurement techniques and systems that allow for traceability of individual wood objects, for optimized resource utilization.
BB. ICT tools and systems making it possible to make current monitoring and calculations of the optimal combinations of reuse, recycling, energy utilization, and renewal of biotic materials regarding benefits/costs in monetary units, energy units and all kind of emissions.
CC. Develop prototypes of new materials containing construction wastes for other application with relative characterization

Research and innovation activities by 2050

A. Create multilateral, international cooperation of dedicated networks and logistic platforms to increase or maintain the viability of transport and recovery of materials by EU-based businesses

3.2 Recycling technologies adapted to complex, durable, miniaturised and material efficient products

Rationale

The EU's ambition is to become the leading continent in the recycling of both abiotic and biotic raw materials and in exporting its recycling technologies worldwide. A good strategy of securing the Intellectual Property Rights (IPR) associated with different recycling technologies is fundamental to gaining tangible benefits globally. However, the landscape is challenging in all respects. In the next decades, an increased demand for purer raw material qualities to manufacture goods is expected, while their recycling will be far more complex and likely to produce lower quality outputs. This is a case in point with regards the concepts of miniaturization, merging of multiple functionalities into a unique device and nanotechnology applications, to name a few, that prevail among the trends in product development.

In the domain of product design and development, the recent trend of product miniaturization demands excellent separation technologies and intensive efforts to recover low volumes of technology metals from high added value consumer goods. Develop innovative recycling technologies that are adequate to new products is pivotal to ensuring a continuous flow of post-consumption materials. The shortening of both technology and product lifecycles and the introduction of disruptive technologies, particularly in photovoltaics, packaging, ICT, batteries, consumer and professional electronics, makes it difficult for the recycling industry to keep pace. The circular economy concept allows a shift towards product design that embraces a cradle-to-cradle approach, instead of the current linear method cradle-to-grave. There is a need to determine a proper flow of secondary raw materials and develop strategies to make for instance paper fibres more resistant to degradation in the recycling loops.

State of play

In the final products, originally abiotic and biotic raw materials can be mixed in complex structures not possible to dismantle or disintegrate, for example in metallic-ceramic-bio composites. Challenges for recycling these types of products encompasses both traceability and lack of certificated materials, resulting that the identification of the elements is not possible without analytical characterization methods.

In the EU and in most developed regions of the world, the mass of electronic devices put on the market has been decreasing in the past years[4]. This fact associated with a corresponding low concentration of valuable raw materials within the available consumer products inhibit the implementation of innovative recycling technologies and infrastructure at commercial scale, the private investment remaining particularly low.

Increasingly, new technologies and innovative products are brought to the market before viable and suitable recycling technologies are in place. On this account, existing recycling technologies and facilities might become obsolete before achieving the foreseen return on investment. Business

[4] http://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics_-_electrical_and_electronic_equipment#EEE_put_on_the_market_and_WEEE_collected_in_the_EU (*verify)*

models based on value creation from particular materials might collapse when technologies change and valuable, critical or potentially hazardous materials for some applications are substituted by highly engineered materials that are made of low value, abundant constituents such as organic molecules, such as organic light-emitting diode (OLED) and carbon-based materials such as graphenes, zeolites, polymers and silicon.

Expected achievements by 2030

Secondary raw materials flow will have been mainstreamed into cross-sectorial systems, as a result of the development of new technologies that are adaptable to small-scale and aligned with circular business models for easy collection, identification of materials and elements, as well as smart separation of the relevant unit targeting its subsequent use after recycling.

Expected achievements by 2050

By 2050, retailers, industries, raw material suppliers and research institutions in the internal market are interwoven and jointly possess a critical mass to produce the technological leadership and know-how required to operating a symbiotic industrial environment in the EU. The collaborative efforts of various institutions and public authorities in member states will have resulted in adjustments of the legal and social framework for the uptake of innovative recycling technologies.

Research and Innovation Activities by 2030

The abiotic and biotic sector

A. Provide new and cost-efficient techniques to allow for chain of custody recyclability assessment.
B. Devise recommendations on technical design for disassembly, recycling and detection.
C. Develop demonstration projects to evaluate reusability and recyclability of specific resource streams at different scales and across different geographical dimensions, including local, city, regional and rural areas.
D. Integrate digital systems to optimize circular design and circularity of raw materials and critical raw materials with a view to increasing the levels of, or realize smart substitutions of, recycled, secondary and waste material in the content of products.
E. Expand systematic research on materials and their properties, modelling routes for tailored material performance throughout the its life-span, within a particular value chain, mainly for bulk applications or critical raw materials. This may assist product design and lead to better understanding on how the distribution of materials can be altered, or recovered efficiently, with the current technologies.
F. Investigate additive manufacturing technologies improving durability and functionality of products as well as streamlining design for easy maintenance, easy upgradability and modularity.
G. Develop incentives for new added value technology solutions and business concept models that allow for expanding the use of recycled and recovered raw materials.
H. Develop tools and systems that enable information exchange on product design, architecture and composition alongside its value chain for increased integration of end-of-life

management into the product's value chain, and for enhanced effectiveness and efficiency of the recycling processes.

I. Develop technologies for improving recycling quality and reducing contamination, recycling of composites, alloys, elements, fibres, flexible recycling process also adapted to small scales.
J. Small scale and mobile technologies to face decreasing volumes of consumer goods and of the concentrations of critical and valuable materials they contain.
K. Develop viable and suitable recycling technologies anticipates massification of potentially disruptive technologies and innovative products in applications that include photovoltaics, packaging, ICT, consumer and professional electronics, batteries.
L. Develop design concepts for ensuring recyclability of hybrid products and technologies for the separation and reuse of used material components.
M. Develop prototypes of new materials containing construction wastes for other application with relative characterization

The abiotic sector

N. Develop mechanical and chemical processing of complex end-of-life products without dissipation of technology metals.
O. Improve the reusability and recyclability of construction materials
P. Improve the reusability and recyclability of wood composites
Q. Develop decision support systems for optimised supply chain management, including multiple reuse of wood, fibres and biomass, linked to forest planning tools for multifunctional forest management.
R. Develop and establish design criteria to ensure the full recyclability of packaging materials, in particular barrier layers and embedded electronics.
S. Develop product design approaches for the reusability of packaging or easy-to-dismantle building components to facilitate optimal sorting and recycling.

The biotic sector

T. Develop models and simulation tools for new product design approaches, and associated new production technologies to obtain more functionality from less material and energy input, e.g. lightweight wood construction or reduced paper grammage.

Research and innovation activities by 2050

3.3 Developing and integrating methods for assessing and optimising cost and benefit in recycling

Rationale

Currently, the assessment of the best material management option is based on a variety of economic, environmental, health and safety, social and functionality assessments. However, it is uncommon that all these variables are brought together in order to compile a conclusive assessment and hence providing solid basis for a truly well-informed and balanced decision. The sought-after solution for both biotic and abiotic raw materials remains to determine the extent of the technological, environmental and socioeconomic advantages or disadvantages of recovering certain materials, especially when primary materials are abundantly available.

State of Play

Despite being a good alternative for sourcing valuable secondary raw materials, recycling processes should not be regarded categorically as safe, environmentally friendly or socially responsible options. In fact, in the final products, originally abiotic and biotic raw materials can be in very complex structures or mixtures and, therefore, energy intensification and contamination of side streams with toxic materials are among the well-known risks associated with their recycling. As a result, currently, abiotic materials such as ceramics, industrial minerals, critical and valuable metals have low recycling rates, while both biotic and abiotic materials can suffer from decreasing quality during recycling.

In addition, the logistic efforts to collect post-consumption materials in geographically challenging regions, associated with an increment in the emissions of greenhouse gases and the transport costs, makes recycling a very complex equation to adequately balancing its costs and benefits.

EOL materials derived from consumer products, in particular electronics or products containing electronic parts, are currently in the centre of the attention given the high value and costs of the different components. The concept of “urban mining”[5] offers opportunities both for dedicated business models and for recovering materials from alternative sources. Certainly, this approach opens opportunities to debate the environmental costs of storing, incinerating or recycling raw materials as well as the environmental payoffs of changing landfill management practices.

Expected achievements by 2030

Thanks to the successful development, test and implementation of appropriate assessment methodologies and comprehensive decision-making support tools, knowledge on how to balance the economic and environmental costs and benefits of collecting and recycling processes will have progressed. The recycling targets of the whole-product EOL using economic, social and environmental indicators will have replaced weight-based material recycling targets.

Expected achievements by 2050

To be completed

[5] The concept of urban mining refers to the extraction, processing and exploitation of materials found in landfills of urban regions LINK

Research and Innovation Activities by 2030

The abiotic and biotic sector

A. Create knowledge base on environmental performance indicators and performance rating systems for materials and buildings.
B. Develop, test and implement assessment methodologies and indicator sets that include parameters such as criticality and circularity of materials, enabling for replacing weight-based targets of material recycling by whole-product and EOL performance targets that account for economic, social and environmental criteria.
C. Develop assessment tools and monitoring systems for international production and trade flows including storage and CO_2 sequestration in forest-based raw materials and wood-based products.

Research and innovation activities by 2050

A. Devise cross-sectoral business concepts, build proper infrastructure and develop suitable technologies to operate 'urban mines'.