VERAM

Vision and roadmap for European raw materials

RM Research Roadmap drafts

Report on Deliverable 5.1

July 2017

D5.1 – RM Research Roadmap drafts

WP5 – Creating the raw materials roadmap 2050

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1.1	12/07/2017	Heini Hyrkkö (FTP) Johan Elvnert (FTP)	First completed draft version
1.2	12/07/2017	Patrick Wall (ETP SMR)	Review, corrections & merging annex 1
1.3	1/06/2018	Heini Hyrkkö (FTP) Johan Elvnert (FTP) Patrick Wall (ETP SMR)	Clarifications incorporated into Executive Summary and Annex 1 following feedback from Project Officer

Disclaimer

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List of Acronyms

EIP RM	European Innovation Partnership on Raw Materials
ETP	European Technology Platform
EU	European Union
RIA	Research and Innovation Area
RM	Raw Materials
VERAM	Vision and Roadmap for European Raw Materials
WP	Work Package

Executive summary

All the activities carried out by the Work Package 5 (WP5) directly contributes to the final objective of the project by establishing a common European Research and Innovation Roadmap 2050 for Raw Materials. By the mid-term phase, coordinated efforts and input provided by the VERAM WP5 partners representing the abiotic and biotic raw material sectors have so far resulted in delivering **Task 5.1: Gathering the material and defining the themes for the research roadmap** and **Task 5.2: Making the research roadmap for raw materials** and, as a result, **Deliverable 5.1 (D5.1) RM Research Roadmap drafts**.

During the first period of the project, a step-by-step approach towards developing the Roadmap drafts 2030 and 2050 was established.

1) In the beginning of the process, the abiotic and biotic partners identified four common research and innovation pillars consisting of a number of research and innovation areas (RIAs) of specific importance to the raw material community. The pillar structure together with the RIAs provided a framework for the Roadmap building on the objectives of the EIP RM while anticipating and responding to arising societal challenges, market-driven needs and technological developments expected by 2050.
2) Setting the scene prior to the actual roadmapping, preliminary input from stakeholders was collected through the first stakeholders' consultation with a view to anticipating common future visions, needs and challenges relevant for the raw material sectors.
3) Composing a Roadmap editorial team bringing together abiotic and biotic partners contributing to planning, drafting and revising the Roadmap drafts.
4) Developing a Roadmap flatplan with the aim to anticipate the final structure and to provide a framework for future revision.

Overall, the drafting process demonstrates a shared effort of the abiotic and biotic sectors towards the achievement of the Roadmap 2050. By the end of May 2017 marking the mid-term of the project, the editorial team has provided input and feedback on the Roadmap draft version 3.5 resulting in **D5.1: RM Research Roadmap drafts**. As next steps, the Experts' Workshop was organised with a view of collecting stakeholders' feedback on the current draft. The workshop will be followed by a broader stakeholders' consultation.

The current Roadmap draft version 3.5 can be found in annex to this report. The draft should not be considered as a completed document but a work in progress, in view of producing a finalised roadmap by the end of the project that will be submitted as Deliverable 5.2: RM Research Roadmap and recommendations.

1. Introduction

The Research and Innovation Roadmap for European Raw Materials forms a key deliverable of the VERAM project. With a view to achieving the final objectives, the first phase of the project contributed to laying the foundation for the final Roadmap and thus meeting the interim objective of producing **D5.1: RM Research Roadmap drafts.**

The roadmapping process can be roughly divided into three phases. The first phase aggregates existing material, viewpoints and knowledge together in order to create a mapping of current state-of-the-art. A key activity in this phase is the definition of a key framework and focus points for the Roadmap. This acts as a basis for the second phase, where the actual roadmaps are created. The third phase, during the second half of the project, elaborates the roadmaps and determines key recommendations. This is then all captured and presented in the final Roadmap document.

This deliverable report shortly describes the activities resulting from the first two phases of the roadmapping. The actual key deliverable, a Roadmap draft can be found attached to this report.

2. Description of the deliverable

The Deliverable 5.1 consists of a Roadmap draft resulting from coordinated input provided by the abiotic and biotic partners through the work carried out by the Roadmap editorial team.

Defining the key themes for the Roadmap

The first phase of the roadmapping consisted of gathering relevant materials and defining the key themes for the Roadmap. In the beginning, the leading project partners of the abiotic and biotic sectors identified four common research and innovation pillars consisting of a number of research and innovation areas (RIAs) of specific importance to the raw material community. The pillar structure together with the RIAs provided a framework for the Roadmap building on the objectives of the EIP RM while redirecting the objectives of the RM sectors to address future societal challenges, market-driven needs and technological developments expected to arise by 2050. Each RIA comprises a set of concise research and innovation activities demonstrating concrete steps towards achieving the objectives of the Roadmap by 2030 and 2050. In support of the development of the Roadmap, the Roadmap pillar and RIA structure has been incorporated into the VERAM portal[1], a dedicated database showcasing the current state of play in the area of the research and innovation funding dedicated to the raw material sector.

[1] The VERAM portal has been created and further developed as part of the VERAM Work Package 3 resulting in Deliverable 3.5 – Web based information handling portal submitted in August 2016.

MS7 1st Stakeholder Consultation

Setting the scene prior to launching the Roadmap process, preliminary input from stakeholders was collected through the first stakeholders' consultation with a view to anticipating common future visions, needs and challenges relevant for the raw material sectors.

Consultation on the future vision for European raw materials
1. *Envisioned futures: How do you envision your sector / value chain / professional position in the future? Name three phenomena that will bring about the biggest change?*
2. *Achieving my future reality: What could you do to achieve this vision and how would you describe your role in achieving it?*
3. *Innovation pathways: What kind of technological or scientific breakthroughs (perhaps developed by other stakeholders) would be required to achieve your vision in 2050?*
4. *Risks: What are the risks associated by your sector that hinder from achieving the envisioned future and which strategies should be applied to mitigate these risks?*

Figure 1. The questions of the 1st stakeholder consultation

The online consultation was carried out in September 2016 targeting stakeholder groups and funding networks across the relevant raw material sectors and value chains. The results were analysed and then presented and discussed at a stakeholders' workshop in October 2016 (*for further information about the workshop, see the WP3 deliverables*).

As a result, over 40 stakeholders from the biotic and abiotic sectors participated in the consultation by sharing their views on the envisioned future of raw materials and thereby contributed to the preparatory work of the roadmapping. Overall, meeting the objectives of **MS7: 1st Stakeholder Consultation** laid the foundation for the work towards developing the actual Roadmap commencing in the following phase.

Making the Research Roadmap for raw materials

Soon after the stakeholders' consultation the Roadmap process was launched. As a WP5 leader, FTP set up a Roadmap editorial team composed of the WP5 partners taking over the tasks in relation to planning, drafting and revising of the Roadmap. Bringing together 12 partners from the abiotic and biotic sectors, the Roadmap editorial team held its first meeting in December 2016 agreeing to a draft structure of the roadmap. Based on the discussions, the first drafts were produced between the editorial team meetings resulting in the draft Roadmap version 1.0.

The 2nd VERAM Roadmap editorial team meeting took place at the end of January 2017. Following the input provided during the first drafting period, the partners revised and redefined the initially suggested pillar structure with a view to better reflecting the value chain approach. As a result, the first drafts were synchronised with the revised Roadmap pillar framework resulting in the draft Roadmap version 2.0.

As next steps, a Roadmap flatplan was developed in order to anticipate the final structure and to provide a framework for future revision. Building on the revised structure, FTP continued revising the draft Roadmap with the assistance of the editorial team members. By the end of May 2017 marking the mid-term of the project, the editorial team had provided feedback on the draft Roadmap 3.5 which contributed to delivering **Deliverable 5.1: RM Research Roadmap drafts**.

Framework for the Raw Materials Roadmap draft v.3.0
Pillar I: Fostering a sustainable RM supply to feed existing and new value chains
RIA 1.1 New exploration and harvesting technologies for sustainable supply
RIA 1.2 Mobilising an increased RM supply from EU sources
Pillar II: Resource efficient processing, refining and converting of raw materials
RIA 2.1 Development of resource efficient processing, refining and converting technologies
RIA 2.2 Valorisation of production residues
Pillar III: Maximising material closed loops by recycling consumer products, buildings and infrastructure
RIA 3.1 Increasing collection through efficient sorting, separation and detection
RIA 3.2 Recycling technologies adapted to complex, durable, miniaturised and material efficient products
RIA 3.3 Developing and integrating methods for assessing and optimising methodologies costs and benefits in recycling
Pillar IV: Raw materials in new products and applications
RIA 4.1 Substitution of critical raw materials
RIA 4.2 Development of new bio-based products
RIA 4.3 Raw materials for hybrid and composite materials and applications

Figure 2. The Pillars and RIAs of the draft Research and Innovation Roadmap

3. Conclusions

The draft Roadmap v.3.5 marks the mid-term of the project and the roadmapping process. As a next step carried out by the WP5, the draft Roadmap was exposed to experts' views and feedback at a workshop organised by FTP together with ETP SMR and Cefic in June 2017. The workshop brought together over 60 experts from across the raw material sectors to discuss the current draft R&I activities and to provide their feedback on the Roadmap. Following up on the results of the workshop, a broader stakeholders' consultation will be launched paving the way for the final Roadmap.

Annex 1 – VERAM Research & Innovation ROADMAP 2050 (draft 3.5)

VERAM Research & Innovation ROADMAP 2050

Draft 3.5

A Sustainable and Competitive Future for EU Raw Materials

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Why a Raw Materials Research Roadmap?

Demographic changes, among others population growth in developing countries and ageing population in developed countries, combined 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. 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 EU is dependent on imports of many raw materials that are crucial for a strong European industrial base, an essential building block of the EU's growth and competitiveness. Even if some raw material sectors are less dependent on import, the raw materials markets are tightening everywhere, requiring new developments and innovations throughout the sectors and value chains. To secure a sustainable supply, Europe is therefore 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 long-term vision and roadmap to 2050 is crucial in order to achieve European economic growth and restructuring. Therefore, a more coordinated approach towards raw materials management will help reduce external supply dependency and lead to an efficient use of resources, improve the competitiveness of EU industry, and its environmental impact and eco-efficiency.

The mid- and long-term research roadmap ambition is to tap the full potential of primary and secondary raw materials and to boost the innovation capacity of the EU raw materials 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. This can only be done by gaining relevant knowledge about raw material value chains in Europe and if all the stakeholders, including the relevant authorities, raw materials and downstream industries, research communities and society work towards the same objectives.

European raw materials in today's economy and the scope of this Roadmap

VERAM investigates future fields of research and innovation for the European abiotic and biotic raw material sectors. The scope of VERAM covers non-energy, non-agricultural raw materials, including forest resources, wood, paper and natural rubber as well as minerals, metals and aggregates.

The abiotic value chain

This section will be further developed during the second part of the project, taking into account the input from the second stakeholders' consultation.

The biotic value chain

The European biotic raw material sector is in the heart of the bioeconomy allowing for replacing fossil-based with sustainable, renewable raw materials.

The forest-based sector is one of Europe's largest, and includes the woodworking, pulp and paper and printing industries, as well as forest owners. It sustainably manages forests covering 37 % of the EU's land area. The European forest-based sector can sustainably increase its primary wood production by at least 30 % compared to the level in 2010[1]. Forest tree breeding and improved silvicultural regimes and the foreseen medium term unavoidable climate change may add another 25-50 % sustainable increase in annual increment by 2050. In addition to the stem wood sources another 15-25 % biotic dry substance may be sustainably extracted from branches, needles, stumps and bark as raw material substances and/or bio-energy. All figures given include important environmental and recreational concern implying improved planning for utilisation of forest land and landscape, for raw materials, biodiversity, recreation, water protection and other ecosystem services.

However cost-efficient and value adding forest and industry technology including harvesting and logistic operations, planning and business models has to be further developed. This would strengthen the EU industrial base while adding around €100-150 billion in annual turnover to the EU economy. Recirculation and reuse of biotic raw materials might have similar impact on the raw material security of the EU economy. Together with light-weight and/or long lasting, carbon-sequestrating and resource efficient products and materials it can reduce the carbon footprint of many products to a fraction of what it is today.

[1] Approximately 60% of the current annual increment of stem wood is utilized from forests regarded as "Growing stock in forests available for wood supply" according to EUROSTAT 2017 [link].

The role of Raw Materials in the World 2050

The EU Raw Materials sectors need to foster a sustainable and competitive supply and use of raw materials to feed existing and new value chains, while ensuring base loads from EU resources, decreasing import dependencies and ensuring resilience of the EU industrial base through resource diversification.

- The raw materials sector is the backbone of a circular economy and main driver of a symbiotic industrial environment in Europe.

- European raw materials sustain the needs of people across the world. Biotic and abiotic raw materials are sourced sustainably through flexible, circular and knowledge-based systems that allow outstanding levels of customization and transparency throughout the value-chain.

- The EU raw materials sectors possess the know-how and technological capacity to adjust to the manifold innovations of upstream processes.

- The sectors embrace digitalisation and practical applications of digitisation in the sector. Traditional value chains will be revolutionised; Current processes will change radically and become data-driven. New business models will develop.

- The raw material sectors develop and implement improved and better adapted measurable scientifically based values/indicators/standards associated with sustainability through the whole value chain where needs have been identified using newly developed data management systems.

- As a result of a successful cross-sectoral collaboration, EU raw materials producers compete, complement and finds synergies with each other, which decreases import dependency and ensures the resilience of the EU industrial base through resource diversification.

- A long history of innovation leadership and entrepreneurial spirit attracts investments to Europe and secures the further development of the EU economy. Better access to raw materials will strengthen the EU economy, develop and reinforce its position of EU sourced primary- and secondary obtained RMs by decreasing import dependencies and ensuring base load supply trough diversification at source.

- Education and training is ever more important to maintain a competent and innovative work force

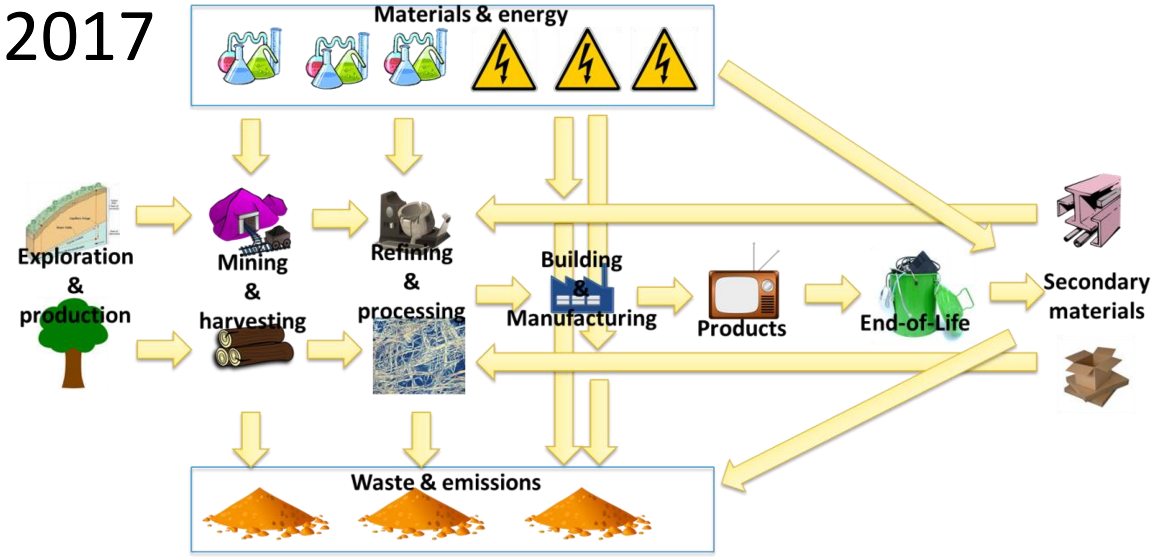

Figure 1: Raw material sector value chain in 2017

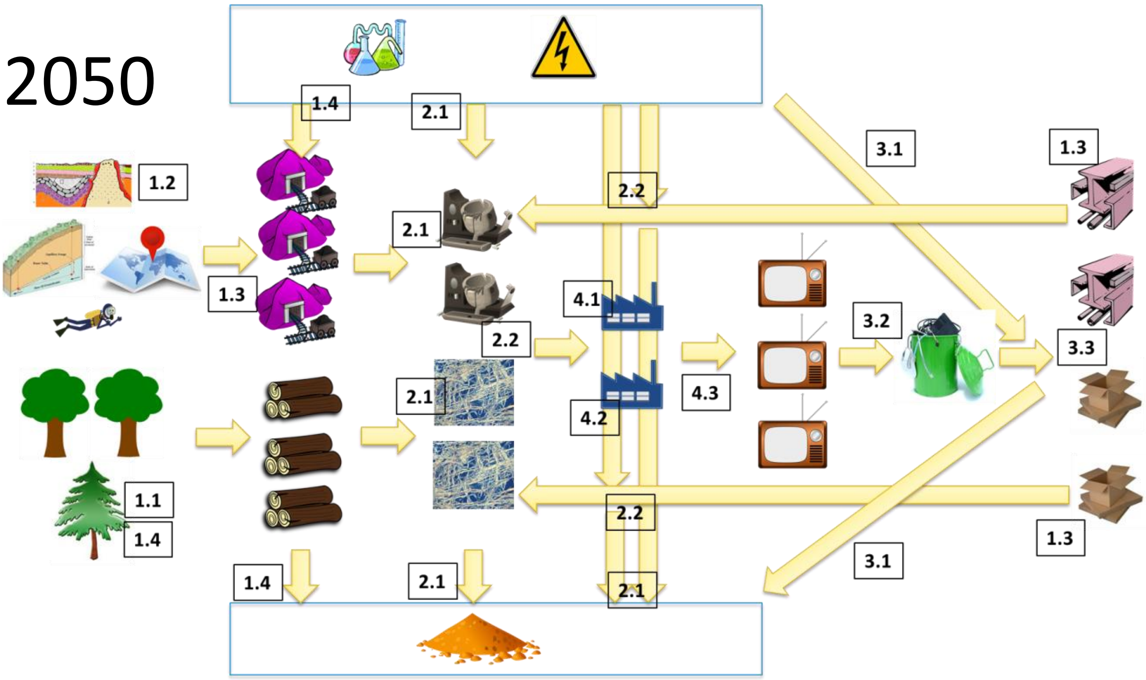

Figure 2: The outlook of the raw material sector value chain by 2050

The Structure of the Roadmap: 4 Pillars & 10 Research & Innovation Areas

Achieving the vision for sustainable and competitive supply of raw materials from Europe, as described in the Vision 2050, will require significant investment in research and innovation and partnership across the value chains. VERAM has led the biotic and abiotic sectors to defining shared overall objectives and strategic research and innovation activities that will help achieve these targets up until 2050.
Four key research and innovation pillars have been identified that will unlock the full potential of the European raw materials research and innovation building on the synergies of the abiotic and biotic raw materials sectors.

The VERAM Research and Innovation Roadmap 2050 defines a concrete set of research and innovation activities grouped under the four main pillars and 10 Research and Innovation Areas (RIAs) with a view to addressing the key challenges identified by the raw material stakeholders. Each RIA contains a list of concrete activities that need to be undertaken to achieve the overall 2050 targets.

THE VERAM ROADMAP STRUCTURE

Pillar I: Fostering a sustainable supply of raw materials to feed new and existing value chains

- 1.1 New exploration and harvesting technologies for a sustainable supply
- 1.2 Mobilising an increased supply of raw materials from EU sources

Pillar II: Resource efficienct processing, refining and converting of raw materials

- 2.1 Development of resource efficient processing, refining and converting technologies
- 2.2 Valorisation of production residues

Pillar III: Maximising material closed loops by recycling consumer products, buildings and infrastructure

- 3.1 Increasing collection through efficient sorting, separation and detection
- 3.2 Recycling technologies adapted to complex, durable, miniaturised and material efficient products
- 3.3 Developing and integrating methods for assessing and optimising cost and benefit in recycling

Pillar IV: Raw materials in new products and applications

- 4.1 Substitution of critical raw materials
- 4.2 Development of new biobased products
- 4.3 Raw materials for hybrid and composite materials and applications

Figure 3: The VERAM Roadmap: four Pillars and ten research and innovation areas

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

Mining, quarrying, timber logging and harvesting have been sustaining human civilisation with raw materials since history began. Also in the foreseeable future, the gathering of metals, minerals, aggregates and biomasses from natural sources will continue to be essential for 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.

Key research and innovation areas

1.1 New exploration and harvesting technologies for 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 sector: 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 sector: The intelligent and efficient production and use of biotic raw materials and the further development of precision forestry 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: 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: Contrary to what is happening in many other parts of the world, the EU's growing stock is increasing. In 2010, the annual increment of Europe's forests regarded as available for wood supply was 720 million m3, while the annual harvest was 427 million m3, equivalent to 59% of the increment[2]. Though variation is large, no EU country have harvested above the increment in forests available for wood supply[3]. Still, the supply of woody biomass is far from evident for economic reasons as well as environmental concerns. However, there is strong scientific evidence for a large mitigation effect by forest net-photosynthesis and the storage of carbon in standing wood as well as wood-based products. There is also strong scientific evidence for the possibility to grow and utilize wood from forests for several rotation periods (seed to harvest) without losses in wood productivity. However, there is need for more knowledge concerning effects on general biodiversity, effects of forest operations on different species, recreational preferences and trade-offs from different management regimes. But to make wood raw material economically available there is also need for increased operational efficiency getting increased value added, less waste, lower operational costs and reduced environmental loads.

[2] EUROSTAT 2017 [link]
[3] EUROSTAT 2017 [link]

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. New, partly and fully 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: Europe has further developed a comprehensive intra-EU database of primary resources (minerals and metals), and carried out the assessment of economic value for these identified resources. 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 have been implemented, as well as sensors in extraction and mine processing have been installed. Full automation and autonomous equipment is a reality. New mines are fully automated, existing mines have been upgraded with electrified machinery. Mining small deposits: 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, and waste and tailings handling (regarding land use and efficient utilisation of deposits).

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. Research and innovations 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. An important part of this has become possible by RIA on ICT and standardisation of production and forest information and GEO-data. This digitalizing revolution have made all forest machines closely integrated and coordinated with customers manufacturing processes.

Together with RIA for improved machine technology ICT-assistance have reduce 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 (after harvesting), enforcing and continuously recording the sustainability of all forest operations. 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

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.
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.

Required research and innovation actions by 2030

The abiotic and biotic sector

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

The abiotic sector

B. Improve geochemical and geophysical exploration methods and prospecting techniques with a view to increasing the resource diversity in Europe.
C. Enhance drill logging technologies to obtain more cost-efficient and more environmentally friendly exploration.
D. Reprocess current soil and residue samples using modern analytical techniques for higher recovery of old mine tailings and other deposits.
E. Improve systems to collect and predict ore-body information, including seam and grade definition
F. Investigate hydraulic hoisting technologies to reduce energy consumption on haulage
G. Explore technologies that enable alternative mining sources, including space mining, e.g. asteroid mining.
H. Develop technologies and methods that allow for exploring and extracting minerals from sea bed deposits, deep-sea mining and mining under special conditions
I. 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
J. Test new, and adapt conventional, design layouts and operations to suit automation to decrease the number of workers in quarries and mines
K. Develop configurable, open, integrated interactive planning systems using new ICT
L. Make data available across operations with a view to increase efficiency and safety
M. Investigate means to create stability of automated mining operations at greater depths.
N. Apply new improved health, safety technologies: electrification of haulage machinery for rough terrain

The biotic sector

O. Develop efficient ICT systems for precision quantification and characterisation of forest-based wood materials i.e. precision inventory
P. Develop efficient ICT systems for planning of precision deliveries to industry customers taking the entire value and supply chains and customers into consideration

Q. Apply ICT to develop precision forestry to enhance harvesting and silviculture operations for next generation trees
R. Develop intelligent forest operation systems and smart solutions for human-machine-terrain interactions.

Required research and innovation actions by 2050

This section will be further developed during the second part of the project, taking into account the input from the second stakeholders' consultation.

1.2 Mobilising an increased supply of raw material from EU sources

Rationale

Due to the increasingly deeper mines 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. Empty loads are a waste, and therefore, new transportation means and organisation are required.

For secondary resources collection, transportation and delivery of final recycled material/product to market is critical.

State of play

Currently most transportation is not electric and developing and introducing electric vehicles is not without challenges. Electrified train haulage of ore is also under development.

Expected achievements by 2030

By 2030 larger mines should 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.

Expected achievements by 2050

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.

There will be no more people underground or in the quarries themselves.

Smaller mines should have achieved a certain degree of automation.

Required research and innovation activities by 2030

The abiotic and biotic sector

A. 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.

B. 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

C. 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, CO_2 emissions, and energy consumption.

D. Foster training and capacity building of technicians for efficient management of logistics with innovative ICT solutions
E. Create standardisation systems for new, smart and integrated transport and logistics systems that also includes indicators on sustainability and security, with a view to ensuring fair competition among traditional players and fostering implementation of such systems by SMEs.
F. 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

The abiotic sector

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

The biotic sector

I. 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.
J. Develop new inventory techniques for determining quantity, quality, dimensions and specific properties of forest resources.
K. 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
L. Analyse and monitor changes in forest ownership and their implications for forest management, new opportunities and markets.
M. 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.
N. Assess the economic, social and environmental benefits and risks associated with the use of genetically-improved trees.
O. Improve sustainable short-term rotation management schemes for woody biomass production.
P. Develop flexible planning and decision support tools for obtaining sustainable wood supply from multipurpose forest landscapes.
Q. Monitor emotional and fact-based societal perceptions of forest management practices, reused and recycled wood-based products, bio- and nanotechnology and its derived products.
R. 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.
S. Develop efficient technology for low soil impact, minimize rutting and increase accessibility to wood resources where soil bearing capacity is limited.

Required research and innovation activities by 2050

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

PILLAR 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. Thanks to the deployment of advanced technologies that improve the purity of raw materials, today's mills and plants make more products/input from smaller amounts of raw materials, which also reduces the environmental footprint.

At the same time, increasingly, the circular economy opens 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 the material input into production and optimise raw materials purity or ability to store photosynthetically sequestrated carbon. Moreover, developing integrated technologies for industrial symbiosis will help develop and integrate new value chains, creating conditions for cross-sectorial collaboration following the principles of a 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

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

Rationale

Achieving resource efficient production will require novel and innovative technologies that optimise the use of valuable resources (materials, energy, water) in the raw materials industry. Innovative materials' processing, refining and converting technologies will help enhance and continuously determine raw materials quality and performance while maintaining or improving the functionalities. Increasing yields and raw materials recovery will allow for upgrading the resources and therefore can decrease other processes inputs as well as open up more resources to be processed.

Satisfying demanding consumers requires a transition to agile production for mass customization tailored to market requirements. This in turn requires more flexible production and assembly processes. Developing flexible, on-demand production stages that adjust the production for the demands of the markets.

State of play

Currently, raw materials production is delivering economically marketable materials using available processing refining and converting technologies There is not enough research focusing on achieving higher purity levels in materials providing solutions with higher strength, lower resistance, lighter weight, increased control of light spectrum, and greater chemical reactivity, among other benefits, for new applications. The implications for future recycling are also often not considered.

Pulp and paper production is characterised by highly-efficient production facilities with high capital costs. Improved resource efficiency of the biotic value chains' main processes depends on breakthrough innovations in characterising, processing/refining and sorting and transporting the best available wood material at the forest source by knowledge, ICT and new harvesting technology. In a longer perspective tree breeding and forest management can increase the value and quantity of wood and fibres for pulp and paper products. 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. Resource-efficient processes imply integrated production and processing chains that supply resources 'on demand'-basis.

In **mineral processing,** in-demand critical metals can often be found in low grade deposits or are a by-product of the processing of a major metal or rarely make up even 5% of collected secondary material. The major difficulties encountered to supply these metals to the market are cost and energy efficient beneficiation/pre-processing and metallurgical processing which enables the refining/recovery 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 size due to weathering and increase interlocking of ores.

In **metallurgy and metals recovery**, securing raw materials supply requires tackling the complete value chain, particularly the relation between a resource and a process. Numerous projects have failed because of the lack of an economic and sustainable process to concentrate and extract in-demand metals from resources. On the contrary, mediocre ore bodies are/have been operating mines thanks to an effective and appropriate metallurgical 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 production technologies will 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. 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. Wood and fibre-based building constructions, furnishing and storing considerable amounts of carbon and have increased substitution of many fossil based products.

Achieving seamless data exchange along the value chain from exploration down to the production of more complex, durable, miniaturized and material efficient products, fit for a circular economy. Implementation of modelling, monitoring and automation tools for processes has been achieved by 2030. Data-driven processes and production tools and systems include economic and environmental benefits/costs predictions and current detailed follow-up of resulting performance.

Demonstration of technologies to reduce heavy industry emissions, which would permit an overall reduction by 50% of the energy demand and 35% of the carbon footprint, as compared to 2010 emission values (High TRL, link and synergies with SPIRE).

Expected achievements by 2050

Optimised production and material flows have been achieved through the use of big data applications. Monitoring applications for optimised energy, material and water use contributes to reduced resource consumption and production costs.

Carbon Capture and Storage (CCS) and Carbon fixation is achieved, exploiting the CO_2 generated as feedstock for new streams, in which the biomass is evolved seamlessly.

- Integration of sustainable extraction and processing in-situ, including mineral processing operations underground.
- New technological processes for treatment and extraction of poly-metallic ores and materials;
- Quality control, sorting processes and transportation will be managed by mobile and distributed through sensor technologies both for primary and secondary resource management.
- Use of artificial intelligence (AI)

Required research and innovation activities by 2030

The abiotic and biotic sector

A. 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

B. Invent functional surface treatment to enable bulk material reduction, enhance durability or extend life-cycle
C. 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
D. Develop production technologies with significantly optimised energy efficiency and energy management throughout production
E. Use information and communications technology (ICT) to meet highest process efficiency, improving material flow, resource efficiency, process stability, machine productivity, etc.
F. Enhance the microbiological stability of industrial water systems
G. Develop innovative energy-efficient screening, classification and de-watering technology
H. Apply new product design approaches from less material and energy input
I. Develop purification in hydrometallurgy as well as pyrometallurgy and wood-based deliveries

The abiotic sector

J. Create innovative crushing and grinding technologies, the most energy-intensive parts of mineral processing, to reduce energy use

The biotic sector

K. Analyse the possibilities for primary refining processes at forest harvesting to fully utilise the great variability of forest wood and fibre properties
L. 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 activities by 2050

This section will be further developed during the second part of the project, taking into account the input from the second stakeholders' consultation.

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, can enhance companies' and Europe's competitiveness internationally.

The residues could be also seen as assets, novel raw materials for products, not just as means of industrial symbiosis. Currently residues or side streams are more and more treated as by-products and there are already substitution examples of how added value functionality of processes residue has substituted other materials.

State of play

Abiotic sector

During the processing, refining and converting of the raw materials 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 forest industry, 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 etc. 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 improving the valorisation of residues as a source of raw materials in another sector. Innovative industrial symbiosis that integrate various value-chains and create new raw material sources and thus new business models building on the concept of a circular economy have been put into practice involving multiple stakeholders. Novel industrial symbiosis concepts will strengthen the competitiveness of the European industries laying the ground for new, emerging value chains. The positive impact will result in increased by-product valorisation and an overall reduction in waste.

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, e.g. 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.

Minimisation and valorisation of production residues through optimising both metallurgical and constructive systems for the recovery of valuable elements from complex and low grade feedstocks and technologies for residual matrix valorisation, while providing safe sinks for toxic remnants. Minimisation of not-targeted outputs (e.g. as in in-seam and thin seam mining), or, when unavoidable, valorising these outputs (e.g. valorising, slags, sludges and aggregates).

Expected achievements by 2050

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

Required research and innovation activities by 2030

The abiotic and biotic sector

A. Develop value-added products from by-products and extracted components from process water
B. Develop additive manufacturing in production, for example 3D-printing, injection moulding etc.
C. Develop concepts for turning the wastewater treatment plant into an energy-producing entity
D. Generate knowledge of useful or harmful chemical compounds / innovation for the removal of chemicals, inks, additives etc.

The abiotic sector

E. Develop hydrometallurgical processes for low-grade and non-conventional ore deposits, for example complex polymetallic ores, etc., by prioritising deposits having the most promising potential
F. Enhance biometallurgical processes (extraction and concentration of metals)
G. Improve treatment of complex ores and secondary material streams
H. Optimise metal yields and energy efficiency of metallurgical processes
I. Develop thermodynamics of complex metal mixes
J. Research into CO2 sequestration and industrial symbiosis in order to find solutions for processing of carbonaceous minerals
K. Develop high energy/intensity processes (plasma technology, electro-beam, etc.)
L. Research dust confinement and analysis techniques
M. Define for each potential minor element (As, Hg, Se, Tl, Cd…) and association of minor elements, some
N. Develop new separation technologies (hydrometallurgy and/or pyrometallurgy or combination of both)
O. Improve recovery of energy from slags
P. Recovery of valuable substances from (sewage) slags such as Phosphorus
Q. Develop chemical, physical and mechanical characterisation of construction raw materials wastes

R. Research alternative energy sources that can be efficiently integrated in the building materials production plants

S. Invent new concepts for the re-use of treated water, for example, industrial symbiosis.

T. Research into CO2 sequestration and industrial symbiosis in order to find solutions for processing of carbonaceous minerals

S. Develop life cycle analyses (LCA) of products taking entire value chains into the system boundaries.

Required research and innovation activities by 2050

This section will be further developed during the second part of the project, taking into account the input from the second stakeholders' consultation.

PILLAR 3: Maximising material closed loops by recycling consumer products, buildings and infrastructure

With a view to manufacturing more material-efficient and durable consumer products, buildings and infrastructure, materials compositions tend to become more complex and diverse in the future. This trend is leveraged by the concept of circular economy embedded in the EU industrial policy, which is expected to trigger significant shifts in research and technology development to deploy strategies such as service economy[4], ecodesign, industrial symbiosis and waste prevention.

The circular economy further gives momentum for 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 also including possibilities to utilize energy from bio-based products. It is important to increase knowledge and develop tools for analysing best available alternatives concerning product quality, energy consumption, environmental loads from reuse and recycling (cleaning and separation processes).

From the very outset at the product design phase innovative actions 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

[4] Service economy: http://www.msidata.com/what-is-servitization

3.1 Increasing collection through 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 its turn also relieves the pressure of extracting and harvesting of resources from nature. However, complete recycling of products, parts and components with the goal to recover 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 when in low concentrations. Impurities, undesired elements (e.g. heavy metals) or degraded molecules (e.g. polymers, 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.

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 matter of 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 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]. 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.

The same needs to be achieved for the recycling of critical and essential raw materials, where significant deficits still exist, with low recycling rates for most technology metals, in many cases even being below 5%.

[5] http://ec.europa.eu/environment/waste/construction_demolition.htm

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].

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, thus 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 will have emerged and underpinned EU-based businesses.

Research and innovation activities by 2030

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).

The abiotic sector

E. 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),

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

photovoltaic, etc. and the interface optimisation, addressing interdependencies of the steps by using a systems approach.

F. 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 that allows substituting for primary raw materials.
G. 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 traditional and new applications.
H. Recover gallium and germanium from fly-ashes on an economic scale.
I. 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.

The biotic sector

J. 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.

The abiotic and biotic sector

K. 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
L. Explore waste and recycling technologies that provide effective sinks for (eco-)toxic substances and materials in order to avoid reuse in a circular economy
M. Develop innovative technologies for the value-added use of separated and extracted components from wastewater treatment.
N. Research the potential of disruptive technologies and innovation and their impact on product's EOL phase.
O. 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.

The abiotic sector

P. Development of material and energy-efficient collection, cleaning, sorting and refining technologies.

The biotic sector

Q. 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.
R. 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.

S. 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.
T. Research the treatment and pre-treatment of recycling stock, including enzymatic processes, for pulp and paper for recycling and other wood-based products.
U. Develop ways to strengthen fibres so that they become more resistant to recycling loops

The abiotic and biotic sector

V. 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.).
W. Develop new logistic concepts and manufacturing technologies for improved utilization of C&DW.
X. Develop new certification and traceability methods for construction products in order to have a better control and repeatability of the performances of the final product.
Y. Implement traceability projects for processed/refined/converted/finalised raw materials to ensure the quality tracking and sustainability measurement beyond the limits of OEM with a view to developing labels, standards and certifications for the whole value chain.

The abiotic sector

Z. 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

AA. 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.
BB. Develop non-destructive wood property measurement techniques and systems that allow for traceability of individual wood objects, for optimized resource utilization.
CC. 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.
DD. 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 the different recycling technologies is fundamental to gain tangible benefits globally. However, the landscape is challenging in all respects.

In the domain of product design and development, the recent trend of product miniaturisation 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 ensure a continuous flow of post-consumption materials. The shortening of both technology and product lifecycles and the introduction of disruptive technologies particularly in, e.g. photovoltaics, packaging, ICT, batteries, consumer and professional electronics, makes it difficult for the recycling industry to keep pace.

Finally, the circular economy concept requires product design to be planned according to a cradle-to-cradle approach, instead of the current linear method cradle-to-grave. Determine the proper flow of secondary raw materials within a market that rather demands primary raw materials for high added value applications is a case that needs to be better sorted out.

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.

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, e.g. in metallic-ceramic-bio composites. Challenges for recycling these types of products encompasses both traceability of, 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]. 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

[7] EUROSTAT (find the link)

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, e.g. organic light-emitting diode (OLED) and carbon-based materials (graphene, graphene oxide…), zeolites, polymers and silicon.

Expected achievements 2030

Secondary raw materials flow will have been mainstreamed into cross-sectorial systems, as a consequence of new technology developments 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 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 of the 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 optimise circular design and circularity of raw materials and critical raw materials with a view to increasing the levels of, or realise 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.

The abiotic sector

H. Develop mechanical and chemical processing of complex end-of-life products without
A. dissipation of technology metals.
I. Improve the reusability and recyclability of construction materials
J. Improve the reusability and recyclability of wood composites
K. 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.
L. Develop and establish design criteria to ensure the full recyclability of packaging materials, in particular barrier layers and embedded electronics.
M. Develop product design approaches for the reusability of packaging or easy-to-dismantle building components to facilitate optimal sorting and recycling.

The abiotic and biotic sector

N. 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.
O. Develop technologies for improving recycling quality and reducing contamination, recycling of composites, alloys, elements, fibres, flexible recycling process also adapted to small scales.
P. Small scale and mobile technologies to face decreasing volumes of consumer goods and of the concentrations of critical and valuable materials they contain.
Q. 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.

R. Develop design concepts for ensuring recyclability of hybrid products and technologies for the separation and reuse of used material components.
S. Develop prototypes of new materials containing construction wastes for other application with relative characterization
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 absolutely 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.

Also, 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, with a particular reference to 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”, meaning the extraction, processing and exploitation of materials found in landfills of urban regions, offers opportunities both for dedicated business models and to recover 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 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. Whole-product EOL performance recycling targets that uses economic, social and environmental indicators will have replaced weight-based material recycling targets.

Expected achievements by 2050

This section will be further developed during the second part of the project, taking into account the input from the second stakeholders’ consultation.

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’.

PILLAR 4: Raw materials in new products and applications

By 2050, a greater demand for new materials (e.g. metals and alloys, biobased products, hybrid and composite materials, nanomaterials) is foreseen, conferring enhanced performances to advanced products. In response to consumers demand. Criticality aspects are dealt in the constant effort to limit the impacts critical raw materials have on final products.

These new advanced products also include the emerging biobased solutions and applications that will play a major role in society enabling the shift from fossil-based towards renewable and biobased society. On the other hand, substitution of scarce and critical raw materials will be achieved by developing alternative materials in certain applications, or by replacing those applications with an equivalent technology that does not rely on the key raw materials.

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

Also in the relatively conservative **construction sector**, there is an increased need of 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 **medical, surgery and diagnostics sectors** heavily rely on critical RM resources (think of the NdFeB magnets in Magnetic resonance apparatuses): to sustain the European excellence role worldwide either a reliable source or a high value substitution need to be implemented.

State of play

As of 2017, the list of Critical Raw Materials (CRM) counts 20 materials (or element groups: Heavy RE, Light RE, PGM). 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 (PGM), 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 is reduced by 50% with respect to the levels of 2015. Despite the higher volume of goods consumed, the EU has achieved to reduce the net import of critical raw materials by more than 25%.

Expected achievements by 2050

Substitution projects for critical raw materials are implemented with success and lead to a global process of consumer products re-thinking, if not real 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 encompass the current concepts, and through a deep process starting in holistic way from the conception phase, drive the manufacture and use phases. Thanks to this, the best performances and highest levels of sustainability can be achieved, for the benefit of a global community of consumers.

Aspects of awareness, training and education are fundamental to ensure the capillary penetration of the substitution efforts, in particular whenever the substitute is not in an optimal cost-performance position. Given the long term implicit with substitution actions, the perceived impacts on the population, and the in-depth knowledge on the real benefits attained, are never to be forgotten.

Required research and innovation activities by 2030

A. Substitute critical raw materials by composition, including the application in energy, ICT, alloys; demonstration and implementation projects covering the following subjects:
    a. Demonstration of energy conversion (wind turbine, electric motor) exploiting permanent magnets having more than 30% reduced CRM contents
    b. Photovoltaic materials with rated reduced CRM contents below 30% current standard, demonstrating the functionality at no energy conversion reduction
    c. Energy storage, enabled through low CRM contents (50% reduction with respect to current SoA batteries) and at improved energy density
    d. Explore new materials (e.g. ceramics, composites…) not relying on the super-alloying elements of critical raw materials that provide advantages in terms of density, thermal resistance, toughness and mechanical performances

B. Substitute critical raw materials by integrated design and whole value chain approach, leading to more sustainable and high added value materials exploited in products Demonstration of the value chain for new products
   a. New materials embedded into new products by design
   b. Smart solutions and new business models associated to a material revolution leading to EU independency from CRM

Required research and innovation activities by 2050

This section will be further developed during the second part of the project, taking into account the input from the second stakeholders' consultation.

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.
Apart from fossil fuel based materials currently bio-based materials take advantage of photosynthesis for sequestration of carbon-dioxide. This makes a completely different situation and analyses when considering reuse, recycling, energy utilization and renewal by bio-products. High rates of forest utilization and increased forest growth can combine carbon sequestration in bio-based products, energy utilisation of currently sequestrated carbon instead of releasing fossil carbon (and increasing CO_2), while high growth rates in productive forests currently sequestrates more carbon than older less productive forests (big storage, but low or no current sequestration).

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. New products from, for example, nanocellulose, lignin or hemicellulose, can replace current fossil-based, non-renewable polymer or elastomer materials in various products and applications, including chemicals, composites, textiles, plastics, construction materials and as carbon fibre, to name a few. Adding new functions and enhanced properties to existing wood-based products, such as connectivity, anti-counterfeiting and water-repellence, will offer new ways to differentiate European production from global competition, with higher value and tailor-made solutions.

This shift from fossil-based products towards low-carbon, renewable resource has potential to fundamentally shake the future supply of raw materials globally. Supplying the markets with sustainable and competitive alternatives that are “made in Europe” will in turn help the EU improve the competitiveness of its industrial base and tackle major societal challenges related to the resource scarcity and climate change.

State of play

Today, 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, the potential of the material from renewable, biobased sources remains largely untapped. Many of the projected biobased applications are still under development in terms of a mass deployment and commercialisation. Clear trends are however visible, as the development of new non-wood fibre sources, bio-composites, printed electronics, microfibrilated cellulose, exciting new packaging concepts, new forms of paper used every day as well as cellulose from a host of new sources are in the loop.

Expected achievements by 2030

The EU circular economy policy has been widely anchored to promoting the use of renewable, biobased raw materials. Several biobased products and applications have been commercialised and are largely used as substitutes for materials from non-renewable sources. Advanced biobased products and applications ranging from wood-based textile fibres to biocomposites, from biochemicals to nanocellulose, have been developed creating green growth and jobs locally and regionally in all parts of Europe.

The durability of wood is improved by more than 100%, using specific additives and conditioning processes, leading to a better use of the natural resources. New products based on engineered wood (either surface processed, composite or bulk modified) are becoming available and permit the optimisation of use of high value renewable materials.

Traceability methods are effectively applied to wood materials and products leading to certification of the correct processes and fair resources exploitation.

Biomass fly ash is used in addition to common blast furnace slag, fly ash and silica fume, in the preparation of blended cement. Biomass fly ash is also used as a substitute of common aggregates in concrete to produce lightweight materials or in geotechnical applications.

Advanced biocomposites used, for example, for car parts, as well as new building materials have been introduced.
Bioplastics (derived either from native wood polymers or re-built from wood-based monomers like ´syngas´) will bring novel bio-solutions to the packaging sector.
Regenerated cellulose fibres have been used for decades to make textiles; the coming years will see further advances in this segment as in building materials.
Materials that react to stimuli such as electrical current, temperature fluctuations, or chemical compounds useful in a broad range of domains, such as wood preservation, healthcare, packaging and the media.
Advanced wood-based materials with innovative self-healing properties will reduce maintenance needs significantly.

Expected achievements by 2050

An integrated, circular, flexible and modular concept of factory is developed and deployed, permitting in seamless way the industrial symbiosis between biotic and abiotic material streams. Concept like Carbon Capture and Storage (CCS) and Carbon fixation is achieved, exploiting the CO_2 generated as feedstock for new biomass value chains.

Required research and innovation activities by 2030

A. Develop value-added applications of extracted wood polymers, nanofibrils, lignin, xylan, pulp fibres and paper, for example, for carbon fibres or ultra-lightweight composites.
B. Develop environmentally-friendly multifunctional varnishes and laser coatings with micro-encapsulations.
C. Adapt biomimetic design approaches and, in general, the integration of recycling-oriented product design criteria into the development processes of new biobased products.
D. 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. adhesive systems based on renewable resources).

E. Develop weatherproof panels, fibre-based insulation materials and wood-polymer composites suitable for exterior use.
F. Invent new textile fibre qualities based on cellulose for replacement of cotton fibres in textiles.
G. Improve existing, long-lasting adhesive systems for different kind of boards.
H. 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.
I. Enhance the material efficiency of packaging with, for example, new lightweight construction approaches.
J. Integrate sensor and information systems in packaging materials – printing applications using functional inks and tags carrying anti-counterfeiting information.
K. Explore the applicability of wood- and fibre-based material in medical applications.
L. Develop smart and intelligent features for applications based on printed electronics or printed biosensors, e.g. in packaging.
M. Look out for more lightweight and hi-tech products in the future that will be moulded, extruded or assembled from wood components.

Required research and innovation activities by 2050

This section will be further developed during the second part of the project, taking into account the input from the second stakeholders' consultation.

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 the costumer can select the most preferable and suitable product for his need in a wide range of products. High performance, high quality and low cost are the key aspects together with a product development time as short as possible. Moreover, recently the life-cycle energetic cost of the product, its durability and the possibility of recycling starts to be considered as a key requisite.

To satisfy all the foregoing aspects the use of sophisticated optimization techniques is rapidly growing with the development of nano-structured and nano-functionalised materials. Contemporarily, the development of new manufacturing processes, e.g. additive manufacturing is used when the challenging structures, light weight, biomimicry, customizing is needed e.g. in medical implants.

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 for example 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 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 the way things are designed. New types of composites concepts can be derived from hybrid construction systems, combining the best properties of biotic and non-biotic 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 sector performance. 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.

Required research and innovation activities by 2030

A. Develop biocompatibility, miniaturization and nanotechnology for applications in advanced (neuro)bionics.
B. Create business models based on opening up a raw material pool and conversion of traditional mills to new markets.
C. Develop cost-effective integrated prefabricated building systems including hybrid and composite materials, timber and other biobased construction materials.
D. Further develop the multi-material concepts and multi-functionality for wood and wood-based products in interior fittings, furniture and everyday products.
E. Develop indoor system solutions that promote flexibility regarding changes in use (ageing inhabitants, changing family structures, growing children).
F. Develop cheap, more durable and resistant composites, alloys and multilayer materials that enable the extension of product life time
G. Develop construction products that can ensure the comfort and health of environments for occupants.
H. Develop monitoring systems to improve the durability of construction products.
I. 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
J. Explore new building materials installation and fixation systems focused on the development of new industrialized construction methodologies.
K. 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 activities by 2050

This section will be further developed during the second part of the project, taking into account the input from the second stakeholders' consultation.

GLOSSARY

This section will be completed when the draft Roadmap is nearing completion during the second part of the project.

VERAM partners

EUROPEAN TECHNOLOGY PLATFORM
ON SUSTAINABLE MINERAL RESOURCES

Forest-based Sector
Technology Platform

cefic

vito
vision on technology

cnrs
dépasser les frontières

UNIVERSITÀ
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Business

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Projektträger Jülich
Forschungszentrum Jülich

RINA CONSULTING

VTT

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Contact us

This section will be completed when the draft Roadmap is nearing completion during the second part of the project.