**VERAM Research & Innovation ROADMAP 2050**

*Draft 3.6*

**Version for Public Consultation**

*A Sustainable and Competitive Future for EU Raw Materials*

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# Why a Raw Materials Research Roadmap?

**Demographic changes**, such as population growth in developing countries and ageing population in developed countries, coupled with increasing standards of living and urbanisation trends will foster a greater demand for products and applications linked to human wellbeing, health, hygiene and sustainability. As a consequence, a worldwide demand for raw materials is expected to increase while global resources and land become scarce.

To meet the challenges caused by the **global warming** and waning natural resources, a shift towards a more resource efficient economy and sustainable development is becoming more crucial than ever. Meanwhile, trends such as the emerging ”sharing economy” and changing raw material demands as new technologies develop, will reshape the world we live in and influence our need for raw materials. The opportunities enabled by emerging technologies, digitalisation, artificial intelligence (AI) and additive manufacturing applications will bring about unforeseeable breakthroughs in technologies and organisation of human work.

Securing reliable and undistorted access to raw materials is crucial to boosting growth, jobs and competitiveness in Europe. Currently, the EU is dependent on imports of many raw materials that are crucial for a strong European industrial base.

Europe is confronted with several challenges along the entire raw materials value chain composed of exploration, extraction, processing and refining, manufacturing, use and recycling as well as substitution. Yet, innovation in raw materials value chains remains untapped despite the sector’s great potential. A more coordinated approach towards raw materials management will help reduce external supply dependency and lead to an efficient use of resources.

To achieve these goals, a long-term vision and roadmap to 2050 aims to tap the full potential of raw materials supply and use in Europe and to boost the innovation capacity of the sector, turning it into a strong sustainable pillar of the EU economy and an attractive industry, whilst addressing societal challenges and increasing benefits for society.

# Abiotic and Biotic Raw Materials

The Roadmap 2050 for European raw materials envelopes relevant research and innovation activities of non-energy, non-agricultural raw materials used in industry, including metallic minerals, industrial minerals, construction materials, aggregates as well as wood and natural rubber. In addition, as part of the circular economy concept, secondary raw materials[[1]](#footnote-1) will become more and more integral part of the materials consumption, requiring targeted research and innovation efforts.

The Roadmap distinguishes two raw material categories: the abiotic and biotic sectors encompassing the entire value chain from primary raw material extraction and harvesting and their transformation through processing or refining and the valorisation of waste into secondary raw materials to closed loops materials flows and the development of new products and applications to substitute fossil-based and/or critical raw materials.[[2]](#footnote-2)

#### The abiotic value chain

*To be developed*

#### The biotic value chain

The **European biotic raw material sector** is in the heart of the bioeconomy providing means to tackle global challenges by replacing fossil-based raw materials with sustainable, renewable raw materials sourced in Europe. Forests cover 42% of EU’s land area. **The forest-based sector** is a key enabler for a low-carbon, biobased society. The sector consists of four major sectors: woodworking, furniture, pulp and paper manufacturing and converting and printing, as well as forest owners. However, the value-chain is producing a wide range of products ranging from packaging, textiles, hygiene articles and furniture to bioplastics, bio-composites, carbon fibres, textile fibres and biochemicals. **Natural rubber** is a strategic raw material, on which the European industry has a complete import dependency. Natural rubber is mainly produced in Asia (93 %). Hevea, a native tree from South America, is currently the only commercial source of natural rubber. Guayule (Parthenium argentatum) is one of the alternative sources growing on marginal lands in semi-arid regions of European Mediterranean countries.

# The structure of the Research Roadmap

To secure the competitiveness and sustainability of the European raw material sector will require significant investment in research and innovation and fostering synergies between and across different value chains. The biotic and abiotic raw material sectors have therefore identified four key priorities and ten research and innovation areas, including a number of activities with a view to addressing the key concerns of raw materials community as well as societies and citizens at large, as identified by the Vision 2050. The concrete research and innovation activities cover specific needs within supply and production of raw materials, creating closed loops, and developing new products and applications.

**THE STRUCTURE OF THE VERAM RESEARCH AND INNOVATION ROADMAP**

# PRIORITY 1: Fostering a sustainable supply of raw materials to feed new and existing value chains

The acquisition of primary raw materials through mining, quarrying, timber logging and harvesting have been sustaining human civilisation since history began. Also in the foreseeable future, the gathering of metals, minerals, aggregates and biotic materials from natural sources will be essential to supply most manufacturing operations. However, the palette of raw materials seen today is likely to change drastically, as new consumer patterns evolve and technologies that allow for various substitutions of scarce materials or for climate friendly processes develop.

Today, demands for raw materials along with increasing economic and environmental public demands for sustainability and resource efficiency require new technologies, digital solutions and decision-making tools to support more accurate sourcing and transportation of raw materials from mines and forests. Therefore, this priority area focuses on research and innovation activities to leverage several practical challenges; collecting raw materials most often relies on heavy machinery and the working environment is hazardous. The operations are capital-intensive with relatively low margins. Harvesting operations and open mining operations are susceptible to shifting weather conditions and typically the primary collection is at low concentrations and has to be separated from waste and slag, raising environmental concerns.

***Research and innovation areas***

*1.1 New exploration and harvesting technologies for a sustainable supply*

*1.2 Mobilising an increased supply of raw materials from EU sources*

## 1.1 New exploration and harvesting technologies for a sustainable supply

#### Rationale

**Abiotic:** Globally, the mining industry faces multiple challenges: higher costs for deeper exploration and extraction, extended time for permitting, and the technological and economic feasibility of mine development are challenges to tackle in Europe as well as anywhere in the world. Land use for mining and quarrying is an important environmental challenge: sites make, changes to land, some are irreversible and increased volumes of traffic are associated with the industry. New mine and quarry applications are rejected on the grounds of various environmental issues and in some countries existing operations only get a few years permit at a time. Moreover, the industry produces noise and dust, which is a nuisance to local communities.

**Biotic:** To maintain and strengthen the competitiveness of the European forest-based sector, it is crucial to secure efficient, sustainable and high quality raw material supply. The provision of raw materials and the further development of efficient and environmentally-friendly forest operations for biomass supply chains are core activities of the forest-based sector.

#### State of play

**Abiotic:** Already today, some of the world’s smartest, and most energy- and resource-efficient mines and quarries are operating in Europe. However, Europe’s mineral potential is under-explored both with regard to subsurface, particularly deeper than 150 meters, and at sea in the EU Member States exclusive economic zones.

**Biotic:** The EU’s growing stock is increasing. In 2010, the annual increment of Europe’s forests was 768 million m³, while the annual harvest was 484 million m³, equivalent to 63 % of the increment [LINK]. Though variation is large, in no EU country does the harvest exceed increment. Still, the supply of woody biomass is far from evident for economic reasons as well as environmental concerns. To increase sustainably and economically viable supply of biomass, there is a need to improve operational efficiency resulting in added-value less waste, lower operational costs and reduced environmental loads.

#### Expected achievements by 2030

By 2030, Europe has developed further technological leadership aiming at economically viable and environmentally sound mineral extraction and forest harvesting operations. Full automation and autonomous equipment is a reality. New autonomous mining and harvesting systems have increased productivity and improved the working environment for operators. Enhanced health and safety measures taken in the mines and harvesting have significantly reduced number of days lost due to workers’ sickness or injuries

**Abiotic sector:** The newly developed exploration technologies for land- and sea-based mineral deposits have been up-scaled and piloted. Tools to assess the resource potential in technical infrastructure and products put on the market have been developed across Europe. New technological extraction methods have been tested on extended pilot scales and have been applied across a series of minerals. Novel process control through intelligent use of IT has been implemented, as well as sensors in extraction and mine processing has been installed. Larger mines have reached a certain degree of automation with driver-less drill rigs and vehicles in surface and underground mines and quarries managed from computer consoles. In small deposits mining, the “mine-to-go” for selective, small-scale mining has been piloted. Recovery and use of geothermal energy from deep mines have become regular. Innovative, energy-efficient transportation in the mine and quarry have been implemented. The sector has achieved the target ‘zero-impact’ mining and quarrying and has evolved performances in the areas of sustainable management of water, health and safety conditions.

**Biotic sector:** Research and innovation towards new, highly productive machine technology, including semi-automation and full-automation harvesting and terrain transport systems, measurement and processing technology have made forest harvesting and transportation considerably more efficient. New supply-chain standards, remote sensing technologies and accessible GEO-data has made all forest machines closely integrated and coordinated with customers manufacturing processes. Improved machine technologies and ICT systems have reduced rutting problems and assists forest operations regarding retention patching, concern of cultural heritage, water protection areas and other environmental concerns. The monitoring systems in the harvesting machines have also had a great impact on efficiency and environmental concern in following silvicultural operations, enforcing and continuously recording the sustainability of all forest operations.

#### Expected achievements by 2050

**Abiotic sector:** By 2050 larger mines should have reached full automation with driver-less drill rigs and vehicles in surface and underground mines and quarries managed from computer consoles. Larger mines should have introduced robots to conduct flexible tasks. The full exploitation process will be automated from extraction to product delivery and will be managed in real time and by one central hub, while smaller mines should have achieved a certain degree of automation. There will be no more people underground or in the quarries themselves. In marine mining, environmentally sound and sustainable extraction of identified sea deposits has been made possible. In deep mining, mines and quarries across Europe have zero-impact on water and climate change. Dedicated technologies for space mining and urban mining have been proposed and tested.

**Biotic sector**

#### Required Research and Innovation Actions by 2030

**The abiotic and biotic sector**

1. Identify technologies required to sustain smart and automated mining and harvesting operations

**The abiotic sector**

1. Improve geochemical and geophysical exploration methods and prospecting techniques with a view to increasing the resource diversity in Europe.
2. Enhance drill logging technologies to obtain more cost-efficient and more environmentally friendly exploration.
3. Reprocess current soil and residue samples using modern analytical techniques for higher recovery of old mine tailings and other deposits.
4. Improve systems to collect and predict ore-body information, including seam and grade definition
5. Investigate hydraulic hoisting technologies to reduce energy consumption on haulage
6. Explore technologies that enable alternative mining sources, including space mining, e.g. asteroid mining.
7. Develop technologies and methods that allow for exploring and extracting minerals from sea bed deposits, deep-sea mining and mining under special conditions
8. Improve hard rock cutting techniques and deploy continuous cutting machines for [automated] and efficient operations within small deposits, deep-sea mining and special conditions mining
9. Test new, and adapt conventional, design layouts and operations to suit automation to decrease the number of workers in quarries and mines
10. Develop configurable, open, integrated interactive planning systems using new ICT
11. Make data available across operations with a view to increase efficiency and safety
12. Investigate means to create stability of automated mining operations at greater depths.
13. Apply new improved health, safety technologies: electrification of haulage machinery for rough terrain

**The biotic sector**

1. Develop efficient ICT systems for precision quantification and characterisation of forest-based wood materials i.e. precision inventory
2. Develop efficient ICT systems for planning of precision deliveries to industry customers taking the entire value and supply chains and customers into consideration
3. Develop forest-based standardised information systems like StanForD (Communication with Forest machines), papiNet Forest Wood Supply & Bioproducts, WoodX, Packaging, Pulp, Paper, Fine paper, Logistics, Label stock, Recovered paper, Logistics etc.
4. Apply ICT to develop precision forestry to enhance harvesting and silviculture operations for next generation trees
5. Develop intelligent forest operation systems and smart solutions for human-machine-terrain interactions.
6. Analyse and monitor changes in forest ownership and their implications for forest management, new opportunities and markets.
7. Develop new tree breeding strategies that include quantitative and molecular genetic tools aiming at sustainable and high yield of biomass, improved wood quality and resistance to stress.
8. Assess the economic, social and environmental benefits and risks associated with the use of genetically-improved trees.

#### Required Research and Innovation Actions by 2050

*To be developed*

## 1.2 Mobilising an increased supply of raw material from EU sources

#### Rationale

Due to the increasingly deeper mines, the haulage of the ore is one of the main energy consuming factors. At the same time, the transportation of the ore underground and in the pit as well as transportation of the product leaving the mine to the customer come with a number of emissions that are undesirable and costly. Furthermore, empty loads are a waste. Therefore, new transportation means and organisation are required.For secondary resources collection, transportation and delivery of final recycled material/product to market is critical.

**Biotic sector:** The intelligent and efficient production and use of biotic raw materials and the further development of precision forestry[[3]](#footnote-3) for efficient and environmentally-friendly operations, transport systems and management models for biomass supply chains are core activities of the biotic value chains. Improving technology for managing and utilising growing forest resources can be achieved through the measurement and planning systems adding value at a minimum environmental load while contributing to developing highly productive harvesting and transport systems integrated with general and specific industry requirements.

#### State of Play

**Abiotic sector:** Currently most transportation is not electric and developing and introducing electric vehicles is not without challenges. Electrified train haulage of ore is still under development.

**Biotic sector:** More precise information systems to guide harvesting operations are under development, relying on technologies such as remote sensing, navigation systems and geographic information systems. In addition to providing knowledge about the quantitative and qualitative performance, more knowledge is needed concerning the effects of forest operations on general biodiversity and different species, recreational preferences and trade-offs between different management regimes.

#### Expected Achievements by 2030

By 2030, Europe has further developed a comprehensive intra-EU database of primary resources on minerals and metals, and carried out the assessment of economic value for these identified resources.

**Biotic:** A new generation of resource inventory systems and flexible planning tools, enabling precise information on quantity and quality on local, regional and global scales, has evolved. New forest management and wood supply systems have improved the integration along value chains from forest to end-product, shortening lead times, increasing capital turnover, improving profitability of forest ownership and reducing environmental impacts. Small-scale private forest and land owners have been provided means to actively manage forests for wood production and other new services with the support of ICT tools.

The consequences of changing ownership structures for wood supply are better understood and this knowledge is used to advise on policy, reducing the negative impacts of these changes.

#### Expected Achievements by 2050

*Text to be developed*

By 2050, Europe has completed the inventory and classification of EU primary and secondary raw materials sources. In terms of exploration and inventory of mining resources, the database has been updated with the results of the 2nd and 3rd actions.

#### Required Research and Innovation Actions by 2030

**The abiotic and biotic sector**

1. Develop incentives for small-scale private forest and land owners to actively manage forests for wood production and other new services with the support of ICT tools that enable forecasting earning opportunities based on multiple options of forest management.
2. Develop new (or adapt existing) ICT solutions for new, smart and integrated transport and logistics systems from local and regional to global scale, including road trucks and multimodal transport solutions and technology
3. Investigate opportunities to increase capacity to transport low weight loads, while reducing the number of modals in transit and minimising environmental impacts on the soil, CO2 emissions, and energy consumption.
4. Foster training and capacity building of technicians for efficient management of logistics with innovative ICT solutions
5. Create standardisation systems for new, smart and integrated transport and logistics systems that also include indicators on sustainability and security, with a view to ensuring fair competition among traditional players and fostering implementation of such systems by SMEs.
6. Develop tools and measurement techniques that provide the industry with fair and correct information on different raw material alternatives and their economic, social and environmental considerations
7. H. Monitor emotional and fact-based societal perceptions of forest management practices, reused and recycled wood-based products, bio- and nanotechnology and its derived products.

**The abiotic sector**

1. Develop concepts for long term successive land use planning for the whole life cycle of the extractive operation.
2. Compile a modern database and economic assessment of primary and secondary resources across the EU *(to be continued until 2050)*

**The biotic sector**

1. Assess and develop scenarios for the availability and valorisation of forest-based raw materials in Europe in the global context under changing economic, social and climatic conditions.
2. Develop new inventory techniques for determining quantity, quality, dimensions and specific properties of forest resources.
3. Explore new space technologies to generate forest-related data, including high resolution space data, LIDAR-, IR- and radar data and to present those data layers together with relevant trade and climate change data
4. Improve sustainable short-term rotation management schemes for woody biomass production.
5. Develop flexible planning and decision support tools for obtaining sustainable wood supply from multipurpose forest landscapes.
6. Monitor emotional and fact-based societal perceptions of forest management practices, reused and recycled wood-based products, bio- and nanotechnology and its derived products.
7. Develop efficient technology for harvesting, extraction, processing and sorting terrain transportation to road side, including new ICT-systems, novel forest machine felling head measurement technology and models for processing characterisation, semi- and full automation support for increased harvesting and log processing efficiency.
8. Develop efficient technology for low soil impact, minimize rutting and increase accessibility to wood resources where soil bearing capacity is limited.

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#### Required Research and Innovation Actions by 2050

1. Complete modern database and economic assessment of primary and secondary resources across the EU

# PRIORITY 2: Resource efficient processing, refining and converting of raw materials

Activities to foster resource efficiency in processing, refining and converting of primary and secondary raw materials have resulted in a continued relative reduction in energy and water use and material input in the European raw material industries per tonne of material produced. However, the deployment of new technologies with in-built artificial intelligence and the big data will not only contribute to a more resource efficient production but allow for adjusting raw material input to a new era of customised manufacturing imposed by conscious customers and shifting market demands. Meanwhile, the circular economy will open up new business models for production side streams that become valuable raw materials for new products and reuse, paving the way for integrated industrial symbiosis that benefit from old and new value chains.

The EU’s roadmap for a resource-efficient Europe outlines a vision of structural and technological changes that are required to move towards a decreased concentration of carbon-dioxide and other green-house gases, resource-efficient and climate-resilient economy by 2050. To achieve these goals requires further technological innovation that can reduce material input into production and optimise the use of raw materials allowing for consumer-driven flexibility which will be enabled by automation and data-driven production sites. Moreover, developing integrated technologies for industrial symbiosis will help develop and integrate new and old value chains, creating conditions for cross-sectorial collaboration following the principles of the circular economy.

**Key research and innovation areas**

2.1 Development of resource-efficient processing, refining and converting technologies

2.2 Minimisation and valorisation of production residues

## 2.1 Development of resource efficient processing, refining and converting technologies

#### Rationale

Satisfying demanding consumers demands a transition to agile production and mass customization tailored to market demands. This in turn requires more flexible, on-demand production and assembly processes. At the same time, automated processes and big data solutions, such as planted sensors, will help control and adjust material flows and steer processes towards a new phase of customization-orientated production that is not only focused on increasing productivity and efficiency but on agility and responsiveness. The development of new innovative technologies to foster resource efficient material use will continue to play a key role by offering many opportunities to improve raw material quality and functionalities while saving on energy and water throughout processing, refining and converting.

#### State of play

Thanks to the deployment of advanced technologies improving the purity of raw materials, today’s mills and plants produce more from smaller amounts of raw materials, which also reduces the environmental footprint. Nevertheless, resource-efficient processes imply integrated production and processing chains that supply resources ‘on demand’-basis.

**Pulp and paper production** is characterised by highly-efficient production facilities with high capital costs. Breakthrough innovations in wood and fibre industry technologies, pulping, water recycling, energy recovery and process control may also require changes in demanded and preferable wood and fibre deliveries.

In **mineral processing**, the major difficulties encountered to supply in-demand, critical metals to the market are cost and energy efficient beneficiation/pre-processing and metallurgical processing which enables the refining of such elements in addition to the base metals metallurgical cost. Moreover, a majority of the unrecoverable losses lie today at macro-scale, and will expand tomorrow since primary ore bodies particles size will tend to shift towards smaller particles.

In **metallurgy and metals recovery,** securing raw materials supply requires tackling the complete value chain, particularly the relation between a resource and a process. Because primary or secondary resources tend to continue to become more complex and lower grade, while environmental requirements drastically change, the associated metallurgical processes will continue to raise more technical challenges.

#### Expected achievements by 2030

New resource-efficient production technologies have significantly helped achieve the targets set in the EU’s strategy for a low carbon economy. More flexible production units, to respond to future consumer needs and with a highly skilled workforce, will have made an important contribution to higher production efficiency. Deployment of technologies to reduce heavy industry emissions have contributed to the reduction of energy and water demand and carbon footprint. The positive impact will result in lighter tailor-made products, lower demand for raw materials and additives, increased by-product valorisation and an overall reduction in waste.

#### Expected achievements by 2050

In customer-driven manufacturing, optimised production and material flows have been achieved through the use of big data applications. Seamless data exchange along the value chain from exploration and harvesting to the production of material efficient products contribute to reduced resource consumption and supplying markets and suppliers with customised products.

#### Required Research and Innovation Actions by 2030

**The abiotic and biotic sector**

1. Develop production technologies of both primary and secondary raw material resources that satisfy more demanding processor’s and manufacturers’ specifications to comply with changing standards and legislation
2. Invent functional surface treatment to enable bulk material reduction, enhance durability or extend life-cycle
3. Develop enhanced separation and fractionation technologies for material components to enable their optimal use for adapted processes and products, especially in dry conditions to reduce water consumption
4. Develop production technologies with significantly optimised energy efficiency and energy management throughout production
5. Use information and communications technology (ICT) to meet highest process efficiency, improving material flow, resource efficiency, process stability, machine productivity, etc.
6. Enhance the microbiological stability of industrial water systems
7. Develop innovative energy-efficient screening, classification and de-watering technology
8. Apply new product design approaches from less material and energy input
9. Develop purification in hydrometallurgy as well as pyrometallurgy and wood-based deliveries

**The abiotic sector**

1. Create innovativecrushing and grinding technologies, the most energy-intensive parts of mineral processing, to reduce energy use

**The biotic sector**

1. Analyse the possibilities for primary refining processes at forest harvesting to fully utilise the great variability of forest wood and fibre properties
2. Develop production technologies with significantly optimised energy efficiency and energy management in defibration of wood, drying of sawn timber, production of panels, paper and board or in transportation.

#### Required Research and Innovation Actions by 2050

*To be developed*

## 2.2 Valorisation of production residues

#### Rationale

A near-to-zero-waste concept aims at minimising waste and by-products throughout the production process. Turning residues into “feed” materials across industrial value chains help create fully-integrated industrial symbiosis across the raw material sectors. This results in novel business opportunities building on new and old value chains that enhance cross-sectorial cooperation following the principles of a circular economy. Such strategies for industrial symbiosis, in which waste or by-products of one industrial process is re-inserted as a resource in another, contributes in turn to boosting the competitiveness of European industries globally.

#### State of Play

Already today, residues and side-streams are more and more being treated as by-products demonstrating examples of how processing residues can be turned into added value with advanced functionalities to substitute fossil-based materials.

During the processing, refining and converting of raw materials within **the abiotic value chain,** typically by-products, side-streams or wastes are produced simultaneously. There is a huge potential to reduce waste or increase the value of current low value side-streams or by-products.

**In the biotic value chain**, an increased use of residues from raw material processing, for example bark, chips, sawdust, to make wood panels or pulp have significantly increased resource efficiency since 1990. Nevertheless, further progress is essential – including new possibilities for extraction and utilization of forest based materials also including branches, needles and stumps. These biotic resources are partly needed for soil rutting protection, nutrient balances, but still a considerable amount 10-25% of the entire stem volume (depending on region, species etc.) might be utilized as additional raw material sources from forestry.

#### Expected achievements by 2030

Integrated production of primary and secondary raw materials surpasses the traditional division of the value chains resulting in improved input of residues as a source of raw materials into another sector. Innovative industrial symbiosis that integrate various value-chains and create new raw material sources have been put into practice involving multiple stakeholders and emerging value chains.

Innovative technologies for secondary processing have been developed to make waste a resource, residues as an asset, including critical raw materials. Raw materials and nutrients can be recovered from wastewater streams, such as phosphorus, or from tailings or industrial side streams, including the utilisation of the rest of the residues as well, for example, in the forms of aluminosilicate-based products on the other industrial or consumer sector. The developed new and improved technologies shall be used for piloting the reprocessing of suitable old tailings and end-of-life material streams.

#### Expected achievements by 2050

Highly integrated, circular, flexible and modular concept of factory is developed and deployed, permitting the industrial symbiosis within and between biotic and abiotic sectors.

The production of waste is minimised or valorised by the recovery of valuable elements from complex and low-grade feedstocks combined with technologies for residual matrix valorisation, while providing safe sinks for toxic remnants in inert slags, sludges and aggregates.

#### Required Research and Innovation Actions by 2030

**The abiotic and biotic sector**

1. Develop value-added products from by-products and extracted components from process water
2. Develop additive manufacturing in production, for example 3D-printing, injection moulding etc.
3. Develop concepts for turning the wastewater treatment plant into an energy-producing entity
4. Generate knowledge of useful or harmful chemical compounds / innovation for the removal of chemicals, inks, additives etc.
5. Invent new concepts for the re-use of treated water, for example, industrial symbiosis.
6. Recovery of valuable substances from (sewage) slags such as Phosphorus
7. Research dust confinement and analysis techniques

**The abiotic sector**

1. Develop hydrometallurgical processes for low-grade and non-conventional ore deposits, for example complex polymetallic ores.
2. Enhance biometallurgical processes (extraction and concentration of metals)
3. Improve treatment of complex ores and secondary material streams
4. Optimise metal yields and energy efficiency of metallurgical processes
5. Develop thermodynamics of complex metal mixes
6. Research into CO2 sequestration and industrial symbiosis in order to find solutions for processing of carbonaceous minerals
7. Develop high energy/intensity processes (plasma technology, electro-beam, etc.)
8. Develop new separation technologies (hydrometallurgy and/or pyrometallurgy or combination of both)
9. Improve recovery of energy from slags
10. Research into CO2 sequestration and industrial symbiosis in order to find solutions for processing of carbonaceous minerals
11. Develop life cycle analyses (LCA) of products taking entire value chains into the system boundaries.

#### Required Research and Innovation Actions by 2050

*To be developed*

# 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

## 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 valueof 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 detectionwill determine theperformance of the recovered materials in their new application. Innovative solutions in these recycling streamsare 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 efficienciesand 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[[4]](#footnote-4) 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%[[5]](#footnote-5). 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 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[[6]](#footnote-6).

#### 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**

1. 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.
2. 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.
3. 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.
4. 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).
5. 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
6. Explore waste and recycling technologies that provide effective sinks for (eco-)toxic substances and materials in order to avoid reuse in a circular economy
7. Develop innovative technologies for the value-added use of separated and extracted components from wastewater treatment.
8. Research the potential of disruptive technologies and innovation and their impact on product’s EOL phase.
9. 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.
10. 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.).
11. Develop new logistic concepts and manufacturing technologies for improved utilization of C&DW.
12. Develop new certification and traceability methods for construction products in order to have a better control of demolition waste.

**The abiotic sector**

1. 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.
2. 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.
3. 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.
4. Recover gallium and germanium from fly-ashes on an economic scale.
5. 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.
6. Development of energy-efficient collection, cleaning, sorting and refining technologies.
7. 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**

1. 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.
2. 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.
3. 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.
4. 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.
5. Research the treatment and pre-treatment of recycling stock, including enzymatic processes, for pulp and paper for recycling and other wood-based products.
6. Develop ways to strengthen fibres so that they become more resistant to recycling loops
7. 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.
8. Develop non-destructive wood property measurement techniques and systems that allow for traceability of individual wood objects, for optimized resource utilization.
9. 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.
10. Develop prototypes of new materials containing construction wastes for other application with relative characterization

#### Research and innovation activities by 2050

1. 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[[7]](#footnote-7). 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 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**

1. Provide new and cost-efficient techniques to allow for chain of custody recyclability assessment.
2. Devise recommendations on technical design for disassembly, recycling and detection.
3. 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.
4. 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.
5. 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.
6. Investigate additive manufacturing technologies improving durability and functionality of products as well as streamlining design for easy maintenance, easy upgradability and modularity.
7. Develop incentives for new added value technology solutions and business concept models that allow for expanding the use of recycled and recovered raw materials.
8. 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.
9. Develop technologies for improving recycling quality and reducing contamination, recycling of composites, alloys, elements, fibres, flexible recycling process also adapted to small scales.
10. Small scale and mobile technologies to face decreasing volumes of consumer goods and of the concentrations of critical and valuable materials they contain.
11. 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.
12. Develop design concepts for ensuring recyclability of hybrid products and technologies for the separation and reuse of used material components.
13. Develop prototypes of new materials containing construction wastes for other application with relative characterization

**The abiotic sector**

1. Develop mechanical and chemical processing of complex end-of-life products without

dissipation of technology metals.

1. Improve the reusability and recyclability of construction materials
2. Improve the reusability and recyclability of wood composites
3. 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.
4. Develop and establish design criteria to ensure the full recyclability of packaging materials, in particular barrier layers and embedded electronics.
5. Develop product design approaches for the reusability of packaging or easy-to-dismantle building components to facilitate optimal sorting and recycling.

**The biotic sector**

1. 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”[[8]](#footnote-8) 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

#### Research and Innovation Activities by 2030

**The abiotic and biotic sector**

1. Create knowledge base on environmental performance indicators and performance rating systems for materials and buildings.
2. 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 CO2 sequestration in forest-based raw materials and wood-based products.

#### Research and innovation activities by 2050

1. Devise cross-sectoral business concepts, build proper infrastructure and develop suitable technologies to operate ‘urban mines’.

# PRIORITY 4: Raw materials in new products and applications

By 2050, a greater demand for new complex materials, including alloys, hybrid and composite materials, nanomaterials, is foreseen, that are expected to confer enhanced performances to advanced products in response to consumers demand. The substitution of scarce or energy-intensive materials can be in turn achieved by developing applications with an equivalent technology that does not rely on the same raw materials.

New advanced products include the emerging biobased solutions and applications that will be key enablers in the shift from fossil-fuels towards a sustainable low-carbon society. The trend highlights the development of new material properties for new products and greater flexibility in manufacturing and production contributing a wiser use of raw materials through product design.

**Key research and innovation areas**

4.1 Substitution of (critical) raw materials in new technology & energy applications

4.2 Development of new biobased products

4.3 Development of new material applications & new markets

## 4.1 Substitution of critical raw materials

#### Rationale

The substitution of critical raw materials is strongly related to the secured supply of raw materials in the EU. R&D results are expected to heavily impact on the substitution of critical raw materials, particularly in the following sectors:

**In transportation**, the main driver is energy efficiency, related to the issues of weight reduction and electrification. Weight reduction can be achieved by replacing traditional raw materials with composites and alloys, i.e. multi-materials. Electrification of cars pushes the market to develop new battery storage systems and/or more durable hydrogen fuel cells, as well as to permit higher density electric motors to be used.

**Electronics and consumer goods** are becoming smarter and more complex, most of them including more than 50 raw materials to provide all functionalities. The technology lifetime of these appliances is substantially shorter than the lifetime of raw materials. Product replacement is mostly triggered by next generation products, providing high level of performances for the same or less cost. Use of critical and expensive raw materials in these products is continuously reduced by down-gauging, ICT technology, new production technologies, for example circuit board printing and thin film, using less raw material quantity for same or better functional performance.

**Energy sector** is seeking for a continuous growth of volume of advanced materials, permitting to generate, convert and transport energy at the highest efficiency and with minimum losses. This has a particular emphasis when dealing with renewable, as is the case of photovoltaic energy. The higher efficiency demanded from the process industry is related to the intensive use of **catalysts**, optimizing the use of raw materials and intermediates, limiting the use of polluting or noxious chemicals, and increasing yield in a sustainable way.

In the **construction sector**, there is an increased demand for advanced materials with new (multi) functionalities as (self) monitoring, self-healing as well as ability to improve the durability, the energy efficiency, the health and comfort of environments.

The European **medical and diagnostics sectors** heavily rely on critical raw material resources to sustain the level of excellence worldwide. Therefore, either a reliable source of raw materials or a high value substitution need to be guaranteed.

#### State of play

As of 2017, the list of critical raw materials (CRM) counts 20 materials[[9]](#footnote-9). The methodology for assessing criticality has been defined in 2010, and since 2011 every three years the list is updated, on the basis of the technical and market demand of materials, as well as the socio-economic world conditions. It is understood that there will always be critical materials, needed by the industry for their technological functions. The list of such material will evolve with time and with the industrial priorities. The efforts of substitution will be concentrated on ensuring access to the relevant function, enabled by the critical materials, overcoming the risk of shortage.

Currently, substitution projects are lacking propulsion to cross the “valley of death” and to bring the results of R&D activities into products solving the issues of criticality addressed. The aspects of strategic relevance and long-term vision of such projects usually clash against the difficulties in terms of entrepreneurship to sponsor long term investments, as well as the inherent risk in substituting something that risks becoming obsolete by natural product cycle.

#### Expected achievements by 2030

A number of (critical) raw materials, such as rare earth elements (REE) and platinum group metals (PGMs), are substituted in consumer goods or in large energy generation and storage facilities, permitting this strategic segment to reduce the risks of disruption. For example, the volume of supply of neodymium (Nd) and dysprosium (Dy) for magnets has been reduced by 40% with respect to the levels of 2015 while the volume of supply of cobalt (Co) for batteries has been reduced by 50% with respect to the levels of 2015. Despite the higher volume of goods consumed, the EU has achieved the reduction of net import of critical raw materials by more than 25%. LINKS

#### Expected achievements by 2050

Substitution projects for critical raw materials are implemented with success leading to a global process of consumer products re-thinking, if not a substantial revolution. The way energy is produced, transformed, stored and transported is involved as well, generating a common understanding of the problem and a common front from the side of consumers. Innovative generation of products has encompassed the current concepts, and a holistic process starting from the conception phase, drive the phases of manufacturing and consumption. Aspects of awareness, training and education are fundamental to ensure the penetration of the substitution efforts, in particular whenever the substitute is not in an optimal cost-performance position.

#### Required Research and Innovation Activities by 2030

1. Substitute critical raw materials by composition, including the application in energy, ICT, alloys; demonstration and implementation projects covering the following subjects:
   1. Demonstrate the energy conversion, for example in wind turbines, electric motors, by exploiting permanent magnets with more than 30% reduced content of critical raw materials
   2. Demonstrate the use of photovoltaic materials with reduced content of critical raw materials remaining below 30% of current standards.
   3. Create energy storage which is enabled through a low content of critical raw materials, with 50% reduction with respect to current state-of-the-art batteries, and with improved energy density.
   4. Explore new materials, such as ceramics, composites, independent on the super-alloying elements of critical raw materials that provide advantages in terms of density, thermal resistance, toughness and mechanical performances.
2. Substitute critical raw materials by integrated design and whole value chain approach, leading to more sustainable and high added value materials and value chains for new productions through the demonstration of:
   1. New materials embedded into new products by design
   2. Smart solutions and new business models associated to a material revolution leading to EU independency from critical raw materials

#### Required Research and Innovation Activities by 2050

*To be developed*

## 4.2 Development of new biobased products

#### Rationale

Building a circular bioeconomy in Europe requires significant investment in the development of new and sustainable alternatives to current fossil-based materials. Converted from renewable biological resources, biobased products and applications cover several sectors ranging from the forest industry to chemicals and biocomposites, cross-cutting the society and human needs in our everyday life.

The rich and complex chemical and physical composition of wood, bark and other parts of a tree, contain great potential for a broad range of innovative properties to be exploited and incorporated in future wood-based products. Advanced properties improving the application of biobased products include light-weight, biodegradability, composite properties as well as functioning as natural thermal and electrical insulators. New products from cellulose, lignin or hemicellulose and resins will become valuable resources in a world that craves more raw materials.

#### State of play

Today, cellulose pulp and sawn wood are the primary products of the forest-based industries. These are further refined into a spectrum of products, ranging from commodity to consumer products. Yet, many new applications are under development or are yet to be ready for mass deployment and commercialisation. Clear trends are however visible, as the development of new non-wood fibre sources, bio-composites, printed electronics, micro-fibrillated cellulose, exciting new packaging concepts, new paper qualities. Rubber-based products are essential for the automotive industry and speciality products. However, research is needed to determine optimal or “good enough” purity levels in materials that offer solutions with higher strength, lower resistance, lighter weight, increased control of light spectrum, and greater chemical reactivity, among other benefits, for new applications.

#### Expected achievements by 2030

Several new biobased products and applications have been commercialised and are largely used as substitutes for materials from non-renewable sources. Applications ranging from clothing to skyscrapers have been developed creating green growth and jobs. Wood and fibre-based building constructions, furnishing and storing considerable amounts of carbon and have increased substitution of many fossil-based products. Additive manufacturing has substantially improved production processes through the integration of enhanced material properties, such as connectivity, anti-counterfeiting and water-repellence to existing wood-based products. The durability of wood has been upgraded using specific additives and conditioning processes. Advanced biocomposites used for instance in automotive parts, new construction materials have been introduced while bioplasticswill bring novel solutions to the packaging sector. Meanwhile new wood-based products with self-healing properties will significantly reduce maintenance needs.

#### Expected achievements by 2050

The biobased products have taken over the markets providing highest possible value added from primary and secondary raw materials. The renewable and recyclable products satisfy the demands of the 2050 consumer and society. Wood-based construction materials have helped the sector achieve an 80 % CO2 emission reduction by providing a carbon storage while replacing other energy and carbon-intensive construction materials. Packaging plays even a greater role in society offering advanced and smart solutions for smaller- and larger-sized packaging based on advanced design and nanotechnology while producing less waste. Investment in research, development and innovation has led to the full deployment of new biorefinery processes to produce textiles, chemicals and new materials, including composites and pharmaceutical products, for customized market needs.[[10]](#footnote-10)

#### Required Research and Innovation Actions by 2030

1. Develop value-added applications of extracted wood polymers, nanofibrils, lignin, xylan, pulp fibres and paper, for example, for carbon fibres or ultra-lightweight composites.
2. Adapt biomimetic design approaches and, in general, the integration of recycling-oriented product design criteria into the development processes of new biobased products.
3. Improve existing, long-lasting adhesive systems for flake boards, medium density fibre board (MDF), oriented strand board (OSB) and plywood boards as well as for glulam by using ingredients which are not based on fossil resources and are free of emissions (e.g. long-lasting adhesive systems based on renewable resources).
4. Develop new weatherproof panels, fibre-based insulation materials and wood-polymer composites suitable for exterior use.
5. Improve the performance of packages and wood- or fibre-based packaging materials, not limited to mechanical properties but including, for example, resistance to moisture and microbial contamination, in particular prevention of microbial activity in food packages with the help of shielding gases or active substances.
6. Integrate sensor and information systems in packaging materials – printing applications using functional inks and tags carrying anti-counterfeiting information.
7. Develop smart and intelligent features for applications based on printed electronics or printed biosensors, e.g. in packaging.
8. Develop enhanced lightweight and hi-tech products in the future that will be moulded, extruded or assembled from wood components.

#### Required Research and Innovation Actions by 2050

*To be developed*

## 4.3 Raw materials for hybrid and composite materials and applications

#### Rationale

The product manufacturing has evolved from the mass production of the past, when a small range of products were designed, to a job-shop manufacturing of the present, where customers can select the most preferable and suitable product for their need from within a wide range of products. High performance, high quality and low cost are the key aspects together with as short as possible product development time. Moreover, recently the life-cycle energetic cost of the product, its durability and the possibility of recycling plays a more and more crucial role.

To satisfy the demands of customers, the use of sophisticated optimization techniques is rapidly growing with the development of nano-structured and nano-functionalised materials. At the same time, the development of new manufacturing processes, such as additive manufacturing responses to the requirements for more light-weight materials, biomimicry with a view to customizing the needs in medical implants, for example.

Composites combine different materials in order to create a new material with improved properties and performance. Composites could include both biotic and abiotic material sheets in a wide range of applications from transportation to construction, ranging from metal composites and reinforced plastics such as fibre-reinforced polymers applied in aeronautics and automotive to concrete and mortars panels used in building and infrastructures.

Hybrid materials are composites including two materials mixed at the microscopic scale – nanometric or molecular level – in order to create more homogenous or even new material properties.

#### State of play

The fabrication of composite structures and products is evolving from manually labour intensive to automated manufacturing methods, including the use of intelligent feedback monitoring systems and robotic technology. Developments in automated integration of the pre-form fabrication and moulding make already available technologies more desirable for economics and productivity.

#### Expected achievements by 2030

Composites are widely employed in building materials and in consumers goods, giving rise to a revolution in product design. New types of composites concepts can be derived from hybrid construction systems, combining the best properties of biotic and abiotic materials in high performance, prefabricated and fully finished modular elements and structures for housing. Miniaturisation and nanotechnology development are key enablers for advanced (neuro)bionics, for which biocompatibility is likely to be much more of an issue than design for recycling.

Harmonised data exchange along the supply chain and between stakeholders will increase the performance of the industry. Business models will be based on consumer and end-user perceptions. Interactive communication will play an important role.

#### Expected achievements by 2050

The technology adaptions such as additive manufacturing, biomimicry of materials, self-healing of materials have substituted many linear economy solutions. Large diffusion on nano-structured and nano-functionalised materials have been achieved.

#### Required Research and Innovation Actions by 2030

1. Develop biocompatibility, miniaturization and nanotechnology for applications in advanced (neuro)bionics.
2. Create business models to open up a raw material pool and conversion of traditional mills to new markets.
3. Develop cost-effective integrated prefabricated building systems including hybrid and composite materials, timber and other biobased construction materials.
4. Further develop the multi-material concepts and multi-functionality for wood and wood-based products in interior fittings, furniture and everyday products.
5. Develop indoor system solutions that promote flexibility regarding changes in use (ageing inhabitants, changing family structures, growing children).
6. Develop cheap, more durable and resistant composites, alloys and multilayer materials that enable the extension of product life time
7. Develop construction products that can ensure the comfort and health of environments for occupants.
8. Develop monitoring systems to improve the durability of construction products.
9. Develop construction products that can be dismantled and modularised considering also the reversibility of the manufacture, in order to collect raw materials during maintenance or product end-of-life without (or with small) further chemical/physical/mechanical operations
10. Explore new building materials installation and fixation systems focused on the development of new industrialized construction methodologies.
11. Develop applications that allow the use of secondary materials with higher concentrations of impurities or degraded molecules, thus offering new market opportunities for recyclates.

#### Required Research and Innovation Actions by 2050

*To be developed*

1. Polymers, glass, composites, ceramics, metal scraps, (non-energy, non-agricultural raw materials processing residues and side-streams e.g. tailings, sludges, slags, dusts, scales…) [↑](#footnote-ref-1)
2. <http://ec.europa.eu/eurostat/web/environmental-data-centre-on-natural-resources/natural-resources/raw-materials> [↑](#footnote-ref-2)
3. The concept of precision forestry takes advantage of best available knowledge and applied ICT. Standardised production records (thinning and final cut) from Cut-To-Length (CTL) harvesters can be intensively utilised for planning of next harvesting operation (thinning records and selection harvesting records) and silviculture operations for next generation trees (Final cut operation records for soil fertility, but rot and other potential pest and insect problems, mobility problems etc.)). [↑](#footnote-ref-3)
4. http://www.cepi.org/system/files/public/documents/publications/recycling/2016/FinalMonitoringReport2015.pdf [↑](#footnote-ref-4)
5. http://ec.europa.eu/environment/waste/construction\_demolition.htm [↑](#footnote-ref-5)
6. Target laid by the EU Waste Framework Directive for 2020 <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0098> [↑](#footnote-ref-6)
7. <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)* [↑](#footnote-ref-7)
8. The concept of urban mining refers to the extraction, processing and exploitation of materials found in landfills of urban regions LINK [↑](#footnote-ref-8)
9. Or element groups: heavy rare earth (RE), light RE, platinum group metals (PGMs) [↑](#footnote-ref-9)
10. Unfold the future – 2050 Roadmap to a low-carbon bioeconomy, CEPI, 2011 <http://www.cepi.org/system/files/public/documents/publications/environment/2011/roadmap_final-20111110-00019-01-E.pdf> [↑](#footnote-ref-10)