Lombardy Roadmap for Research and Innovation on Circular Economy

R&I priorities enhancing Circular Economy in Lombardy

Executive Summary

The Lombardy Roadmap for Research and Innovation on Circular Economy intends to provide a framework for the development of a sustainable, low carbon, resource efficient and competitive strategy for the transition to a more circular economy in the Lombardy Region, under a smart specialization perspective. It represents a versatile cultural and technical reference that can stimulate the cooperation between public and private stakeholders with the aim to build strategic initiatives on circular economy. Based on the priorities of the roadmap, which are widely shared among regional stakeholders, private and public investors can cooperate to support emerging initiatives with financing instruments which include public administration incentives and innovative additional financing tools.

The elaboration of this roadmap started in 2019, seeking the challenge of the Lombardy's Smart Specialization Strategy (in brief S3) to give answers and, where possible, anticipate market changes, to address new social and cultural needs.

In particular, after the third update of Lombardy S3, formalised in DGR X/7450/2017, Circular Economy has been introduced as one of the main drivers to foster the development of mature into emerging industry in the Region. Accordingly, the Roadmap has been recognised as an opportunity to define a structured strategy to boost circular economy in the region starting from the needs and the priorities collaboratively pointed out by diverse regional stakeholders.

Going beyond the regional dimension, the document is well suited as reaction of Lombardy Region Government to the climate and environmental world challenges settled by ONU Agenda 2030 and to drive the sustainable transition on the territory. It is also the result of the long-lasting effort of Lombardy Region to cooperate with other Italian and European Regions in the definition of cooperation strategies which reinforce regional competitiveness by exploiting synergies and complementarities to achieve wider critical mass for global competition (for example in the "4 Motors of Europe", "Vanguard Initiative", "S3 Platforms on Smart Specialization" of the European Commission). Thus, the implementation of roadmap priorities leads to the reinforcement of inter-regional cooperation for the establishment of new European value chains.

Moreover, the roadmap includes the lesson learnt from the Covid-19 emergency that is generating tremendous impacts globally and, in particular in Lombardy Region. Such a crisis showed that research and innovation, coupled with the flexibility and entrepreneurial vocation of companies, can be the major response to face the challenges of this type of disruptive unpredictable events. Circular economy can play an important role in these situations and the roadmap highlights some specific priorities to be pursued to make regional system more robust, resilient, and faster in the economy restarting phase.

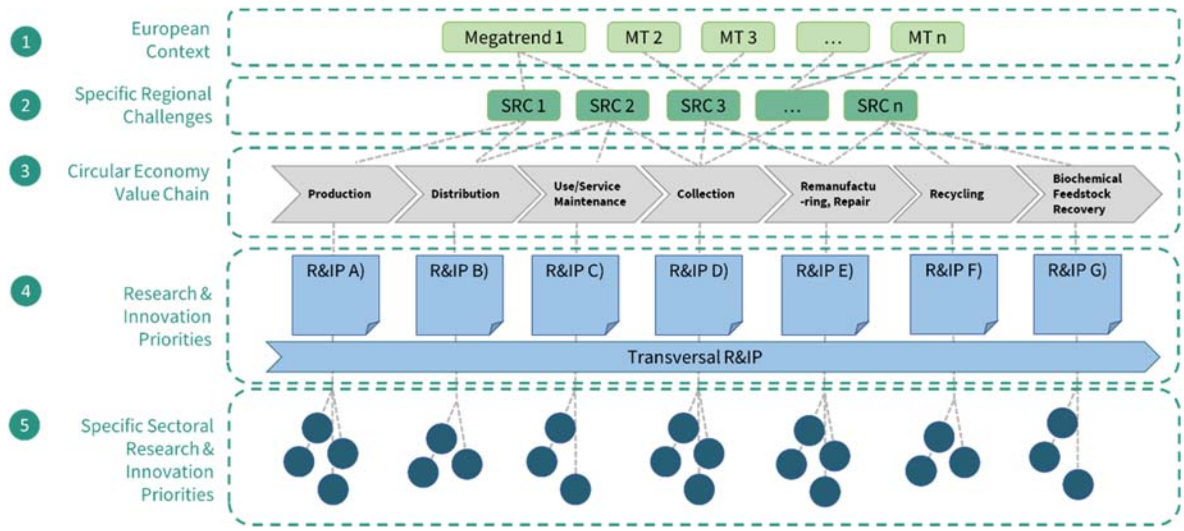
The document is structured in 3 main sections. While **Chapter 1** and **Chapter 2** are providing, respectively, an overview of the European and National context, and the Lombardy Region vision and challenges related to Circular Economy, the core part of the document is reported in **Chapter 3,** where Research and Innovation Priorities have been described together with the details of the methodology implemented for their identification. In this chapter, the relevance of such priorities in relation to the post-Covid19 emergency and, more in general, to the setup of more robust and resilient systems is also presented.

More in details, **Chapter 1** illustrates the new institutional context raised at European and national level. The European panorama is driven by the adoption of the European Green Deal Investment Plan aimed at accelerating the transition from a linear to a circular economy and at defining sustainable products and process policies. It will set minimum requirements to prevent environmentally harmful products from being placed in the EU market and identify options to prioritise reuse and repair before recycling. The Plan specifically emphasises sectors such as for example textiles, construction, electronics and plastics, etc. Regional circular economy priorities for these sectors are reported in the detail in **Section 3.II.**

At national level, Italy defined an institutional framework oriented to a new industrial policy aimed at increasing the competitiveness of “Made in Italy”, rethinking the way of doing business and consuming in a more sustainable and innovative way.
Accordingly, the budget law for 2020 contains some first measures for the "Green Deal", with the establishment of a fund for public investments (€ 4.24 billion for the period 2020 - 2023), intended to support innovative projects and investment programs with high environmental sustainability. Investments for the circular economy will be supported, as well as for the decarbonisation of the economy, urban regeneration, sustainable tourism, adaptation and mitigation of the risks deriving from climate change. The definition of these projects will be supported by the system of the National Technology Clusters which, in turn, include as members the Regional Technology Clusters. Thus, this document, which was realized in close cooperation with the Lombardy Technology Clusters as organizations supporting the regional governance, is supposed to significantly influence national policies, being Lombardy the first Region in terms of contribution to Italian Manufacturing volume and performance.
Lombardy Region is following the path of sustainable development reacting through its own legislative framework and supporting the measures targeting new market opportunities and emerging social needs for a smarter and safer territory. The **Chapter 2** lists the main regional strategic documents which allowed the design and implementation of the various operational programs, that assigned high priority to research and innovation on sustainability. They are the result of a deep synergy and alignment of the two Directorates General (DG Research, Innovation, Universities, Export and Internationalisation and DG Environment and Climate). More in details, the main programming documents are: the Regional Development Program - PRS (2018-2023); the Law “Lombardy is Research and Innovation”; the “Three-Year Strategic Plan for Research, Innovation and Technology Transfer”, and the “Smart Specialisation Strategy of Lombardy Region”.
Finally, Chapter 2 introduces the collaborative process followed by Lombardi Region and its stakeholders for the elaboration of the Roadmap for Research and Innovation on Circular Economy. This roadmapping initiative, activated by Lombardy Region as a cross-sectorial action involving multiple directorates and stakeholders, was launched by DG Research with the need to complement the S3 with transversal key approaches. The Roadmapping Group

was led and coordinated by DG Research, AFIL – Lombardy Intelligent Factory Association (the regional technology Cluster represented regional Advanced Manufacturing) and Finlombarda, the regional finance in-house company. Representatives of the 9 Lombardy Technological Cluster[1] participated to the roadmapping process have represented the priorities of their specialization areas and invited also their key stakeholders (companies, universities and research bodies) to suggest new or confirm the identified priorities. Thus, the definition of the Regional Circular Economy Roadmap is based on relevant inter-cluster cooperation process. In parallel, Lombardy Region launched a public consultation in October/November 2019, asking all regional stakeholders and civil society to propose shared paths for sustainable development to be integrated as input in the definition of "Sustainable Development Strategy". The survey registered 2300 participants (of which the 76% were individuals, 9% businesses, 8% public organizations, 5% third sector and 2% research bodies) and Circular Economy was one of the main topics proposed by respondents.

Chapter 3 describes in detail the methodology implemented for the definition of regional R&I priorities related to circular economy. As reported in the figure below, it consisted in a mixed top-down/bottom-up approach which was adapted from the already tested and consolidated approach developed by the Italian National Technology Cluster on Intelligent Factory, in cooperation with AFIL - Lombardy Intelligent Factory Association, and applied for the definition of the national Roadmap on Intelligent Manufacturing[2]. Research and innovation priorities were described with reference to the Circular Economy Value Chain Model entailing all lifecycle phases, from production to recycling.



Roadmapping Model

[1] AFIL – Associazione Fabbrica Intelligente Lombardia, CATAL – Cluster Alta Tecnologia Agrofood Lombardia, CLM – Lombardy Mobility Cluster, LE2C – Lombardy Energy Cleantech Cluster, LGCA – Lombardy Green Chemistry Association, Lombardy Lifesciences Cluster Association, Lombardy Aerospace Cluster, SCC – Smart Cities and Communitites, TAV – Tecnologie e Ambienti di vita

[2] Roadmap per la Ricerca e Innovazione Fabbrica Intelligente: https://www.fabbricaintelligente.it/roadmap-fabbrica-intelligente-industria-4-0/

According to this methodology, the R&I priorities were identified combining specific sectorial economy challenges deriving from the regional smart specialization (bottom-up approach) with the broad international and European megatrends and research directions (top down approach). The Roadmap considers the 7 Specialization Areas of Lombard's S3 (Aerospace, Agro-food, Eco-industry, Creative and cultural industries, Advanced manufacturing and Smart Mobility), highlighting the cross-sectoral potential of Circular Economy topic.

The resulting set of Research and Innovation priorities is summarised in the following table and are described in detail in the roadmap explaining motivations and technical challenges.

<table>
<tr><th>A. Production</th><th>B. Distribution</th></tr>
<tr><td>• Design for Circular Economy
• Circular Production Processes
• Enabling traceability in product and processes
• New Cross-Sectorial Business Models for Circular Economy
• Support to Circular Economy Oriented Production</td><td>• Establishment of Synergies Among Forward and Reverse Logistics
• Development of Market/Pricing Strategies to Increase the Willingness to Buy of Sustainable Products
• Exploitation of Local Production-Distribution-Consumption Networks
• Circular Economy Driven Public/Private Procurement</td></tr>
<tr><th>C. Use and Service</th><th>D. Collection</th></tr>
<tr><td>• Product Life-Cycle Extension
• Product-Service System</td><td>• Reverse Logistics
• Citizens engagement and incentives</td></tr>
<tr><th>E. Remanufacturing / Repair</th><th>F. Recycling</th></tr>
<tr><td>• Innovative Remanufacturing Technologies
• Distributed and Flexible Remanufacturing Networks</td><td>• Innovative technologies for sorting and recycling</td></tr>
<tr><th colspan="2">G. Biochemical Feedstock Recovery</th></tr>
<tr><td colspan="2">• Development of New Biotechnologies
• Valorise bio-waste to support the transition from fossil based to bio-based processes</td></tr>
</table>

The set of R&I Priorities is complemented with "Boundary conditions and barriers for Circular Economy" in *Legislation and Regulation, Piloting and demonstration infrastructures, Education and skills, Awareness and culture* and *Ecosystem building.* In these areas, a set of additional priorities are addressed for the establishment of Circular Economy, which are transversal to the thematic priorities and are necessary enablers for any Circular Economy implementation strategy. For them, recommendations and envisaged strategic actions to be implemented by diverse stakeholders are suggested (policy makers, industrial associations, universities and research bodies, companies, Clusters).

In conclusion, two **Annexes** are included in the document to report in details specific R&I priorities in the targeted sectors, complemented with numerical data highlighting the relevance of those sectors for Lombardy Economy and their Circular Economy potential. Such an information allows to appreciate the importance of circular economy for the sectors of regional specialization, to concretely estimate the impact of circular transformation in the Region and, especially, to engage stakeholders at large scale in the verticalization of circular economy solutions that will be developed by addressing roadmap priorities, that are horizontal to the sectors.

This roadmap will also contribute to the definition of the Smart Specialization Strategy of the Lombardy Region 2021-2027, within which the achieved results in terms of Circular Economy will also be valued.

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Preface

The circular economy is gaining growing attention as a potential way for our society to increase prosperity, while reducing demands on finite raw materials and minimising negative externalities. Such a transition requires a systemic approach, which entails moving beyond incremental improvements to the existing model as well as developing new collaboration mechanisms.[3]

Sustainable development is a political, economic, social, cultural revolution that will not only concern the achievement of environmental targets by nation, region, city, but will change the way of understanding the economy and finance, will stimulate the growth of businesses and market development will design a new welfare paradigm and influence the educational and cultural models of citizens and communities.

In this context, circular economy offers a promising alternative strategy for industrial development and job creation to the traditional manufacturing-led growth pathway. With the right enabling conditions, the circular economy could provide new opportunities for economic diversification, value creation and skills development.

Lombardy Region intents to boost circular economy concept at the heart of its economy, exploiting both a technology push and a market driven approach. The Lombardy Roadmap on Research and Innovation for Circular Economy Roadmap (briefly, Roadmap) is one of the main results of a significant cultural and decision-making leap. The government has activated cross-sectorial actions involving multiple Directorates and regional stakeholders in a wide participative and collaborative process.

[3] Ellen MacArthur Foundation (2016): "The New Plastics Economy: Rethinking the future of plastics"

CHAPTER 1 - European and National context

1.I Extracts from EU Regulation

The transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised, is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy. Such transition is the opportunity to transform our economy and generate new and sustainable competitive advantages for Europe.[4]

Circular Economy encourages economic, environmental and social sustainability and business competitiveness in the long term. It can also help to:

- Preserve resources – including those that are increasingly scarce, or subject to price fluctuation.
- Save costs for European industries.
- Unlock new business opportunities.
- Build a new generation of innovative, resource-efficient European businesses – making and exporting clean products and services around the globe.
- Create local low and high-skilled jobs.
- Create opportunities for social integration and cohesion.

Actions at EU level can drive investments, create a level playing field, and remove obstacles stemming from European legislation or its inadequate enforcement. Actions on the circular economy therefore ties in closely with key EU priorities, including jobs and growth, the investment agenda, climate and energy, the social agenda and industrial innovation, and with global efforts on sustainable development.

On 2nd December 2015, the European Commission (EC) put forward a package to support the EU's transition to a circular economy. On 4th March 2019, the Commission reported on the complete execution of this plan, with all 54 actions included delivered or being implemented. This will contribute to boost Europe's competitiveness, modernise its economy and industry to create jobs, protect the environment and generate sustainable growth. The identified actions within **European Action Plan** are meant to make implementation clear and simple, promote economic incentives and improve extended producer responsibility schemes,

[4] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Closing the loop - An EU action plan for the Circular Economy (Brussels, 2.12.2015 COM (2015) 614 final)

to unlock the growth and jobs potential of the circular economy. They also support the circular economy in each step of the value chain – from production to consumption, repair and remanufacturing, waste management, and secondary raw materials that are fed back into the economy with a focus on different sectors (e.g. plastic, food waste, critical raw materials, construction and demolition, biomass and bio-based materials),
Among the measures presented in the EU Action Plan:

- Eco-design work plan 2015-2017 and request to European standardisation organisations to develop standards on material efficiency for setting future Eco-design requirements on durability, reparability and recyclability of products.
- Establishing an open, pan-European network of technological infrastructures for SMEs to integrate advanced manufacturing technologies into their production processes.
- Action on Green Public Procurement: enhanced integration of circular economy requirements, support to higher uptake including through training schemes, reinforcing its use in Commission procurement and EU funds.
- Support to Member States and regions to strengthen innovation for the circular economy through smart specialisation strategies.
- Assessment of the possibility of launching a platform together with the EIB and national banks to support the financing of the circular economy, etc.

The action plan focusses on action at EU level with high added value. Making the circular economy a reality will however require long-term involvement at all levels, from Member States, regions and cities, to businesses and citizens. With this statement, Member States are invited to play their full part in EU action, integrating and complementing it with national action.
The circular economy will also need to develop globally. Increased policy coherence in internal and external EU action in this field are mutually reinforcing and essential for the implementation of global commitments taken by the Union and by EU Member States, notably the **U.N. 2030 Agenda for Sustainable Development** and the G7 Alliance on Resource Efficiency. The EU Action Plan is instrumental in reaching the Sustainable Development Goals (SDGs) by 2030, in particular Goal 12 of ensuring sustainable consumption and production patterns.

In order to address climate change and economic inequality, turning the problems into opportunities in all areas, European Commission launched the package called **"*Green Deal*".** The Green Deal is the 1,000-billion-euro green investment plan for the next ten years, approved on the 15th January by the European Parliament. The plan which, in line with the provisions of the EU budget 2021-2017, provides that at least 25% of European funds are destined for green projects - has obtained the go-ahead from the European Parliament, which says it is ready to modify any legislative reform while to achieve the goals set.

The European Green Deal highlights the potential of a circular economy for new economic activities and jobs. The Circular Economy Monitoring Framework already shows that 4 million

people work in circular economy related fields, a 6% increase from 2012. These activities generated almost EUR 147 billion in value added in 2016.
Strategy that firstly establishes a rigorous roadmap to make the EU economy sustainable, indicating actions to stimulate the efficient use of resources, thanks to the transition to a circular and clean economy, halting climate change, putting an end to the loss of biodiversity and reduce pollution.

In the Communication on the European Green Deal, the European Commission committed to the adoption of a new **Circular Economy Action Plan**[5] to accelerate and continue the transition towards a circular economy.
The action plan was adopted together with the **EU Industrial Strategy**[6] in order to mobilise the industrial sector and all the value chains towards a model of sustainable and inclusive growth, ensuring efficient and clean resource cycles. Starting from the Industrial Strategy, for the EC Circular Economy competes directly to achieve the industrial transformation.
The new action plan foresees the lifecycle of products and materials to ensure a sustainable use of resources and tackle resource-intensive sectors (e.g. textiles, construction, electronics, and plastics). The new Circular Economy Action presents measures to:

- Make sustainable products the norm in the EU;
- Empower consumers and public buyers;
- Focus on the sectors that use most resources and where the potential for circularity is high such as: electronics and ICT; batteries and vehicles; packaging; plastics; textiles; construction and buildings; food; water and nutrients;
- Ensure less waste;
- Make circularity work for people, regions and cities,
- Lead global efforts on circular economy.

It aims to speed up the transition away from a linear economy and "will include a sustainable products policy, to boost design, production and marketing of sustainable products." It sets minimum requirements to prevent environmentally harmful products from being placed in the EU market and identify options to prioritise reuse and repair before recycling. The plan includes also measures to empower consumers to contribute to the circular economy. One of these measures is to provide them with reliable, verifiable and comparable information on products' sustainability features and tackle false green claims.

[5] Communication from the Commission to the European Parliament, the Council, the European Economic And Social Committee and the Committee of the Regions "A new Circular Economy Action Plan For a cleaner and more competitive Europe" COM/2020/98 final (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN)

[6] Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions "A New Industrial Strategy for Europe" - Brussels, 10.3.2020 COM (2020) 102 final

The new action plan fosters a well-functioning and integrated internal market for secondary raw materials to ensure that they are safe, competitively priced and reliable. Opportunities of closing loops for biological materials are considered too.

In both documents, Industrial Strategy and Circular Economy Action Plan, Research and Innovation is the “way” “*to learn, adapt and if necessary, reset the way of doing things to allow to move forward. The mindset should shift from risk averse to failure tolerant. This needs to be reflected across the board and innovation should be embedded in the policy making. As part of the work on better regulation and strategic foresight, it will ensure that policies are innovation-conducive*”[7].

1.II Extracts from National regulation

Following the 2030 Agenda, the **Italian Strategy for Sustainable Development** shapes a new vision towards a circular, low-emission economy, resilient to climate impacts and to other global changes endangering local communities, prioritising the fight against biodiversity loss, alteration of the fundamental biogeochemical cycles (carbon, nitrogen, phosphorus) and land-use change.
Italy is working, together with the European Union and its Member States, to define a common framework for addressing and reflecting the challenges of the 2030 Agenda. In this context, the EU Green Deal provides the main reference for Member States in setting their internal strategic objectives.

At national level the Italian government with the National law approved on 12 December 2019, n. 141 (in G.U. 13/12/2019, n. 292) established a specific fund to support investments in environmental sustainability aimed at promoting the transition to the circular economy. Moreover, the Budget Law for 2020 foresees a considerable public investment plan supporting the development of a Green Deal. The initiative encourages the development of sustainable companies and projects through two new investment funds. The main goal is to activate urban regeneration and energy conversion projects and to encourage the use of renewable sources, as well as the issue of green government bonds, the "green bonds". The Ministry of Economy and Finance may also intervene, through the granting of one or more guarantees, in order to support specific investment programs, also in public-private partnerships, aimed at realizing economically sustainable projects.
In this framework, also the **Industry 4.0 Plan** adopted by the Italian Government could be an opportunity to support the transition to a circular economy, both by generally enhancing investments in research, development, innovative technologies and by encouraging the diffusion of systems based on collection and analysis of large amounts of data. All this with the aim of making production processes more efficient in terms of time and resources used.

[7] A New Industrial Strategy for Europe - Brussels, 10.3.2020 COM (2020) 102 final, page 10

1.III National Circular Economy framework

According to the annual “Report *on circular economy*”[8] published by the Circular Economy Network and ENEA (National Agency for new technologies, energy and sustainable economic development), Italy is the top performer in terms of circular economy implementation, ahead of the United Kingdom, France, Germany and Spain.

The Italian Ministry of the Environment, in collaboration with the Ministry of Economic Development elaborated a general framework of the circular economy as well as a definition of the strategic positioning of Italy on the subject, in continuity with the commitments adopted under the Paris Agreement on climate change, of the United Nations 2030 Agenda on sustainable development, within the G7 and in the European Union.

It is necessary to put in place a change of paradigm that starts a new industrial policy aimed at sustainability and innovation capable of increasing the competitiveness of the Italian product and manufacturing, and which also forces to rethink the way of consuming and doing business. Italy has the characteristics and capabilities to do it and must take the opportunity to develop new business models that know how to make the most of Made in Italy and the role of small and medium-sized enterprises (SMEs).

The transition to a circular economy requires structural change and innovation is the cornerstone of this change. Italian SMEs can leverage on their creativity and flexibility to re-think their products and processes according to the new circular economy paradigm. Such an evolution of the production model represents also an opportunity to create new markets for Italian SMEs and to consolidate their presence in the global value chains.

[8] The full report (in Italian) can be downloaded from the following websites:
www.circulareconomynetwork.it
www.fondazionesvilupposostenibile.org

CHAPTER 2 - Regional vision and challenges

2.I Extracts from Regional Regulation

The **Regional Development Program - PRS (2018-2023)** has placed sustainability among the five priorities of regional government action, as a "*distinctive element of administrative action and as an opportunity to improve the quality of life of the Lombard citizens, reconciling the needs for productive growth and involving all the players in the area: from businesses, citizens, from schools to public administrations*"[9].

The Regional Development Program also proposes the ratification of a ***"Lombardy Agreement among all concerned public and private stakeholders***"[10]; this agreement will stand for the regional mutual commitment" thus, defining the priorities of the regional intervention. The abovementioned Agreement promotes the adoption of the principle of sustainable development – in both public and private decision-making processes - in order to **make Lombardy one of the leading region in Europe in terms of sustainable policies, biodiversity and ecosystem services conservation, circular economy, energy transition** towards the development of renewable sources and decarbonisation, thus, encouraging a coherent and integrated relationship between the economic, social and environmental dimensions.

Within the Agreement, the Region provides the assessment and monitoring of the regional planning in terms of sustainability and a catalogue of good practises and enhancement of dissemination and promotion actions, for the definition of the **Regional Strategy for Sustainable Development** by 2020. Indeed, Lombardy Region is committed to prepare this strategy as a measure of the partnership agreement signed with the Italian Ministry of the Environment. The Agreement was signed by 54 representatives of main institutions, associations and universities in Lombardy. The subscribers commit to implement the principle of sustainable development within its own scope of activity and to contribute to the creation of the Regional Strategy for Sustainable Development and to its implementation. Moreover, each subscriber is required to define independently and according to its own nature, organisation and purpose, its own commitment schedule and the implementation time and to provide information about the progress in implementing the program, at the Annual Sustainable Development Forum, to review and update the program, at least once a year.

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[9] Regional Development Program – Programma Regionale di Sviluppo della XI Legislatura, BURL, Serie Ordinaria n. 30 - 28 luglio 2018

[10] The "Lombardy Agreement among all concerned public and private stakeholders" was formalized in September 2019

With the Regional Development Program (2018-2023) and consequently with the Agreement on Sustainable Development, Lombardy Region defines the main priority actions, such as:

- **Gradual transition to a low carbon emissions economy** (green economy and circular economy) as a factor of territorial development.
- **Renewed competitiveness for companies and for climate change mitigation**.

In the Lombard Pact on Sustainable Development, "Transition to circular economy" has been identified as one of the areas of intervention, as a development model for production systems and material flows management.

In November 2016, Lombardy Region has approved the Law "Lombardy is Research and Innovation" , which establishes the Regional Forum for Research and Innovation composed of highly qualified experts in the scientific field, social and humanistic disciplines. Since 2017, the Forum defines frameworks and methods of public participation regarding technical/scientific advancements and, in general, regarding innovation-led phenomena that may potentially be implied in having a significant impact on society and economy .

More recently, in the contest of an evolving waste regulation framework determined by the EU Circular Economy Package, the Regional Council approved on the 21st of January 2020 the policy act "*Towards a circular economy plan"* which determines the broad lines of the regional waste management programmes on the basis of two key objectives: dematerialize the economy improving resources efficiency and reduce waste production and favour the market for secondary raw materials (ref. resolution XI/980).

2.II The operative framework

In operative terms, Region launched actions in order to allow the entire Lombardy production system to deal with successful transition to Industry 4.0, the energy transaction and the circular economy.

Given the multi-level governance structure, each Directorate General of Lombardy Government, with relevance to the topic, quotes circular economy in their own proceedings, some i.e.: DG Economic Development supports the technological upgrade of SMEs and the optimization of production, organizational and management processes, with particular attention to the circular economy and the sustainability of the entire production process; DG Agriculture, Food and Green Systems sustains the enhancement of sustainability of production and ecosystems through the application of two regional directives, Nitrate and Atmospheric pollution directives that are aligned with the policy of national Ministry of the Environment too.

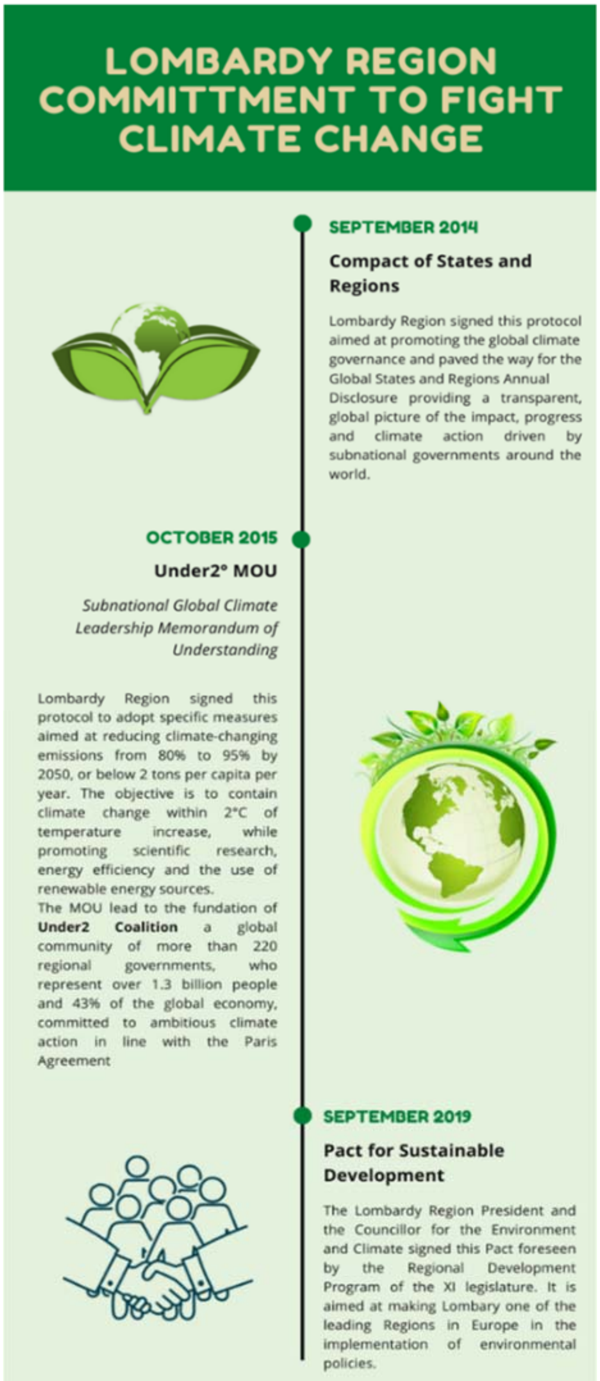

Figure 1. Lombardy Region measure to fight climate change

In this context, the role of the *regional research and innovation policy* is underlined within the **"Three-Year Strategic Plan for Research, Innovation and Technology Transfer"** foreseen by the Law "Lombardy is Research and Innovation", which identifies 6 megatrends with a strong impact on Lombardy population needs: *Ageing of society, Population increase, Urban population growth, Migratory flows, Climate change, Fourth industrial revolution;* more in details, the strategic plan targets multiple aspects of sustainability and circular economy, for example the reinforcement of a "sustainability ecosystem" where industrial and human activities are supported by innovative technologies and methods to reduce the impact on natural resources and landscape. Specific regional challenges were identified in the plan, such as the development of technologies and approaches for the sustainability of production processes, environmental monitoring, control and preservation of natural resources, technologies and approaches for sustainable food manufacturing and consumption, etc.

Circular Economy is also highly relevant in **Lombardy Smart Specialisation Strategy (S3)**, in different regional specialisation areas: agri-food, advanced manufacturing, energy, bioeconomy, aerospace, sustainable mobility. In particular, for each specialisation area, Region proposes specific development themes through Work Programmes[11] (WPs), which are updated every two years, with some extensions. Based on these WPs, the calls addressed to companies, universities as well as research and technological institutes are published.

Both, the "Three-Year Strategic Plan for Research, Innovation and Technology Transfer" and the "Smart Specialisation Strategy" with its WPs, aim at launching regional measures for

[11] DGR XI – 2695-2019 Approvazione "Programmi di Lavoro Ricerca e Innovazione (2020 - 2023)"

rethinking the current economic model and boosting a gradual transition towards circular economy production systems, where products do not cease to generate value at the end of life, as they are reintroduced into the system thanks to an adequate product and process design.

From now on, thanks to these actions the Region has the possibility to specifically target sustainability in its policies and this document will further contribute to detail the needs of the region in terms of Research and Innovation for Circular Economy and give insight on this topic during the shape phase of the new Smart Specialization Strategy (2021-2027) and Thematic WPs accordingly.

Moreover, building on the participative approach, Lombardy Region moved a step forward by setting up in April 2019, the so called *"Observatory for circular economy and energy transition"*. It is a permanent working table, chaired by the Directorate General Environment and Climate, among the regional government and all the trade associations (industry, handicraft, commerce, agriculture), the trade unions, the environmental associations, the consumer associations, the Universities and research centres. The goal of the Observatory is to co-design the regional action for circular economy and decarbonisation by making shared proposal for new regional regulations, programs, measures or initiatives and by transferring at a national level the needs of the stakeholders and proposing solutions, since Lombardy is a driving force in Italy for the circular economy. The Observatory addresses as main priorities value-chains and sectors of particular relevance in Lombardy for their economic, environmental and social impact such as: built environment, sewage sludges, smelting slag, plastics, food waste, etc.

2.III The process towards the Lombardy Roadmap for Research and Innovation on Circular Economy

In line with the above-described institutional framework, Lombardy Region has implemented a dedicated process for the elaboration of the regional Roadmap for Research and Innovation on Circular Economy, taking into account territorial peculiarities and specialisations.
The Directorate General Research, Innovation, University, Export and Internationalization (briefly, DG Research) in collaboration with Directorate General Environment and Climate established a Roadmapping Group for the design of the Roadmap for Research and Innovation on Circular Economy (briefly, Roadmap). The Roadmapping Group was led by DG Research, AFIL – Lombardy Intelligent Factory Association and Finlombarda, the regional finance in-house company. It was also composed of representatives of the Lombardy Technological Clusters (Figure 2**Errore. L'origine riferimento non è stata trovata.**). To complement this group, Clusters invited their key stakeholders, from companies, universities and research bodies, to get involved in the process supporting the identification of barriers and opportunities related to Circular Economy application in their specific field, thus contributing to the definition of R&I priorities.

Figure 2. Roadmap Working Group

The Roadmapping Group has also interacted constantly with the ongoing activities of the regional *"Observatory for Circular Economy and Energy Transition"* and with the *"Sustainable Development Steering Committee".*

Key-members of the roadmapping group were already involved in relevant research and innovation processes for the establishment of circular economy approaches in the Region and at European level. Since 2014, involved Clusters managed working groups composed of companies, universities and research centres and targeting various aspects of sustainability and circular economy.

In particular, AFIL established the working group on "De- and Re-manufacturing" that consolidated a regional supply chain aimed at implementing circular products and processes in alignment with regional industrial specialisation. The collaborative activity of members of the De- and Remanufacturing working group of the AFIL Cluster, in cooperation with Regional and European Institutions, led to the consolidation of a specific regional culture and competence on circular manufacturing in Lombardy.

Moreover, AFIL – Lombardy Intelligent Factory Association, LGCA – Lombardy Green Chemistry Association, LE2C – Lombardy Energy Cleantech Cluster are participating committed by Lombardy Region to European inter-regional initiatives such as the "Vanguard Initiative-New Growth Through Smart Specialisation" and the "S3 Platform on Industrial Modernisation".

CHAPTER 3 - Lombardy Roadmap for Research and Innovation on Circular Economy

3.I The Methodology

The process followed for the elaboration of the “Lombardy Region Roadmap for Research and Innovation on Circular Economy” consisted in a mixed top-down/bottom-up approach, which was guided and coordinated by the Lombardy Technological Clusters and involved a nourished and heterogeneous group of stakeholders including representatives of regional authorities, industrial associations, universities, research centres and companies, both SMEs and Large Enterprises.

The implemented methodology was derived and adapted from the already tested and consolidated approach developed by the Italian National Technology Cluster on Intelligent Factory (CFI)[12]. In its national Roadmap on Intelligent Manufacturing, R&I priorities were defined starting from the analysis of socio-economic mega-trends and sectors specificities. Finally, strategic “Actions Lines” able to turn the outlined challenges into opportunities were identified.

AFIL, the Lombardy Region Technology Cluster on Intelligent Factory, was the promoter of such a national methodology. After having defined its regional strategic manufacturing innovation roadmap in 2014, it actively participated to the elaboration of the Italian roadmap by representing priorities of the Lombardy manufacturing ecosystem and by suggesting successful roadmapping practices that had been experienced at local level.

Based on such a role and past experience, AFIL coordinated the inter-cluster cooperation process for the definition of the Regional Circular Economy Roadmap, under appointment of Lombardy Region Government (DG Research). A specific methodology, adapted from the previously cited one, was proposed and adopted (Figure 3).

[12] Roadmap per la Ricerca e Innovazione Fabbrica Intelligente: https://www.fabbricaintelligente.it/roadmap-fabbrica-intelligente-industria-4-0/

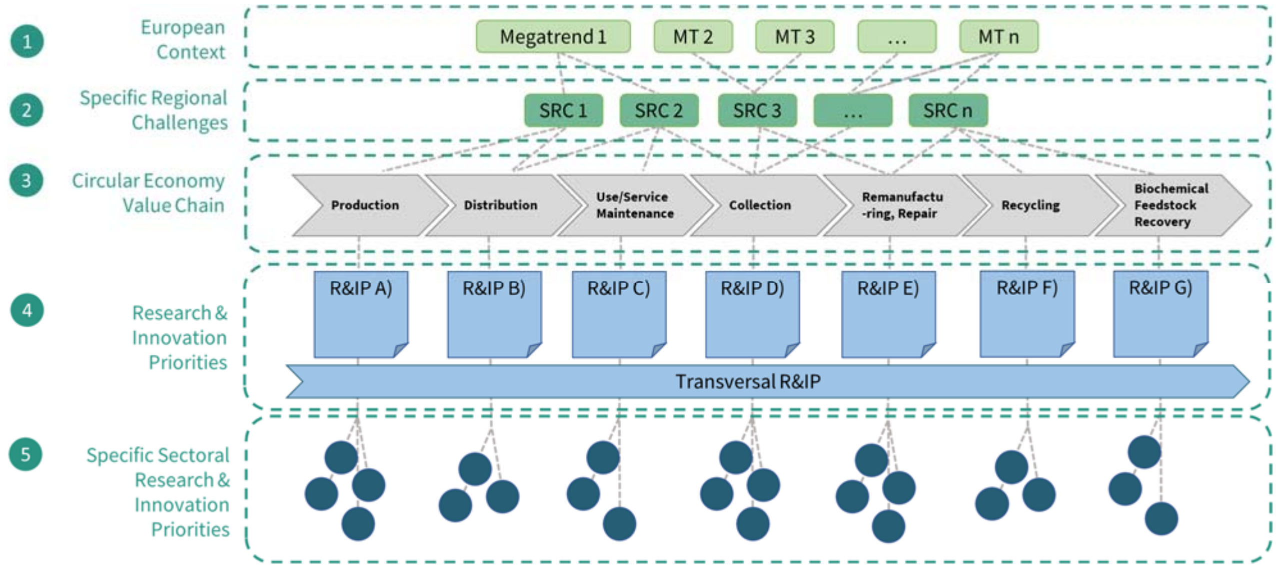

Figure 3. Roadmapping Model

Following a top-down approach, moving from the analysis of the socio-economic megatrends in the ***European Context*** and the identification of national and ***Regional Specific Challenges*** [*see. Chapter 1 and Chapter 2*], a set of specific challenges were identified thanks to the analysis carried out by Lombardy Region and Finlombarda (*boxes 1 and 2 of Fig.3*).

Meanwhile, Lombardy Technological Clusters involved in the Roadmapping Group, collected bottom-up inputs from regional stakeholders involving companies, research centres, universities and associations which operate in the various sectors of the Lombardy industrial eco-system. Through several guided steps, these stakeholders identified the main opportunities and barriers emerging while implementing Circular Economy solutions in practice. To complement information collected by Clusters from the regional innovation ecosystem, the results of two previous European projects in the area of Circular Economy (SCREEN[13] and CIRCE[14]) in which Lombardy Region participated (directly or through the involvement of the Cluster AFIL) were used as source of additional information.

This process led to a very detailed map of circular economy opportunities and barriers in specific sectors of regional specialisation, categorised as **"Specific Sectoral R&I priorities"** (box 5 of Fig.3) and extensively reported in the Annex 1 of the document.

With the objective to identify and formalize the specific thematic areas and research and innovation priorities targeting Circular Economy challenges and opportunities with a systemic view, the Circular Value Chain model has been taken as reference framework. According to this framework, emerged sectorial opportunities and barriers were associated to the various

[13]SCREEN- Synergic CirculaR Economy across European regioNs: https://www.screen-lab.eu/

[14] CIRCE – European regions toward Circular Economy: https://www.interregeurope.eu/circe/

value chain steps (box 3 of Fig.3). In particular, the Circular Economy Value Chain model[15], representing the value chain steps of circular processes, from production to valorisation of waste, has been chosen as methodological reference for the definition of circular economy opportunities, challenges and priorities (Figure 4).

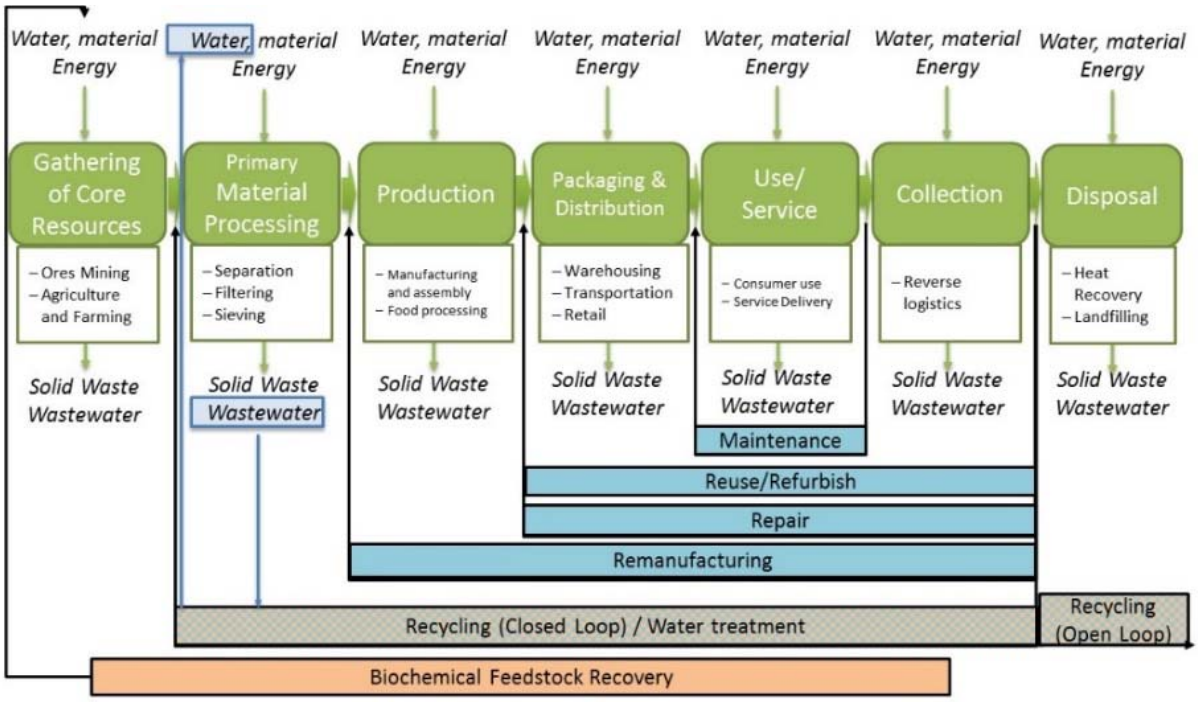

Figure 4. Circular Economy Value Chain model

Finally, the last step of the methodology consisted in the generalization of sector-specific challenges and opportunities with the aim of deriving ***Research and Innovation priorities*** that are transversal to multiple sectors and that, if properly addressed at the level of enabling technologies and methods, can generate wide impact in the transition towards the circular economy model (box 4 of Fig.3). Not only technical priorities have been considered, but also boundary conditions and barriers such as: *Legislation and Regulation, Piloting and demonstration infrastructures, Education and skills, Awareness and culture and Ecosystem building* [*see. Section 3.IV*]. These Research & Innovation priorities represent the main result of the roadmap and the main input to address future regional policies.

[15] Synoptic report Opportunities, Barriers and Value Chain analyses - https://www.interregeurope.eu/circe/library/#folder=1632

3.II From methodology to action

As already anticipated, the Lombardy Circular Economy roadmapping activity was lunched by Lombardy Region as an inter-cluster initiative, with the intent of defining a regional innovation and development strategy in the framework of Circular Economy, with a cross-sectoral dimension and deeply grounded on the needs of the regional stakeholders. Lombardy Technological Clusters were invited to actively participate in this process and to mobilise their members throughout the whole process, from the collection of input to the validation of the contents elaborated.

In total 6 inter-cluster roadmapping groups meetings were organized to carry out the process from April to December 2019.

A workshop *"Let's build together the Lombardy Roadmap on Circular Economy"* took place in Lombardy Region to widely share with companies and other actors (associations, universities, enterprises large and SMEs etc.) the methodology and to collect additional inputs from the regional stakeholders. Finally, the sectoral R&I priorities were aggregated and described in this document as main input for the Lombardy Regional Government for shaping the future R&I policies on Circular Economy.

A public consultation was also lunched by Lombardy Region in October/November 2019, asking stakeholders and citizens to define shared paths for sustainable development to be integrated as input in the definition of "Sustainable Development Strategy". In particular, Circular Economy was one of the main topics addressed. About findings from survey: 2300 participants (of which: 76% as an individual; 9% - business; 8% - public institutions; 5% - third sector; 2% - research bodies); Considering the creation of a favourable context for Circular Economy development, Lombard citizen recognises among the 3 most relevant enabling factors: i) to **improve the legislative, fiscal and financial context** (i.e. tax incentives complementary to national ones in certain fields, such as investments in universities, start-ups and research centres), ii) to **invest in the development of human and social capital** (i.e. with programmes of innovation and entrepreneurship in schools, adult continuing education, scholarships for attracting specialised talents), iii) to **support the opening of new markets for sustainable products** through actions to raise awareness among citizens and public and private institutions.

The results of this public consultation were used to validate the identified Strategic Research & Innovation Priorities, as well as to further integrate the specific sectoral priorities.

Relevant regional sectors with high circular economy potential

In the elaboration of the Lombardy Roadmap for Research and Innovation on Circular Economy, a specific effort was spent to include priorities and barriers expressed by the sectors that contribute most to the regional economy and Specialization Strategy, on the one hand, and that present high potential in terms of circular economy benefits on the other.

From the **economic point of view[16]**, **Manufacturing is the most important regional sector** with 62 billion € of value added generated (33% of the total regional value added in non-financial business economy) and a total workforce of 904.762 million people (28% of the employees in the regional non-financial economy business sectors). Considering subsectors, the main contribution to the value added is generated by the *machinery and equipment* sector (16,3%), *metal products (*14%), *rubber and plastic* (6,9%) and *food products* (6,8%). Similarly, from an employment perspective, the most influential manufacturing subsectors are metal products (16,7%), machinery and equipment (15%), food products (7,2%) and rubber and plastics (6,4%).

Moreover, Lombardy is the first region in EU28 in terms of employees in the following manufacturing subsectors: *textiles* (7,3% of the relative workforce in EU28), *rubber and plastics* (3,4% of the relative workforce in EU28), *metal products* (4,2% of the relative workforce in EU28) and *electrical equipment* (4,9% of the relative workforce in EU28).

In addition to these sectors, *aerospace* industry is a specific specialization which contributes to the 1,6% of added value and 1,5% of regional employment generated by the "manufacturing of other transport equipment" sector.

Lombardy is the **second region** in EU28 in the **construction** sector in terms of total workforce, with 225.570 employees (2,25% of the relative value added in EU28) and a total value added of about 10 billion € (1,8% of the relative value added in EU28). The subsector "*construction of buildings*" accounts for the 21% (2,23 billion €) of the total value added generated in construction and the 22% (55.768 employees) of the total workforce.

Finally, the **Italian bioeconomy represents the 10.1% in terms of production and 7.7% in terms of employees of the national economy[17]**. At regional level, there are 4.000 companies operating in the bioeconomy sectors, with 40.000 employees. Among these *Research on innovative biotechnologies* (162 companies out of 768 in Italy) and in the *bioeconomy linked to pharmaceutical products* (248 companies out of 630) represent and important regional specialization. The biotechnology research sector has recently doubled in the last five years: at national level, from 346 to 768 companies and from 830 to 2170 employees; in Lombardy, from 66 to 162 companies and from 275 to 501 employees.[18]

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[16] Reference for NACE classification: http://ec.europa.eu/competition/mergers/cases/index/nace_all.html
 - EUROSTAT Database 2016(N.of employees and N.of Companies):
https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=sbs_r_nuts06_r2&lang=en

- ISTAT Database 2017(Turnover and Gross Value Added):

http://dati.istat.it/Index.aspx?DataSetCode=DCSP_SBSREG

[17] "La bioeconomia in Europa", 5th Report, March 2019

[18] Data elaborated by Innovhub-SSI and Chamber of Commerce of Milan, Monza Brianza and Lodi, based on companies register 2014, 2018, 2019

In terms of **Circular Economy potential**[19]**,** it emerges that in Lombardy region Construction, Waste Collection and Metals are the sectors with the highest volumes of waste generated. Despite the high volume of waste, **Construction** is also one of the sectors with the highest percentage of waste recycled (88,52%). The same is for the **Metal** sector, which has a percentage of waste recycled around 90%, if we consider the "Metal products" segment. This percentage decrease until 45,80% taking into account the "Basic metal" segment, whose performance is aligned with the **Waste collection** sector (45,80%).

Machinery and **Textile** are also notable in terms of Circular Economy Potential, with a volume of waste generated respectively equal to 227.698,20 and 121.828,70 and a share of waste recycled equal to 79,04% and 68,34%.

On the other hand, **Rubber and plastics, Chemicals** and Basic Metals are the sectors with the highest percentage of waste landfilled, respectively 83,53%, 46,60% and 52,11%.

Based on these evidences, this roadmap is taking into account the input of the above-cited sectors, represented by the Clusters that participated to the roadmapping process. The sectors are: *Aerospace, Automotive, Biomass, Built Environment, Food, Metals, Machinery, Plastics, Textile, Electrical and Electronics Equipment.*

The roadmap will be a dynamic document that will be periodically updated considering the evolution of industry and of regional specialisation. Accordingly, in future revisions, additional sectors of increased economic and circular impact will be included, as already emerged in the Observatory for circular economy and energy transition.

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[19] Circular Economy potential inferred with specific indicators, suggested in the Ellen MacArthur Foundation document "Delivering the Circular Economy-A toolkit for policymakers". [i) Volume of waste generated by the sector, ii) Share of waste recycled, iii) Share of waste landfilled iv) Share of waste inciner]

3.III Strategic Research & Innovation Priorities

The following chapters provides a detailed description of the identified Strategic Research & Innovation priorities.

A. Production

Production encompasses the methods and the processes that contribute to the transformation of input materials and components into to the output core value-added product of the value chain.

A.1 Design for Circular Economy

The evolution of the criteria with which a product is conceived and designed is essential to support the transition from a Linear to a Circular Economy. The aim of this Strategic Research & Innovation Priority is to integrate Circular Economy thinking in the product design and engineering stages. The objective is to facilitate the product post-use value retention through material recycling and re-use and component remanufacturing. This can be fostered by achieving extensive re-use of secondary materials into new products and the realization of products that are easier to repair and disassembly and with an extended useful lifetime.

The scope of this priority is to boost the development of novel design concepts and methods to anticipate the consideration of resource efficiency, materials and component re-use options and product upgrade through multiple use-cycles since the early-stage product design phase. In line with the above methodology, the identified Strategic Research & Innovation Priority “Design for Circular Economy” sub-priorities are:

A.1.1 Product design criteria for Circular Economy

High-tech and complex products are nowadays conceived and designed with low consideration of how their structure and bill of materials impact on the overall product lifecycle. The challenge is to define novel criteria, principles and methods to design products where the use of critical raw materials is limited, which are engineered to be easily tested and disassembled, in which components may be remanufactured for multiple use-cycles and where significant fractions of recyclable materials are integrated.

Design for circular economy criteria should be adopted in support of the development of innovative products which embed key characteristics to foster their proper management along the life cycle. Beneficial circular economy criteria are: design for disassembly, fostering easily accessible and reversible joints; design for remanufacturing, fostering modular components and subassemblies; design for recycling, fostering the selection of recyclable materials and the avoidance of hazardous substances.

A lifecycle-oriented product design enables an effective preservation of the product’s added value through its use-cycles. The implementation of circular economy criteria expands the business opportunities related to these products, from the commercialization to their in-use and post-use management and material/function recovery and reuse.

A.1.2 Design targeted to increase the percentage of secondary raw materials in new products

The use of secondary raw materials in the production of new goods and products shall be enhanced and increased in order to achieve a sustainable Circular Economy model. However, existing technical barriers such as the variability of recovered materials quality and return flows, the lack of material certification protocols and poor material standardization and characterization techniques discourage manufacturing companies to leave the current dependency on virgin material consumption.

Legislation can certainly have an important role in motivating manufacturers to design their product integrating higher fractions of recycled materials, without compromising performance (e.g., eco – design directive and Minimal Criteria Principle in Green Public Procurement). However, innovative design methods, capturing the effect of secondary material use on the product performance, as well as decision support systems for the identification of the best material properties and mix between primary and secondary sources for specific application scenarios could make this practice viable from an economic and product function standpoint.

By the development of sustainable certification protocols applicable to the re-usable materials as well as to the final products embedding these materials it is possible to extend the market attractiveness of the opportunity. The goal is to increase the percentage of secondary raw materials used in the production of new products[20].

A.1.3 Co-design between manufacturers and recyclers

A major barrier for the effective dismantling and recycling of products after their use-cycle is the incompatibility between the designed product features (bill-of-materials, joints, etc.) and de-manufacturing/recycling process and system capabilities.

Co-design (sometimes called participatory design or co-operative design) is a collaborative product development approach which involves a group of stakeholders interested in the product and involved in different phases of its value-chain. A co-design approach will help ensuring that the design outcomes meet individual needs by also targeting a common systemic sustainable design target. Co-design for circular economy should thus involve the major actors of the product circular value-chain and should rely on innovative solutions to support such collaborative value-creation process.

Novel information sharing solutions to support product co-design activities, integrating manufacturing, de-manufacturing/recycling, and remanufacturing perspectives should be

[20] DESIGNING FOR A CIRCULAR ECONOMY - The conceptual design of a circular mobile device – Ellen MacArthurFoundation.

promoted. Information sharing and value re-distribution among different stakeholders of the value chain are indeed important enablers for such emerging collaborative circular economy business models.

A.1.4 Consumer-driven co-design

The traditional product development process is driven by the customer's needs and specifications. In the same perspective, with the objective to increase their market acceptance rate, products embedding Circular Economy features should be designed in compliance with consumers expectations and needs, thus unlocking new market opportunities for such "green" products.

These products should embed functional characteristics that are co-designed with the consumers, should valorise the re-usable materials and components residual mechanical and aesthetical properties, thus targeting the distribution of affordable price products with specific consumer-oriented functions. Systematic quality-oriented design tools such as the House of Quality[21] should be enhanced to exploit these opportunities and to understand and manage the relations between the Circular Economy-driven product design features and the consumers' needs.

A.2 Circular Production Processes

With the objective to achieve a Circular Economy mature production phase, innovation shall be brought to the production process-chain. The process-chain is crucial because of its high energy consumption, the generation of product and material waste, scraps and by-products as well as its fundamental role in providing to the product the target functionalities required by the consumers. Moreover, in order to achieve an efficient production of circularly designed products, which embed recycled materials and innovative components and joints, a reliable and robust process-chain needs to be designed, operated and controlled.

A circular production process needs to meet the requirements of products designed for circular economy while minimizing production-related material and energy waste. The scope is to build an optimal product-process co-evolution, where the cradle-to-market manufacturing circularity is maximized.

A.2.1 Waste and scrap reduction "Toward zero-waste manufacturing"

Zero-waste manufacturing is a paradigm aiming at smoothing production waste by preventing the generation and propagation of defects in the process-chain and by reducing or reusing components or by-products during the manufacturing process. The challenge is to achieve more circularity in the management of production scrap, by-products and residual waste.

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[21] J.R. Hauser, D. Clausing, The House of Quality, Harward Business Review. May-June 1988 (1988) 3–13.

The reduction and revalorization of manufacturing defects and waste can be achieved by the implementation of advanced data-enhanced technological solutions in manufacturing systems. Some examples include the development of cyber-physical systems for quality-oriented feedforward process control aiming at the reducing the propagation of defective parts in the process-chain, the development of inspection and traceability solutions for supporting the implementation of low-contaminated scrap recovery and re-use streams, the development of high-value waste and by-products re-use strategies, such as metal chip solid-state recycling.

The reduction of scrap and waste through the development and validation of innovative zero-waste manufacturing paradigm will positively contribute to the environmental and economic sustainability of the production phase.

A.2.2 Re-valorisation of secondary products and by-products through industrial symbiosis[22]

Industrial symbiosis is the process by which waste or by-products of an industrial process-chain (including heat, energy, water, and un-used materials) become input resources for another process-chain. Industrial symbiosis creates an interconnected network which strives to mimic the functioning of eco-systems, within which energy and materials cycle continually circulate with lower amount of waste produced. Industrial symbiosis contributes to reduce the environmental footprint of the industries involved. Virgin raw materials are required to a lesser extent, and the need for landfilling waste is reduced. It also allows value to be created from materials that would otherwise be discarded and so the materials remain economically valuable for longer than in traditional industrial systems.

Although industrial symbiosis is attracting interest in the scientific community, examples of application in industrial eco-systems are still very limited. In this context, the development of formal approaches to state the pre-conditions to profitably develop such cross-sectorial and local eco-systems, the proposal of systemic methods to assess the benefits of these business solutions, the analysis of the legislative implications of these operational modes, the development of digital platforms to support the dynamic (re)-configuration of such eco-systems and the wider adoption of symbiotic business models in discrete part manufacturing are challenges that should be prioritized in order to develop significant set of business demonstrations of the benefits of industrial symbiosis in real settings.

A.2.3 Enhanced process robustness and flexibility for reusing components and materials from post-use products as production inputs for new products

Secondary raw materials as well as production waste and scrap are characterized by higher variability and different properties (e.g. mechanical properties, contaminations, colour) with

[22] European Commission - Industrial Symbiosis.

respect to virgin raw materials. In this context, the re-use of these streams in a Circular Economy perspective would require the enhancement of manufacturing technologies and systems to be endowed with adequate robustness and flexibility levels, enabling their effective adaptability to properly manage variable and mixed input material flows. The integration of scalable technologies as well as technologies for inspecting, tracking and labelling input material flows can overcome the barrier of secondary raw materials condition variability and uncertainty.

Production systems capable to react to input material variability through the integration of hardware (flexible production equipment, sensors) and software (as downstream compensation, feed forward controls, cyber-physical systems) solutions are an essential enabler for circular, closed-loop manufacturing, value chains.

A.3 Enabling traceability in product and processes

The traceability of the characteristics and conditions of the product structure, the key components and the materials along the phases of the circular value-chain is a critical asset for enabling the correct evaluation of the product environmental performance, of the potential alternative circular economy options, in view of increasing the re-usability of resources.

Potential solutions traceability of products and processes include the development of open and centralized digital platforms in which relevant information can be provided in input by the stakeholders, stored and shared through multi-side access capabilities. This solution would be further expanded by coupling the idea of smart products enhancing the applicability of embedded sensors and tagging systems able to automatically provide relevant product, component and material information along the product life cycle.

Security, information ownership, revenue streams and product liability transferring are aspects to be further investigated in view of the large-scale industrial implementations of these solutions.

A.3.1 Data acquisition

Nowadays, several solutions are available for the management of product life-cycle data. Especially in the modern contest of Industry 4.0, the acquisition and storage of a large amount of data (the so called 'big data') has been achieved. However, the acquisition of life-cycle data in a circular economy perspective is not yet been adequately developed. Investigation of the most valuable data to acquire and store during the product life cycle, in view of achieving a sustainable large-scale implementation of circular economy business cases, is still in the early development phase.

Two major set of data would be needed in order to unlock Circular Economy potentials. Firstly, relevant data coming from the product engineering, production, distribution and service phases would be needed in order to elaborate realistic figures on the evolution of the product structure and components along its life-cycle phases, as well as on its geographical location and volumes. The acquisition and semantic organization of these data shall receive particular attention. Secondly, information about the specific conditions of the product, components and materials along the use-cycle should be gathered. Available technologies for enhancing product data collection include for example barcodes, contact memory buttons and Radio Frequency Identification Devices (RFID), etc., for smart products, supported by suitable Internet of Things (IoT) solutions. Since the quality of the Circular Economy decision is strongly influenced by the quality of the information available, the most proper technology must be chosen in terms of completeness, accuracy, accessibility, interpretability, and uniqueness of the stored information.

A.3.2 Data storage and sharing

Since the collection of product data and information involves several stakeholders, cooperation among the different actors of the value-chain is required, within and beyond the borders of individual companies and sectors. The achievement of this goal would be possible if data are not retained inside proprietary local databases but are shared through the exploitation of adequate digital multisectoral platforms.

Such digital platforms shall be designed in order to guarantee multi-sided access of the different actors for a continuous data upgrading, in line with security and legal constraints. Moreover, specific set of services should be designed and integrated in order to support, for example, demand-supply matching, circular production planning, value-chain simulation and sustainability assessment thus supporting the identification of the most suitable circular routes for specific products, components and materials. Sustainable business models shall also be designed and investigated for such multi-sided platforms in order to enhance the quality of the stored information, of the related services and to achieve the extended use and scale of these digital Circular Economy platforms.

A.3.3 Protocols standardization

Traceability should be supported by specific standards and protocols to ensure security, data protection, and data sovereignty and to regulate data ownership and intellectual property. Especially when data are sensitive and shared among different actors, actions and measures must be implemented to correctly treat strategic data. Special attention shall be given to ensure secure traceability of the product and process data that are stored and transferred using the aforementioned digital platforms. Furthermore, such protocols should comply with the business strategy of these platform, enabling a fair and effective use of the stored information to unlock the underlying circular economy potentials, avoiding the risk of introducing barriers to the wide adoption of these digital solutions. Special attention should be given to products and materials ownership and responsibility transferring among stakeholders of the circular value-chain. The use of emerging technological solutions, such as the block-chain technology, could support the definition and implementation of such protocols, in line with European legislations too.

A.3.4 Certification of re-usable products, components and materials

The definition of proper certification mechanisms and the characteristics of the related business entities responsible for certification is an essential step to unlock circular business models. Certification shall be applied to the products, components and materials circulating within the circular value-chain in order to increase the level of confidence for industries and consumers re-using these resources. In line with this objective, specific technologies, methods, procedures and policies should be developed to define the scope, the mechanisms, the characterization contents and the outcomes of certification, in line with the business requirements, for different product categories, materials and sectors. The expected benefits of the wide-spread adoption of certification procedures include the increase in the stability of re-usable materials and products volume and conditions, the activation of multiple re-use cycles opportunities, ultimately increasing the attractiveness of high-value circular business options.

A.4 New Cross-Sectorial Business Models for Circular Economy

Innovative sustainable methods to design products and processes can raise the potential of a circular economy industry in Lombardy. However, in order to be widely spread, the boundaries of the current linear, within-sector, business models should be expanded towards the systematic development of cross-sectorial business models, effectively designed to unlock the existing circular economy opportunities. A new cross-sectorial approach is indeed needed to exploit the existing re-use, remanufacturing and recycling opportunities within high-value solutions.

In order to create a concretely competitive environment of industrial stakeholders engaged in a regional circular economy network, which is in turn part of a wider international network, each industrial node which uses and transforms materials should be connectable with the others in terms of materials, products and information flows. This concept can be declined exploiting several circular economy options, including open loop recycling, repurposing and re-use of products and components in other sectors, biochemical feedstock recovery using industrial and commercial scraps, cross-sectorial industrial symbiosis. For such cross-sectorial circular routes, the value proposition, revenue models, and the value-chain architecture in each sector/industry should be re-defined in a coherent way, targeting a fair and accepted distribution of risks and monetary flows. Such a model should take a direct consideration of financial and business risks, also considering time-related delays between product distribution and re-usable resource collection from the market.

This business model re-design should consider the main sectors of regional specialization in a systemic regional strategic perspective. In this way, various sectors of excellence will be reinforced through the pervasive introduction of circular economy practices and the exploitation of all possible synergies generated by the variety of regional specializations. In this way, also environmental benefits achievable at regional ecosystem level will be maximised.

A.5 Support to Circular Economy Oriented Production

A virtuous Circular Economy-oriented manufacturing and product lifecycle management has potential to release relevant economic and operational resources and efforts which nowadays other institutions and organizations dedicate to the management of production and post-use waste. In a win-win long-term perspective and in line with the Extended Producer Responsibility (EPR) principle, such institutions could therefore actively support Circular Economy-oriented industrial initiatives offering economic and operational support. For example, resource savings obtained by the establishment of such virtuous, secure, and direct industrial management of scraps and waste in mature contexts could be invested to foster and expand the development of new virtuous circular loops in emerging strategic product areas. Moreover, actions as legislative simplification, operational support and local clustering and cross-sectorial linking would increase the exploitability of profitable circular economy strategies. In this perspective, the development of suitable systemic what-if analysis methods and tools, such as business dynamics, would support the identification of the most proper set of actions, depending on the local business context and eco-system configuration.

B. Distribution

Distribution encompasses all the operations dealing with the packaging of the value-added final product, and its distribution to the users and consumers.

B.1 Establishment of Synergies Among Forward and Reverse Logistics

Factory-to-market distribution and collection of post-use products from the market to the treatment facilities are nowadays commonly considered as two independents, separated logistics flows, often operated by different stakeholders. However, by properly innovating the current supply chain, it seems possible to better synchronize forward and reverse logistics flows, thus contributing to reduce costs, the environmental footprint, ultimately increasing post-use product collection rates for more stable circular value-chains. Concrete opportunities in the development of this priority are provided by enhanced technological solutions for the traceability of products and information sharing (*see priority A.3*), coupled with innovative decision making tools for the integration of forward and reverse logistics in an optimized multi-directional products transportation network. Moreover, more systematic involvement of retailers, design and adoption of customer offers for product substitution and upgrade or obsolete component replacement options and consumer reward mechanisms seem to be effective innovation directions for increasing collection rates while, at the same time, increasing the consumer loyalty towards sustainable circular products.

B.2 Development of Market/Pricing Strategies to Increase the Willingness to Buy of Sustainable Products

Sustainable products which embed secondary raw materials or developed by following circular design principles often suffer of competitiveness and market attractiveness, since their price is higher than conventional products, due to the high material recovery cost, and they are perceived as lower quality products by consumers. A set of customized marketing and pricing strategies should therefore be developed in order to increase the market readiness to demand and value these products.

Sustainability-driven marketing strategies and life-cycle oriented incentives for the purchase and use of circular products can provide additional “willingness to buy” to sustainable products. Increasing the consumers’ awareness of the measurable environmental benefits of purchasing sustainable goods seems to be another strong leverage while developing circular economy-oriented market strategies. Furthermore, the measurement and certification of sustainable product performance (*see priority A.3.4*), and the effective communication to consumers may contribute to a more conscious perception of these products by customers.

Despite the stand-alone benefit of increasing sales by market/pricing strategies, the increase of production rates may provide additional advantages in terms of cost savings generated by circular economy and amplified by economies of scale.

B.3 Exploitation of Local Production-Distribution-Consumption Networks

In conventional supply chains, raw materials gathering, production and distribution can be decentralized in different areas of the globe. This configuration of the supply chain has the advantage of exploiting local smart specializations and enabling transformation cost reductions. However, it extends the transportation routes of materials, components and products thus negatively affecting the environmental performance. Moreover, it increases the external dependencies of local economies and sectors, especially from the critical supply of raw materials viewpoint. On the contrary, circular value-chains may be based on the short value-chain concept, enabling the flow of secondary raw materials and sustainable products in the local ecosystems, close to the market demand.

An opportunity which derives from the traceability of products and information sharing *(see priority A.3*) is the implementation of local production-distribution-consumption networks served by suppliers of secondary materials and components which are embedded in the same local industrial network. In order to foster the establishment of this model, systematic solutions to identify missing links in the local circular value chains and find levers and mechanisms, to support the overcoming of these gaps, are needed. For example, special operational conditions and incentives could be created to establish locally specific business entities that provide extended impact in the Region, going being the individual industrial impact of that value-chain stage but propagating to the overall eco-system.

Such an approach will contribute to the reduction of logistics costs, of material supply risks and availability risks, thus improving the overall profitability of the circular economy paradigm implementation in the Region.

B.4 Circular Economy Driven Public/Private Procurement

Public and private procurement of sustainable consumables and assets have potentials to strongly influence the overall market share of circular products. On one hand, public procurement should be regulated by guidelines which include the sustainability of purchased products and goods as evaluation factors driving tenders. On the other hand, governmental incentives to private companies which invest in circular economy driven private procurement are effective solutions to boost the circular economy market. Such solutions should be widely accepted and positively perceived by the industrial stakeholders, in order to be implemented. Improving public and private procurement of circular products is expected to boost circular economy by increasing the demand stability of sustainable products transformed within a circular value-chain, thus reducing the risks for companies investing in circular value-chains.

C. Use and Service

This phase encompasses the industrial activities in support of the consumer while using the product functionality, with specific focus on the related services.

C.1 Product Life-Cycle Extension

In a traditional linear value chain, and especially for consumer products, the shortening of product life cycles and the increasing dynamics of innovation cycles may reduce the producer interest towards prolonging the in-use lifetime of a product. This results in the frequent substitution of a repairable, or even still functioning, item by the customer, resulting in massive waste flows of acceptable residual function products. The challenge is to implement innovative and profitable market strategies and services which can extend the use-phase of products, providing business attractiveness to the producers.

Specific life-cycle extension services could be implemented in a circular value-chain to profitably manage the use phase of products in order to spread their lifespan, still preserving business attractiveness. Examples include the implementation of data and traceability enhanced predictive maintenance strategies, aiming at avoiding the deterioration of product functions and performance before they reflect in a perceived need for product change. Such services will make it possible to maintain the original functionality of a product longer. Another example includes product upgrade services targeted to the substitution of key components in modular and reconfigurable products to upgrade their functionalities and continuously meet evolving customer requirements and needs. The upgraded products would then provide similar functionality of a corresponding new product, while preserving its original platform architecture. In both cases, specific strategies for proactively offering maintenance and product updates depending on the observed in-use conditions of the product and the user – product interaction modes may be useful to increase the added values of these services.

Life cycle extension strategies and the related services can contribute to increase the added-value of producers while reducing the need for new resources, to increase the customer loyalty to a specific brand or product model, establishing a long-term relationship between the consumer and the producer. Furthermore, it can contribute reducing the disposal or low value treatment of still functioning products.

C.2 Product-Service System

The wider implementation of the product-service system paradigm, based on the non-ownership, product sharing and pay-per-use principles, can be extremely beneficial from a circular economy perspective. On the one hand, according to this vision the manufacturer remains the owner of the product along its use-cycles and can actively and profitably manage product maintenance, remanufacturing, upgrade and collection, keeping a tight control on the product flows in terms of volume and geographical location. On the other hand, the utilization rate of the product can be increased through the product sharing principle, reducing the consumption of under-exploited resources.

Despite the benefits of product-service systems, further efforts need to be directed towards the development of business technical and non-technical preconditions for the wide diffusion of these solutions. From a technical point of view, customized applications of product tracking, traceability and condition monitoring technologies as well as the development of decision support systems properly elaborating these inputs in view of an optimized management of the product-service system shall be developed. From a non-technical point of view, specific business model and value creation mechanisms shall be formalized in this new circular business context. Moreover, proper risk management practices especially targeted to investments payed back by revenues temporally distributed along the product use-phase shall be designed.

Unlocking product-service system under a circular value-chain perspective can have tremendous impact on the reduction of under-utilized resources and materials, the increase in the collection rate, and the increase of added value by implementing remanufacturing, upgrade and re-use options at large scale, ultimately making high-tech, complex products available at lower price to users, thus extending the market attractiveness of sustainable products.

D. Collection

It encompasses all the operations to collect post-use products, components and materials from the market and consumers back to the industrial transformation phases of the circular value-chain.

D.1 Reverse Logistics

Reverse logistics for aftermarket plays a central role in the implementation of an effective and profitable circular economy. Beyond the aforementioned needs of integration between forward and reverse logistics to optimize the transportation network (*see priority B.1*), reverse logistics should be driven by dedicated protocols for enhancing the take-back of products and wastes and by effective safety measures for the transportation of hazardous goods.

D.1.1 Proactive "take-back" protocols for re-use

In a circular economy perspective, it is sometimes valuable to collect post-use products before their end-of-life to enable less invasive, and therefore expensive, recycling, remanufacturing and/or upgrade transformation processes. This product, component and material re-use oriented take-back of products from the market should therefore be driven by pre-determined protocols and related manufacturer-customer agreements which exploit the monitoring of the product itself during its lifecycle, to spot the best time to retire the good, in order to optimize the balance between expected residual useful life losses and remanufacturing or recycling expenditures. Such strategy should also be supported by specific economic-financial models to decide the product condition thresholds and boundaries to activate different take-back and circular options, depending on the actual demand for re-use. This proactive take-back approach would contribute to anticipate the value drop of a product and maintaining its value by systematically implementing the most profitable circular economy option. This priority is in synergy with the one introduced in Section C.1 (page 39).

D.1.2 Waste management protocols

Waste management is an essential step to enable and unlock high value circular economy solutions. Product, component and material damage and deterioration during waste management can seriously undermine the feasibility of high-value treatments. The reduced contamination of the collected flows and the continuous provision of the required waste material volumes may contribute to supply to the transformation plants high quality and stable quantity of re-usable secondary resources.
Innovative protocols and mechanisms should be designed, developed and tested to support waste management, also supported by innovative digital technologies. Attractive solutions include the development of low-cost distributed pre-industrial sorting of waste for homogenous collection of purified fractions directly at the source, thus extending the concept of separate collection. Moreover, the adoption of tracked and controlled waste collection and

storage systems, with capabilities to pre-characterize the properties of the collected waste and share this information with treatment facilities, would be of industrial interest. Furthermore, innovative consumer-centric collection models to be implemented to those products that are usually hardly collected have to be designed and developed.
The collection of stable and poorly contaminated material flows would turn into higher quality secondary resources, with improved properties and at lower cost. This would enable a more effective and stable re-use of products, components and materials under a circular value-chain perspective.

D.1.3 Safety in hazardous products transportation

The trans-boundary transportation of hazardous materials is regulated as established in the European Agreement Concerning the International Carriage of Dangerous Goods by Road, ADR. ADR covers the classification and labelling of dangerous goods, and their transportation in terms of vehicle specifications and equipment needs.
However, modern products embedding hazardous materials are becoming more and more complex presenting a wide variety of potential emergence causes during their transportation. A more systematic and collaborative approach for deriving guidelines, protocols and rules for the safe transportation of such products is needed, also exploiting the availability of advanced digital technologies and distributed sensoring solutions. Starting from the principles established in the ADR, specific collaboration should be promoted between the OEMs, the dismantlers/recyclers and the logistics operators, aimed at identifying the possible emergency situations and their potential solutions. Moreover, artificial intelligence and data-analytics may be exploited for learning the existing risks emerging from distributed experiments. Furthermore, new transportation modules equipped with sensors able to retrieve data on the conditions of the transported items shall be designed.
A strong connection between all the key actors of the value chain in a Circular Economy perspective, mediated by the legislative frame, enables a more aware and safe transportation of hazardous products, speeding-up the necessary preparations, promoting a quick intervention in case of emergency and clarifying responsibility in case of accidents.

D.2 Citizens engagement and incentives

Citizens engagement on the value and rules of a correct disposal of products and the implementation of specific incentives are the foundation for improved post-use product, component and materials take-back from the market to the industrial transformation phases of the circular value-chain.

D.2.1 Increase the return rate of valuable post-use products

The impact of consumers' behaviour in the market on the take-back of products is relevant for increasing the volume and quality of returning goods. It is therefore of paramount important to enhance the customers' awareness and commitment towards virtuous and proactive return practices of post-use products through the reverse logistics channels.

Awareness increase initiatives and incentives can boost the return rate of products, effectively increasing the overall availability of post-use products, components and materials in the circular value-chain. Possible innovations include the use of digital solutions for timely providing usable information on the correct product disposal options to consumers, and the development of specific information packages and campaigns to increase the awareness of consumers toward the importance of virtuous collection practices. Moreover, the definition of proper reward incentives, involving for example municipalities and retailers, seems to be effective for implementing revenue sharing mechanisms being consumers among the relevant stakeholders of a circular value-chains. Such actions should support increasing the volume and quality of returning resources thus increasing the industrial profitability of circular business practices.

E. Remanufacturing, Repair

At technical levels, different high-level business options for circular economy have been proposed to generate benefits by exploiting various value-creation mechanisms:

- *Repair:* relates to the correction of specified faults in a product. Repair refers to actions performed in order to return a product or component purely to a functioning condition after a failure has been detected, either in service or after discard. It decreases consumption, because the product's lifecycle is extended. After repair, products are then packaged, and distributed to the market.

- *Remanufacturing for function restore* it returns a used product to at least its original performance with a warranty that is equivalent or better than that of the newly manufactured product. A remanufactured product fulfils a similar function to the original part. It is manufactured using a standardized industrial process, in line with technical specifications.

- *Remanufacturing for function upgrade:* the process of providing new functionalities to products through remanufacturing. Remanufacturing with upgrade aims to extend products' value life enabling the introduction of technological innovation into remanufactured products in order to satisfy evolving customers' preferences and, at the same time, preserving as much as possible the physical resources employed in the process.

Specific innovation priorities should be developed to extend the use of these valuable practices in different sectors, as a lever for establishing new product function-oriented circular economy practices in industry.

E.1 Innovative Remanufacturing Technologies

E.1.1 Artificial Intelligence (AI) for the characterization of the product residual state

The reliable and precise characterization of the conditions of complex post-use products is fundamental for properly taking decision on the remanufacturability of the product, thus avoiding economic losses in remanufacturing due to incorrect classification and product quality assessment. This critical phase can be enhanced by combining data gathered from the product in-use phase and data observed during the post-use product testing, inspection and characterization phases.

To this aim, the use of artificial intelligence (AI) techniques seems adequate. These methodologies have the double advantage of being capable to exploit multiple data sources and being self-optimizing, thus increasing the accuracy and reliability of the analysis through learning and training. AI can be exploited both at operational level, for example through image processing algorithms to support defect recognition in post-use products, or at decisional level, to assess the most effective remanufactured product application scenario, the remanufactured product residual lifespan and to predict the expected performance.

The adoption of AI techniques in remanufacturing has the potential to considerably reduce remanufacturing costs and lead-times, ultimately increasing the product regeneration rates. Moreover, it can increase the customer acceptance level of remanufactured products, by selecting the best features of the product depending on the customer demand and paving the way for extended warranties on the remanufactured products.

E.1.2 Digital technologies for the simulation of remanufacturing processes

Remanufacturing processes are characterized by extremely high variability in the condition of the input post-use products, not observed during the manufacturing phase. For this reason, it can be said that each remanufactured product undergoes a custom multi-stage process-chain setting, involving multiple cleaning, disassembly, inspection, reprocessing and re-assembly steps, because of its unique post-use quality state. In support of the design and management of such complex process-chains, digital technologies and computer aided engineering systems for process/system design, management and control would be extremely beneficial in order to shorted process chain set-up times.

The data gathered from the incoming product testing and characterization phases shall be enhanced by simulation technologies, Digital Twins and Cyber Physical Systems (CPSs) in order to identify the best process-chain settings depending on the product conditions. The digital modelling and analysis of the remanufacturing process-chain would enable an item to item quality-oriented control of the remanufacturing process-chain, ensuring high quality of the remanufactured product and increased production efficiency, in line with the zero-defect remanufacturing paradigm.

E.1.3 Decision support systems for remanufacturing

Nowadays, strategic decisions about the remanufacturability of post-use products are mainly based on human experience. However, in presence of high complexity products and multiple recycling, remanufacturing and re-use circular routes, this approach can easily result to be inefficient, with high risk of misclassification and poor decisions which can directly translate into competitiveness losses for remanufacturers. Moreover, in presence of additional post-use product characterization data and multiple potential circular routes, a more systematic and formalized approach towards decision making seems to be a fundamental enabler for improving remanufacturing process chains performance.

In this context, a decision support system should take in input the available product and components characterization data (*see Section E.1.1, page 44*), the active optional circular routes, the actual demand and the remanufacturing system state and should analyse such input information to suggest optimal circular routes for the key product components and materials. Further integration of artificial intelligent and learning algorithms could be investigated to improve the quality of the decision along multiple implementation cycles.

Such decision support system will make remanufacturing decisions more systematic, enabling knowledge-based remanufacturing and improving traceability of the overall remanufacturing process chain, also providing space for improved circular economy production planning and control.

E.1.4 Automation, flexibility, and efficiency in disassembly operation

Disassembly operations are commonly adopted to retrieve target components before remanufacturing and recycling operations. However, the large variability of complex post-use products, the demanding quality requirements on recovered components and materials as well as the increasing attention on safety and ergonomics call for innovation in the design of disassembly processes and workstations.

New technical solutions and concepts of hybrid automation are needed for improved flexibility and efficiency of disassembly processes, as a suitable alternative to purely manual processes. These solutions should enable flexible handling of post-use products as well as enhanced selectivity in disassembly processes, grounding on the most innovative collaborative robotics, artificial intelligence, and cyber-physical systems technical enablers. Moreover, specific solutions for improving the efficiency of manual disassembly processes are promising, including digital instructions for disassembly, operators' monitoring for error avoidance, augmented reality solutions for learning and training of operators.

Such solutions should reduce set-up and processing times in disassembly operation, ultimately smoothing disassembly operational costs, also reducing human exposure to hazardous materials risks and increasing the target component and material selectivity, thus opening new opportunities for innovative, enhanced circular economy business cases.

E.1.5 Novel technologies and strategies for Remanufacturing / Repair / Reconditioning

The remanufacturing of a product always entails a set of advanced transformation processes to restore the functions of the product or component under treatment. Being implemented on highly variable and unpredictable component conditions, these processes should be endowed with high degree of flexibility and adaptability to the specific component conditions. Promising solutions to this challenge seem to be represented by integrated hybrid subtractive / additive technologies, able to provide new shape and functionalities to metallic components. While cracks, scratches, nicks and burrs can be removed by subtractive machining, the reconditioning of product functions can be performed through additive processes providing advantage of flexibility in processing free-form geometries and the ability of feeding different materials. Innovative cold spraying and coating technologies are also emerging solutions to provide the required surface functionality to the component. The ability of scanning the damage, obtaining a digital model of the component, and adapting the processing strategy depending on the defect seems to be a promising dynamic process-planning option.
By increasing the flexibility and quality of current reconditioning and repair enabling technologies and strategies would support the increase of the remanufacturing process-chain technical capabilities, contributing to extend the application scenarios as well as to increase

the quality and performance of regenerated products, thus extending the profitability of the circular business model.

E.1.6 Product upgrade processes

Remanufacturing for function upgrade represents a high value-added circular solution for updating the functionalities of upgradable products to fulfil dynamic customer requirements along the product life cycle. However, the product upgrade paradigm should be supported by suitably designed product upgrade strategies, systems and processes to be profitably implemented in the market, ultimately grasping the business opportunities of such high value options.

Although remanufacturing for function upgrade benefits from innovation applied to the remanufacturing for function restore business option, specific developments are required that are proper of this strategy. For example, novel production planning models should be developed to jointly capture the customer dynamic requirement evolution and the remanufacturing system workload and demand, being the socio-economic systems highly coupled. Moreover, new processes to incrementally upgrade the component functionality should be designed and developed. Furthermore, the modular structure of the upgradable product can be exploited to increase the degree of standardization and automation of the underlying transformation processes. If properly designed, developed and validated such strategies could contribute to the wide diffusion of the remanufacturing for function upgrade strategy, enabling to achieve the overall industrial uptake of the highest value circular economy business option.

E.2 Distributed and Flexible Remanufacturing Networks

The availability and diverse conditions of post-use products strongly affect the capability of centralized remanufacturing factories to keep a constant and controlled input flow. Moreover, the diversity in competencies and skills required to remanufacture the key components in complex products, such as mechatronic products, call for the establishment of networks of cooperating stakeholders for remanufacturing integrating the needed capabilities in a dynamic geometry structure.

To overcome these limitations, innovative business models should be explored. For example, the concept of “Remanufacturing as a Service”, namely the creation of a capillary network of small enterprises, capable of implementing flexible multi-product remanufacturing processes, would enable the dynamic management of post-use collected products by involving different stakeholders on the local territory. This capillary strategy can effectively mitigate the unpredictable fluctuation of the remanufacturing market input products, avoiding costly investments in centralized over-dimensioned capabilities guarantee, in the same way, the required quality of remanufactured products. Information sharing, revenue distribution and match-making services can suitably support the operation of such networks (*see Section A.3.2*). The development of these remanufacturing networks in the local eco-system can boost the development of remanufacturing in the Region by reducing the risks linked with considerable investments in facilities and technology acquisition.

F. Recycling

Recycling can be implemented in a *Closed* or *Open Loop* strategy. In the first case, it is defined as “a resource recovery method involving the collection and treatment of waste products for use as raw material in the manufacture of the same or a similar product”[23].

Closed Loop recycling of a material can be done indefinitely, without properties degradation (upcycling). In closed loop recycling, the inherent properties of the recycled material are not considerably different from those of the virgin material, thus substitution is possible.

Open Loop recycling refers to the conversion of material from one or more products into a new product, involving degradation in the inherent material properties (downcycling). In open-loop recycling, the inherent properties of the recycled material differ from those of the virgin material in a way that it is only usable for other product applications, substituting other materials.

Closed-loop recycling, in particular, is a more sustainable concept than Open Loop Recycling, in the sense that recycling of a material can be theoretically done indefinitely, without significant degradation of properties. However, in the current practices, closed loop recycling is rare while open loop recycling is more widely adopted. Therefore, all the reported priorities aim at improving the performance of current recycling technologies and systems in order to improve the grade and recovery rates of the output material streams, thus enabling higher added-value material re-use practices in a circular value-chain.

F.1 Innovative technologies for sorting and recycling

F.1.1 Selective disassembly for high-quality recycling

A major opportunity for increasing the capability of re-using waste materials into high value applications is to increase the quality of the recovered materials by applying an upstream high-quality sorting through the selective disassembly of homogeneous components before size reduction and sorting. Selective disassembly, mainly applicable to the post-use treatment of large infrastructures and products, such as those in the construction, naval, railway and aerospace industries, consist in the fast identification of key materials in the product components, in the selective disassembly of homogenous components and material fractions and in the on-site separation of such fractions in dedicated containers, prior to the transportation to the fine selection and recycling. In spite of the huge benefits in terms of quality of the recovered fractions, selective disassembly currently is poorly implemented being more expensive than traditional destructive dismantling processes. Therefore, innovative strategies, processes and technologies are needed to support an efficient

[23] EEA (European Environmental Agency), “EEA Glossary,” 2004.

industrial implementation of selective disassembly in view of a high value-reuse of the recovered fractions.
Several solutions are promising to support this virtuous recycling strategy but need to be further developed before the industrial uptake. For example, advanced on-site material inspection and characterization solutions for identifying the material composition of the key product components are needed. Such solutions should be coupled with digital technologies and data management systems, for exploiting product design information during the disassembly phase. Moreover, technical solutions for automated macro-sorting of disassembled components, such as collaborative robotics, can be useful to reduce classification and selection errors. Since the selection takes place on-site, it appears promising to develop modular and movable systems for implementing the sorting strategy close to the disassembled infrastructure. Furthermore, data transfer technologies based on Internet of Things may be needed to provide visibility on the recovered materials directly to the downstream fine treatment plants. The development of sectorial guidelines and standards for selectively disassembling specific products and components may be useful for process repeatability at large scale.
Selective disassembly would unlock several opportunities: from an environmental perspective, it makes it possible to recover recyclable or reusable parts and components with a consequent reduction in the quantity of material to be disposed; from an economic perspective, since increasing the reuse permits to limit the use of new raw materials and components, thus saving production energy and costs.

F.1.2 Design of flexible and reconfigurable recycling systems

Recycling systems are continuously challenged by the need of processing a continuously variable and always evolving input streams, mainly due to the product models evolution in the market. While traditional manufacturing processes can rely on controlled and rather stable quality raw materials, in recycling, different products and different end-of-life conditions make each input batch unique with respect to the others. Moreover, the secondary material market is characterized by high turbulence and variability in the material values and this creates further uncertainty to the recycling industry revenues. In spite of these challenges, current recycling systems are monolithic in their design and poorly capable of being adapted and reconfigured depending on different input material properties and market conditions. To overcome this variability, the new generation of recycling systems of the future should be characterized by high flexibility, reconfigurability and adaptability to profitably handle variable material streams.
In this view, several innovative solutions are promising. For example, new multi-level recycling system models, able to integrate the process physics and system dynamics in a unique framework, shall be developed to support system designers to jointly select the system layout and the characteristic process parameters, in order to achieve target grade and recovery levels for the valuable materials. Furthermore, new size reduction and separation process control solutions should be developed, exploiting cyber-physical systems capabilities for the on-line adaptation of the process parameters depending on the

characteristics of the input batches. Moreover, new intrinsically flexible separation technologies should be adapted, by integrating different separation principles within the same machine. Finally, new adaptable material transportation solutions, supporting material flow reconfiguration in the plant should be integrated in recycling systems, also supported by emerging plant distributed monitoring and control solutions.
The design, development and validation of such innovative solutions for the recycling systems of the future would considerably reduce the life cycle and operational costs of the system, by making the recycling plants more robust to market changes and product evolutions. Moreover, it will increase the level of modernization of recycling systems in an industry 4.0 perspective, thus increasing the traceability and reporting capabilities about actual material recovery and grade rates, thus making it easier to quantify the overall recycling rates in the Region.

F.1.3 In-line material identification through optical systems

With the objective to provide intelligence to the recycling system and enable adaptability to different post-consumer products and conditions, the application of innovative in-line material characterization technologies, based on vision systems, can provide capabilities for: i) a full materials data storage and traceability, ii) a remote monitoring and control of the separation processes, and iii) an easy reconfiguration of the system.
Indeed, it would enable the recycler to have a continuous visibility of the material under treatment, gathered in-line and during the process, thus avoiding expensive and time-consuming off-line sampling material characterization procedures, such as those typically implemented by using Inductively Coupled Plasma - Mass Spectrometry (ICP-MS), Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES), Scanning Electron Microscopy (SEM). To this aim, a promising solution seems to be the development of multi-sensor material characterization systems. Such systems, integrating in-line multiple optical sensors and cameras, for example Hyper-spectral Imaging (HSI), Multi-spectral Imaging (MSI), X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF) for product and material characterization would exploit the identification capabilities of different technologies in the same machine settings. Post-processing Artificial Intelligence algorithms as well as specific calibration methods and set-ups need to be investigated in order to achieve high material and product identification capabilities.
Information about the product/material under treatment is relevant at different stages of the de-manufacturing process-chain: before the process, with the aim to estimate the value and the composition of End-of-Life products and to set the proper process flow; during the process, for process control purposes; after the process, for quality control and continuous improvement/optimization. This priority would support all the objectives, moving towards the establishment of more autonomous and controllable recycling systems of the future.

F.1.4 Robotics for sorting

Current recycling systems are highly based on the use of various manual sorting stages for increase the homogeneity and liberation degree of material streams to be sorted and separated. Indeed, manual sorting is effective in presence of complex, highly mixed and difficult to identify materials. However, manual sorting in the upstream separation process stages may lead to safety and ergonomics risks for the operators, due to the presence of hazardous substance contamination of input streams, the high loads involved, and the material conditions (corrosion, jamming, dirt, etc.). Therefore, with the goal of improving the operators' condition in recycling systems and guaranteeing a high sorting quality and repeatability the use of robotic sorting seems to be a promising solution.

Robotics sorting systems shall be endowed by reliable systems for fast identification of the materials and components to be sorted. Moreover, they should be equipped with flexible grippers to grasp highly inhomogeneous materials and components. Finally, due to the current recycling system volumes, they shall be designed and fine-tuned for application in high throughput contexts.

These innovative identification and sorting technologies can lead to an increase in quality of recycled aggregates and materials, while increasing safety and providing enhanced ergonomics to workers operating in modern recycling systems.

F.1.5 New recycling and recovery technologies

The profitability of recycling business models is strongly connected to the quality, volume and value of obtained secondary raw materials. To achieve high quality secondary material streams and support the transition to a wider adoption of closed loop recycling, innovative recycling process-chains and technologies should be investigated and scale up to the industrial maturity level. This priority is especially useful for emerging complex waste streams such as multi-layer materials, including composites, plastics, in particular black plastics, and electronics products.

For example innovative integrations of advanced mechanical recycling processes, such as high-voltage fragmentation, thermal processes, such as low temperature or controlled environment pyrolysis processes, and chemical recycling processes, such as hydrometallurgical processes, can increase the recovery and grade rate of complex material flows while reducing the environmental footprint of the process-chain. To support the modern industrial implementation of these innovative process-chain, the proper integration of advanced process-chain analysis models and digital twins would make it possible to fine tune the process-chain parameters and to digitally validate performance before the investments and the industrial implementation.

Another promising area of innovation is represented by solid-state recycling. Solid-state recycling has been proposed as a viable and eco-efficient alternative to thermo-chemical processes for end-refining and re-production of light metals in bulk as well as sheet components. The recovered material is treated by means of plastic deformation and directly formed into the final product. The main advantage of this technology is the avoidance of melting process for the material through the use of cold or hot re-forging, re-forming and powder metallurgy technologies. The drawbacks are the need for highly pure recovered input materials, which makes solid-state recycling applicable mainly to industrial scraps and chips formed during metal cutting processes.

Both innovation priorities will contribute to enhance the capabilities of current recycling systems to gather high-quality secondary material sources to support the re-use of recovered fractions in high-value applications thus unlocking the potentials for circular value-chains in the regional eco-system.

G. Feedstock Recovery

It is a process of restoring materials found in the waste stream to a beneficial use which may be for purposes other than the original use, e.g. resource recovery in which the organic part of the waste is converted into some form of usable energy. In particular, biological materials have intrinsic energetic power. The extraction of it before the disposal of the product/material allows an increase in resource productivity. Usually, the energy is extracted by the formation of natural gas and/or heat due to chemical digestion, or by soil restoration.

G.1 Development of New Biotechnologies

G.1.1 New bio-based technologies based on eco-friendly concept

Circular Bioeconomy responds to the environmental challenges the world is facing, oriented to reduce the dependence on natural resources by using bio-waste to produce energy and bio-based products. Industrial Biotechnologies, are considered the "key" for the development of the bioeconomy; they are able to generate value from what is considered worthless (for example, CO2 or wastewater), transforming waste into a resource, according to the principles of the circular economy. However, using biomass is not enough. For a real sustainability, biomass must be used efficiently and ideally for purposes for which there are no other renewable alternatives, in order to respond to economic challenges, environmental and social issues already mentioned. The term "new bio-technologies" includes two research streams and applications. First of all, it refers to the manipulation of genomes to synthesize valuable products, which opened the way for synthetic biology. Secondly, it refers to the intrinsic reaction capacity of microorganisms (fungi and bacteria) or biological agents for product development.

The application of these new technologies is closely related to the starting biomass, it’s a tailor-made activity, highly personalized service, designed and implemented case by case based on the specific needs that emerged in the contingency.

For this reason, every biotechnology application will be developed with physical, chemical, bio-chemical and biology characteristics (for example temperature, pH, pressure and water concentration).

G.2 Valorise bio-waste to support the transition from fossil-based to bio-based processes

One of the central pillars of a circular economy is feeding materials back into the economy and minimising waste being sent to landfill or incinerated, thereby capturing the value of the materials as far as possible and reducing losses.
New instruments and technologies should be developed in order to use biomass waste sources also for the reduction of use of fossil fuels in the framework of the energy transition.

In particular, biomass that represent a waste for some sectors (such as sewage sludge) can be an alternative feedstock, then a resource, for industries in different sectors (i.e. use of biomass waste streams).

3.IV Boundary conditions and barriers for Circular Economy

Although Circular Economy paradigm represents a great opportunity for the entire regional ecosystem, joint efforts and improvements are still needed to overcome the non-technical barriers that are affecting the transition toward Circular Economy models. These barriers have been identified as *Legislation, Regulations and Incentives, Pilot and Demonstration Infrastructures, Education and Skills, Awareness and Culture* and *Ecosystem Building.*

Legislation and regulation

Authorities at different levels (i.e. Regional, National and European) play a strategic role in supporting businesses toward their transition to Circular Economy. As of today, there are still several barriers represented by regulation and taxation that discourage companies in implementing Circular Economy solutions. For example, concerning the usage of raw materials, it is hampered by existing regulation and taxation patterns, which often make virgin raw materials cheaper than secondary ones. In addition, the lack of harmonisation across EU Member States in the definition and implementation of integrated and aligned plans is also hampering the widespread of circular economy business models. Indeed, the absence of a strong and consistent waste management protocols among Europe is leading to inefficiencies, which make the recycling processes more costly.

Another important aspect that should be fostered by authorities is the definition of specific goals and targets for companies as well as metrics for product certifications, to state baseline industrial situations with respect to circular economy, to fix target objectives, and to quantitatively track progresses towards these objectives a comprehensive metrics, including a set of multi-dimensional Key Performance Indicators (KPIs), should be developed. Such metrics should also support the comparison among circular initiatives in different sectors. Although an initial attempt has been made, through the Monitoring Framework – COM (2018), further actions are needed to bring these indicators in operation at Regional level and to make them accepted and shared by the stakeholders.

Piloting and demonstration infrastructures

To achieve a large scale impact and fundamental transformation of the regional industrial eco-system towards circular value-chains, investments in research and innovations for the development of innovative technologies and new business in Circular Economy should be complemented by specific measures and support instruments to guarantee the industrial uptake of innovative technologies and models by industry. Indeed, beside fostering R&I actions, it is fundamental to support companies in the uptake and integration of those technologies in their production systems and business practices.

Pilot and demonstration infrastructures and facilities represent key assets to be developed in the region based on stakeholders needs and priorities, in line with the Lombardy Region activity within the European Vanguard Initiative – New Growth Through Smart Specialization. These infrastructures should be the results of public-private investments, aimed at building industry-oriented pilot demonstrators or upgrading existing laboratories and infrastructures able to ensure the uptake of Circular Economy practices by local companies through proper resources, competences and knowledge. Such infrastructure should integrate pilot plant solutions, needed by industry to validate high-risk investments in circular economy businesses before the industrial implementation. They should integrate a multidisciplinary set of advanced and innovative enabling technologies and digital innovations (TRL 7-8) and should exploit the regional Smart Specializations in synergic way to offer services to regional end-users, mainly manufacturing companies, to solve specific sustainability-oriented problems related to their products. The underlying principle of "test before invest" is driving this priority, setting up "one stop shop" technology gateways that can demonstrate to industry integrated circular economy solutions and business models, de-risking the private investments.

Education and skills

New competencies and capabilities need to be spread among stakeholders to extract the maximum potential from Circular Economy activities and to ensure the transition toward Circular Economy paradigm at all levels. Accordingly, actions need to be implemented both at academic and industrial level building new competencies and knowledge from one side while improving already existing skills on the other side.

More in details, universities should reflect on the design of specific courses targeted to key topics (i.e. De-and Remanufacturing technologies, materials...) which provide students with the required skills and competencies. In these new study programmes, field training should be considered bring students into factories experimenting new skills in the real factory environment.

In parallel, training courses should be designed and activated also for workers and employees, giving them the opportunity to improve their competencies and skills toward Circular Economy. Thus, Teaching factories will assume a strategic role in unleashing the potential of Circular Economy.

Awareness and culture

Although Circular Economy practices are becoming more and more widespread across several sectors, there is still the need to raise awareness on the impact and benefits generated by Circular Economy models, not only on citizens but also on industrial actors, who are in some cases still reluctant in the use of materials and/or products recovered from waste.

In particular, in a B2B context, it is necessary to generate a market for secondary raw materials, building trust and reliability among customer and suppliers on the quality and compliance of recovered products and/or materials. More in general manufacturers need to fully understand the value of maintaining the value of products and materials rather than destroying it through landfilling, incineration and downcycling. As outlined previously, authorities can play a strategic role in this sense, providing specific protocols and standards for certifications.

The same can be done in the B2C context, fostering actions targeted to improve Circular Economy culture and raise awareness on the positive impacts coming from the adoption of consumables obtained by Circular Economy practices as well as on the role that each person can play in enhancing recycling and/or recovery of EOL products.

Ecosystem building

An existing barrier towards the creation of a sustainable and circular economy in the region is the high fragmentation of competences and technical capabilities and the lack of interaction between the local stakeholders. Local actors need to understand the importance of creating networks, in order to grasp business opportunities together and contribute to the development of circular initiatives.

Therefore, it is strategic to encourage the creation of stable networks of stakeholders in the region, identifying complementarities, creating synergies along the value chain and promoting the innovation and best practice exchange. In this context, SMEs should be specifically supported considering the difficulties that they may encounter in implementing sustainable solutions, allowing them to understand on the mid and long-term objectives and benefit of the transition to Circular Economy.

To this end, Regional Technological Clusters can play a strategic role as intermediaries favouring interactions among the Regional authority, companies, universities and research centres, in order to create research and innovation projects and sustainable paths to scale-up innovative solutions and to promote the creation of networks in the area of circular economy.

3.V Emerging Circular Economy Requirements and Societal Needs linked to the COVID - 19 emergency

The recent Covid-19 crisis showed that global supply chains and production systems, as they are currently conceived, are not prepared to face disruptive events such as pandemics. More in general, as it was experienced in the last years, manufacturing is vulnerable against big disruptive events that limit value chains operations (such as earthquakes, wars, political and social conflicts, etc.), such as in raw materials production and supply, logistics and distribution, factories operations, international cooperation, etc.

The impact of such a vulnerability is dramatic since, all in a sudden, production systems are not able to supply anymore products and services needed to guarantee citizens' health, welfare and proper functioning of modern economies.

During the Covid-19 emergency, the manufacturing ecosystem of Lombardy Region gave an extraordinary proof of reactivity to re-convert and re-organize productions in order to fulfil the immediate needs of products needed to face the emergency. This was possible thanks to the combination of multiple competences and technologies that characterize the various regionals specialization sectors, traditional enterprise vocational attitude for flexibility and manufacturing, with special regard to SMEs, as well as to Regional ecosystem research and innovation capabilities, where companies, Universities Research and Technology Organizations and Associations are used to cooperate, supported by Technology Clusters, in research and innovation projects and initiatives.

However, such an experience showed clearly that the potential of research and innovation, that represent one of the strongest leverages to respond to such crises, needs to be exploited before such crisis happen in order to equip the manufacturing ecosystems with the enablers that are needed to increase their robustness and resilience.

Circular Economy can play an important role in this sense. More than revolutionizing the priorities identified in previous sections, resulting from a wide, long-term and regionally-shared strategic process remaining valid for medium-long term programming, the Covid experience shows that some of the identified priorities should be taken close consideration for the above mentioned goals. Such priorities can be declined in the crisis specific context. Thus, the scope of this chapter is to identify, among the research and innovation priorities included in this Roadmap, those more suitable to respond strategically to the specific requirements and needs of the current emergency situation, in line with the new Regional Circular Economy socio-economic model promoted by this Roadmap. Priority identification and contextualization is proposed in the following table, where priorities descend from specific challenges that need to be addressed during crises times, the requirements they pose and the innovative solutions that can be adopted to address them.

Challenge and motivation	Requirements and needs	Innovative solution	Roadmap Circular Economy Priorities
During and after the pandemic, there will be shortage of key resources and primary materials supplied worldwide, or delivered locally, to feed production value-chains. It is of paramount importance to enhance the local eco-system to increase the local supply of secondary materials as well as to increase the flexibility of production systems in accepting both virgin and secondary materials.	Increasing the availability of secondary raw materials in the local eco-systems by dynamically setting up local circular value-chains on-demand. Increasing the robustness, adaptability and flexibility of production systems in order to accept both virgin and secondary raw materials.	Cloud based platform for value-chain integration and local dynamic circular value-chain building.	• **A.2.2**: Re-valorisation of secondary products and by-products through industrial symbiosis • **A.3.2:** Data storage and sharing • **A.5:** New Cross-Sectorial Business Models for Circular Economy.
		Cloud-based platform for dynamic cooperation and production capacity sharing.	• **A.3.2:** Data storage and sharing. • **A.5:** New Cross-Sectorial Business Models for Circular Economy. • **B.3:** Exploitation of Local Production-Distribution-Consumption Networks. • Ecosystem building
		Co-design of products containing considerable fractions of secondary raw materials whose formulation may be modified over time. Methodologies and processes for fast design and certification of new products.	• **A.1.1:** Product design criteria for Circular Economy. • **A.1.2:** Design targeted to increase the percentage of secondary raw materials in new products. • **A.1.4:** Consumer-driven co-design. • **A.3.4:** Certification of re-usable products, components and materials
		Adaptation and flexibility of production systems and value-chains for accepting both virgin primary materials and increased fraction of re-usable secondary materials.	• **A.2.2:** Enhanced process robustness and flexibility for reusing components and materials from post-use products as production inputs for new products. • **A.5:** Support to Circular Economy Oriented Production.
During the pandemic diffusion, people is requested to stay home and lockdown strategies are put in place. This poses challenges to distributed waste collection practices as well as opportunities for safe re-use of products.	Increasing the capacity of safely storing waste at collection sites. Improving the door-to-door waste collection capabilities. Improving traceability and safe re-use in local consumption areas.	Design and produce fully recyclable temporary waste storage capacity extension systems.	• **D.1.2:** Waste management protocols. • **D.1.1:** Proactive “take-back” protocols for re-use.
		Design and demonstrate low-cost, decentralized and small volume, sorting and separation urban plants to be installed in residential building to safely purify re-usable materials.	• **D.1.2:** Waste management protocols. • **D.1.3**: Safety in the transportation of hazardous products. • Awareness and culture
		Set-up new collection schema supporting re-use and safe resource and product sharing	• **D.1.1:** Proactive “take-back” protocols for re-use. • **D.1.2:** Waste management protocols. • **D.1.3**: Safety in the transportation of hazardous products. • Awareness and culture

During the pandemic diffusion, adopted lockdown measures also include the interruption of production activities. However, the municipal waste flows are massive as consumption continues. This would require solutions for a continuous operation of waste treatment facilities in safe environments.	Specific measures for ensuring health of recycling plant employees and automatize waste treatment operations are needed.	Sensor-Based Sorting Systems in waste Processing.	• **F.1.1:** Selective disassembly for high-quality recycling. • **F.1.3:** In-line material identification through optical systems.
		Robotics enabled collection, disassembly, sorting and processing of the waste.	• **F.1.4:** Robotics for sorting. • **F.1.5:** New recycling and recovery technologies. • **E.1.4:** Automation, flexibility, and efficiency in disassembly operation
		Remote control of recycling processes and systems for recycled material quality. Virtual technologies and other digital technologies allowing remote operations of plants and minimizing the number of employees for plants operations.	• **F.1.2:** Design of flexible and reconfigurable recycling systems.
During the pandemic diffusion, there is lack of availability of protection equipment, such as masks and glows. Moreover, all shops except food shops are closed and this causes the lack of specific small products, components and materials for normal life at home, such as glasses, bowls, jars, handles, glasses rods, etc.	Low cost technologies for urban or domestic production, starting from parametric downloadable files adaptable to the consumer needs. Such temporary products should be easy to recycle and re-use after the pandemic period. Solutions for locally producing protection equipment at reduced costs, potentially using secondary resources.	3D printing for urban or direct customer manufacturing of the protection equipment and other house components, with reduced material consumption and avoidance of waste.	• **A.2.2:** Enhanced process robustness and flexibility for reusing components and materials from post-use products as production inputs for new products. • **E.1.5**: Novel technologies and strategies for Remanufacturing / Repair / Reconditioning. • Education and skills • Awareness and culture
		Local production and distribution of easily recyclable masks and protection equipment made of recycled materials, certified and tested.	• **B.3:** Exploitation of Local Production-Distribution-Consumption Networks. • **A.1.2:** Design targeted to increase the percentage of secondary raw materials in new products. • **A.1.4:** Consumer-driven co-design. • **A.3.4:** Certification of re-usable products, components and materials.
During the pandemic diffusion, huge amount of post-use medical devices and support materials (masks, protective suits, gloves, etc.) made of multi-layer polymeric materials, textile and composites are disposed, which should be safely treated and recycled by specialized process-chains.	Development of safe high-capacity, temporary facilities for the treatment of medical waste, in view of a circular economy compliant material re-use.	Design, development and testing of controlled environment thermal recycling-based process-chains and plants for temporary high-capacity treatment of medical devices for the recovery and re-use of polymeric and fiber fractions.	• **F.1.2:** Design of flexible and reconfigurable recycling systems. • **F.1.5:** New recycling and recovery technologies.

During the pandemic the road and rail transportation of goods in Europe is not interrupted. However, as many industrial facilities are closed, there is need of spare parts and components for vehicle maintenance.	A continuous supply of high-quality remanufactured components is needed for the aftermarket.	Develop innovative remanufacturing solutions for collecting and regenerating post-use components to match the constant demand for high-quality parts for the European aftermarket, in spite of the temporary lockdown of industrial value-chains.	• **E.1.1:** Artificial Intelligence (AI) for the characterization of the product residual state • **E.1.2:** Digital technologies for the simulation of remanufacturing processes • **E.1.3:** Decision support systems for remanufacturing • **E.1.4:** Automation, flexibility, and efficiency in disassembly operation • **E.1.5**: Novel technologies and strategies for Remanufacturing / Repair / Reconditioning • **E.2:** Distributed and Flexible Remanufacturing Networks.

Conclusions

This document is the result of a collaborative initiative, which involved several actors of Lombardy innovation ecosystem and led to the identification of Research and Innovation Priorities for Circular Economy in Lombardy Region. As first step of the policy design process, Lombardy Region has identified in this Roadmap a source of inputs for the definition of its industrial policies, targeting specific challenges, needs and priorities emerged from the regional stakeholders. Considering the cross-sectorial potential of Circular Economy solutions, priorities have been outlined involving representatives of the 7 Lombardy Specialization Areas (Aerospace, Agro-food, Eco-industry, Creative and cultural industries, Advanced manufacturing and Smart Mobility).

More in details, thanks to a mixed approach, European and National contexts were analysed along with the inputs collected from the regional innovation ecosystem. The resulting set of Research and Innovation priorities were transferred into this Roadmap considering the different aspects that characterise the different Lombardy Specialization Areas and highlighting the peculiarities of the main Lombardy industries.

A. Production	**B. Distribution**
• Design for Circular Economy • Circular Production Processes • Enabling traceability in product and processes • New Cross-Sectorial Business Models for Circular Economy • Support to CE Oriented Production	• Establishment of Synergies Among Forward and Reverse Logistics • Development of Market/Pricing Strategies to Increase the Willingness to Buy of Sustainable Products • Exploitation of Local Production-Distribution-Consumption Networks • Circular Economy Driven Public/Private Procurement
C. Use and Service	**D. Collection**
• Product Life-Cycle Extension • Product-Service System	• Reverse Logistics • Citizens engagement and incentives
E. Remanufacturing / Repair	**F. Recycling**
• Innovative Remanufacturing Technologies • Distributed and Flexible Remanufacturing Networks	• Innovative technologies for sorting and recycling
G. Biochemical Feedstock Recovery	
• Development of New Biotechnologies • Valorise bio-waste to support the transition from fossil-based to bio-based processes	

In addition to value-chain based priorities, the Roadmap highlights the need of focusing on a set of non-technical priorities to favour the transition to Circular Economy enabling the adoption of systemic approach rather than the implementation of incremental improvements to the existing linear model. Those priorities, summarised as *Legislation and Regulation, Piloting and demonstration infrastructures, Education and skills, Awareness and culture* and *Ecosystem building* have been detailed in terms of recommendations and strategic actions to be implemented by several stakeholders (from policy makers to industrial associations, from universities and research bodies to companies).

Therefore, this Roadmap will serve as guideline for Lombardy Region to further strengthen its Smart Specialisation Strategies and update its policies with regional innovation ecosystem needs. To this end, updates will be constantly delivered in alignment with new programming periods and in coordination with Smart Specialisation and Sustainable Development Strategies. Furthermore, this document will be also exploited to identify synergies and complementarities with other regions in terms of R&I priorities, thus establishing strategic collaborations in specific domains based on S3 strategies.

Annex 1 – Specific Sectoral R&I Priorities

Aerospace

R&I Priority	R&I Sectoral Priority	Description and envisaged solutions
A1 Design for Circular Economy	**Structures optimisation**	Implementation of advanced engineering and design systems aimed at reducing weight and optimise the usage of materials, through the implementation of Life-Cycle Management and eco-design principles.
A1 Design for Circular Economy A.4 New Cross-Sectorial Business Models for Circular Economy	**New materials development**	Introduction of new innovative materials for aeronautics components production.
A.4 New Cross-Sectorial Business Models for Circular Economy C.1 Product life-cycle extension E.2 Distributed and flexible remanufacturing networks	**New business model and services for sharing & Product lifecycle extension**	Identification of new business model aimed at maximising the products utilisation and product lifecycle extension: • Simulation can be used instead of real machines to increase the products duration and reduce environmental impact at the same time • Substitution of components which are at the end of their life • Conversion of planes to other applications (from civil to logistic transportation)
E.1 Innovative remanufacturing technologies	**Regeneration, Reuse and recycle**	The need of reducing the aircrafts weight has favoured the use of composite materials that now require further developments, such as: new recycling processes of dull materials to allow a low environmental impact recovery of large quantities of material (either end-of-life planes parts or wastes from the processing) Metal and electrics components are regenerated ad re-introduced in the market according to their residual life.
D.1 Reverse logistics	**Reverse logistic optimisation**	Identification and creation of consumers-recycler networks facilitating reverse logistics and products dismantling.

Automotive

R&I Priority	R&I Sectoral Priority	Description and envisaged solutions
A.1 Design for Circular Economy A.2 Circular Production Processes A.3 Enabling traceability in product and processes A.4 New Cross-Sectorial Business Models for Circular Economy	**Reuse of EoL materials directly within by steel-processing plants, with minimal pre-processing and waste.**	Development of advanced technologies for dismantling, size-reduction, separation and sorting that allow high throughput treatments.
A.1 Design for Circular Economy	**Coordination among recycling and design phases: Co-Design between recycler and product designer.**	Norms and information sharing systems to develop a co-design, which takes into account technical difficulties of de-manufacturing and recycling. In parallel with those norms, it could be beneficial to develop guidelines within each company, designed with consortia and recyclers.
A.2 Circular Production Processes	**Use of fine powder from tires as raw material for modified asphalt manufacturing**	In the steel mill industry, around 20% of dross is landfilled, even if they have suitable structural properties to be reused. The same is true also for the fine metal parts recovered from lead batteries, and the glass from cathode ray tubes. Change the regional legislation on materials/products classified as waste when they are re-usable as secondary raw materials in other applications (e.g. fine tire powder, steel dross)
A.2 Circular Production Processes	**Use of dross produced by steel works as secondary raw material**	
A3. Enabling traceability in product and processes	**Detailed data about products is existing, but not easily accessible.**	An interesting proposal is the creation of a norm/standard for the management of product data. This should point out which is the subset of data, among all the data owned by producers, that would be useful to the recycler, and enable their easy re-constructability and/or transferability. To do that, the group agrees upon the fact that it would be necessary to carry out an extensive research to identify the nature, quantity and quality of such "recycling" data.
A.2 Circular Production Processes A.4 New Cross-Sectorial Business Models for Circular Economy	**Use components and materials from End-of-Life products as production inputs for new products.**	The circular economy normative process should be informed by scientific and technical results of tailored research projects, and should involve materials, chemical, and environmental experts. It should base on quantitative and objective environmental studies and impact assessments. The solution proposed is the creation of sub-texts within the norm, which would be added modularly in time, and take into account the specificity of each application. This would demand the creation of a normative process, similar to the one applied to new pharmaceuticals (with different stage of trials) to understand if each application would be environmentally safe or not.
A.5 Support to CE Oriented Production	**Manufacturer-centric circular economy, in order to have a higher economic return from circular practices.**	Conformity norms should be compulsory for all products. An EPR legislation revision is needed. Facilitate and make compulsory the information flow along the value-chains to increase traceability. Create partnerships with other regions with massive presence of carmakers and designers.

C.1 Product life-cycle extension	**Recover material/product before it is classified as waste (as in the repair cafes)**	Promote new financial models to support circular material re-use. Rise the number of courses in universities about business models for materials/products recycled.
C.2 Product-Service System	**Car sharing and/or integrated mobility systems allows a higher control over the vehicle life cycle, because the vehicle is owned by the company delivering the service during the use phase. This means that the maintenance, and post-use treatment of vehicles could be performed more efficiently, and in a more controlled way.**	"Communication and awareness campaigns for citizens/companies finalized to sustainable mobility. Support research, innovation and pilot actions towards the identification of circular economy businesses non combustion engine cars, exploiting non-ownership car sharing models. The fleet management can provide information about the vehicle lifecycle and maintenance facilitating the post-use phase. Moreover, the fleet managers can leverage on the critical mass of vehicles available to exploit mass-economy and boost profitability of end-of-life CE strategies.
E.1 Innovative remanufacturing technologies	**Use of innovative technologies (e.g. collaborative robots) to quickly disassemble cars (less time needed equals a diminished cost to recover components)**	Conversion of car demolition businesses into “Smart Dismantlers” which make recoverable and reusable materials and component from car, available for further treatment, on demand.
E.1 Innovative remanufacturing technologies **E.2 Distributed and flexible remanufacturing networks** **F1. Innovative recycling technologies**	**Identification of technologies, value chains and business models for electric vehicles remanufacturing and recycling.**	Norms and information sharing systems to develop a co-design, which takes into account technical difficulties of de-manufacturing and recycling. In parallel with those norms, it could be beneficial to develop guidelines within each company, designed with recycler
F1. Innovative recycling technologies	**Higher recycling efficiency of collected waste**	Increase the link between manufacturer and de-and remanufacturer, by creating common discussion tables and sharing technological innovations. The cluster could help in this activity. The objective is the creation of metrics to baseline and track progress. This solution aims to illustrate and to enlighten the need for further actions in a comprehensive and comparable manner.

Biomass

R&I Priority	R&I Sectoral Priority	Description and envisaged solutions
A.1 Design for Circular Economy	**Product design for circular bioeconomy**	Lombardy Region ranks among the main biomass producing regions, both from the forestry sector and from the agricultural and agri-food sector. Mapping the biomass supply - including novel and alternative feedstocks (biowaste, CO2, marine biological resources) building on existing knowledge, approaches and tools would foster the design phase for biomaterial and related processes which is usually have numbers of inputs and techniques to take into account.
A.3 Enabling traceability in product and processes	**Inter-regional waste management protocols**	Trans-regional transportation and exchange of waste could become a relevant circular economy enabler if properly regulated and managed. This opportunity aims to develop safe and conscious inter-regional waste management protocols. In particular, these protocols shall be focused on the enhancement, both in terms of quality and traceability, of the procedures of waste management, from collection to recycling in every sector. The development of IT waste management platforms in a Zero Waste perspective could support the transparent implementation of such protocols.
A.3 Enabling traceability in product and processes	**Standardization of waste management**	The development of common rules and standard procedures for waste management, from collection to recycling of end of life products, can support a more efficient and effective recovery and recycling of goods across all sectors.
A.4 New Cross-Sectorial Business Models for Circular Economy	**New business models for bioeconomy start-ups**	The bio-economy sector is populated by large companies that exploit economy of scale to reduce the impact of their high cost infrastructure and stay competitive on the market. However, several innovative business opportunities are emerging in small medium enterprises and local business stakeholders that could be enhanced through innovative business models in order to reach the market. This opportunity aims to develop new business models in biomass and, more in general in bioeconomy, to encourage and improve the creation of innovative start-ups in this field. Such business models should create the economic and financial preconditions for these business opportunities to emerge with sustainable and credible growth patterns.
A.4 New Cross-Sectorial Business Models for Circular Economy	**Implementation of a multi-user web platform for value-chain integration**	Information sharing among different stakeholders of the value-chain is one of the most promising enablers for emerging circular economy business models. A cross-sectorial web platform should be implemented for the creation of a virtual market containing the description, the volumes and the geographical localization of the waste materials coming from different sectors (for example, from construction and to textile to other sectors). The platform should be multi-users, in the sense that multiple stakeholders should provide and retrieve information, in different stages of the value-chains. For example, plant managers may provide data related to processing capabilities, product designer may retrieve data about material characteristics, recyclers may retrieve data about products to be processed. In the Lombardy Region, ANCE Lombardia (construction sector), ANPAR (recycling sector) and Centrocot (textile sector) are independently setting up or already testing similar digital platforms.

B.3 Exploitation of Local Production-Distribution-Consumption Networks	**Local production – consumption chains of biomass**	Supporting the development of a local circular value-chain, from production to consumption, could reduce the logistics costs in the biomass sector and become a promising strategy, especially for biomass from forest resources, agricultural, industrial and civil sludge production waste. For example, in the wood sector, a smart use of forest resources could enhance local economies by enabling use both in the industrial and manufacturing sectors as well as in energy production. As another example, the sewage sludge valorisation can decrease the resource loss (by landfilling) and increase the decarbonisation. However, enhanced knowledge of the specific production-consumption capabilities at local level, aiming at the establishment of a stable local value-chain, should be gained at regional level. An additional example is represented by the usage of ""energy crops"" in fields not used for cultivation can provide feedstock with stable quality and quantity since the production is constant. Moreover, energy crops can be traced."
B.3 Exploitation of Local Production-Distribution-Consumption Networks	**Promote stable and competitive supply of sustainable biomass**	The use of biomasses for bio-based production has several advantages. The biomass use in bio-based industries is important for those sectors to decarbonize. Following the implementation of Circular Economy waste management provisions, it is expected that important bio-waste quantities will become available.
D.2 Citizens engagement and incentives	**Enhance the role of customers (civil society) towards circular economy**	Customers need to become more and more aware of their power to influence the way companies design, produce and distribute their products. Large public institutions can play an important role in this transition by becoming themselves conscious customers of green products and thus influencing the manufacturers' attitude towards circular economy.
E.2 Distributed and flexible remanufacturing networks	**Developing multi-regional pilot innovation facilities**	Several initiatives have been launched at European level to support industry in the transition to more sustainable circular economy businesses. However, innovations and demonstrators developed within projects find significant barriers in achieving the market as companies see circular economy as a high-risk investment area. The major barrier is the lack of infrastructures or platforms that can incorporate these innovative technologies and services within integrated pilot plants to show-case to industry the developed technologies in real industrial environments and to boost their private exploitation and replication at industrial scale. Such infrastructures should act as "technology gateways" that any business sector can use. Enhanced support should be dedicated to the building and operation of multi-regional Pilot Facilities which will substantially improve sustainable innovation capacity of Europe. The development strategy should ground on the Smart Specialization Strategies of the Regions and regional best practices, thus exploiting the local eco-systems to achieve extended impact at European level This concept is a crucial element in dealing with societal challenges as the development of a sustainable, innovative and knowledge-based economy in Europe, creating jobs and meeting climate change targets.
G.1 Development of new biotechnologies	**Promote valorisation of biomass waste**	Supporting a systemic approach to innovation, for the development of tailored technologies for valorisation of specific local biomass, waste streams as well as CO2, also with the aid of advanced digital technologies for big-data analysis, optimization and automation. New innovation processes (such as co-combustion technologies) that allow a better use of all non-food competing biomass sources, can help to decrease the loss of valuable resources, mainly in the energy sector.

		Among the innovative challenges proposed by the main players operating in the biomass sector, there is the possibility of developing and designing environmentally friendly mono-material products. A concrete example is represented by the production of bioplastics and bioproducts from renewable sources such as corn.
G.2 Turning fossil-based processed processes into bio-based processes	**Promote industrial symbiosis in the biomass sector**	Creating, through a cooperation with the stakeholders, a Bioeconomy marketplace in order to match the demand and supply of biomass, technology, and services. Collect and share data on biomass and biowaste actual and potential availability, technological processes, research project, in order to put into practice and showcase industrial symbiosis, technological innovation and best practices. In order to guarantee enough access to alternative biomass sources, reduce the coal dependency, and reduce the import of fuel, it is expected that dedicated instruments will promote the collection and valorisation of bio-waste. In particular, biomass that represent a waste for some sectors (such as sewage sludge) can be an alternative feedstock, then a resource, for industries in different sectors (i.e. use of biomass waste streams).

Built Environment

R&I Priorities	R&I Sectoral Priority	Description and envisaged solutions
A.1 Design for Circular Economy	**Design of new buildings as "material banks"**	Design and build new buildings in a way that they can be disassembled and recovered.
A.2 Circular Production Processes	**Increase the quantity of secondary raw materials use in the built environment**	The growth of secondary raw materials use in the built environment is an important opportunity that can be boosted in particular by increasing the percentage of recycled materials in the construction of new infrastructure (e.g. binder, milled material, aggregates, concrete). In order to develop this opportunity an important policy option is to stimulate the regional authorities towards the development of new technical specifications and legislations targeted incentivizing material re-use in construction. More concretely, in this context the relevance acquired by the MEC (Minimum Environmental Criteria) in Green Public Procurement policies seems to be a real opportunity. The challenge is to increase the MEC relevance (currently compulsory, but no fees or penalties are foreseen in case these principles are not adopted) and the percentage of recycled materials through mandatory laws for the private sector.
A.2 Circular Production Processes	**Reuse of built environment waste materials**	In Lombardy, particular attention is placed on the reuse of building components of particular value, namely historical or architectural (as bricks, tiles, ornamental stones, wrought iron, beams), aiming at extending their life-time and preserve their conditions. An alternative destination and application should be thought also for other waste materials coming from the built environment with short lifetime, thus providing an effective solution to the associated problem of disposal of these materials (avoiding landfilling and the related issues), targeting the goal of "zero-waste" in building and construction.
A.3 Enabling traceability in product and processes	**Certification for sustainable buildings and infrastructure**	Inspired by existing standards for the energy classification of buildings, this opportunity aims at promoting the use of standard and certification protocols for a new building classification based on sustainability. Different degrees of certifications can be reached depending on the environmental footprint of the building and infrastructures. A fundamental feature of building footprint should be related to the adopted materials. In this direction, the percentage of recycled materials used during their construction (e.g. containing recycled and manufactured aggregates, fly ashes) should reduce the value of the building environmental footprint. This certification could boost the use of recycled materials and aggregates in the construction sector.
A.3 Enabling traceability in product and processes	**Environmental certification of products**	This opportunity aims at offering verified, transparent and comparable environmental information about a product sold to the market, both concerning technical aspects and the environmental sustainability. Such information shall be useful for enhancing the capability of properly treating or disposing these products at the end-of-life. Moreover, it should be integrated into proper eco-design legislation to motivate manufacturers to increase the environmental performance of their products.

A.3 Enabling traceability in product and processes	**Enhance (the quality and traceability of) the procedure of waste management, from collection to recycling in built environment**	This opportunity can be significantly supported through the implementation of the EU Protocol for built environment, in particular working for the best transposition and effective use in each European contest (country), with specific and effective, sound and coherent links with the national and regional laws, in order to make it really operational. This Protocol complies with the Construction 2020 strategy, as well as the Communication on Resource Efficiency Opportunities in the Building Sector. The Protocol consists of 5 components (the first three are based on the C&D waste management chain and two are of a horizontal nature). a. Waste identification, source separation and collection; b. Waste logistics; c. Waste processing; d. Quality management; e. Policy and framework conditions. Widespread the protocol at a national scale is an opportunity. This Protocol has been developed for application in all 28 EU countries and has the following target groups of stakeholders.
A.3 Enabling traceability in product and processes	**Inter-regional waste management protocols**	Trans-regional transportation and exchange of waste could become a relevant circular economy enabler if properly regulated and managed. This opportunity aims to develop safe and conscious inter-regional waste management protocols. In particular, these protocols shall be focused on the enhancement, both in terms of quality and traceability, of the procedures of waste management, from collection to recycling in every sector. The development of IT waste management platforms in a Zero Waste perspective could support the transparent implementation of such protocols. As an example, traceability is fundamental for textile, concerning for example the chemicals used during production. The product passport in the textile already exists and is related to ECOTEX. ECOTEX is a textile international standard for companies created by companies themselves. ECOPASSPORT is the quality certification aimed at evaluating the sustainability of the value chain.
A.4 New Cross-Sectorial Business Models for Circular Economy	**Implementation of a multi-user web platform for value-chain integration**	Information sharing among different stakeholders of the value-chain is one of the most promising enablers for emerging circular economy business models. A cross-sectorial web platform should be implemented for the creation of a virtual market containing the description, the volumes and the geographical localization of the waste materials coming from different sectors (for example, from construction and to textile to other sectors). For example, in built environment sector a mapping of materials available at local level can be useful to make stakeholders aware of the construction stocks that can be used to create new materials from remanufacturing or recycling. And it is also useful for a designer who can take in account the available secondary resource near the project area from the beginning of the design process. The platform should be multi-users, in the sense that multiple stakeholders should provide and retrieve information, in different stages of the value-chains. For example, plant managers may provide data related to processing capabilities, product designer may retrieve data about material characteristics, recyclers may retrieve data about products to be processed. In the Lombardy Region, ANCE Lombardia (construction sector), ANPAR (recycling sector) and Centrocot (textile sector) are independently setting up or already testing similar digital platforms.

A.4 New Cross-Sectorial Business Models for Circular Economy C.1 Product life-cycle extension	**Identification of new business model to extend the buildings duration**	New business model can be defined with the aim to extend the life of buildings promoting maintenance process, thus reducing the amount of wastes (i.e. constructors can offer a bundle of product-service instead of simply sell the buildings)
D.1 Reverse logistics	**Reverse logistics in built environment**	This opportunity aims at establishing a network to support the return of homogeneous waste coming from the demolition to the producer through a selective process. When a product normally moves through the forward supply chain network, the aim is to reach the distributor or the final customer. A reverse logistic should be designed to transfer post-use components and materials for the purpose of capturing value, or proper disposal. In the reverse logistic the manufacturing firm should then organize the shipping of the waste, testing, dismantling, repairing, recycling or disposing the product. In order to avoid the delivery of inert waste in landfill, a solution could be to set up a CLSC (Closed-Loop Supply Chain). Building materials would be extended after the end of life of the building itself by keeping them in the loop through systematical extraction, purification and repurposing. They will be reused in some parts of other buildings or they will be inserted in the secondary material markets. This procedure might include reusing the extracted items directly or after different levels of recovery processes.
D.2 Citizens engagement and incentives	**Enhance the role of customers towards circular economy**	Customers need to become more and more aware of their power to influence the way companies design, produce and distribute their products. Large public institutions can play an important role in this transition by becoming themselves conscious customers of green products and thus influencing the manufacturers' attitude towards circular economy.
E.1 Innovative remanufacturing technologies	**Increase the (quality of the) regeneration of (target) city areas and thus increase the recovery of construction and demolition waste**	An important element for achieving Circular Economy principles in the construction sector is the development of standardization policies targeting urban regeneration. The standardization policies on urban regeneration will address the recovery of city areas and, in parallel, the recovery of important quantities of construction and demolition waste. Lombardy Region has launched a working group to implement it. Such concept should be further boosted through the promotion and implementation of live demonstration and pilot projects proving the benefits of this approach in specific urban areas under renovation.
E.1 Innovative remanufacturing technologies	**Remanufacturing (with upgrades) o of plant systems and architectural components**	Reconditioning of plant systems and architectural components before the demolition
E.1 Innovative remanufacturing technologies F.1 Innovative technologies for sorting and recycling	**Improve the efficacy of recovery processes**	Reduce the impact (LCA) of recovery processes focusing on quality and not on quantity. Requirements imposed by law should be more challenging procedures should be clearer.
F.1 Innovative technologies for sorting and recycling	**Increase the quality of recycled aggregates (and of all the materials used in building)**	A major challenge for unlocking the massive re-use of post-use materials in the built environment sector is the achievement of high-quality standards of the recovered recycled materials. Actions targeted to increase the quality of the produced aggregates, in order to increase their use in different sectors, supporting the development of homogenous input flows

		in the recycling plants and the use of the best available technology for plant design and installation should be supported. This objective can be achieved by innovative material inspection and quality control methodologies, innovative identification and sorting technologies, more effective material separation practices and strategies to select high quality and re-usable materials in the construction industry.
F.1 Innovative technologies for sorting and recycling	**Pre-demolition audit to enhance selective demolition**	A major opportunity for increasing the capability of re-using waste materials in building demolitions originates from the idea of selectively disassembling homogeneous building components before size reduction and sorting. Indeed, once materials are mixed in traditional demolition, the challenge to identify and sort them before re-use arises, which is cause of loss of quality and purity of the recyclates, ultimately affecting their re-use potentials. To overcome this problem, the selective disassembly of buildings should be implemented to facilitate the reuse or recycling of valuable materials such as wood, structural brick, and high functional finished components like windows, doors, cabinets, and decorative materials. However, selective disassembly is more expensive than traditional processes. Therefore, the economic and financial conditions as well as the proper support technologies for selective demolition should be properly investigated and fine-tuned.
F.1 Innovative technologies for sorting and recycling	**Waste recovery from renovation activities**	In Italy the building renovation-refurbishing activities are usually more frequent than the demolition activities. In particular, the main practice is the micro-renovation, defined as the renovation activities on small buildings or on small parts of them. The high number of these micro-demolitions produces high amount of waste, with low quality. Thus, it is of paramount importance to focus on the improvement of these practices, boosting the development of a stable network for collecting, processing and re-using materials from renovation activities. Such activities are usually spread on the regional territory, more difficult to monitor than building demolition, and require specific protocols to be turned into valuable secondary material sources.

Electrical and Electronics Equipment

R&I Priority	R&I Sectoral Priority	Description and envisaged solutions
A.1 Design for Circular Economy A.2 Circular Production Processes	**Increase the percentage of secondary raw materials used in the production of EEE goods**	Enhance and increase the use of secondary raw materials in the production of electric and electronic equipment, exploiting cross-sectoral analysis and promoting the introduction of sustainable certification of the final goods.
A.4 New Cross-Sectorial Business Models for Circular Economy B.3 Exploitation local production-distribution-consumption networks E.2 Distributed and flexible remanufacturing networks	**Implementation of a web platform**	Development of a web platform could be strongly helpful to support a real and effective "secondary raw materials" flow favouring also cross-sectoral approaches.
E.1 Innovative remanufacturing technologies F.1 Innovative technologies for sorting and recycling	**Boost EEE maintenance, repair, reuse and remanufacturing economy**	Enhancement of the maintenance, repair, reuse and remanufacturing of electric and electronic equipment, enabling a closed loop framework.
F.1 Innovative technologies for sorting and recycling	**Characterisation of materials before recycling**	Development of technologies to support the identification of materials to enable the knowledge-based recycling
F.1 Innovative technologies for sorting and recycling	**Increase the percentage of materials (e.g. rare elements metals…) recovered from WEEE**	Improvement of current technologies and development of new technologies and processes to increase the percentage of materials recovered from Waste from Electric and Electronic Equipment, as precious metals and rare earths.
D.1 Reverse logistics	**Inter-regional waste management protocols**	Development of inter-regional waste management protocols. In particular, they will be focused on the enhancement, both in the quality and in the traceability, of the procedure of waste management, from collection to recycling in every sector, working also to develop IT waste management system in a Zero Waste perspective.
D.2 Citizens engagement and incentives	**Enhance the role of customers towards circular economy**	The customers need to be more aware of their power to change the way companies produce their products. Institutions need promote and favour changes that are needed in the sectors.

Food

R&I Priority	R&I Sectoral Priority	Description and envisaged solutions
A.4 New Cross-Sectorial Business Models for Circular Economy	**Integration of agro-food industry, biotechnological industry and green chemistry into the new bio-economy industry**	The food supply chains are large in volumes, significant in economic and environmental terms and central to the management of many biological materials. They currently generate significant amounts of waste and are associated to high environmental impacts. The waste streams are generated during harvesting, storage and transport prior to primary processing (primary stream), during primary processing within the agro-food industry (secondary stream) and during production or consumption by end users (tertiary stream). This is recognized as a priority sector where accelerating the circular economy would be beneficial and where EU policy has a particular role to play. This include also the idea of valorising food and beverage industry wastewaters based on the outcomes of the EU H2020 Saltgae project involving partner Regions in CIRCE (e.g. Lombardy, Slovenia). To do so, novel R&D and industrial collaborations will be identified within these Regions, starting from Saltgae partners, to ensure further scaling up and future potential industrial implementation of Saltgae outcomes.
A.3 Enabling traceability in product and processes	**Development of secure control and traceability systems along the value-chain**	The development of innovative digital control and traceability systems could allow the identification of the products throughout the whole value chain and detect eventual failures on machinery that can damage the quality of food (i.e. systems able to assess the microbiological quality of water).
A.4 New Cross-Sectorial Business Models for Circular Economy	**Implementation of a multi-user web platform for value-chain integration**	Information sharing among different stakeholders of the value-chain is one of the most promising enablers for emerging circular economy business models. A cross-sectorial web platform should be implemented for the creation of a virtual market containing the description, the volumes and the geographical localization of the waste materials coming from different sectors (for example, from construction and to textile to other sectors). The platform should be multi-users, in the sense that multiple stakeholders should provide and retrieve information, in different stages of the value-chains. For example, plant managers may provide data related to processing capabilities, product designer may retrieve data about material characteristics, recyclers may retrieve data about products to be processed. In the Lombardy Region, ANCE Lombardia (construction sector), ANPAR (recycling sector) and Centrocot (textile sector) are independently setting up or already testing similar digital platforms.

A.1 Design for Circular Economy **A.3 Enabling traceability in product and processes**	**Smart Packaging g to save or recover resources.**	The development of smart packaging and labelling could make it possible to increase the traceability of food packaging, to achieve a more controlled and safe value chain, and the reduction of waste, thus positively influencing both producers and customers. However, since the cost of smart packaging may be higher than the cost of traditional packaging solutions, the development of new legislations and incentives aiming at promoting these innovative packaging design solutions should be envisaged.
A.4 New Cross-Sectorial Business Models for Circular Economy	**New products and new markets identification within a cascade approach**	With the aim to valorise secondary raw materials, new products and new markets should be identified where to exploit them (i.e. recovery of molecules form products or sub-products for different applications, CO2 Extraction, production of biomethane, biotransformation of food waste through insects, insects-based bio plants)
B.3 Exploitation of local production-distribution-consumption networks	**Promote local and urban food growing**	Moving food production closer to the consumption areas is a virtuous practice that has the benefits of reducing logistics costs and environmental impacts, at the same time posing lower requirements on packaging performance and increasing the traceability of the food chain. For these reasons, it is becoming more and more attractive for citizens, especially in high density urban areas. As a consequence, if properly implemented, this opportunity will make it possible to reduce CO2 emissions and packaging material use, thus leading to a reduced amount of packaging waste. Furthermore, it is expected that the short value chain can reduce food waste, because food is consumed more directly, a better prediction of demand is possible, and overproduction is avoided. However, actions are needed to further boost this practice, such as the creation of specific markets for distributing urbanely grown food, the development of specific campaigns for consumers' awareness creation and the support to urban food growing areas.
B.3 Exploitation of local production-distribution-consumption networks	**Enhance the territorial network for the recovery and re-distribution of food waste**	The objective is to enhance the development of a network of territorial stakeholders (GDO outlets, shops, distributors, canteens) for reducing food waste. For example, Banco alimentare della Lombardia manages a hub for collecting and recovering surpluses in delimited territories in Lombardy, redistributing them to charitable structures in the same territory. The benefits of the network are: 1. to ensure a better dietary mix for the assisted person; 2. to maximize the collection from mid / small groups leveraging on the local presence; 3. to optimize the recovery of fresh food and cooked meals by improving the efficiency through the creation of local food bank warehouses; 4. to activate networks of relationships on the territory that can create links and implications in terms of inclusion and social cohesion. Such a virtuous approach should be further supported at larger scale, promoting the development of new pilot applications in areas currently not covered by this service and establishing links with relevant stakeholders distributed on the regional territory.

C.1 Product life-cycle extension	**Increase the products shelf-life**	Development of sustainable systems for the extension of product shelf-life through the creation of new concepts (i.e. usage of microorganism to impede the development of organisms that cause the food deterioration.
D.1 Reverse logistics	**Improve reverse logistics efficiency starting from the nutritional needs of customers**	The idea of further developing and making more efficient the logistics chain from the end-of-life product collection to the repair/remanufacturing/recycling of components could be widespread and applied to products and goods in all sectors. An opportunity comes from the synergic exploitation of forward and reverse logistics chains and from the enhancement of the strategic role of retailers in the reverse logistics, which provide a direct contact to customers but is currently mainly unexploited.
D.2 Citizens engagement and incentives	**Enhance the role of customers towards circular economy**	Customers need to become more and more aware of their power to influence the way companies design, produce and distribute their products. Large public institutions can play an important role in this transition by becoming themselves conscious customers of green products and thus influencing the manufacturers' attitude towards circular economy.
D.2 Citizens engagement and incentives	**Improve the effectiveness of food waste reduction programs in companies**	This opportunity aims at developing inter-regional food waste management protocols to obtain the standardization on waste management from collection to recycling and improving the effectiveness of food waste avoidance programs in companies.
C.1 Product life-cycle extension **C.2 Exploitation of product-service models to implement the CE paradigm**	**Increase the performance of school canteens on food waste**	Food waste in schools is a significant challenge that should be addressed to reduce food waste in the Region. This opportunity aims at extending the scope of Siticibo Ristorazione in School canteens, best practice of Lombardy Region, through the full deployment of the program, also including the collection of cooked meals in addition to bread and fruit already recovered. The most significant policy option includes the development of specific legislations fixing targets to the amount of food waste. Further actions should aim at improving the availability of infrastructures to manage fresh food in this context, to boost the development of technological solutions for higher food traceability and to develop pilot applications in specific educational contexts.
G.1 Development of new biotechnologies	**Application of new industrial technologies to improve food recovery processes**	Development of new biomass technologies for food recovery

Machinery

R&I Priority	R&I Sectoral Priority	Description and envisaged solutions
A.1 Design for Circular Economy	**Design optimization to increase performance and reduce material utilization**	Machine tools are often designed following traditional design paradigms, in order to achieve stiffness and vibration damping. The utilization of advanced simulation and generative design tools can improve the performance and precision of machine tools, allowing better utilization of materials in machine tools manufacturing, better precision and increase in machine precision and scrap reduction
A.1 Design for Circular Economy	**Use of digital technologies for energy / maintenance management during manufacturing**	The use of technologies related to "Industry 4.0" paradigm (sensing, big data analytics, PaaS cloud systems, etc.) could help machine tools users to collect data about the state of any given machine and its evolution. This will allow the optimization of energy utilization (at machine level and also at group/component level): Data analytics performed on machine tools (locally or at family level) will also allow the implementation of preventive maintenance strategies, anticipating the failure of machine's key component. This will reduce the production of defective products, reducing unnecessary scraps, energy waste and increasing safety of the machine.
A.1 Design for Circular Economy	**Design of high performance/low consumption components for machine tools**	The integration of component design of machine tools with ICT /Industry 4.0 technologies would lead to a sophisticate implementation of strategies for the reduction of energy consumption in machine tool. More in detail, the components could have an adaptive behaviour derived by the combination of IoT and optimization algorithms even based on AI strategies. The objective is an advanced and granular analysis and management of energy consumption.
A.2 Circular Production Processes	**Integration between additive and subtractive processes**	The creation of parts basing on the combination of additive process, used to create the main geometry of parts, followed by finishing performed by subtractive processes (such as milling or turning) will reduce the need to remove big volumes of chips by the raw parts, with benefits in terms of: • material and tools consumption • energy saving • needs to collect and recycle chips • utilization of coolants Furthermore, some operations to realize raw parts, such as casting, can be eliminated, with advantages in terms of material wasting and energy consumption
A.4 New Cross-Sectorial Business Models for Circular Economy **E.1 Innovative Remanufacturing Technologies**	**Utilization of additive manufacturing to enhance the maintainability of machine tools**	The additive manufacturing techniques have a great utilization potential in machine tools manufacturing. In fact, machine tools: • need high performance components • are often customized on end users' needs • are manufacturing in very small/unitary batches

		The application of additive manufacturing on machine tools production would impact on sectoral value chain in terms of • reduction of spare parts to be stored • logistics of spare parts, with less necessity to deliver physical elements in favour of local manufacturing by additive service centres • reduction of energy and material utilization related to the elimination of spare parts preventively manufactured • easy revamping of machine tools, allowed by higher flexibility in design and manufacturing of parts used to renew old/used machines
C.1 Product Lifecycle Extension	**Modularity in machine tools design**	A modular design of machine tools, with standardized (almost at manufacturer level) will allow an easier reconfiguration of machine tools, better revamping and an optimal adaptation to new needs of the end users, keeping unchanged the main frame of the given machine

Metals

R&I Priority	R&I Sectoral Priority	Description and envisaged solutions
A.2 Circular Production Processes	**Transform by-products to new feedstock or (secondary) raw materials for Internal recycling or use in other industries**	On average, the production of one tonne of steel results in 200 kg (in electric arc furnace steelmaking) to 400 kg (in blast furnace steelmaking) of residues. These include slags, fume dusts, sludges, scale and other materials. All these residues contain a relevant fraction of iron and metal oxides. Therefore, iron & steelmaking residues must be revalorized either within the steelmaking process or as industrial by-product as raw materials source via industrial symbiosis or internal cascading use for several reasons: • The tightening environmental legislation makes the landfill disposal of wastes more expensive; • The high content of iron and metal oxides makes residue valuable raw material for BOF and EAF charge. • The chemical and physical properties allow reuse of residues and by-products of steel plant in other industries or contexts such as cement industry, construction sector, Zn production, fertilizer or soil amendment in agriculture sector, etc.
A.2 Circular Production Processes	**Valorisation of societal residues and by-products of other industries in the steel plant**	Steel industry is also looking at residues from other industrial sectors as alternative carbon materials (ACM). Examples are: • plastic residues as chemical feedstock for Coke oven where the coke quality allows the addition of 1- 2% of plastics in the coal blend. • plastic residues injected in the BF • Rubber from tires, plastics, ASR and biomass residue have potential application as slag foaming agent in the EAF as substitute of coal.
A.2 Circular Production Processes	**Energy recovery for industrial/urban symbiosis**	The recovery of waste heat is certainly of first importance in iron & steelmaking route. In the EAF route, energy is mainly lost through cooling water and off-gas, which altogether contain about 40% of the total energy input to the EAF and 5-10% of the energy required by the complete production route. For reducing cooling water losses, specific technological developments are required on shell and roof panels or to increase the tightness of furnace openings. For recovering the losses from off-gases different ways are possible: • scrap pre-heaters can be used with many scrap grades and avoid dioxin formation due to de novo synthesis. • new heat exchangers that can operate at high temperature, high dust concentration and in corrosive environment. In such cases, innovative cost-effective technologies have to be adapted for heat valorisation at high, medium and low temperature, low- and high temperature and a proper scheme for industrial-urban symbiosis, such as use of steam for

		electrical energy production (i.e. Organic Rankin Cycles), heat pumps and district heating. • conversion technologies that allow using waste gases to produce valuable syngas to be used internally in steel plant or in other sectors (mainly chemicals) The integration in steel plants of dedicated H2 production technologies, e.g. making use of some high-temperature waste heat streams, can also be of interest to be used in the steel plant, either for its calorific or reducing potential.
D.1 Reverse logistics **F.1 Innovative technologies for sorting and recycling**	**Smart management of waste and scrap**	Steel is 100% recyclable and for endless times. Therefore, the use of secondary iron (scrap) has to be maximised. A major part of long products can be manufactured from large portions of obsolete scrap without a significant alteration of their processing parameters and of their final properties. The same accounts for many hot rolled commercial strip grades, although the level of tramp elements needs to be carefully controlled. One of the issues with increasing amount of scrap is how to produce high-quality products from scrap: tramp elements (such as copper, tin, ..) can influence the quality of low and ultra-low carbon steels, low nitrogen steel grades are difficult to produce via an electric steelmaking route. This requires scrap quality improvements through the development of new standards, collection and sorting practices (including more stringent quality monitoring systems), plus innovations in scrap pre-treatment processes to separately recover the metals contained in coatings and in hybrid materials (sandwich panels, etc). Although specific studies and investigations have been carried out, several issues have also to address: • Development of technologies to support the identification/ characterization of scrap and its end-of-life state to enable the knowledge-based recovery, sorting and better tracing of critical alloys elements along the recycling value chain; • Scrap (pre-)processing for improving scrap quality: - removal of metallic coatings of tin zinc (limited economic viability solutions based on hydrometallurgy or thermal treatment are currently available) - separation of scrap into low and high residual fractions is partially feasible through the application of advanced physical separation techniques (sorting, shredding, size and density classification, …). - improvements on the whole value chain, which even might imply changes in the design of products to allow for easier separation of unwanted compounds in steel scrap • Industrial and economic feasible solutions for refining steel melts to remove non-volatile tramp elements; Firstly, the use of secondary iron (scrap) has to be maximised. This requires scrap quality improvements through the development of new standards, collection and sorting practices (including more stringent quality monitoring systems), plus innovations in scrap pre-treatment processes to separately recover the metals contained in coatings and in hybrid materials(sandwich, panels, etc).
F.1 Innovative technologies for sorting and recycling	**Optimization of raw materials characterization and sorting**	Development of technologies to support the identification of materials and end-of-life state to enable the knowledge-based recovery

	Digital technologies for environmental impact assessment	Key enabling technologies of Industry 4.0 are nowadays pervasive and will be intensively applied to improve process flexibility and reliability as well as total product quality control. However, such techniques can be successfully applied to provide key performance indicators for sustainable resource efficiency. This kind of technologies can greatly support also the task of energy efficiency, through the development of intelligent systems for flexible energy management and smart interaction with energy grids.
	Life cycle assessment (LCA) and life cycle thinking (LCT)	Life Cycle Thinking (LCT) is a recognized worldview as beneficial to society and Steel industry wishes to promote it. However, the present methodology is still not perfect and methodological innovation are needed to create a dynamics that would open up to interdisciplinary cooperation, from sociology, socioeconomics to scientific ecology by encompassing the various communities of LCA, Material Flow Analysis (MFA) or Energy & Exergy Flow Analysis, economic global modellers, etc..

Plastics

R&I Priority	R&I Sectoral Priority	Description and envisaged solutions
A.1 Design for Circular Economy	**Eco-design for plastics products**	Promote a "design for re-manufacturing" targeted to conceive monomaterial products or engineered to easily recover all the components. This can also overcome the "over-packaging" issue, which lead to the exaggerated use of plastics in packaging usually with marketing purposes. Use of natural fibres with thermoplastic polymers for the production of sustainable compounds which can be treated by convectional technologies (i.e. extrusion, injection)
A.1 Design for Circular Economy	**Increase the percentage of recycled plastics into new products**	Closed loop plastics recycling has been successfully implemented in several sectors (e.g. automotive, electronics and white goods) by re-using industrial plastic scrap from injection moulding or forming processes. However, there is potential to properly extend this approach also to post-use plastics, already in the market. This opportunity can be exploited by collaborating with plastics industries to have a percentage of recycled material inside new plastic products that is higher than the current value, thus significantly reducing virgin plastic production.
A.1 Design for Circular Economy **A.2 Circular Production Processes**	**Increase the percentage of secondary raw materials used in the production of goods**	This objective of this opportunity is to enhance and increase the use of secondary raw materials in the production of plastic goods. A particular focus should be placed to the development of sustainable certification protocols applicable to the re-usable materials as well as to the final products. This would increase the customer acceptance towards product re-using plastics, thus extending the market attractiveness of this approach.
A.1 Design for Circular Economy **A.2 Circular Production Processes**	**Increase the production of sustainable and biodegradable plastics**	Increasing the production of more sustainable and biodegradable plastics, not based on petroleum and non-renewable natural resources, can limit the environmental burden of traditional plastics, being in turn beneficial for the human health, the marine species survival, and to the ocean.
A.3 Enabling traceability in product and processes	**Enhance (the quality and traceability of) the procedure of waste management, from collection to recycling in every sector**	This opportunity, coming from a cross-sectoral analysis, aims to build a common protocol on waste management from collection to recycling of end of life products, enabling a more efficient recover and recycling of goods. These protocols can be thought in two directions: towards citizens and towards companies and institutions, to support to build awareness and credibility and achieve long-term sustainability of the system.

A.2 Circular Production Processes **A.4 New Cross-Sectorial Business Models for Circular Economy**	**Identification of specific application field for the recovered material based on its quality**	Due to technological limitations recycling processes on plastics cannot be continuously reiterated (Downgrade). There is the need of identifying the proper application to ensure the reemission of recovered materials into products according to their quality
A.4 New Cross-Sectorial Business Models for Circular Economy	**Implementation of a multi-user web platform for value-chain integration**	Information sharing among different stakeholders of the value-chain is one of the most promising enablers for emerging circular economy business models. A cross-sectorial web platform should be implemented for the creation of a virtual market containing the description, the volumes and the geographical localization of the waste materials coming from different sectors (for example, from construction and to textile to other sectors). The platform should be multi-users, in the sense that multiple stakeholders should provide and retrieve information, in different stages of the value-chains. For example, plant managers may provide data related to processing capabilities, product designer may retrieve data about material characteristics, recyclers may retrieve data about products to be processed. In the Lombardy Region, ANCE Lombardia (construction sector), ANPAR (recycling sector) and Centrocot (textile sector) are independently setting up or already testing similar digital platforms.
D.1 Reverse logistics	**Improve reverse logistics efficiency in every sector**	The idea of further developing and making more efficient the logistics chain from the end-of-life product collection to the repair/remanufacturing/recycling of components could be widespread and applied to products and goods in all sectors. An opportunity comes from the synergic exploitation of forward and reverse logistics chains and from the enhancement of the strategic role of retailers in the reverse logistics, which provide a direct contact to customers but is currently mainly unexploited.
D.1 Reverse logistics	**Standardization of waste management procedures from collection to recycling**	The development of common rules and standard procedures for waste management, from collection to recycling of end of life products, can support a more efficient and effective recovery and recycling of goods across all sectors.
D.1 Reverse logistics	**Inter-regional waste management protocols**	Trans-regional transportation and exchange of waste could become a relevant circular economy enabler if properly regulated and managed. This opportunity aims to develop safe and conscious inter-regional waste management protocols. In particular, these protocols shall be focused on the enhancement, both in terms of quality and traceability, of the procedures of waste management, from collection to recycling in every sector. The development of IT waste management platforms in a Zero Waste perspective could support the transparent implementation of such protocols. As an example, traceability is fundamental for textile, concerning for example the chemicals used during production. The product passport in the textile already exists and is related to ECOTEX. ECOTEX is a textile international standard for companies created by companies themselves. ECOPASSPORT is the quality certification aimed at evaluating the sustainability of the value chain.

D.2 Citizens engagement and incentives	**Enhance the role of customers towards circular economy**	Customers need to become more and more aware of their power to influence the way companies design, produce and distribute their products. Large public institutions can play an important role in this transition by becoming themselves conscious customers of green products and thus influencing the manufacturers' attitude towards circular economy. They can also play a strategic role in enhancing the quality of source-separated plastics.
F.1 Innovative technologies for sorting and recycling	**Plastic recycling processes**	The enhancement of innovative technologies for recycling will contribute to the further optimisation of mechanical plastic recycling processes as well as enhance chemical recycling process allowing to obtain monomers

Textile

R&I Priority	R&I Sectoral Priority	Description and envisaged solutions
A.1 Design for Circular Economy	**Increase of the percentage of recycled materials**	Legislation can have an important role in motivating manufacturers to design their product integrating higher fractions or recycled materials, without compromising in performance. The challenge is to design targeted and well-accepted laws aiming at increasing the percentage of recycled materials used in products, thus increasing circular economy opportunities. A potential opportunity, already well investigated, is to boost the Minimal Environmental Criteria principle in Green Public Procurement. Other opportunities come from eco-design directive, currently under development at EU level.
A.1 Design for Circular Economy	**Influencing fashion designer in the use of secondary raw materials (textiles)**	Inducing fashion designers to make clothes including recovered textiles is an opportunity that could be better exploited. Although several fashion brands and fashion designers are becoming more sensitive to sustainability issues, the use of waste textiles into the design of new collections remains limited. Possible actions include the design of specific incentives, the promotion of sustainability-oriented marketing initiatives and awareness creation initiatives targeted to consumers, thus leading to a more sustainable sector and to a lower production of wasted textiles.
A.1 Design for Circular Economy	**Design for recovery**	Influence fashion designer to think clothes materials in a way that it can enable the circular economy approach, making them easily separable at the end of their life.
A.2 Circular Production Processes **A.4 New Cross-Sectorial Business Models for Circular Economy**	**Reuse of textiles in other sectors**	Material re-use is a promising circular economy alternative that could be more widely exploited for the waste materials coming from the textile sector. A relevant example is the reuse of wasted textiles as secondary raw materials in the built environment sector, becoming an insulator material to be used during the construction of buildings. Since the built environment sector is a high-volume sector, such an approach may significantly decrease the un-processed waste produced by the textile industry.
A.2 Circular Production Processes **F.1 Innovative technologies for sorting and recycling**	**Sustainable textile manufacturing**	The objective of this opportunity is to invest in textile SMEs implementing innovative circular economy solutions, both in terms of sustainable technologies for textile manufacture and processes for large scale re-use of fibers. This will increase recyclability rates of textile materials and, in turn, will create a market for recycled fibers, yarns and manufactured clothes.
A.3 Enabling traceability in product and processes	**Enhance (the quality and traceability of) the procedure of waste management, from collection to recycling in every sector**	This opportunity, coming from a cross-sectoral analysis, aims to build a common protocol on waste management from collection to recycling of end of life products, enabling a more efficient recover and recycling of goods. These protocols can be thought in two directions: towards citizens and towards companies and institutions. This would enable to support building awareness and credibility and achieve long-term sustainability of the circular system.
A.4 New Cross-Sectorial Business Models for Circular Economy	**Implementation of a multi-user web platform for value-chain integration**	Information sharing among different stakeholders of the value-chain is one of the most promising enablers for emerging circular economy business models. A cross-sectorial web platform should be implemented for the creation of a virtual market containing the

		description, the volumes and the geographical localization of the waste materials coming from different sectors (for example, from construction and from textile to other sectors). The platform should be multi-users, in the sense that multiple stakeholders should provide and retrieve information, in different stages of the value-chains. For example, plant managers may provide data related to processing capabilities, product designers may retrieve data about material characteristics, recyclers may retrieve data about products to be processed. In the Lombardy Region, ANCE Lombardia (construction sector), ANPAR (recycling sector) and the partnership Centrocot (textile sector) - UNIVA (association of industries from different sectors) are independently setting up or already testing similar digital platforms.
A.4 New Cross-Sectorial Business Models for Circular Economy	**New business model and low-cost technologies for eco-textile**	Identification of new business model and low-cost technologies to be applied in textile sector.
A.4 New Cross-Sectorial Business Models for Circular Economy	**Support for new circular textile start-ups**	Through a careful and continue cross-regional value chain analysis, potential synergies among different sectors may arise, especially targeting start-ups. Indeed, start-ups are at the core of the innovation eco-system of a Region. Thanks to their light and dynamic structures and the less established brand vision, start-ups can experiment innovative circular business cases and expand them in line with the company growth strategy. An opportunity comes from the extension of the Advance London program good practice (established by LWARB) to other Countries to support young start-ups. Lombardy region shows a real interest on this possibility.
B.2 Development of market/pricing strategies to increase the willingness to buy sustainable products **D.2 Citizens engagement and incentives**	**Greater involvement of fashion companies**	Fashion brands can develop a specific survey for their suppliers in order to clarify their environmental and social performance on relevant circular economy topics, such as resource saving, transport impact reduction, packaging reduction, short value chain introduction, clear labelling and origin of the clothes, sharing the sustainability principles and visions with their customers, directly ay the retail points. This would be a first step towards the improvement of the percentage of recycled materials into new clothes, making the sustainability their first brand paradigm. In order to trigger high response rate to these initiatives, specific awarding methods targeted to conscious customers who provide their feedback could be designed.
C.1 Product life-cycle extension	**Reduction of waste due to structural degradation of textile materials during the production, use and maintenance phases (along the value chain).**	Innovative procedures and technologies should be designed and tested to enable a considerable reduction of waste caused by structural deterioration of textile products and materials during production, use and maintenance phases, along the value chain. This waste is segregated by the product throughout its lifetime and it is irreversibly lost in the environment, posing serious challenges. A major objective should be, for example, the mitigation of microplastics impact caused by textile washing processes.
D.1 Reverse logistics	**Increase second-hand clothes collection and redistribution**	In textile clothing two types of waste streams are significant, including clothes that lost their original functionality, due to extensive use, as well as clothes that are “unsold items” and become waste due to obsolescence and market reasons. From both streams, an increased amount of textile waste could be redistributed and used in second-hand collection channels. The objective of this opportunity is to increase the reuse of clothes that are still wearable, by donating them to poor people or by reinserting them in the

		redistribution cycle, with the possibility to increase their attractiveness through the possibility of a redesign of the clothes.
D.1 Reverse logistics	**Improve reverse logistics efficiency in every sector**	The idea of further developing and making more efficient the logistics chain from the end-of-life product collection to the repair/remanufacturing/ recycling of components could be widespread and applied to products and goods in all sectors. An opportunity comes from the synergic exploitation of forward and reverse logistics chains and from the enhancement of the strategic role of retailers in the reverse logistics, which provide a direct contact to customers but is currently mainly unexploited.
D.1 Reverse logistics	**Standardization of waste management from collection to recycling**	The development of common rules and standard procedures for waste management, from collection to recycling of end of life products, can support a more efficient and effective recovery and recycling of goods across all sectors. Starting from the Cross-cutting project ECAP (European Clothing Action Plan) the need of a standardization of waste management from collection to recycling emerges. This action could enhance and increase the recovery of waste clothes.
D.1 Reverse logistics	**Inter-regional waste management protocols**	Trans-regional transportation and exchange of waste could become a relevant circular economy enabler if properly regulated and managed. This opportunity aims to develop safe and conscious inter-regional waste management protocols. In particular, these protocols shall be focused on the enhancement, both in terms of quality and traceability, of the procedures of waste management, from collection to recycling in every sector. The development of IT waste management platforms in a Zero Waste perspective could support the transparent implementation of such protocols. As an example, traceability is fundamental for textile, concerning for example the chemicals used during production. The product passport in the textile already exists and is related to OEKO-TEX. OEKO-TEX is a textile international standard for companies created by companies themselves. ECOPASSPORT is the quality certification (related to chemicals) aimed at evaluating the sustainability of the value chain.
D.2 Citizens engagement and incentives	**Citizen education on textile recovery through the introduction of separate collection**	Starting from different good practices regarding second-hand clothes (as "La Terza Piuma" in Lombardy region or "Humana" in Catalonia region) and taking inspiration from different campaigns (such as the "Love Your Clothes" campaign in LWARB region), targeted to textile users, and citizens in general, it is possible to favour the development of an efficient separate collection schema for textiles. This would be a pre-requisite for an efficient treatment of textiles targeted to their re-use.
D.2 Citizens engagement and incentives	**Enhance the role of customers towards circular economy**	Customers need to become more and more aware of their power to influence the way companies design, produce and distribute their products. Large public institutions can play an important role in this transition by becoming themselves conscious customers of green products and thus influencing the manufacturers' attitude towards circular economy.
F.1 Innovative technologies for sorting and recycling	**Increase the recovery of waste clothes**	The Lombardy Region produces 13-15 kg per year per person of wasted clothes, but only 2-3 kg are actually recovered. If properly exploited, this material availability opportunity can be exploited to develop new concepts of sustainable clothes made of recycled textile. For example, textile materials can be reused and inserted into new clothes, thus reducing the amount of generated clothes waste and virgin material usage, at the same time.

Annex 2 – Sectoral Analysis

NACE Code	Role in the regional economy				Circularity potential			
	Employees in the region * (n°)	Turnover (B€)	Gross Value Added (B€)	Companies in the region * (n°)	Volume of waste generated	Share of waste recycled	Share of waste incinerated	Share of waste landfilled
C10 - Manufacture of food products	65.111	24,16	4,29	5.679	N/D	N/D	N/D	N/D
C13 - Manufacture of textiles	43.062	7,90	2,32	3.379	121.828,70	68,34%	0,73%	1,33%
C14 - Manufacture of wearing apparel	38.717	5,66	1,48	5.012				
C16 - Manufacture of wood and of products of wood and cork (...)	20.795	3,14	0,91	4.389	533.466,60	91,00%	8,31%	0,00%
C17 - Manufacture of paper and paper products	16.560	4,58	1,18	962	226.776,30	87,13%	10,53%	0,23%
C19 - Manufacture of coke and refined petroleum products	1.843	11,24	0,90	39	206.886,60	18,26%	0,00%	0,00%
C20 - Manufacture of chemicals and chemical products	46.096	21,01	4,85	1.334	484.806,70	17,06%	3,33%	46,60%
C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	21.874	9,84	3,18	179	323.554,50	43,76%	5,34%	0,56%
C22 - Manufacture of rubber and plastic product	57.640	16,46	4,34	3.175	248.239,70	11,76%	0,59%	83,53%
C24 - Manufacture of basic metals	41.915	21,42	3,70	1.211	2.418.679,30	45,80%	0,00%	52,11%
C25 - Manufacture of fabricated metal products, except machinery and equipment	151.111	25,71	8,79	15.652	1.087.548,90	90,20%	0,00%	0,03%
C26 - Manufacture of computer, electronic and optical products	27.847	5,73	2,02	1.476	15.989,20	58,64%	0,34%	3,74%
C27 - Manufacture of electrical equipment	NA	11,76	3,18	2.615	274.468,90	89,10%	0,01%	0,00%
C28 - Manufacture of machinery and equipment n.e.c.	133.904	33,38	10,24	7.080	227.698,20	79,04%	0,19%	0,32%
C29 - Manufacture of motor vehicles, trailers and semi-trailers	23.593	8,57	1,81	448	116.457,40	80,96%	0,02%	6,77%
E36 - Water collection, treatment and supply	4.129	1,24	0,52	101	236.030,80	56,60%	1,00%	0,36%
E37 - Sewerage	30.007	0,40	0,16	1.537	415.832,50	78,09%	4,66%	5,25%
E38 - Waste collection, treatment and disposal activities; materials recovery	22.473	5,29	1,51	1.032	6.976.479,60	48,44%	18,48%	14,73%
F41 - Construction of buildings	56.410	12,56	2,23	19.736	11.582.726,00	88,52%	0,00%	6,71%
J61 - Telecommunication	18.241	10,16	4,36	953	1.949,60	79,84%	0,90%	2,10%

Sources: "Number of Employees" and "Number of Companies" - AFIL elaboration from Eurostat 2016*:
"Turnover" and "Value Added" - AFIL elaboration from Istat 2017**
Circularity Potential Indicators - Database of Environmental Directorate General of Lombardy Region

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