European Commission

ERA
Industrial technology roadmap **for circular technologies and business models**

in the textile, construction and energy-intensive industries

Research and Innovation

ERA industrial technology roadmap for circular technologies and business models in the textile, construction and energy-intensive industries

European Commission
Directorate-General for Research and Innovation
Directorate E — Prosperity
Unit E.1 — Industrial research, innovation and investment agendas
Contact Doris Schröcker, Angelo Wille, Adrian Marica
Email EU-INDUSTRIAL-TECHNOLOGY-ROADMAPS@ec.europa.eu
doris.schroecker@ec.europa.eu; angelo.wille@ec.europa.eu; adrian.marica@ec.europa.eu
RTD-PUBLICATIONS@ec.europa.eu
European Commission
B-1049 Brussels

Manuscript completed in December 2022
1st edition

PDF	ISBN 978-92-76-53903-2	doi:10.2777/188014	KI-07-22-585-EN-N

Luxembourg: Publications Office of the European Union, 2023

EUROPEAN COMMISSION

ERA industrial technology roadmap for circular technologies and business models

in the textile, construction and energy-intensive industries

2023 Directorate-General for Research and Innovation

TABLE OF CONTENTS

FOREWORD

MARIYA GABRIEL
Commissioner for innovation, research, culture, education and youth

This second industrial technology roadmap report is dedicated to the EU industrial sectors for textile, construction and energy-intensive industries. It is an important element of the New European Innovation Agenda to align research and innovation investments at EU and national levels to foster the development and uptake of innovative technologies within a pan-European Innovation Ecosystem. As an industrial technology roadmap under the new ERA for Research and Innovation, it supports the implementation of the updated EU Industrial Strategy, by linking key partnerships under Horizon Europe with industrial ecosystems under the Industrial Strategy.

Investments in material and product innovation are needed to ensure a pole position for the EU in future markets in the three industries, such as advanced sustainable bio-based textile. The New European Innovation Agenda offers many opportunities to unlock investments in relevant deep tech innovations, notably to textile, construction and energy-intense industries. Besides, the circular economy components of the Recovery and Resilience Plans have the potential to play a key role for many Member States to catch up on the way towards a circular economy.

The report presents evidence of the important role of small companies, in particular startups, in developing new business solutions and calls for more investments in technology development by companies, which have high circularity potential. We have a vibrant startup scene, which should capitalise on the New European Innovation Agenda and its ambitions, among others, to increase venture capital investments. Further, startups focusing on designing advanced materials represent between one (construction) and two fifths (textile) of startups involved in developing circular industrial technologies in general.

This roadmap emphasises the need to develop innovative technologies, notably deep tech innovations, for the entire lifecycles of products and materials, from sourcing of raw materials, design and production to use, collection, recycling, and reuse. When addressing circularity, technologies cannot achieve their full potential unless they are employed in a coordinated manner. This warrants a lifecycle approach in technology development as well as in investment pipelines with synergies across support instruments from Research, Innovation and Education to deployment, avoiding over-investments into end-of-life technologies. It will be crucial for all innovation ecosystems to incorporate the circular economy principles already in materials' design and development, in line with existing initiatives, such as the Materials 2030 Roadmap.

The findings of this roadmap also show that the potential of deep tech innovations is high in all three industrial sectors. They can support every stage of the circular cycle, help design and trace advanced materials throughout the entire product lifecycle and the development of circular business models. They offer cost-effective approaches to increase the sustainability of production and consumption. The EU Digital Product Passport, proposed in the Sustainable Product Initiative, will use the potential of digital technologies to trace materials and to inform industry and consumers.

It is encouraging to see that circularity is overall more important to EU companies in the three industrial sectors than it currently is for its global competitors, and that EU companies are leading the overall patenting landscape for technologies.

I trust that you, policy makers, innovators, investors, industry, researchers, NGOs and citizens, will have a very interesting reading and I would be happy if you find it inspiring as a platform to trigger ambitious action.

ACKNOWLEDGEMENTS

The EU industrial technology roadmap for circular technologies and business models in textile, construction and energy-intensive industries has been published in the context of the new European Research Area by the Directorate-General for Research and Innovation (DG R&I) — Directorate E, Prosperity. The project was coordinated under the leadership of Doris Schröcker and Angelo Wille (respectively, Head and Deputy Head of DG R&I.E1 Industrial Research, Innovation & Investment Agendas). This document was produced by Doris Schröcker, Angelo Wille, Adrian Marica, Pauline Sentis, Florence Roger and Evgeni Evgeniev as the main authors.

Peter Dröll, Director for Prosperity in DG R&I, and Andrea Ceglia made substantial contributions to the review of this work. Jürgen Tiedje, Sofie Norager and Dominique Planchon (DG R&I.E3, Industrial transformation,) also contributed to the review of the draft report. In DG R&I, we are also thankful for their inputs to Pavel Misiga and Petra Goyens (DG R&I.B1, Circular Economy & Biobased Systems); to Gergely Tardos (DG R&I.E2, Valorisation policies & IPR); and to Daniel Szmytkowski (DG R&I.G6, Common knowledge and data management service). This report is the outcome of strong collaboration with services all around and beyond the Commission, involving colleagues from the Joint Research Centre (JRC), the Directorates-General for Energy (DG ENER), for Regional Policy (DG REGIO), for Industry, Internal market and SMEs (DG GROW), for Education and Culture (DG EAC), for Environment (DG ENV), the European Innovation Council and SMEs Executive Agency (EISMEA).

Chapter 1 was the result of cooperation with Technopolis Group, as part of a specific contract under a framework contract 'Foresight on Demand', through the work conducted by Kincsö Izsak, and Commission services – DG R&I, DG GROW, DG ENV, DG EAC and the EIT Raw Materials KIC. Our special thanks goes to colleagues from DG ENV: William Neale, Leonor Baptista, Cristian Marti Hedstrom and Nicola Robinson.

Chapter 2 on technologies and business models, and their subsequent assessment, was the result of a collaboration between the European Commission and Technopolis Group. We are thankful for the thorough assessment and analysis work conducted by Kincsö Izsak and Asel Doranova. The evidence collected in this chapter are particularly relevant, bringing new evidence on new circular solutions, following extensive consultations with stakeholders and a dedicated Delphi exercise to collect data.

Chapter 3 on "Investment in R&D and Innovation" received substantial inputs from Technopolis Group on sections 3.1 and 3.5, whereas section 3.2 was authored by Aliki Georgakaki and Ela Ince (both from JRC-Petten, C7). Comments and suggestions on private R&I investments (section 3.3) were received from Alex Talacchi (DG R&I.E1), Athina Karvounaraki (DG R&I. G1), Alexander Tübke (JRC-Seville, B7), Sonia Fereres (JRC.B5), Vilius Stančiauskas and Vilte Girdzijauskaitė (both from PPMI), Data, used for section 3.3 were provided by PPMI and IDEA consortium, based on a framework contract of the European Commission, managed by Alex Talacchi (DG R&I.E1). The section on "EU programmes and investments" received contributions from Audrius Sabunas (DG R&I), Johannes Bunz (EISMEA), Kalina Dinkova (DG ECFIN) and Jitka Vocaskova (DG REGIO). Anabela Marques Santos (JRC) and Andrea Conte (JRC) drafted the sub-section on the ERDF funding from 2014 to 2020.

Chapter 4 on “Framework Conditions” benefited contribtution on: the section on valorisation was provided by Gergely Tardos, in DG R&I.E2 - ‘Valorisation policies & IPR’, with the help of: Stefanie Kalff-Lena, Iiro Eerola, Manon Prado and Federica Baldan. The section on standardisation was coordinated by Andreas Jenet from the JRC and involved contributors from all over the JRC: Amalia Munoz Pineiro (F7), Eric Aries (B5), Maria Jose Cruz Gomez (B5), Silvia Dimova (E4), Marco Lamperti Tornaghi (E4), Alain Marmier (C7), Jose Moya (C7), Fabio Taucer (A5), Rikst Van der Schoor (A5). The section on “The role of infrastructures enabling circularity” is authored by Mirka Gottberg (DG R&I.A3, R&I Actors and Research Careers), with substantial contributions from DG R&I.E1 (Doris Schröcker, HoU, and Evgeni Evgeniev). It also benefited from reviews by Apostolia Karamali (HoU, DG R&I.A3), René Martins (DG R&I.A3), Martyn Chamberlain (DG R&I.A3) and Fabio Taucer (JRC.A5), as well as from written inputs of ESFRI, EARTO, CESAER and their members.

We are grateful to Martina Daly and Balint Linder (DG R&I) for their support in the communication activities.

EXECUTIVE SUMMARY

Industrial technology roadmaps under the new ERA for research and innovation support the implementation of the updated EU Industrial Strategy, by linking key partnerships under Horizon Europe with industrial ecosystems, and combining efforts to disseminate research results and roll them out faster in the economy.

This roadmap focuses on the EU industrial ecosystems for textile, construction and energy-intensive industries. These ecosystems stand out as they have an excessive impact on waste generation and pollution (air, soil and water pollutants) compared to their share of gross value added in the economy. Energy-intensive industries serve various value chains across different EU industrial ecosystems, influencing, among other things, their circularity.

While 2020 data show rather high recovery and recycling rates in the industrial ecosystems for textiles (around 50%) and construction (>70%), this includes to a large extent the reuse of materials in lower value applications ('down-cycling'), such as use in insulation (textiles) or backfilling (construction). Against the background of an almost stable material use rate in the EU between 2010 and 2020, reaching the EU objective of doubling that rate by 2030 requires significant technological innovation. Since circularity concerns all phases of the product lifecycle, measuring and monitoring progress towards achieving a circular economy is complex.

The roadmap analyses 92 technologies for circularity in these three ecosystems. They address all stages of a material's and product's life cycle and are diverse, ranging from use of bio-based or recycled materials in the textile ecosystem, to additive and robotic manufacturing or telematics in the construction ecosystem, to end-of-life technologies, e.g. separation or regeneration of spent solvents, in the energy-intensive industries ecosystem. The analysis includes the technology readiness levels for each of these technologies, as well as their circularity potential, economic performance, contribution to zero-pollution and possible side effects.

When looking at the textile ecosystem, we find that technology development is overall quite well advanced for fibre-to-fibre chemical recycling, replacing raw materials with recycled materials, and automated fibre-sorting technologies. There are, however, several specific challenges to address, including the need to mitigate the current levels of pollution in the production process, by reducing the release of plastic microfibres from textile or material blend separation. Prioritising end-of-life technologies without simultaneously developing design or pre-recycling stages (collection, sorting, and disassembly), could reduce these technologies' beneficial effects. Furthermore, aspects related to consumer behaviour are particularly relevant for the circularity of the textile ecosystem, as the sustainability of the fashion sector is strongly linked to consumption patterns.

As far as construction is concerned, there is a clear need for broad efforts to create change. Even if specific technologies reach higher maturity levels, they would not have a large impact on circularity on their own. For example, advanced dry recovery technologies enable a high yield of non-ferrous metals from mineral aggregates but need a sustainable waste management business model and subsidiary technologies to have an impact. The design, material-sourcing, recycling and repurposing stages have the most potential, while there is less potential in production (construction and deconstruction) itself. Meanwhile the greatest circularity potential, in terms of waste minimisation, resource savings and longer life spans, is expected from technologies employed during the sourcing and design stages, including those in i) urban mining, ii) applications based on building information modelling, iii) modular design, iv) off-site construction, v) digital material passport and vi) supporting digital technologies.

Energy-intensive industries and, in particular, chemical industries are key players, which have a huge influence on the design, durability and lifecycle of materials and products in many value chains. Meanwhile circular solutions play a direct role in the cutting of greenhouse gas emissions from these materials and products. In the chemical sector, the Commission has adopted a Strategic Research and Innovation Plan for Chemicals (SRIP), which sets out R&I priorities for the chemicals sector, with which the current roadmap is fully aligned. The assessment carried out for this roadmap shows that the is a further need to develop technologies that deal with the use of bio-based materials or the inherent recyclability of materials, whose market commercialisation is a crucial step in accelerating the uptake of eco-designed products in industry. Regarding the steel sector, recycling technologies are already advanced, as several robotic technologies for scrap collection and sorting are already commercialised, while others are being developed. In the ceramics industry, an important priority is process optimisation including increased material and energy efficiency, such as industrial symbiosis. Innovating sintering processes, as well as storing and reusing waste heat can help to reduce energy consumption.

- For all ecosystems, it will be crucial to take a life cycle approach for technology development in order to generate the desired impact. For instance, technologies used for recycling construction waste are more effective where buildings are designed accordingly and built with materials that can easily be traced and sorted, similarly for textiles. At the same time, circular economy principles have to be already incorporated in the materials' design and development. This will trigger more systemic change and will affect not only the life of materials but the entire product-service value chain. Digital technologies could accelerate the application of a life cycle approach to products. The design of new materials could help expand the reuse of materials across value chains, thus helping reduce the need for materials and dependencies. This is why the Commission is developing an agenda for the design of advanced materials for innovation markets, which include the three industrial ecosystems.
- Digital technologies and business models play a key role in the transition of all three industrial ecosystems to the circular economy, including in data collection, material tracking and waste management (all depending on the use of traceable materials, which can be separated). Examples of such technologies are: i) artificial intelligence for data analysis and design technologies, ii) block chain for planning and operation of buildings, iii) platform technologies to facilitate supply chain and customer relations as well as iv) virtual and augmented reality to anticipate consumer experiences and influence sustainable consumer behaviour. The upcoming digital product passports, included in the Sustainable Products Initiative, will provide information on a product's origin, composition, and repair and disassembly possibilities, including how the various components can be recycled or disposed of at end of life, which will enable the upscaling of circular economy strategies such as predictive maintenance, repair, remanufacturing and recycling.

EU companies are more active than their global competitors. The EU has the highest share (32%) of companies worldwide active in circular economy technologies compared to, e.g. the US (20%) and China (4.4%).

The EU is also leading in circular economy technology inventions in absolute terms and as a share of green inventions at global level (2010-2018). However, the investments are rather concentrated, made by large R&D spenders in a few Member States (86% of companies in the circular economy sector are found in 9 Member States, with Germany, Spain and Italy at the top). Industry sectors covered early by binding recycling or environmental requirements appear to have a higher number of patents and R&I investments, even if R&D investments and intensity are not that outstanding (e.g. pulp and paper, beverages, metal for packaging, construction, apart from the chemical industry). While most R&D investments are made by large global companies, these companies own only around half of relevant patents. A significant number of patents and other investments in specific circular technologies, as analysed in this roadmap, come from companies outside the textile, construction and energy-intensive industry ecosystems (45% to 55%), including from the digital sector. This evidence warrants a deeper understanding of the role smaller companies, the research sector and start-ups play in developing new business solutions. It also calls for more investments in technology development by companies that have high circularity potential, but are located in Member States that are not at the forefront of the circular economy. Particular attention can be paid to investments in digital technologies linked to circularity. Furthermore, start-ups focusing on designing advanced materials represent between one (in the construction ecosystem) and two fifths (in the textile ecosystem) of start-ups involved in developing circular industrial technologies in general.

All major EU programmes support projects for developing the circular economy, and the Green Deal climate mainstreaming in the Multiannual Financial Framework also covers circularity actions under ‘activities linked to the use of (natural) resources’. European partnerships with industry in Horizon Europe address key challenges related to circularity in the processing and manufacturing, building and bio-based industries. Due to the characteristics of circular technologies for different industrial ecosystems and the need to address the full life cycles of circular products in specific value chains, dedicated windows or investment pipelines for circular industrial ecosystems together with support instruments could help accelerate the transitions.

Most Member States have taken national action to make their economy more circular. Overall, 13% of the Recovery and Resilience Facility budget has been allocated to biodiversity, the circular economy, sustainable water and pollution prevention. Given the current concentration of companies developing and using circularity technologies, there is indeed strong potential to narrow the persistent innovation divide in developing and deployoing circular technologies and business models across the EU. The design and implementation of the Recovery and Resilience Plans concerning their circular economy components has the potential to play a key role in helping many Member States catch up on the path towards a circular economy.

Regulation plays a key role in developing the circular economy as it provides the necessary common level playing field in the EU single market. The announcement and development of ambitious and comprehensive EU rules for circularity in 2019-2020 as well as target dates for recovery of electrical and electronic equipment coincide with a sharp increase in R&I investment.

The EU legislative framework for more circularity is rapidly evolving under the Green Deal. With its legislative proposals in the two Circular Economy Packages in 2022, the EU complements existing recycling targets (2018) for waste reduction and recycling with rules to ensure sustainable products, including a digital product passport for improved traceability, to ensure better data to monitor the circular economy and to empower consumers and public buyers. The new legislation has the potential to provide significant momentum for circular industries.

In addition, there is a fundamental need to develop key indicators capturing the interlinkages between circularity, climate neutrality and the zero-pollution ambition, as announced in the Circular Economy Action Plan, and to make more specific data available on waste, recycling and industrial R&I for lifecycle assessment in key sectors.

Non-legislative framework conditions are of the utmost importance to facilitate the systematic transformation, which is needed for the circular economy. New regulation appears to have triggered an increased publication of standards, but further foresight and research are needed on how to more comprehensively predict standardisation needs for circularity in such sectors. Research and technology infrastructures are available in textile and construction industrial ecosystems across Europe, and they serve as platforms/facilitators for the industries, especially for small and medium-size enterprises and start-ups.

In summary, the transformation of EU industrial ecosystems for textile, construction and energy-intensive industries has only started and will need to be closely monitored. The current leading role of EU industry in patenting, research and innovation for advanced materials and new, more circularity-oriented legislation, inspire optimism, if the EU can manage to bring technologies for full product life cycles to the market and roll them out across Member States and to companies of different sizes.

INTRODUCTION

Transforming industrial production and the consumption of goods into a circular model is critical for the future of our society, where waste and pollution are eliminated, and our natural environment and biodiversity are regenerated ([1]). Scientific data ([2]) suggests that only 8.6% of the 100 billion tonnes of materials which enter the global economy every year are cycled back, which calls for urgent action both at the level of policy and industry.

The shift to a circular economy needs novel approaches to how we produce, consume and recycle goods. As pressure on natural resources increases, we need to produce at higher levels of resource efficiency, we need to consume products that last longer, are repaired, shared and re-used, and we need to recycle at higher rates and at higher quality. In this shift, innovative technologies and techniques are important enablers as they can provide new tools to design more durable and sustainable products, reduce waste, recycle materials and increase recycled content in new products, and automate tasks enabling circular production.

The purpose of the ERA industrial technology roadmap for circular technologies and business models in the textile, construction and energy-intenive industries is to provide an evidence-based assessment of R&D and innovation needs, investment gaps and deficiencies in valorisation, uptake and deployment. The roadmap addresses circular technologies in three industrial ecosystems, which deserve particular attention for their waste generation as well as high circularity potential - textile, construction and energy-intensive industries (including chemicals, metal and steel, and ceramic industries).

The European Commission adopted the new **Circular Economy Action Plan** (CEAP) in March 2020, as Europe's agenda for sustainable growth. In the wake of the COVID-19 pandemic, circularity was reconfirmed as a core element of EU Member States' recovery agendas when it comes to green objectives. The shift to a circular and regenerative economy is considered as a prerequisite to achieve EU's 2050 climate neutrality target, reduce pollution, and halt biodiversity loss. The CEAP focusses on main paths for a circular economy and on value chains that use most resources and where the potential for circularity is high. The CEAP highlights a clear business case for individual companies to become more circular: since manufacturing firms in the EU spend on average about 40% on materials, closed loop models can increase their profitability, while sheltering them from resource price fluctuations, halting negative effects to the environment and biodiversity and contributing to the reduction of CO2 emissions ([3]).

The Commission has presented two circular economy packages to implement the CEAP. The first package ([4]), adopted on 30 March 2022, brought forward legislative initiatives and strategies, such as the Sustainable Products Initiative, including a proposal for the Ecodesign for Sustainable Products Regulation, the EU strategy for sustainable and circular textiles, the proposal for a revised Construction Products Regulation, and the proposal for empowering consumers in the green transition. The second package, adopted on 30 November 2022, includes proposals for a new policy framework on bio-based, biodegradable and compostable plastics, a review of requirements on packaging and packaging waste in the EU, measures to reduce the

([1]) https://www.weforum.org/agenda/2022/02/double-circular-economy-in-ten-years/
([2]) https://www.circularity-gap.world/2022. The Circularity Gap Reporting Initiative by Circle Economy.
([3]) Circular Economy Action Plan
([4])https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

impact of microplastic pollution on the environment, and a legislative proposal for substantiating green claims made by companies.

The New **European Research Area** ([5]) aims to help 'translating R&I results into the economy'. Under its new approach to build stronger bridges from research to innovation in the economy, the Commission aims to make better use of research and innovation results in its effort to create a single, borderless market for research, innovation and technology across the EU. To this end, it guides the development of common technology roadmaps with industry to include R&I investment agendas from basic research to deployment, linking to the work under key research and innovation partnerships with industry under Horizon Europe.

Within the framework of the **ERA Policy Agenda 2022-2024**, ERA Action 12 on "Accelerate the green and digital transition in Europe's key industrial ecosystems" has a strategic focus on the role of industry and industrial R&I. The action links the industrial technology roadmaps to national strategies and needs of industry to have access to technology infrastructures and services. The Commission shall work closely with 21 EU Member States (MS) ([6]), three Associated Countries (AC) ([7]) and seven stakeholder organisations ([8]) that have committed to **ERA Action 12**.

The updated **Industrial Strategy** ([9]) aims to transform the European industry, making it greener and more digital, while remaining competitive on the global stage and avoiding critical dependencies of our economy. The strategy also identifies a series of factors to support industrial transformation and partnerships such as to help industries achieve climate neutrality, to build a more circular economy, and to embed a spirit of industrial innovation among others. The strategy announces the co-creation of transition pathways for EU industrial ecosystems, to which ERA industrial technology roadmaps provide essential research and development elements. All industrial transition pathways will include a section on the potential and need for circularity, and by analysing the role and potential of innovative industrial technologies for the circular economy, and informing public and private research, innovation and deployment agendas, this roadmap will contribute to the efforts to scale up the circular economy from frontrunners to the mainstream economic players.

The **structure of the report** is organised in four chapters, focusing on various analyses and evidence related to R&I in the three targeted industrial ecosystems. *Chapter 1* looks at the landscaping of circularity and its drivers in the three industrial ecosystems. *Chapter 2* offers technology assessment framework and analysis of business models for the three industrial ecosystems. *Chapter 3* provides estimates of investment needs, offers data analysis of company investments, looks at patenting trends in green and circular technologies and presents an overview of EU and national public investments and programmes. *Chapter 4* discusses framework conditions, including overall challenges and barriers, regulatory and non-regulatory conditions, as well as analysis on valorisation and standardisation in the field of circular technologies, and it offers a discussion on the role of research and technology infrastructures enabling circularity.

([5]) COM(2020)628, 30.9.2020.

([6]) Austria, Belgium, Bulgaria, Czechia, Cyprus, Denmark, Estonia, Finland, France, Germany, Denmark, Italy, Ireland, Lithuania, Netherlands, Poland, Portugal, Slovenia, Slovakia, Spain, and Sweden.

([7]) Georgia, Israel and Norway.

([8]) Committee of the Regions, European Association of Research and Technology Organisations, European Regions Research and Innovation Network, European University Association, Science Europe, the GUILD, and UAS4 Europe.

([9]) https://ec.europa.eu/info/sites/default/files/communication-industrial-strategy-update-2020_en.pdf

THREE INDUSTRIAL ECOSYSTEMS AND THEIR TRANSITION TOWARDS INDUSTRIAL CIRCULARITY: TEXTILE, CONSTRUCTION, ENERGY-INTENSIVE INDUSTRIES

The textile, construction and energy-intensive industries (including chemicals, metal and steel and ceramics) ecosystems have been identified as having a major impact on the environment and with a particular significance when addressing circular industrial technologies. Textile and construction are identified among the key product value chains in the Circular Economy Action Plan. This chapter provides an overview of these three industrial ecosystems and presents their current status of circularity. It gives then an overview about the main circular economy scenarios identified in related EU strategies.

1.1. Landscaping of the industrial ecosystems and a snapshot on their circularity

Textile

Key indicators

The textile ecosystem forms an important part of the EU economy, with a turnover of EUR 163 billion and over 67 000 companies ([10]). At ecosystem level, it employed around 4 million workers in 2020. According to Eurostat, the gross value added of the ecosystem in 2019 was around EUR 86.3 bn, accounting for 0.7% of the total EU value added for that year. Small and medium-sized enterprises (SMEs) are the backbone of the ecosystem and represent over 99.5% of all businesses and employ 74.4% of the workforce. The textile ecosystem encompasses the transformation of natural (e.g. cotton, flax, wool, linen), man-made synthetic and artificial fibres (e.g. polyester and viscose) into yarns and fabrics, home textiles, industrial filters, technical textiles, carpets and clothing. It also includes the production of leather and fur, leather goods and footwear. The fashion industry is the main outlet for textile products. It comprises the

Figure 1.1: Shares of total EU textile industry production per EU MS

Source: Eurostat, Annual enterprise statistics for special aggregates of activities (NACE Rev. 2), shares of total EU production in 2020.

([10]) Eurostat, Annual enterprise statistics for special aggregates of activities (NACE Rev. 2) (sbs_na_sca_r2) manufacturing of intermediate goods and fashion goods, as well as the distribution of these products to the markets operated by wholesalers, agents, and retailers ([11]).

Figure 1.1 shows that the textile industry related production is concentrated in Italy, Germany, Spain, Portugal, Poland and France. Over 40% of EU apparel is produced in Italy ([12]). The highest shares of the textile industrial ecosystem in the workforce can be found in Bulgaria, Portugal and Romania ([13]).

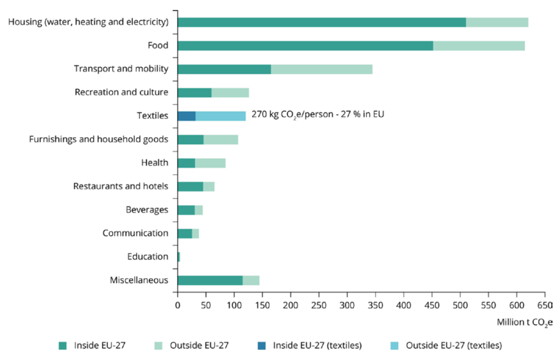
The European textile ecosystem operates in global value chains. In 2021 the value of imports, mainly from Asian countries (30% from China) amounted to EUR 106 billion. On the other hand, the EU exports had a total value of EUR 58 billion and placed the EU as the worldwide second exporter after China ([14]).

Snapshot on circularity and environmental impact

The textile ecosystem is resource-intensive with significant impacts on climate change and the environment (air, water and soil pollution). Environmental pressures include resource use, land use, climate change and releases of pollutants ([15]). In the EU, the use of textiles, most of which are imported, on average accounts for the fifth highest negative impact as regards material use and CO2 emissions (4% of global emissions) and third highest as regards water and land use from a global lifecycle perspective ([16]).

To produce and handle all clothing, footwear and household textiles purchased by EU27 households in 2020, an estimated 121 million tonnes of CO2 were emitted (270 kg CO2 equivalent per person). Only 27% of CO2 emissions take place within Europe (see Figure 1.2) ([17]).

Figure 1.2: Greenhouse gas emissions in the upstream supply chain of EU-27 household consumption domains, million tonnes CO_2 equivalent, 2020



Source: European Environment Agency, 2020.

([11]) CSIL (2021). Data on the EU Textile Ecosystem and its Competitiveness and Annual Single Market Report 2021
([12]) CSIL (2021). Data on the EU Textile Ecosystem and its Competitiveness
([13]) Eurostat, calculations on the share of textile in employment in each MS (NACE C13, C14, C15)
([14]) Euratex, Facts & Key Figures, 2022
([15]) https://www.eea.europa.eu/publications/textiles-in-europes-circular-economy
(16) Textiles and the environment: the role of design in Europe's circular economy — European Environment Agency (europa.eu)
([17]) https://www.eea.europa.eu/data-and-maps/figures/greenhouse-gas-emissions-in-the-1

Most of the pressures and impacts related to the use of clothing, footwear and household textiles in Europe occur in other regions of the world, where they are mostly produced ([18]). It is estimated that globally about 16-35% of microplastics released to oceans are from washing synthetic textiles ([19]) and that 20% of wastewater is produced only during the dyeing and finishing phases of textiles production ([20]).

Fast-changing fashion trends and a decrease in product quality have reduced the use time of clothes by 36% over the past 20 years ([21]), showing the importance of circular design to support longevity and durability of textile products.

In the period between 2015 and 2019, the EU textile ecosystem has however decreased its greenhouse gas (GHG) emission intensity, i.e. slightly reduced its GHG emissions while it increased the added value ([22]).

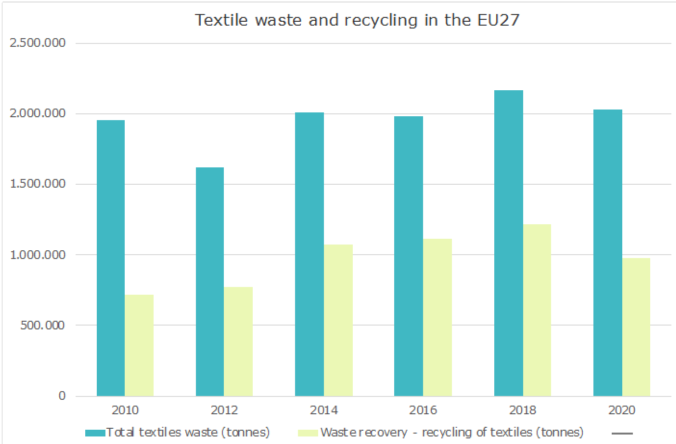
Globally, it was estimated that 73% of clothes end up landfilled or incinerated, and that less than 1% of textile waste is recycled fibre-to-fibre ([23]).

In most EU Member States, a large percentage of post-consumer clothing ends up as part of municipal waste ([24]).

According to Eurostat data (see Figure 1.3), the volume of total EU textile waste remained in the order of about 2 million tonnes with some fluctuations over 10 years and the amount of waste produced in 2020 was 4% higher than in 2010. The volume of recovered - recycled ([25]) textile waste has increased between 2010 and 2018 and then dropped in 2020. The question is if the positive trend may turn again (or if the 2020 value is owed to the impact of the pandemic). Recycling is understood as ‘any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes’ (it is not fibre-to-fibre recycling). The recovery-recycling rate is around 50%, but this is because the definition include the reuse of materials at lower value (recycling into industry wipes or various downcycling options such as use in insulation, upholstery padding or other low-grade products ([26])). The Joint Research Centre (JRC) of the Commission notes, however, that only 38 % of the new textile products are eventually collected separately for reuse or recycling ([27]).

([18]) https://www.eea.europa.eu/publications/textiles-in-europes-circular-economy
([19]) https://www.eea.europa.eu/publications/microplastics-from-textiles-towards-a
([20]) GFA and Mckinsey & Company (2021). Scaling circularity, https://globalfashionagenda.org/news-article/scaling-circularity-a-policy-perspective/
([21]) https://www.eea.europa.eu/publications/textiles-in-europes-circular-economy
([22]) European Commission (2022), Annual Single Market Report.
([23]) EMF (2017) A New Textiles Economy: Redesigning fashion’s future
([24]) Köhler, A., Watson, D., Trzepacz, S., Löw, C., Liu, R., Danneck, J., Konstantas, A., Donatello, S. and Faraca, G., Circular Economy Perspectives in the EU Textile sector, EUR 30734 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-38646-9, doi:10.2760/858144, JRC125110.
([25]) According to Eurostat, recycling is understood as a subset of recovery
([26]) Köhler, A., Watson, D., Trzepacz, S., Löw, C., Liu, R., Danneck, J., Konstantas, A., Donatello, S. and Faraca, G., Circular Economy Perspectives in the EU Textile sector, EUR 30734 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-38646-9, doi:10.2760/858144, JRC125110.
([27]) Circular economy perspectives in the EU textile sector, Joint Research Centre Technical Report, 2021

Figure 1.3: Textile waste and recycling performance in the EU 27



Source: Technopolis Group calculations based on Eurostat data ([28]), Generation of waste by waste category, hazardousness and NACE Rev. 2 activity, All NACE activities plus households

From 1st January 2025, it will become a legal obligation to separately collect municipal textile waste ([29]) leading to far greater waste feedstock. Major efforts and investments will be required to maximise the value of this feedstock.

([28]) Total textile waste has been calculated using all the NACE industries as input sources. This is aligned with the definition of the category Textile Waste, which is also used to measure the waste recovery – recycling of textiles.
([29]) Waste Framework Directive Article 12b, 2018/851

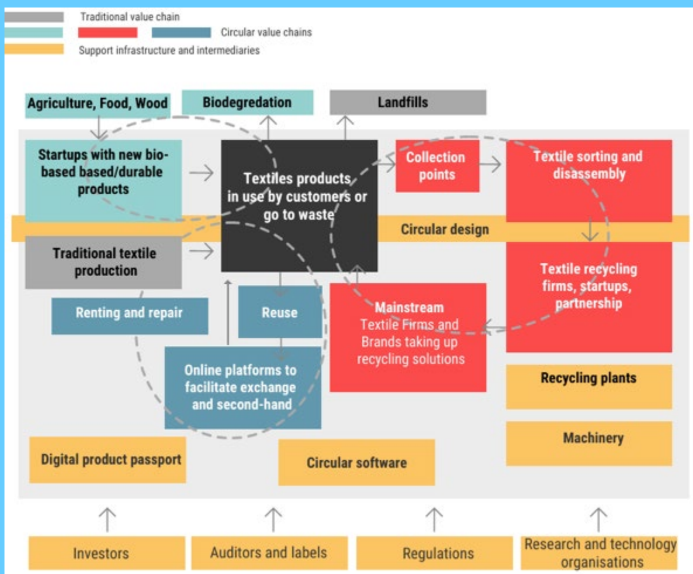
Box 1.1 | Sustainability in the textile industrial ecosystem

The circular economy in the textiles industry would start with reducing the volume of new production and keeping products in circulation for as long as possible. Material propensities should ensure that the products can be saved from landfill.

Stakeholder communities which focus on sustainability can be grouped around key circular economy models and types of technology such as 1) recycling and recycled materials, 2) bio-based materials and circular design, and 3) reuse, resell, rent.

In terms of stakeholder groups, the value chains of fashion textiles and industrial textiles must be separated since they have different waste streams. Their opportunities for reuse or recycling are different with various players involved in the circular transition.

Figure 1.4: Alternative circular value chain pathways in the textile industry



Source: Technopolis Group, 2022

The biggest European markets for recycled textiles include Italy, Germany, France, Netherlands, Belgium and Poland ([30]). Of the various materials, recycled polyester boasts the highest popularity, followed by nylon, cotton and wool. Products made from recycled materials are also often in specific categories only, for example, outwear, swimwear, shoes, rags, and mattresses. The market is driven by the rise in demand from end user industries and decreasing costs of production.

([30]) https://www.cbi.eu/market-information/apparel/recycled-fashion/market-potential

Construction

Key indicators

The construction ecosystem is a key industry within the EU economy, with a turnover of EUR 2,201 bn and composed of 5.3 million companies. At ecosystem level, it employed about 24.9 million people ([31]) in the EU. According to Eurostat, the gross value added of the ecosystem in 2019 was EUR 1 158 billion, accounting for 9.6% of the total EU value added ([32]). 99.9% of companies in the ecosystem are SMEs, which represent 75.5% of employment in the ecosystem and 71.2% of its total added value ([33]). On top of this, 90% of these SMEs are micro-companies. The construction ecosystem covers several activities including building and infrastructure, construction product manufacturing, engineering and architectural services and other economic activities (e.g. rental and leasing of machinery and equipment, employment agencies) ([34]).

Figure 1.5: Shares of total EU construction industry production per EU MS

Source: Eurostat, Annual enterprise statistics for special aggregates of activities (NACE Rev. 2), shares of total EU production in 2020.

Figure 1.5 indicates that the construction industry is present in every Member State, but the highest contribution to EU total production in terms of value is provided by Germany, France, Italy and Spain. The share of construction in the workforce of the business economy is in almost all Member States above 10% ([35]).

Snapshot on circularity and environmental impact

The construction ecosystem is hugely resource and emission intensive in terms of greenhouse gas, air pollutant and noise emissions.

([31]) Eurostat, Annual enterprise statistics by size class for special aggregates of activities (NACE Rev. 2) (sbs_sc_sca_r2)
([32]) Eurostat, Annual enterprise statistics for special aggregates of activities (NACE Rev. 2) (sbs_sc_con_r2)
([33]) European Commission (2022). Annual Single Market Report
([34]) European Commission (2021). Annual Single Market Report
([35]) Eurostat, calculations on the share of construction in employment in each MS (NACE N81, M71, F)

GHG emissions from material extraction, manufacturing of construction products, construction and renovation of buildings are estimated at 5-12% of total national GHG emissions ([36]).

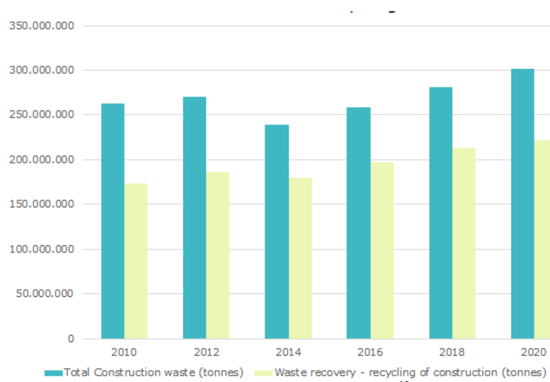
According to Eurostat data (2019), construction accounts for 2% of the CO2 emissions and 5% of the fine particles pollution. Environmental pollution is generated during the construction and installation phases and when products reach the end of their life.

In the EU, buildings are responsible for around 50% of resource extraction and consumption, 50% of energy consumption, 30% of water consumption and more than 30% of the EU's total waste generated each year. Moreover, about 65% of total aggregates (sand, gravel and crushed rock) and 20% of total metals are used by the construction sector.

Construction and demolition waste produced in the EU annually is about 450-500 million tonnes ([37]). Construction and demolition waste contains a variety of materials such as concrete, bricks, wood, glass, metals and plastic. In terms of volume, the ecosystem has the largest waste stream in the EU across all industries.

Figure 1.6 showcases the total waste and waste recovery-recycling for the category 'Mineral waste from construction and demolition' (EWC-Stat 12.1). Waste increased to more than 300 million tonnes in 2020. Waste recovery-recycling is high and steadily increased between 2010 and 2020. The recovery-recycling rate of more than 70% is however partly explained by the inclusion of the reuse of materials at lower value. The EU Waste Framework Directive's conditions for recycling include indeed recovery options such as backfilling, landfilling or other low-grade applications, which substantially hamper the potential to move to a truly circular waste management system ([38]). The recovery rate of construction and demolition waste varies also greatly across the EU, ranging from less than 10% to 90% ([39]).

Figure 1.6: Construction waste and recycling performance in the EU 27



Source: Technopolis Group calculations based on Eurostat data, 2022 ([40])

([36])https://www.boverket.se/sv/byggande/hallbart-byggande-och-forvaltning/miljoindikatorer---aktuell-status/vaxthusgaser/

([37]) https://www.interregeurope.eu/find-policy-solutions/webinar/collection-and-recycling-of-construction-and-demolition-waste-key-learnings

([38]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098

([39]) Eurostat, 2018. Circular Economy Indicators, Recovery rate of construction and demolition waste

([40]) The indicators for total waste and waste recycling cover the waste category 'Mineral waste from construction and demolition' (EWC-Stat 12.1).

Durability is another important aspect of the circular economy. In the case of construction, it describes the 'ability of the building system and its materials not to exhibit significant deterioration over time that implies the loss of functionality for which they were designed'. Durability of components and materials therefore has a direct impact on the lifespan of built structures and systems in their entirety. There is no general indicator capturing the level of durability present in the whole industry. Adaptability and modularity are relevant to optimising use of building space and to driving durability.

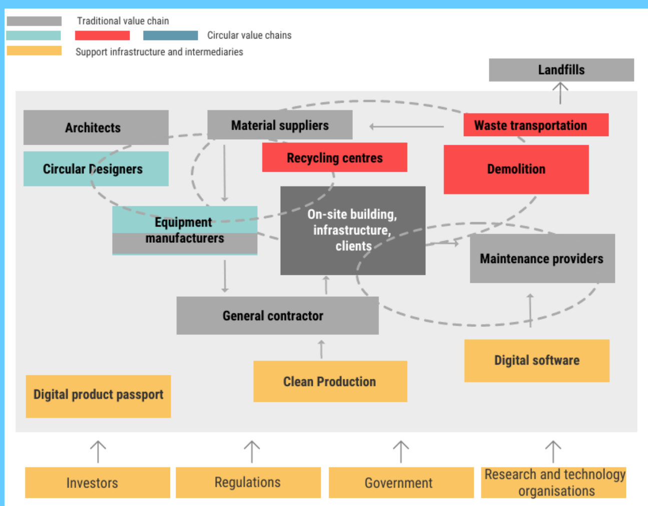
Box 1.2 | Sustainability in the construction industrial ecosystem

The value chain in the construction ecosystem is complex, scattered and only partially integrated.

The materials used in the construction industry are subject to several stages of treatment, starting with a pre-deconstruction audit & waste management plan, then hazardous waste removal and selective de-construction and disassembly, and leading to on-site operations, which effectively introduce a major logistical step into the material flow process.

After this logistical step, materials can be further processed based on their characteristics, qualities, and abilities. While some materials can be reused or recycled and therefore fed back into the circular flow of construction materials, others are being recovered to produce energy or materials, or landfilled.

Figure 1.7 Desired material flow in the construction industry and supporting policies



Source: Technopolis Group, 2022

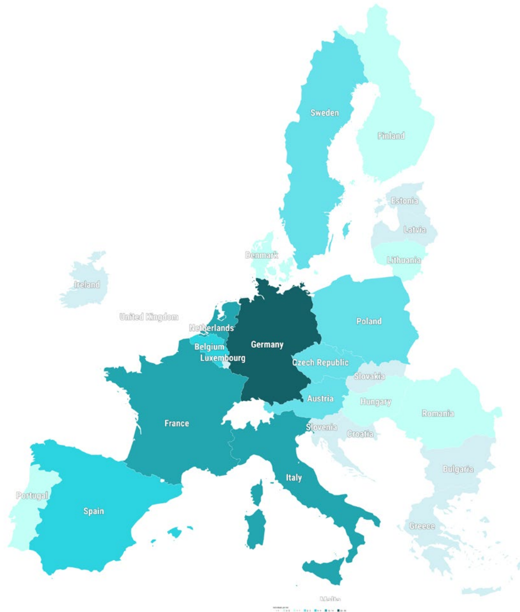
Energy-intensive industries

Key indicators

The EII ecosystem is at the same time developer and provider of materials for different value chains as well as closely integrated with waste and recycling industries due to EIIs' need for secondary raw materials ([41]).

The EII ecosystem has a turnover of EUR 2 200 billion and comprises more than 548 000 companies. It employed about 7.8 million people in 2019 ([42]). According to Eurostat, it generated EUR 549 bn of gross value added in 2019, accounting for 4.55% of total EU value added in 2019. Regarding the structure of the ecosystem, SMEs represent 99.4% of the companies active in the EII market and employ 50.9% of the total workforce. EIIs cover chemicals, steel, paper, plastics, mining, extraction and quarrying, refineries, cement, wood, rubber, non-ferrous metals, glass, and ceramics.

Figure 1.8: Shares of total EU industrial production in EII per EU MS



Source: Eurostat, Eurostat, Annual enterprise statistics for special aggregates of activities (NACE Rev. 2),

These industries normally operate as intermediate suppliers for other supply industries.

According to Figure 1.8, the EIIs' production value is concentrated in Germany, France and Italy. Germany, Poland and Italy have the biggest workforces in Europe ([43]).

This report deepens the analysis specifically of three sectors: chemicals, metal and steel, and ceramics:

- The chemicals industry is one of the largest manufacturing sectors in the EU27. It employs 3.4 million people and provides a gross value added of EUR 335.4 bn ([44]).

([41]) European Commission (2021). Annual Single Market Report, 2021, Brussels, 5.5.2021 SWD(2021) 351 final
([42]) European Commission (2021). Annual Single Market Report, 2021, Brussels, 5.5.2021 SWD(2021) 351 final
([43]) Eurostat, calculations on the share of construction in employment in each MS (NACE: C17,C20,C22-25)
([44]) https://cefic.org/a-pillar-of-the-european-economy/facts-and-figures-of-the-european-chemical-industry/our-contribution-to-eu-industry/

- The EU steel industry supports 2.5 million jobs in the EU27 and creates EUR 134.5 bn of gross value added ([45]).

- The ceramics industry employs 200 000 people and has a gross value added of EUR 9 bn in the EU27 ([46]).

Snapshot on circularity and environmental impact

The EII ecosystem is a major contributor to GHG emissions, air pollutants and noise. In terms of GHG, EII were responsible for about 17 % of the total EU GHG emissions in 2019 ([47]). The production of chemicals, steel, plastics, ammonia and cement emits more than 530 million tonnes of CO2 per year (including electricity and end-of-life emissions) in the EU ([48]). In particular, the steel industry accounted for 15% of the CO2 emissions in the EU in 2020 ([49]). Similarly, the manufacture of chemicals and chemical products represented 5% of the total CO2 emissions in the EU, and 3% of the fine particles pollution ([50]).

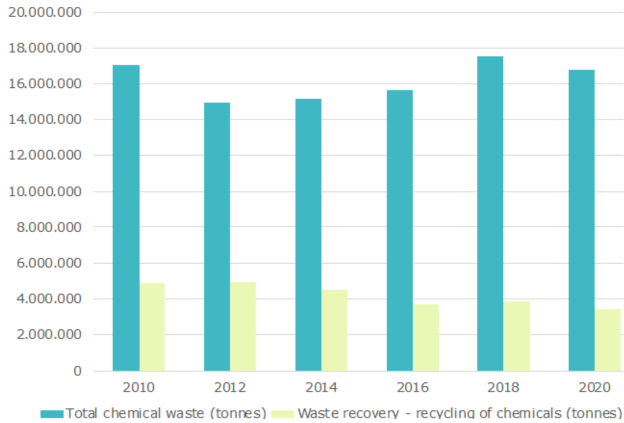
The EIIs overall reduced their emissions between 1990 and 2018 by 30%, which represented 28% of the total emissions reduction in the EU according to the data inventory of the European Environment Agency ([51]).

EIIs emit various environmental pollutants such as chemicals with toxic properties that remain in the environment for a very long time ([52]).

According to Eurostat data, the waste recovery of chemicals (total of hazardous and non-hazardous) decreased by 30% over the period from 2010 to 2020. Additionally, the total chemical waste generated in the EU27 has fluctuated over the years and it kept increasing since 2012 with a slight drop from 2018 to 2020 (Figure 1.9).

([45]) https://www.eurofer.eu/assets/publications/brochures-booklets-and-factsheets/european-steel-in-figures-2022/European-Steel-in-Figures-2022-v2.pdf
([46]) https://cerameunie.eu/ceramic-industry/
([47]) https://ec.europa.eu/growth/industry/sustainability/buildings-and-construction_en
([48]) Materials Economics (2019). Industrial Transformation 2050 – Pathways to Net-Zero Emissions from EU Heavy Industry
([49]) https://ec.europa.eu/info/sites/default/files/swd-competitive-clean-european-steel_en.pdf
([50]) Eurostat data (2020)
([51]) industrial-value-chain-for-a-carbon-neutral-europe-sept-2018_file.pdf (glassallianceeurope.eu)
([52])https://ec.europa.eu/environment/chemicals/international_conventions/index_en.htm#:~:text=Persistent%20organic%20pollutants%20(POPs)%20are,human%20health%20and%20the%20environment.

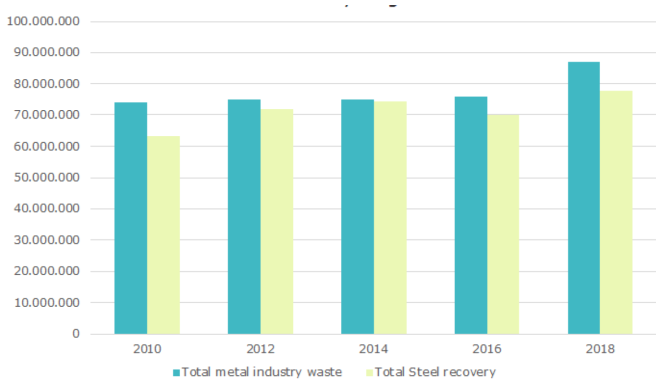
Figure 1.9: Chemical waste and recycling performance in the EU 27



Source: Technopolis Group calculations based on Eurostat data, 2022 ([53]).

Regarding metal, Figure 1.10 shows that the volume of waste increased in 2018. The waste recovery–recycling has been high.

Figure 1.10: Metal waste and recycling in the EU27



Source: Technopolis Group calculations based on Eurostat data, 2022 ([54]).

Box 1.3 | Sustainability in the EII ecosystem

Chemicals

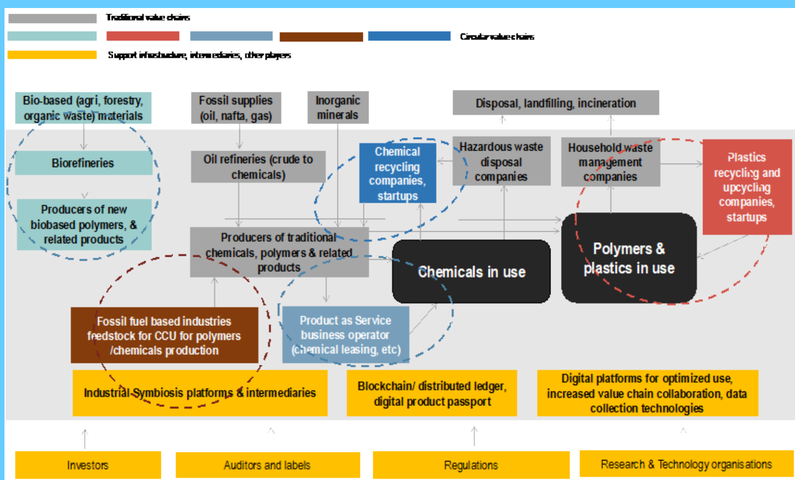
Traditional value chains connecting chemical industries with other industries have been largely linear. Emerging stakeholder communities linked within key circular economy value chains are active in 1) material sourcing including recycling and bio-based raw material supply, 2) new materials, 3) upgraded production processes including improving resource efficiency and industrial symbiosis, 4) product-as-a-service business models, and 5) new recycling technologies and supporting technologies including digital assistance (see Figure 1.11 below).

([53]) Total chemical waste has been calculated using all the NACE industries as input sources. This is aligned with the definition of the category Chemical Waste, which is also used to measure the waste recovery – recycling of chemical.
([54]) Total chemical waste has been calculated using all the NACE industries as input sources. This is aligned with the definition of the category Chemical Waste, which is also used to measure the waste recovery – recycling of chemical.

Key circular value chains can be grouped as follows:

- bio-based chemicals and polymers production;
- valorisation of secondary resources via e.g. carbon capture and utilisation and industrial symbiosis;
- recycling of plastics, which has seen significant interest and growth;
- recycling of chemicals (acids, alkaline, saline wastes, regeneration of spent solvents) which is likely to gain more interest in the future;
- product-as-a-service business models, such as chemical leasing.

Figure 1.11: Circular value chains emerging in chemical industries



Source: Technopolis Group, 2022

Steel & Metal

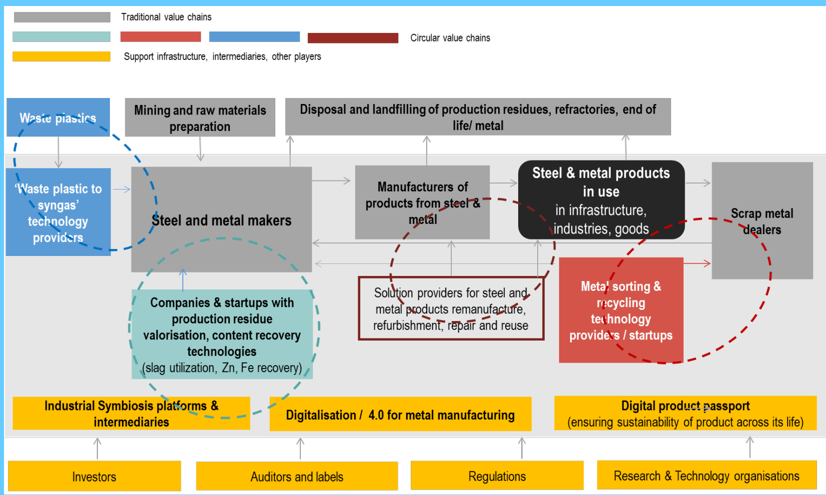
The nature of metals and steel allows unlimited recycling of the material, which makes it the most recycled material in the world. For example, the recycled content of steel packaging in Europe is 58%, while the recycling rate for steel packaging in the EU reached 85,5% in 2020 ([55]). Besides recycling there are other opportunities for circularity in the industry (see Figure 1.12). The existing and emerging circular value chains and relevant stakeholders are the following:

- Production process residue (e.g. slag) valorisation and content (Zn, Fe) recovery where technologies are often developed by steel makers, specialised companies, research organisations, or start-ups;
- Post-use metal scrap recycling, where metal scrap characterisation and sorting technologies are of special need for the industry. Metal scrap dealers, specialised technology providers, as well as key metal industries are involved in related R&I;
- Syngas use for low-carbon steelmaking coupled with plastic waste-to-syngas technology offer a promising option for synergetic circular solution. It is being developed in collaborations between steel makers, researchers and specialised technology companies.

Another promising circular value chains (that is beyond the scope of the present analysis but indicated in the diagram) are related to reuse, extended use of metal product or infrastructure facilitated by remanufacturing, refurbishment, repair, restoring ([56]). Here the role of companies exploiting the metal product/infrastructure and offering repair services is crucial.

([55]) APEAL – the Association of European Producers of steel for packaging, https://www.apeal.org/statistics
([56]) https://worldsteel.org/circulareconomy/ , these CE opportunities belong to other industrial ecosystems

Figure 1.12: Circular value chains emerging in metal and steel industries



Source: Technopolis Group, 2022

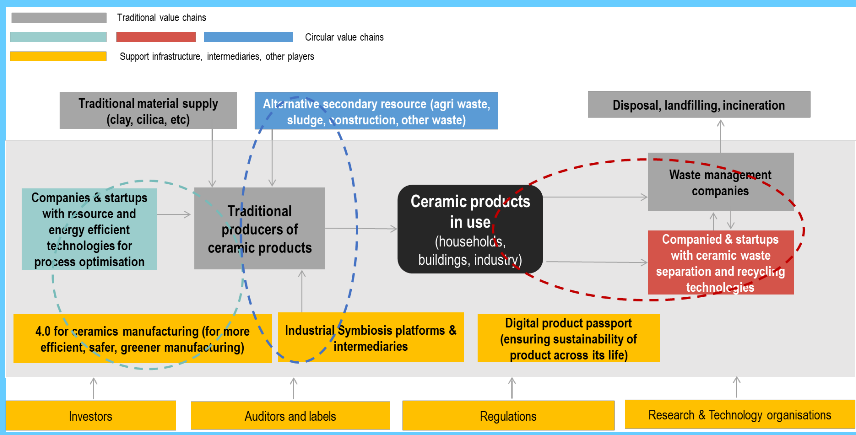
Ceramics

The key circular value chains emerging in the ceramic industry are around (see also Figure 1.13):

- Production process optimisation via resource and energy efficiency technologies – where the key technology developers are (i) largely the ceramic product manufacturers, companies and start-ups providing resource/energy saving technologies;
- Valorisation of secondary raw materials (waste of other industries) via industrial symbiosis – where the key players again are the ceramic industries, the industrial symbiosis intermediaries and possibly also waste management companies who normally deal with the sidestream or end of live waste that can be integrated in the ceramic production;
- End of life ceramic waste diverting from landfill by engaging in waste separation, recycling and making use of it either back in ceramic or other industries, e.g. in construction. In this value chain, the ceramic industries also develop end of life recycling technologies, as well as specialised technology providers offering separation and recycling technologies.

Digital technologies are increasingly offering higher efficiency of the processes for greener, safer and efficient manufacturing. There is also a great potential for digital technologies in industrial symbiosis and recycling of the end of life ceramic products. Digital passport technology can also help in greening the entire lifecycle of ceramic products.

Figure 1.13: Circular value chains emerging in ceramics industries



Source: Technopolis Group, 2022

1.2. Innovative circular industrial technologies in current EU policy scenarios

At EU level, the Circular Economy Action Plan (CEAP) of March 2020 provides a future-oriented agenda for achieving a circular economy. It is one of the main building blocks of the European Green Deal. It is also a prerequisite to achieve the EU's 2030 target for the reduction of climate emissions ([57]) and the 2050 climate neutrality target and to halt biodiversity loss ([58]). The CEAP sets out a set of inter-related legislative and non-legislative initiatives to provide a framework for systemic change in key value chains, to promote more sustainable products and businesses, and to ensure effective waste management. Industrial transformation throughout the full supply and value chains is key to achieving these ambitious targets.

The uptake of circular processes goes hand in hand with the Zero Pollution Ambition, in order to improve human and environmental health by decreasing exposure to harmful substances. The transition to a sustainable economic system is also part of the 2021 update of the EU Industrial Strategy, with notably the transition pathways.

The new European Innovation Agenda Communication ([59]) of July 2022 refers to innovation activities that support the transition to a circular, resource-efficient and digital economy. It includes a special focus on 'deep-tech innovation', which can be defined as transformative business models underpinned by scientific and/or technological breakthrough.

The adoption by the Commission of a proposal for an Ecodesign for Sustainable Products Regulation ([60]) on 30 March 2022 marks a groundbreaking move. By extending the Ecodesign principles and process to cover all non-food products, and

---

([57]) Europe's path to decarbonisation | McKinsey
([58])UN International Resource Panel, Global Outlook Report: https://www.resourcepanel.org/reports/global-resources-outlook
([59])https://ec.europa.eu/commission/presscorner/detail/en/ip_22_4273
([60])https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products_en

applying circularity criteria, it will eliminate the least circular product attributes from the European market. It also brings in not only physical product requirements, but data requirements and a European Product Passport that will pave the way to enhanced traceability and enable B2B value retention actions and business models and better B2C sustainability information. Technical screening criteria will be set out in 2023 that establish what constitutes a “substantial contribution” to circular economy, in the context of the Sustainable Finance Taxonomy. The Delegated Act setting out these criteria will cover a wide gamut of economic activities, and circular business models in general.

The Materials 2030 Manifesto ([61]), signed by seven high-level representatives in the field of advanced materials, underlines that, to remain competitive and meet citizens’ needs for safer and more sustainable advanced materials, Europe needs to strategically rethink advanced materials R&I by adopting *‘a systemic approach to develop the next generation solution-oriented advanced materials which will offer faster, scalable, and efficient responses to the challenges and thus turn them into opportunities for Europe’s society, economy, and environment today and in the future’*. The Manifesto identifies the lack of visibility for advanced materials and asks for a technology push and market pull to connect advanced materials developments with the upscaling to respond to market needs.

Building on the vision of the Materials 2030 Manifesto, a Materials 2030 Roadmap paves the way for implementing this strategy by engaging all materials stakeholders ([62]). As follow-up action, an initiative to further engage stakeholders and prepare a Strategic Agenda on advanced materials has been launched (the Advanced Materials Initiative 2030 - AMI 2030), to coordinate and implement actions throughout Europe until the adoption of the Strategic Agenda.

In December 2022, the Commission will adopt the Recommendation on the assessment framework for safe and sustainable by design chemicals and materials. This framework should, inter alia, guide R&I activities on advanced materials to increase their safety and sustainability over their lifecycle.

In the EU, the overall circular material use rate ([63]) has slightly increased in the last 10 years to 12.8% in 2020 ([64]), but with significant variation across Member States ([65]). However, this indicator is not industry specific, as it measures the share of material recycled and fed back into the economy in overall material use. The CEAP sets the goal of doubling the EU circular material use rate between 2020 and 2030. Implementing the CEAP, the Commission translates this overarching goal into cross-cutting or sector-specific strategies and legislative proposals.

Further indicators related to the Commission’s 8th Environment Action Programme monitoring framework ([66]) refer to raw material consumption ([67]), which shows the amount of extraction required to produce the products demanded by final users, and total waste generation. Between 2010 and 2020, the indicator registered a slight

---

([61]) https://ec.europa.eu/info/sites/default/files/research_and_innovation/research_by_area/documents/advanced-materials-2030-manifesto.pdf
([62]) https://www.ami2030.eu/roadmap/
(63) Indicator included in the Enivronment Action Programme (COM(2022) 357 fina).
([64]) EU’s circular material use rate increased in 2020 - Products Eurostat News - Eurostat (europa.eu)
([65]) Annual Single Market Report 2022
([66]) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0357&from=EN
(67) https://ec.europa.eu/eurostat/cache/egd-statistics/

decrease, from 14.8 tonnes/capita in 2010 to 13.7 tonnes/capita in 2020. However, neither this indicator is available per industry, but rather as an overall indicator, with variations across Member States.

The CEAP announced the revision of the current monitoring system. The Commission and Eurostat established in 2018 a European Circular Economy Monitoring Framework to monitor progress towards achieving the circular economy using available statistical data, including indicators related to applicable legislation. The framework focuses on aspects of the circular economy related to resource use and waste management. Aspects related to maintaining the value of products and materials for a longer period - such as design for circularity, repair, and reuse - are not yet included ([68]). An ongoing study under Horizon Europe will consolidate all knowledge on circularity indicators and address these gaps ([69]).

In 2023, the Commission will present a revised monitoring framework for the circular economy composed of a set of key, meaningful indicators. Those help monitoring progress towards the new policy objectives and targets, and capture the main elements of the circular economy in the context of the 8th Environment Action Programme, the European Green Deal, the 2030 Agenda for Sustainable Development and the EU security of supply in case of a crisis. The new framework provides an holistic view as it measures direct and indirect benefits of becoming circular, valuing the contribution of circular economy in living well within the planetary boundaries and addressing material supply risks.

EU Directives set collection, reuse, recovery and recycling targets that are relevant for the three ecosystems addressed in this roadmap, as described in Table 1.1 below.

Table 1.1: overview of EU targets for the textile, construction and energy-intensive industries

EU Directive	Target Date	EU Target	Relevant sector
Waste Framework Directive (Directive 2018/851 amending Directive 2008/98/EC on waste, article 11)	2025	Preparation for re-use and recycling targets for textiles (among other materials), will be considered by the Commission by 31 December 2024. Member States will have a legal obligation to introduce separate collection of waste textiles by 2025	textile
	2025, 2039, 2035	55% preparation for reuse and recycling of household waste by 2025, 60% by 2030 and 65% by 2035;	chemicals/ plastics, metal
	2020	Preparing for reuse, recycling and other material recovery (incl. beneficial backfilling operations using waste as a substitute) of 70% by weight of construction and demolition non-hazardous waste (excluding natural soils & stone)	construction & ceramics
Packaging Directive	2025 and 2030	65% in 2025 and 70% in 2030 as a minimum by weight of packaging waste will be recycled.	

([68]) https://www.eea.europa.eu/themes/waste/measuring-europes-circular-economy
([69]) Indicators and methods for measuring transition to climate-neutral circularity, its benefits, challenges and trade-offs: https://etendering.ted.europa.eu/cft/cft-display.html?cftId=10786

(94/62/EC as amended)		The following minimum recycling targets for materials contained in packaging waste will be attained:	
		(i) Glass: 2025 and 2030 EU recycling targets are 70% and 75%.	
		(ii) Paper & cardboard: 2025 and 2030 EU recycling targets of 75% and 85%;	
		(iii) Wood: 2025 and 2030 EU recycling targets are 25% and 30%	
		(iv) Metals: Non Ferrous: 2025 and 2030 EU recycling targets are 70% and 80%; Aluminium 50% and 60%	metal
		(v) Plastics: 2025 and 2030 EU recycling targets are 50% and 55%.	chemicals/ plastics
End of Life Vehicles Directive (2000/53/EC) to be revised by end of 2022	01/01/ 2015	Reuse and recovery to a minimum of 95% by average weight of vehicle and year.	metal & chemicals
		Reuse and recycling to a minimum of 85% by average weight of vehicle and year.	metal & chemicals
Batteries Directive (2006/66/EC) currently recvised(2022)	2025, 2030	It's a current requirement that, at least, 50% of a battery's weight must be recycled. From 2025, this requirement will increase to 65% for lithium-ion batteries and to 70% from 2030. Specific recycling requirements will also be introduced for the lithium, cobalt, copper, nickel, and lead content of batteries. For example, the required recycling rate for lithium will increase from 35 to 70% between 2026 and 2030. The EU is seeking to set a 90% recycling rate for cobalt, copper, nickel, and lead from 2026.	metal & chemicals
	2026, 2030	Manufacturers will be required to increase the number of portable batteries they collect by 45% by 2026, and by 70% by 2030.	metal & chemicals
Landfill Directive (1999/31/EC)	2035	limit the amount of municipal waste due to be landfilled to 10% or less	various
WEEE Directive (Waste from Electrical and Electronic Equipment) (2012/19/EC)	2019	Separate collection of ≥ 65% of WEEE in reference to electrical and electronic equipment placed on the market.	metal & chemicals
	2018	For Temperature exchange equipment: Recovery shall be a minimum of 85% by an average weight per appliance; and Component, material and substance reuse and recycling shall be a minimum of 80% by an average weight per appliance.	metal & chemicals

	2018	For Screens, monitors, and equipment containing screens having a surface greater than 100 cm²: Recovery shall be a minimum of 80% by an average weight per appliance; and Component, material and substance reuse and recycling shall be a minimum of 70% by an average weight per appliance.	metal & chemicals
	2018	For Lamps: No recovery target Component, material and substance reuse and recycling shall be a minimum of 80% by an average weight per appliance.	metal & chemicals
	2018	For Large equipment (any external dimension more than 50 cm): Recovery shall be increased to a minimum of 85% by an average weight per appliance; and Component, material and substance reuse and recycling shall be increased to a minimum of 80% by an average weight per appliance.	metal & chemicals
	2019	For Small equipment (no external dimension more than 50 cm): Recovery shall be increased to a minimum of 75% by an average weight per appliance; and Component, material and substance reuse and recycling shall be increased to a minimum of 55% by an average weight per appliance.	metal & chemicals
	2020	For Small IT and telecommunications equipment (no external dimension more than 50 cm): Recovery shall be increased to a minimum of 75% by an average weight per appliance; and Component, material and substance reuse and recycling shall be increased to a minimum of 55% by an average weight per appliance.	metal & chemicals

Scenario for the textile industry by 2030

As part of the CEAP, the EU Strategy for Sustainable Textiles was published in March 2022 ([70]). Its aim is to create conditions and incentives to achieve a sustainable and circular ecosystem by 2030.

The Commission's 2030 vision for textile is that:

'By 2030 textile products placed on the EU market are long-lived and recyclable, to a great extent made of recycled fibres, free of hazardous substances and produced in respect of social rights and the environment. Consumers benefit longer from high quality affordable textiles, fast fashion is out of fashion, and economically profitable re-use and repair services are widely available. In a competitive, resilient and innovative textiles sector, producers take responsibility for their products along the value chain, including when they become waste. The circular textiles ecosystem is thriving, driven by sufficient capacities for innovative fibre-to-fibre recycling, while the incineration and landfilling of textiles is reduced to the minimum'.

The specific measures will include ecodesign requirements for textiles, clearer information to consumers, a digital product passport and a mandatory EU extended producer responsibility scheme. It also sets out measures to tackle the unintentional release of microplastics from textiles, ensure the accuracy of green claims, and boost circular business models, including reuse and repair services. To address fast fashion, the strategy also calls on companies to reduce the number of collections per year, take responsibility and act to minimise their carbon and environmental footprints, and Member States to adopt favourable taxation measures for the reuse and repair sector. The Commission will also promote the shift with awareness-raising activities ([71]).

The Strategy's annex states that the Commission will consider preparing reuse and recycling targets for textiles (among other materials) by 31 December 2024 (as stated in the Waste Framework Directive). It also recalls that Member States will have a legal obligation to introduce separate collection of waste textiles by 2025 under the Waste Framework Directive.

To accompany the textiles ecosystem throughout its transition, the Commission has launched the co-creation of a transition pathway for the ecosystem ([72]), as part of the updated industrial strategy, with a consultation closed on 15 June 2022 and stakeholder workshops in September and October 2022. Scenarios by 2030, including for a more sustainable textile ecosystem, were proposed for stakeholder consultation, including research & innovation investment in circular technologies. The agreed pathway is expected to be published in Q1 2023.

A recent article by McKinsey estimates that fiber-to-fiber recycling could reach 18 to 26% of gross textile waste by 2030. It also shows that, in a base-case scenario, scaling textile fibre-to-fibre recycling in the EU and Switzerland could reduce CO2 emissions

([70]) https://environment.ec.europa.eu/strategy/textiles-strategy_en
([71]) https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2013
([72]) https://single-market-economy.ec.europa.eu/news/stakeholder-consultation-transition-pathway-textiles-ecosystem-2022-03-30_en

by approximately 4 million tonnes by 2030. It would reduce as well the water-use, land-use and chemicals-use ([73]).

Scenario for the construction industry by 2030

The Waste Framework Directive ([74]) published in 2008 set out the target of a 70% recovery rate of materials in the construction value chain by 2020. Most Member States achieved the 70% target ([75]), but some have relied on backfilling which is misleading.

The construction sector is also specifically addressed in the CEAP, in which it was announced that to exploit the potential for increasing material efficiency and reducing climate impacts, the Commission will launch a new comprehensive Strategy for a Sustainable Built Environment. This will promote circularity principles throughout the lifecycle of buildings. As part of this future strategy, the Commission published in March 2022 its proposal for the revision of the Construction Product Regulation ([76]), which will strengthen and modernise the rules in place since 2011. It will create a harmonised framework to assess and communicate the environmental and climate performance of construction products. New product requirements will ensure that the design and manufacture of construction products is based on state of the art to make these more durable, repairable, recyclable, and easier to remanufacture. It will also make it easier for standardisation bodies to create common European standards. The revised Regulation will also offer digital solutions to reduce administrative burden, particularly for SMEs, including a construction products database and a digital products passport ([77]).

In 2020, the Commission published the Renovation Wave Strategy ([78]) to boost renovation in the EU. It aimed to double annual energy renovation rates by 2030. The New European Bauhaus initiative also gives inspiration for beautiful, sustainable, and inclusive buildings.

The Commission is developing a transition pathway for the construction industry ecosystem, in a process of co-creation with industry, interested parties and Member States, to be published in Q1 2023. As part of this work, the Commission published in December 2021 a staff working document ([79]) that proposed scenarios by 2030 for construction to become more green, digital and resilient.

The Commission has also developed and tested Level(s) ([80]) as a common language for assessing and reporting on the sustainability performance of buildings. It is a simple entry point for applying circular economy principles in our built environment. It offers an extensively tested system for measuring and supporting improvements, from design to end of life. It can be applied to residential buildings or offices.

([73]) https://www.mckinsey.com/industries/retail/our-insights/scaling-textile-recycling-in-europe-turning-waste-into-value
([74]) https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en
([75]) https://ec.europa.eu/eurostat/web/products-datasets/-/cei_wm040
([76]) New proposals to make sustainable products the norm (europa.eu)
([77]) https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2013
([78]) https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662
([79]) https://ec.europa.eu/docsroom/documents/47996
([80]) https://environment.ec.europa.eu/topics/circular-economy/levels_en

It was estimated by the International Resource Panel that greater material efficiency could save 80% of the emissions from material extraction, manufacturing of construction products, construction and renovation of buildings ([81]).

Scenario for the EII ecosystem by 2030 and 2050

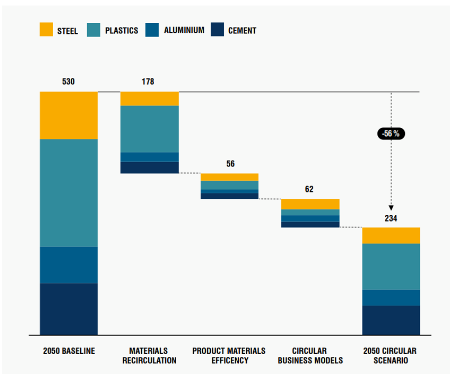
The EIIs supply the materials used across our economy. To achieve climate neutrality by 2050, a fundamental shift to sustainability – including accelerated and deep decarbonisation and a generalised circular transition – is required ([82]). In the EII ecosystem, the green transition requires a fundamental rethinking of traditional production processes, the development of new business models and the creation of whole new value chains ([83]).

A circular economy is only possible with the process industries, given their pivotal importance in the most critical value chains. In the transition towards more recycled, CO2-based and bio-based materials, the process industries play an important role as they can use these materials to replace primary resources ([84]).

EIIs are required to meet several EU recycling targets under the Waste Framework Directive, Packaging Directive, End of Life Vehicles Directive, Batteries Directive, Landfill Directive, WEEE Directive.

Material Economics (2018) ([85]) estimated that a more circular economy can make deep cuts to emissions from heavy industry in an ambitious scenario, as much as 296 million tonnes CO2 per year in the EU by 2050, out of a total of 530. This is equivalent to 56% of the CO2 emissions of the industries studied (see Figure 1.14).

Figure 1.14: The potential to reduce EU emissions in a more circular economy, 2050 (mt of carbon dioxide per year)

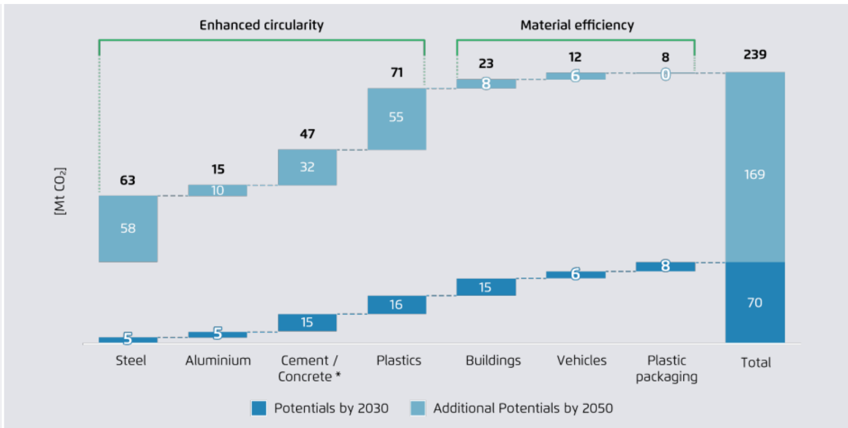


Source: Materials Economics, 2018

([81]) Circular Economy Action Plan
([82]) European Commission SWD For a resilient, innovative, sustainable and digital energy-intensive industries ecosystem: Scenarios for a transition pathway
([83]) European Commission SWD For a resilient, innovative, sustainable and digital energy-intensive industries ecosystem: Scenarios for a transition pathway
([84]) https://www.aspire2050.eu/sites/default/files/users/user85/p4planet_07.06.2022._final.pdf
([85]) the-circular-economy-a-powerful-force-for-climate-mitigation.pdf (sitra.fi)

A report from Agora Energiewende ([86]) shows that the enhanced circular and efficient use of materials alone could help abate up to 70Mt of CO2 by 2030, and 239 Mt by 2050, equivalent to 10% and 34% of the total required industrial abatement efforts in the EU by 2030 and 2050, respectively. These reductions would thus be additional and complementary to other abatement actions to reduce emissions from virgin materials production, using new, clean technologies ([87]). As shown in Figure 1.15, the potential to abate CO2 is already significant by 2030, and given more time for adjustment, is even larger by 2050.

Figure 1.15: Estimated abatement potentials from enhanced circularity and material efficiency by material or product in 2030 and 2050 ([88])



*Cement and concrete numbers reflect combined potentials from recirculation and recarbonation of cement and low-clinker concrete formulas.
Source: Agora Industry (2022), based on modelling tools provided by Material Economics

Note: These emissions reduction potentials are estimated compared to a reference scenario based on business-as-usual. Since circularity and material efficiency potentials are taken to be substitutes for (and thus additional to) other reductions of emissions in these value chains via new lower carbon virgin production technologies, this baseline uses today's CO_2 intensities of production for the relevant materials and products.

Source: Agora Energiewende, 2022

EII are relying on circular and resource efficiency solutions as one of the key pathways under the 'Master Plan for competitive transformation of EII Enabling a Climate-neutral, Circular Economy by 2050' ([89]) developed by the High-Level Group on Energy-intensive Industries. The Processes4Planet partnership under Horizon Europe looks to a potential reduction of about one billion tonnes of waste generated in Europe (by process & manufacturing industry and as end-of-life waste) ([90]).

The Commission is co-creating with stakeholders a transition pathway for the chemicals industry, including greening scenarios by 2030/2050. It is expected to be published in Q1 2023.

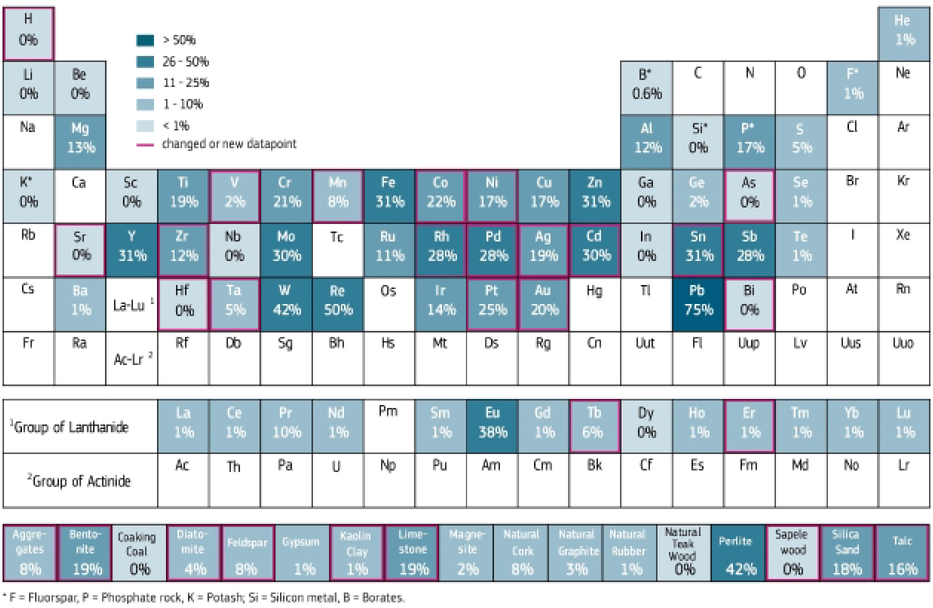
([86]) Agora Energiewende, Mobilising the circular economy for energy-intensive materials, March 2022
([87]) Note that since these actions are additional to and complementary to other abatement efforts, enhanced circularity and material efficiency measures are calculated relative to a business-as-usual baseline reflecting current CO2 intensities of production.
([88]) Agora Energiewende, Mobilising the circular economy for energy-intensive materials, March 2022
([89])https://op.europa.eu/en/publication-detail/-/publication/be308ba7-14da-11ea-8c1f-01aa75ed71a1/language-en
([90]) Processes4Planet Strategic Research and Innovation Agenda, October 2021

1.3. Circularity of critical raw materials (CRMs)

Critical raw materials are crucial for Europe's economy and resilience. EU's secure access to critical raw materials is paramount to the twin transitions, with EU's own production accounting for only 4% of the global supply chain of critical raw materials used in the production of digital equipment ([91]), identified by this report as essential for the circularity of European industry. Furthermore, out of EU's current list of 30 critical raw materials, 27 have a relevance for at least one of the three ecosystems analysed by this roadmap: energy-intensive industries (24), construction (15) and textile (5).

Circularity of critical raw materials can represent a useful tool for reducing European industry's dependency on materials sourced elsewhere. The 2022 Foresight Report indicates that there is a need for **investments in innovation and transition to the circular economy to support EU's access to critical raw materials**. Specific actions identified by the Commission include the **creation of a market for secondary raw materials** by introducing **collection, recycling efficiency and recycled content targets.** However, current figures show that secondary raw materials generally represent a small share in manufacturing in the EU, with few exceptions.

Figure 1.16: End-of-life recycling input rates in the EU



End-of-life recycling input rates (EOL-RIR) in the EU
Source: European Commission (2020), 'Study on the EU's list of Critical Raw Materials (2020)'.

At the same time, both construction and energy-intensive industries have been singled out as industrial ecosystems with a high potential to address dependencies and circularity of critical raw materials.

([91]) European Commission (2022), Strategic Foresight Report

Construction
The construction ecosystem relies on the usage of critical raw materials such as bauxite, lithium, magnesium or rare earth elements, among others. Nonetheless, construction and demolition represent the biggest source of waste, contributing to around a third of all waste in the EU, accounting for 35% of waste in the EU (2017). Most waste generated by construction and demolition comes from building construction, demolition of buildings and civil infrastructure, road construction and maintenance. The sector accounts for a large share of the non-metallic minerals waste flows produced in Europe ([92]).

Energy-intensive industries
EIIs rely on 24 of the 30 critical raw materials identified by the Commission, making the industrial ecosystem one of the most exposed to vulnerabilities generated by dependencies of CRMs. Moreover, chemicals have been identified as key for various strategic supply chains ([93]). Out of 61 identified chemicals as being dependent on third countries, the Commission further identified 6 chemicals that might require particular attention: iodine, fluorine, red phosphorus, lithium oxide and hydroxide, molybdenum dioxide, and tungstates (wolframates). The six chemicals are widely used in key industrial ecosystems, including EIIs, health, renewable energy or agriculture. They are dependent on critical raw materials, such as phosphorous, which is mainly located in Russia, China, Morocco and the US, tungsten, mainly located in China, or lithium, mainly located in Chile

European initiatives to address the circularity of critical raw materials

In her 2022 State of the European Union speech ([94]), President von der Leyen announced the upcoming **European critical raw materials act**. The CRM Act is a legislative proposal (foreseen for the first quarter of 2023) that aims to create a secure, affordable, and sustainable access to the critical raw materials Europe needs to achieve climate neutrality. The EU market is not prepared for the raise in demand of CRMs and the EU cannot continue to rely solely on trade with third countries, as supply chain disruptions are unpredictable.

There is therefore the need to clearly identify CRMs and promote innovation and substitution, building on existing national raw materials agencies and creating a true European network. Such legislation is needed to address challenges at the different stages of the value chain, from extraction to processing and recycling. It will ensure more resilient supply chains as well as a strong and sustainable level playing field for Europe.

Rare earth magnets and motors | The European Raw Materials Alliance (ERMA) has identified 14 projects from mine and urban mine to magnet, with an investment volume of EUR 1.7 billion, which could ensure a production and supply capability of 20% for European rare earths industry by 2030 ([95]). In this regard, ERMA's action plan on rare earth metals and magnets indicates the need of a European Rare Earth Research Factory, that would enable manufacturing and testing of new processes and

([92]) Raw Materials Scoreboard 2021
([93]) SWD (2022) 41 final
([94])State of the European Union 2022, https://state-of-the-union.ec.europa.eu/index_en
([95]) European Raw Materials Alliance (2021) https://erma.eu/app/uploads/2021/09/01227816.pdf

materials on industrial pilot scale. Furthermore, the Alliance identified R&I needs that feed into the circularity of critical raw materials, such as:

- product designs that facilitate the reuse and recycling of rare earth metals;
- recycling of products containing rare earth magnets, with a focus on cost-efficient dismantling lines;
- novel, cost-efficient rare earths extraction and processing routes, including from unconventional rare earth sources (i.e. low-grade ores, non-ferrous metals beneficiation tailings and iron ore tailings, metallurgical waste apatite).

Other critical raw materials | There are further initiatives that foresee the sourcing, production, and recycling of critical raw materials in the EU. Out of the materials that are relevant for the targeted industrial ecosystems, various projects address access to supply and diversification of supply sources:

- **lithium** *(relevant for construction, energy-intensive industries)*: project supported by ERMA for lithium plant, with a planned annual production of 15,000 tonnes of lithium hydroxide monohydrate
- **vanadium** *(relevant for construction, energy-intensive industries)*: the Vanadium Recovery Project, with a focus of saving up to 1.5 million tonnes of CO2 over the next 10 years, as well as diversifying the supply of critical raw materials

1.4. Conclusions

✓ The EU has the general ambition to double the current overall circular material use rate of 12,8% between 2020 and 2030. This goal is being translated in regulatory action, including the update and revision of recovery targets and product sustainability requirements for which the Commission has started to table proposals.

✓ The energy-intensive industries, textile and construction sectors stand out for their resource and emission intensity, with an overproportionate impact on waste generation and the environment (air pollutants and water), compared to their GDP share in the economy. Energy-intensive industries serve a variety of value chains across different EU industrial ecosystems, influencing also their circularity.

✓ In the past ten years, the amounts of waste have not decreased. Construction is the largest source of waste in the EU (450-500 million tons per year, about one third of all waste). Textile waste is about 2 million tons and non-reusable textile are part of municipal waste.

✓ While data show rather high recovery and recycling rates in the textile and construction ecosystems (around 50%, respectively more than 70%), they are partly explained by including re-use of materials at lower value such as for insulation (textile) or backfilling (construction). Globally, less than one percent is recycled “fibre to fibre” for new textile, and it is estimated that only 38% of new textile products are collected after their use in the EU. Recovery and recycling volumes in the chemical sector are lower and show a decrease.

✓ Circular technologies also support decarbonisation and climate mitigation, which is particularly relevant for energy-intensive industries (industrial processes), but also construction and textiles (lifecycle management). The uptake of circular processes goes hand in hand with the Zero Pollution ambition, to improve human and environmental health by decreasing exposure to harmful substances.

- ✓ Because circularity concerns all phases of the lifecycle for products, measuring and monitoring progress towards a circular economy is complex. In addition, there are still only few agreed headline targets to lead the way towards increased circularity and those are scattered in different laws and strategies. The EU monitors the implementation of the circular economy, mainly regarding resource use and waste management. There is no monitoring for now regarding durability and value of materials, which are important components of the circular economy.

- ✓ While strategic R&I agendas for European partnerships set out priorities for circularity, they can not assess their potential impact.

KEY TECHNOLOGIES AND BUSINESS MODELS FOR INDUSTRIAL CIRCULARITY

This chapter provides an overview of the most relevant circular industrial technologies and business models for the three targeted industrial ecosystems (textile, construction and energy-intensive industries). The scoping of the relevant technologies included a broad consultation with industry, research and technology organisations, academia, and circular economy experts, based on the existing Strategic Research & Innovation Agendas (SRIAs) adopted by key Horizon Europe Partnerships (further detailed in this roadmap). The analysis of potential technologies in the three ecosystems was pioneering work, as it could not build on consolidated secondary resources for relevant technologies and the assessment of their potential.

The technologies scoped in this chapter cover the entire lifecycle of products, in line with the overall understanding that a more circular economy could bring profound changes in economies and societies. Beyond technologies and business models, consumers are an integral component of the circular economy, and a better information and awareness on consumers' environmental footprint could lead to better informed decisions when purchasing goods and products ([96]).

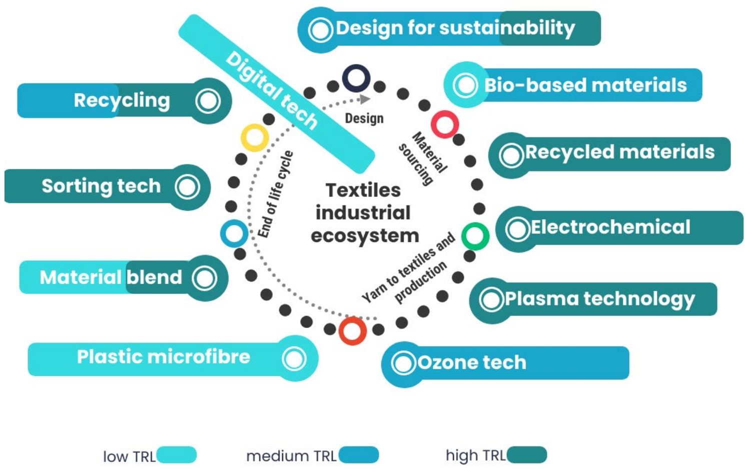
Relevant technologies assessed in the roadmap focus on each lifecycle stage of the products – from raw material extraction and preparation to processing, design, manufacturing, sale, use, and end of life. The assessment of the respective technologies takes into consideration aspects related to 1) technology readiness levels (TRLs), 2) circularity potential, 3) economic performance, 4) contribution to zero-pollution and 5) potential negative/cross-media effects on other areas ([97]).

2.1. Assessment of circular technologies and solutions in the textile industrial ecosystem

Circular technologies in the textile industry have been grouped along the lifecycle stages notably design and material sourcing, production, and end of life with closing the loop and rechannelling materials in the system. Digital technologies support various stages of the lifecycle.

([96]) Joint Research Centre, *Towards a green & digital future. Key requirements for successful twin transitions in the European Union*, 2022.
([97]) A detailed description of the methodology used for the technology assessment exercise, as well as the criteria used is available in Annexes 1 and 2 of this roadmap.

Figure 2.1: Overview of main technology groups relevant for the circularity of the textile industrial ecosystem



Source: Technopolis Group, 2022.

Table 2.1: Summary of assessment results and technology pathways for circular technologies for the textiles industry – design and material sourcing technologies

Technology pathways of R&I activities	TRL	Circularity potential	Economic performance	Contribution to zero-pollution	Possible negative effects
Circular design and alternative materials					
Design for sustainability (durability and disassembly)	TRL 6-9	***	**	**	likely
Secondary bio-based raw materials	TRL4-6	**	*	*	likely
Replacement of raw materials with recycled materials	TRL7-9	***	***	**	likely

Source: Technopolis Group, 2022.

At the first lifecycle stage of **design and preparation of materials**, technologies are available at the highest TRL (TRL 9), such as *fabric optimisation at the garment design stage*, through the use of pattern and marker making software. Some efforts for maturing and scaling up developments would be needed for the *replacement of raw materials with recycled material*s (that is directly related to closing the loop with the end of the lifecycle and hence recycling technologies – TRL 7-9). However, technological readiness of the *fabrication of fibres from secondary bio-based raw materials* is lower, respectively TRL 4-6.

These technologies for the replacement of raw materials with recycled textiles promise high economic feasibility, as they also decrease the demand for chemical dyes and reduce the use of virgin materials significantly. They also appear to have a high potential to reduce pollution.

Technologies and techniques for more fundamental approaches to circularity and supporting *design for sustainability* are estimated between TRL 6 and 9. Design presents many opportunities in terms of design for durability (to create textile products that last longer), but also as design for disassembly that is closely linked to recycling and recyclability. Applying the principles of design for disassembly, the possibility to reuse and recycle products are built in from the very beginning.

Biotechnology enables new technological innovations for producing fibres and textile from the residuals of agriculture, such as rice, maize, bananas, pineapples and sugar cane, or from oilseed and hemp. The fabrication of fibres from secondary bio-based materials can lead to significant reduction of soil pollution. However, there are concerns regarding adverse effects, as agricultural or forestry wastes are needed to conserve soil quality. Moreover, some bio-based leather products have negative environmental impacts related to land-use change and intensification ([98]). Its economic feasibility has been assessed as the least positive among the circular material solutions.

Table 2.2: Summary of assessment results and technology pathways for circular technologies for the textiles industry – yarn to textile and production technologies

Technology pathways of R&I activities	TRL	Circularity potential	Economic performance	Contribution to zero-pollution	Possible negative effects
Yarn to textiles and production					
Circular dyeing processes	TRL1-9	**	*	***	none
Electrochemical pigment colouring	TRL9	*	*	*	likely
Plasma technologies	TRL7-8	**	*	***	likely
Ozone technologies	TRL4-6	***	*	***	none
Plastic microfiber release reduction	TRL1-3	*	*	***	none

Source: Technopolis Group, 2022.

For the process of '**yarn to textile'**, an important challenge is the environmental impact and circular use of dyeing technologies, and the maturity levels of technologies vary. Adding pigments to recycled textiles (deposited electrochemically), a mature technology, can prolong the life span most substantially.

Circular dyeing processes focus on the encapsulation of dye in the wastewater of textile dyeing processes for further reuse. While the TRL is at different stages depending on the specific technique, the recycling of the dye in the wastewater of textile dyeing processes for further reuse would contribute to the reduction of soil pollution. Water-free, circular dyeing technologies that compress carbon dioxide as a solvent in the dyeing process are already quite widely used and actively further developed ([99]).

([98]) Jakob Hildebrandt, Daniela Thrän, Alberto Bezama (2021). The circularity of potential bio-textile production routes: Comparing life cycle impacts of bio-based materials used within the manufacturing of selected leather substitutes, Journal of Cleaner Production, Volume 287
([99]) European Commission, 2019

Plasma technologies reducing the use of chemicals are ready for implementation, with literature also suggesting that they are already successfully employed ([100]) (TRL 7-8). They ([101]) can significantly reduce chemical, water and energy consumption, and water-free textile/yarn technologies can recover and reuse around 95% of the carbon dioxide ([102]).

Ozone technologies, which have been assessed as having a particularly promising circularity potential and reduce water and chemical use, are however considered presently far from ready. While this speaks for dedicated R&I, there is a need for a holistic view on the greenhouse gas emissions for providing ozone technologies, as ozone generation is very energy intensive.

In **production**, technologies that reduce waste by integrating and reusing it in the production process can contribute most to the reduction of water pollution. Technologies related to *compressed carbon dioxide as a solvent in dyeing process* are at TRL-4-6, the use of *pigments in recycled textiles* is at TRL9 and *recycling dye/pigments in wastewater* varies a lot, between TRL1-9.

Technologies for reducing waste by integrating and reusing it in the production can minimise waste most significantly, while re-thinking the traditional apparel cut & sew approach can save most resources.

Plastic microfiber release reduction technologies appear promising, but the best way of disposing the collected microfibres also needs to be addressed, since sending them to landfill could ultimately still lead to leaking out into the environment ([103]).

Table 2.3: Summary of assessment results and technology pathways for circular technologies for the textiles industry – end of lifecycle technologies

Technology pathways of R&I activities	TRL	Circularity potential	Economic performance	Contribution to zero-pollution	Possible negative effects
End of the lifecycle and recycled materials (closing the loop)					
Material blend separation technologies	TRL1-9	***	***	*	none
Automated fibre sorting technologies (near infrared)	TRL7-8	***	***	*	none
Recycling technologies					
* Post-consumer recycling by adding cellulose-based fibres	TRL4-9	***	***	**	none
* Regeneration of used textile materials into yarn	TRL4-9	***	***	**	none
* Chemical recycling: textiles polymers into new polyester products/cellulosic waste of cotton to viscose or lyocell	TRL4-9	***	*	**	likely

Source: Technopolis Group, 2022.

([100]) Zille, Oliveira, and Souto (2005). Plasma treatment in the textiles industry, Plasma Processes and Polymers 12 (2), 98-131
([101]) Zille, Andrea, Fernando Ribeiro Oliveira, and Antonio Pedro Souto. “Plasma Treatment in Textile Industry.” Plasma Processes and Polymers 12.2 (2014): 98–131.
([102]) See also: Maxwell et al., 2015
([103]) https://ellenmacarthurfoundation.org/topics/fashion/overview

The first step to process textiles **at the end of the lifecycle** would be sorting and blend separation. For sorting, n*ear-infrared technologies* for automated fibre sorting exist, although there are problems with multi-material design. They have a high waste reduction potential, and their use can lead to a doubling of the lifespan of textiles currently on the market, according to estimates. *Technologies that separate material blends* as part of the recycling process are overall still at the lowest TRL1-3. *Material blend separation technologies for textile polymers* (for further recycling) are a key first step in the recycling process and have a high potential for circularity but they also represent the biggest challenge of textile recycling. For blends of polyester and cotton or other cellulose-based materials technologies exist at pilot scale, thus up to TRL9.

Recycling technologies exist but at the same time still need further development. This includes the *regeneration of used materials into yarn for new textile,* the transformation of old garments into new raw material, the addition of cellulose-based fibres as well as *chemical recycling technologies*. All these technologies are between TRL4 to 9 and could be interesting for the circular development of Europe's textile sector, close to the customers.

Technologies for the regeneration of used textile materials into yarns promise an important contribution to waste minimisation, with a 50% or higher increase of resource saving. Regenerated yarns can be used to produce textiles products with considerable economic and ecological advantages. This is achieved through the significant reduction of the consumption of water, pesticides and chemical products normally used during production. Together with textile recycling with the addition of cellulose-based fibres, these are technologies expected to have the highest contribution to zero-pollution (reducing especially soil, respectively water pollution).

Chemical recycling can bring textile polymers back to virgin material quality ([104]) and can convert cellulosic waste to viscose and lyocell to respectively 90% and almost 100% ([105]). Some of the biggest worries at the recycling stage concern the damage that certain chemical recycling processes can cause to nature. For instance, the chemical recycling of cellulosic waste of cotton to viscose or lyocell is a highly toxic process and can lead to the unsafe release of solvents in wastewater, having hazardous, polluting impacts ([106]).

Regarding the negative impacts to consider, literature suggests that textile recycling can have negative effect as well if the process is powered by fossil fuels ([107]) and knock-on effects. A risk may be that using cheap, recycled materials in the fabrication of yarn and fibres (such as PET-bottles) in the long run prevents higher-value recycling in those industries and suppresses clothing-to-clothing recycling ([108]). Synthetic textiles cannot be recycled forever and, hence, the recycled material will also pollute the environment when it ends up in the landfill eventually (e.g., polyester from recycled PET is not recyclable at the end of its life and, if incinerated, it still has a huge negative impact on the environment). Textile recycling does not solve the problem of microplastics that needs to be considered in the overall assessment of the technology. Moreover, textile recycling can perpetuate high turnover consumption patterns.

([104]) https://ellenmacarthurfoundation.org/a-new-textiles-economy
([105]) Tencel, 2021
([106]) https://changingmarkets.org/, Changing Markets (2017).
([107]) Circular Economy, 2021
([108]) https://ellenmacarthurfoundation.org/a-new-textiles-economy

Table 2.4: Summary of assessment results and technology pathways for circular technologies for the textiles industry – digital technologies

Technology pathways of R&I activities	TRL	Circularity potential	Economic performance	Contribution to zero-pollution	Possible negative effects
Digital technologies					
Collaborative consumption business models	TRL7-9	**	***	*	likely
Artificial intelligence used for optimisation and analysis	TRL1-3	***	**	**	none
Digital authentication/passport for textile products/materials	TRL4-6	***	**	**	likely
Augmented/virtual reality (tailored fabric/textile selection)	TRL7-8	**	**	*	none

Source: Technopolis Group, 2022.

Digital technologies can have a variety of functions. Collaborative consumption business models are key for the concept of the sharing economy and keeping products in use. Digital technologies to facilitate *collaborative consumption business models* and have a high circularity potential in terms of reducing the carbon footprint of the textiles industry. They are estimated at TRL7-9, many of these systems are already proven in an operational environment. However, there are also some concerns about this technology, as logistics between consumers are not optimised.

Applications with *augmented and virtual reality* used in virtual fabric sourcing or in tailored product selection are interesting from an economic perspective but may have a lower impact on circularity and the industry than other digital technologies, while they can help reduce the increasing package returns by customers in e-commerce. They can give consumers the possibility to experience clothes online and thus support a shift in current consumer behavioural trends, which would reduce the number of packages being sent and returned. These technologies are estimated at TRL7-8.

The maturity level of a *digital authentication/passport for textile products/materials* (a technology that applies to all lifecycle stages) is claimed to be at TRL4-6 with still development needs. If its use meant adding electronics (e.g., tags) to each garment, the related new waste issues, as well as need for further materials, would need to be considered.

⇒ *Digital product passports are identified, alongside ther digital technologies (i.e., Distributed Ledger Technology, Internet of Things) as key digital technologies to support materials tracing, as an essential element to implement a more circular economy. Tracing is crucial to enable the monitoring of materials and products in a circular economy, referring to having real-time information about where materials are at a given moment, and where they have been in the past ([109]).*

Artificial intelligence can be used on customer data, but also to predict the properties of the fabric and materials based on fibre, yarn, and fabric constructional data. AI can be also useful to investigate the quality properties before selecting a material and help

(109) Joint Research Centre, *Towards a green & digital future. Key requirements for successful twin transitions in the European Union*, 2022.

make more environmentally friendly decisions. While promising for recycling and design, these applications are only at TRL1-3. They would also need more efforts to prove their economic performance and scale up concrete applications.

Circular business models in the textile ecosystem

New circular business models go hand in hand with technological advancements to make the textile industrial ecosystem more circular, and they include **circular textile design, renting, sharing and reuse of textiles**. Circular design plays a critical role as it can foster longevity and durability, help optimise resource use and plan with recycling from the start ([110]). The collection and resale of textiles aim to extend their life beyond the first user. New business models are often a result of new cooperation among stakeholders along the supply chain ([111]). At the same time, the digitisation of products, their design, manufacturing, distribution, and retail processes contribute also to favourable framework conditions for new business models.

Cicular business models bring new opportunities for businesses in the textile ecosystem, through decoupling revenues from production and resource use. Thus, companies can make more revenue from fewer new products, which translates in less raw materials use and less pollution and pressure on the environment ([112]). As a consequence, new models and related innovations can play a key role in fostering partnerships between brands, manufacturers, users and other stakeholders and can initiate joint investments into sustainable production, better skills and technologies.

Table 2.5: Main non-technological solutions

Solution	Short description
Circular design/ Design for sustainability	This is an approach that takes into account considerations of the circular economy when designing the textiles product
Textiles rental services	Textile rental services take care of the end-to-end process of sourcing, sizing & fitting, transportation, laundry, repairs & maintenance, storage, and the disposal of textiles.
Collaborative consumption	Platforms and services that enable the swapping, second handing, sharing, lending of clothing. Apps and websites help individuals and businesses to buy and sell second-hand garments and engage in collaborative consumption. Luxury second-hand retail is a current model on rise.
Repair and warranty	Business models that include extending a product's useful life through repair & maintenance and/or selling a durable product through warranty.
Textile collection and resale	Organisational models that recover textiles for reuse and incentivise actors to reconnect and repurpose existing textiles products. In this model, customers are offered a system where they can bring back old clothes and get a discount in return. The clothes are used either for recycle or resale.
Restyle services	Fabrics are used to make new clothing or accessories.

Source: Technopolis Group, 2022.

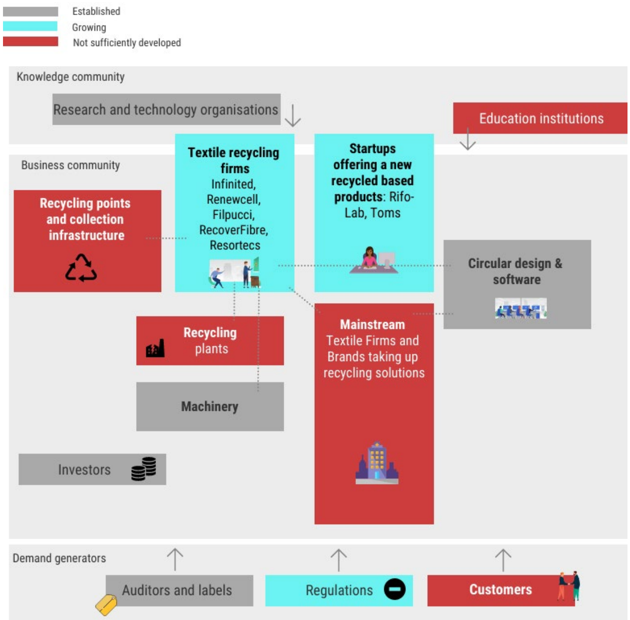
([110]) https://www.eea.europa.eu/publications/textiles-and-the-environment-the

([111]) Pal, S. & Sandberg, E. (2017). Sustainable value creation through new industrial supplyChains in apparel and fashion. In the 17th World Textile Conference of Association – of Universities for Textile (AUTEXT)-Shaping of the Future

([112]) Ellen MacArthur Foundation, *Rethinking business models for a thriving fashion industry*, https://ellenmacarthurfoundation.org/fashion-business-models/overview

Box 2.1 | Zoom on the textile recycling value chain

Figure 2.2: Textile recycling industrial sector



Source : Technopolis Group, 2022

The most rapidly developing community for circular textiles relates to recycled (fibre-to-fibre) materials that act as a new raw material and allow the creation of more sustainable textile products. McKinsey estimated that the textile recycling industry could "*once it has matured and scaled—become a self-standing, profitable industry with EUR 1.5 billion to EUR 2.2 billion profit pool by 2030* ([113])" in Europe. Some of the textile recycling technologies are already mature, according to the previous assessments of this chapter. The use of recycled polyester has soared, particularly in popularity ([114]).

Key stakeholders of recycled textiles are organised along a complex value chain and include **textile recycling and technology firms, start-ups, equipment manufacturers and research and technology organisations**, on the supply side, and **mainstream textile manufacturers, textile companies and brands, but also 'circularity'-born textile start-ups** offering sustainable products, on the demand side.

This ecosystem is underpinned by a range of other stakeholders such as recycling equipment providers, recycling infrastructure managers (collection points), investors, auditors and eco-labels, public institutions (that put in place rules and regulations) and circular public-private partnerships.

Recycling technologies have been pioneered already more than seventy years ago. As the technology matured, several entrepreneurs saw the opportunity and today **the recycling shift is driven by pioneer recycling technology firms, mainstream textile manufacturers and brands and recycled-based textile start-ups.**

Textile recycling firms aim at applying a closed-loop production system and upcycle textile waste. They replace traditional material providers and instead they collect waste, recycle it, spin it into yarn, and deliver that yarn back to the manufacturer or brand. **This transition of the value chain means an opportunity for the EU to generate new value-added activities locally.**

To seize this opportunity, there are several obstacles still to overcome:

- relevant recycling infrastructure needs to be built
- sorting capacities are still underdeveloped, and the lack of effective disassembly technologies acts as a barrier to a sustainable circular clothing operation

([113]) https://www.mckinsey.com/industries/retail/our-insights/scaling-textile-recycling-in-europe-turning-waste-into-value
([114]) https://textileexchange.org/2025-recycled-polyester-challenge/

- recycling needs to be brought closer to the place of waste collection and reuse, as recycled textile can come from old clothing (post-consumer) or from industrial waste (pre-consumer)
- high costs of disassembly, recycling machineries or transportation continue to put pressure on the development of the textile recycling sector
- consumers acceptance of recycled textiles needs to be addressed, as they are perceived as having lower quality than textiles made of virgin fibres.

The **business case for circularity** is justified by several factors including compliance to regulations, new sources of revenue, reduction of production costs, new marketing strategies and de-risking unstable supply chains. **Improving underlying conditions such as prices of secondary materials is of utmost importance for keeping the motivation of businesses for the circular transition.** The cost of recycled products in comparison to virgin products is expected to further drop, which will boost the overall growth of the recycled textiles market ([115]). There is also an increase in demand for cost-effective industrial textiles from the automotive and other end-user industries, which will contribute to the case for the shift to recycled products.

Market related issues include:

- **capacity issues in processing textiles waste efficiently** in Europe and scaling up automated sorting technologies that can handle the separation of usable textile items ([116])
- **textile waste collection and sorting** are not addressed in the same way across countries and more incentive schemes are needed to organise this effectively
- different stakeholders in the value chain need to be interconnected and be able to share product information in a simple and automatic way
- need to educate companies how to deal with the new fibres and materials
- **scaling and capacities of recycling plants**: to move to higher production levels, more recycled materials need to be produced in a cost-efficient way
- **ecolabelling**: according to the Ecolabel Index ([117]), there are 104 eco-labels in the textiles industry. The landscape of ecolabels and monitoring frameworks need further policy attention and investment as it is often confusing for consumers
- **global competition challenges**: there is a danger that recycling capacities will be built up outside of the EU, causing environmental burden as a result of transportation. Currently, half of the ten top recycling textiles firms are from India ([118]). If waste keeps on travelling and sorted out in India, shredded into fibres and spun into yarn in Bangladesh and China before coming back to Europe, most of circular economy values of the circular economy will be lost and the use of recycled materials will be wrongly claimed as environmentally friendly ([119]).

Source: Technopolis Group, 2022

Summary and cross-cutting aspects

Various circular technologies demonstrate higher TRLs, and hence need actions to increase their maturity and test them, before commercial deployment. They further need market pull under favourable framework conditions:

- Recyling technologies and replacement of raw materials with recycled materials
- Design for sustainability and fabric optimisation

([115]) https://www.alliedmarketresearch.com/recycle-textile-market
([116]) See also the report of FibreSort: https://www.nweurope.eu/media/9655/2020305-fibersort-51-final-case-studies-report.pdf
([117]) https://www.ecolabelindex.com/ecolabels/?st=category,textiles
([118]) Key Players | Khaloom, Chindi, Kishco Group, Anandi Enterprises, Usha Yarns Ltd., Renewcell AB, Hyosung TNC Co. Ltd., Martex Fiber, Otto Garne, and Leigh Fibers Inc
([119]) https://www.trendwatching.com/innovation-of-the-day/waste-to-yarn-to-clothing-brightfiber-brings-cleaner-fashion-home

- Plasma technologies and pigments
- Sorting technologies
- Digital platforms and augmented and virtual reality

Many of the technologies are at medium TRL and need more innovative actions such as technology validation in simulation environment with further demo in operational environment at the industry lab:

- Bio-based raw materials
- Compressed carbon dioxide as a solvent in dyeing process and ozone technologies
- Post-consumer recycling by adding cellulose-based fibres, chemical recycling

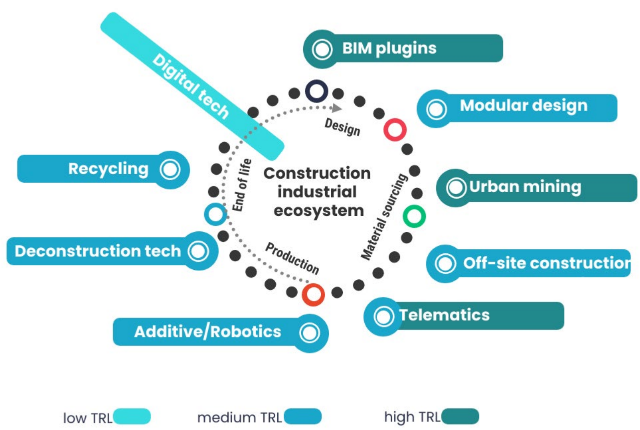
Some of the technologies are at low TRL and need further experimentation:

- Material separation
- Plastic micro-fibre release reduction
- Artificial intelligence technologies

2.2. Assessment of circular technologies in the construction industrial ecosystem

Circular technologies in the construction industry have been grouped into the following categories along the lifecycle: design, raw materials sourcing and production. Digital technologies cut across all stages.

Figure 2.3: Overview of main technology groups relevant for the circularity of the construction industrial ecosystem



Source: Technopolis Group, 2022.

The design and construction phases are critical to overall lifecycle impact of buildings, with architects and engineers needing to pay attention to durability, efficient materials use (avoiding overspecification), modularity and adaptability. Use of Level(s) ([120]) indicators provide a means to boost the circularity and sustainability of buildings.

There is a significant emissions reduction potential from low-clinker cement and concrete formulations and from circular approaches in the cement sector ([121]). This implies boosting high-quality recycled inputs into new clinker or cement production using the smart separation of concrete constituents at end-of-life. There is also great potential in exploiting the natural tendency of cement to “recarbonate” – when calcium-rich hydrated fines reabsorb CO2, and in boosting material efficiency, material substitution and optimisation of cement and concrete formulas.

Table 2.6: Summary of assessment results for circular technologies for the Construction industry – design, material sourcing and end of life technologies

Technology pathways of R&I actions	TRL	Circularity potential	Economic potential	Contributing to zero-pollution	Possible rebound effects
Design					
BIM-compatible plug-ins and applications/4D BIM	TRL6-9	***	***	**	none
Modular design & design for disassembly of buildings	TRL4-6	***	***	***	none
Raw material sourcing					
Urban mining	TRL6-7	***	***	***	likely
Off-site construction	TRL4-9	***	***	***	none
End of life					
Recycling technologies	TRL4-8	**	**	**	likely
* Use wastes (combustion, liquified, stabilised, vitrified or mineral)	TRL7-8	**	**	**	likely
* Recycling and recovering waste from other EIIs	TRL4-6	**	***	**	likely
* Magnetic density separation	TRL4-8	*	**	**	none
* Advanced dry recovery	TRL7-8	*	*	*	none

Source: Technopolis Group, 2022.

([120]) https://environment.ec.europa.eu/topics/circular-economy/levels_en
([121])https://www.agora-energiewende.de/en/publications/mobilising-the-circular-economy-for-energy-intensive-materials-study/

Circular technologies applied at the **design stage of the construction value chain** are key for the green transition of the industrial ecosystem. The current common approach to designing buildings or other infrastructure is not geared towards circularity and has led to poor replaceability of components, insufficient predictability of maintenance needs or incomplete knowledge of the materials used for construction. Technological solutions that are based on Building Information Modelling (BIM) have addressed this gap and become a widely used tool in the construction industry. *BIM-compatible plug-ins* are particularly potent in saving resources and are at medium to high TRLs (TRL 6-9), depending on the specific application.

Alternative design processes are at TRL 4-6. Also in this case, the exact maturity level depends on the field of application, where a clear difference must be highlighted between design and architectural practices on one hand, and the development of components that are suitable for alternative design processes and disassembly on the other. Simulations in BIM models may be used to analyse the reuse potential of the different materials used at the outset of a project. Overall, BIM represents a great opportunity to facilitate circular and sustainable construction, but barriers such as the development of even simple BIM models for end-of-life processing of buildings currently limit its potential. Nevertheless, modular design and anticipating the disassembly are expected to boost the repairability of built structures, and thereby expanding their lifecycles and use lengths by two or more times.

Off-site construction as an alternative **manufacturing process** has the highest maturity among the technologies presented here, whereby additive and robotic manufacturing are less common and at lower TRL still.

Approaching waste as a resource, by e.g. *recycling and recovering waste* and other by-products, is a means already employed nowadays, with medium to high technological maturity (TRL 4-6 and TRL 7-8). Urban mining has been identified as bearing vast untapped potential. Depending on the materials and processes concerned, *urban mining* can be placed at TRL 6-7.

Other technologies employed for sorting processes vary greatly in their maturity, ranging from TRL 1-3 (e.g. *magnetic density separation*) to TRL 7-8 or even 9 (e.g. *advanced dry recovery*). It needs to be stressed, however, that the range of technologies in this domain is vast and not captured in its entirety in this study.

From the perspective of their potential contribution to zero waste, modular design and urban mining, but also off-site construction and magnetic density separation in particular exhibit good or even significant potential in this respect. More streamlined logistics is one of the reasons explaining this assertion.

Great circularity potential lies in **the combination of technologies facilitating recycling, circular design and the sourcing of circular materials.** These solutions do not only promise waste minimisation, but also resource savings, as well as longer life spans. The impact of urban mining may be amplified by more conscious design choices, which, in turn, may be facilitated by more advanced BIM applications, or a generally lower use of resources thanks to standardised components. These potential benefits can furthermore be translated into economic performance and cost savings, where, once again, urban mining, BIM-based applications, modular design, off-site construction and recycling and recovering waste from other energy-intensive industries (EIIs) show greatest potential.

It also needs to be noted that some technologies may potentially also have negative environmental impacts. For instance, modular design, recycling and recovering waste from other streams are believed to also bear some negative effects. The reasons for this are multifaceted and range from the use of additional resources that may not outweigh the benefits achieved through their use, to more energy-intensive processes.

Table 2.7: Summary of assessment results for circular technologies for the Construction industry – digital technologies

Technology pathways of R&I actions	TRL	Circularity potential	Economic potential	Contributing to zero-pollution	Possible rebound effects
Digital technologies					
Digital platforms and marketplaces	TRL7-8	**	***	*	none
Digital twins	TRL4-6	**	**	*	none
Digital passports and blockchain	TRL4-6	***	**	***	none
Big data analytics, artificial intelligence	TRL6-8	***	***	***	none
Augmented and virtual reality	TRL6-8	**	***	**	none

Source: Technopolis Group, 2022.

Digital technologies are already widely used, though with varied degrees of advancement.

Telematics plays already an important role in the construction industry and is a crucial means for automatically generating, disseminating and analysing information. These data can support decision making and significantly boost the robustness with which construction processes can be managed. In doing so, poorly informed operations that are caused by incomplete information can be prevented. In post-construction processes, telematics is integral to information gathering and sharing.

Big data and analytics, artificial intelligence and digital material passports are increasingly perceived as an indispensable element in realising circularity potential in the construction industry. Big data and analytics including AI are being used throughout the supply chain, while augmented and virtual reality are considered for off-site maintenance or supervision. Yet, while being commonly employed, these technologies or also blockchain technology are far from having achieved their highest possible TRL in the context of construction. These technologies are around TRL 4-6.

The purpose and functionalities of Repurposing technologies, aimed at facilitating the interaction with, and exchange of information across the supply chain and with consumers, such as *digital platforms, digital twins and material passports*, are all seen to be in principle well understood by developers and potential users. Further development is still needed, as what is expected to be achieved is more complex and advanced than what can currently be implemented.[3] Issues to be resolved go beyond pure technology development. For example, as regards (digital) material passports, questions on the ownership of materials (e.g. material-as-a-service), business models, or valuation are yet to be resolved.

Digital technologies such as digital twins and digital materials passports promise great potential, for example to significantly minimise waste by 50% or more.

Digital technologies can form the backbone of a circular construction industry in that they provide valuable information throughout the entire value chain and lifecycle that facilitates all other technologies, solutions and processes presented in this analysis. They connect actors in the supply chain and are expected to enable efficiency gains, which translate into cost savings and better economic performance. While digital platforms, big data and analytics as well as augmented and virtual reality stand out in this respect, all technologies in this category bear considerable potential. For instance, "through Horizon 2020's DigiPLACE, over 40 different public authorities, industrial representatives and researchers came together to propose a reference architecture framework and strategic roadmap for platforms that can serve the future development of a construction data space."

Digital technologies are furthermore found to be supportive of varying circular strategies such as enhancing product design, sustainable operations management, and resource efficiency, the optimisation of resource flows, and the tracking and tracing of post-use products. They may contribute to resource and waste optimisation, generative design, performance prediction, personalised services, energy management, BIM and Internet of Things applications, and intelligent buildings.

Blockchain technology and augmented and virtual reality are mostly believed to exhibit modest potential or potentially even do more harm than good. A juxtaposition appears to be at play here. On one hand, the digital technologies considered facilitate coordination and thus boost efficiency. However, on the other hand, with their currently rather moderate maturity levels (see above), their full potential may not have been fully captured and understood yet. This relatively lower maturity level, in turn, exposes a gap in the construction industry's value chain, which is in dire need for greater coordination and integration between stakeholders.

Table 2.8: Summary of assessment results for circular technologies for the Construction industry – production technologies

Technology pathways of R&I actions	TRL	Circularity potential	Economic potential	Contributing to zero-pollution	Possible rebound effects
Production					
Additive and robotic manufacturing	TRL4-6	**	*	*	none
Telematics	TRL 7-8	**	***	*	none
Deconstruction technologies	TRL4-9	*	*	*	

* Heating air classification system	TRL4-6	*	*	*	none
* Attrition cells and scrubbers	TRL7-8	*	*	*	none
* Gravity column	TRL4-9	*	*	*	none

Source: Technopolis Group, 2022.

Production technologies (including construction and deconstruction processes) are generally believed to inhibit moderate to high maturity (TRL4-8). Specific deconstruction technologies include for example *attrition cell*s (that are designed to scrub the surfaces of particulates, liberate deleterious materials) and *gravity column technologies* (that separate particles and materials according to their size and weight). *Additive manufacturing and robotic manufacturing* are currently less common and are at TRL 4-6. Additive manufacturing enables the fabrication of complex 3D objects by adding materials together layer upon layer. Examples include concrete printing as well as the fabrication of components from metals and polymers. Robotics can take over a part of the work previously done by humans, especially repetitive, dangerous, or precision-requiring tasks, such as assembly, lifting, or welding.

Production technologies exhibit the least potential across the circular industrial technologies and solutions that have been assessed in this report. Heating air classification systems, attrition cells scrubbers or gravity column - although important - have less circular potential compared to other technologies. For instance, these technologies appear to be considerably less promising regarding their ability to extend life spans.

Nevertheless, this assessment must be put in the broader context of the sector. Any production technology is pivotal and a central element of a circular construction industry.

Circular business models in the construction ecosystem

The main circular business models encompass circular design, reuse and sharing, but many of the specific business models are tailored to the construction industrial ecosystem. These include performance-based and network-based models and smart contracts of building that allow to make better use of buildings.

Table 2.9: List of non-technological solutions

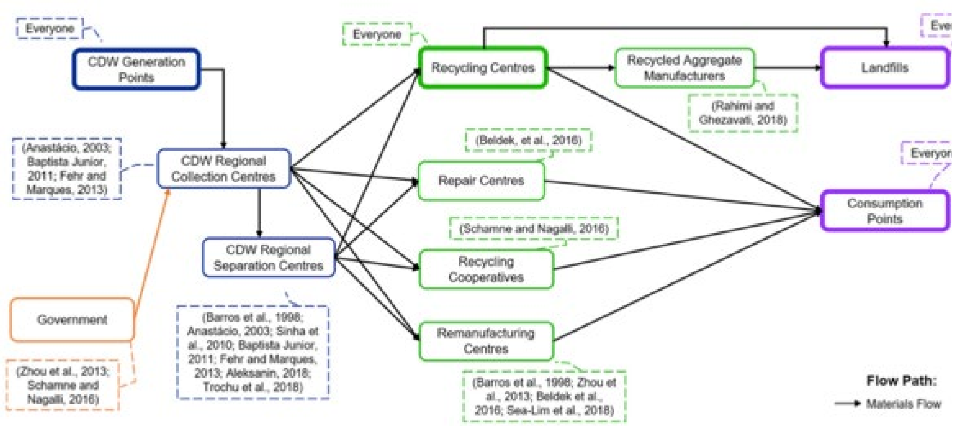
Solution	Short description
Performance-based models	Spreading costs in time with end-of-life phase of building related assets
Green building design	Products, systems and the entire built structures are designed to last longer with a higher residual value.
Network-based models	Including sub-models such as platform-as-a-service (sharing data and knowledge), software-as-a-service or insights-as-a-service (e.g. providing specific information on buildings).
Takeback and reuse services	Services and platforms that enable to exchange of recycled construction materials for reuse
Space sharing services	Services and models that encourage organisations for instance to rent workspace and share location instead of renting a full building
Services that extend the life of buildings	Maintenance and renovation services planned during the lifecycle

Source: Technopolis Group, 2022.

Box 2.4 | Zoom on the construction recycling value chain

Based on a bibliometric analysis of more than 50 academic articles, Brandao et al. (2021) ([122]) identified eleven major nodes which, at the same time, represent the main stakeholders throughout the construction industry's value chain. Except for *government*, all stakeholders are directly involved in the handling, processing, and treatment of materials.

Figure 2.4: Recycling Value Chain and Stakeholders of the Construction Industry



Source: Brandao et al.

Construction and Demolition Waste (CDW) Generation Points are the source of waste, and predominantly concern construction or deconstruction projects. Behind this node, construction companies usually act as key stakeholders. Following the source of CDW, **waste transportation organisations** are crucial throughout the value chain in that they transport CDW between different stakeholder and thereby add locational value to it. As a first major centralised hub, **CDW regional collection and separation centres** separate, handle and process incoming CDW. The **government**, commonly represented by agencies, play a crucial role in enforcing and providing legislation or support measures that foster a circular material flow in the construction industry or in a local or regional environment. An example of administrative support in the form of framework conditions can be found in the EU Construction and Demolition Waste Protocol and Guidelines. ([123])

Continuing the doctrine formulated by the Construction 2020 strategy ([124]) as well as the Communication on Resource Efficiency Opportunities in the Building Sector, ([125]) the EU Construction and Demolition Waste Protocol and Guidelines aims to mainstream circular approaches in the CDW management process by focussing on, and providing solutions to *i) waste identification, source separation and collection, ii) waste logistics, iii) waste processing, iv) quality management,* and *v) policy and framework conditions*.

Further along the value chain, **recycling/remanufacturing centres and companies** are CDW recovery facilities of various forms and serve as central instances in the preparation of construction materials to be fed back into the material loop. Should recovery or recycling not be possible or viable anymore, **landfills** are the destination for some materials. For those that can be recovered/-cycled, **consumption** points provide clients of different types (e.g. construction companies, government) with materials that have gone through the processing stages.

The **business case for circularity in the construction ecosystem** is justified by several factors, including cost reduction and higher profit margins, and solving challenges of material shortages.

([122]) https://journals.sagepub.com/doi/full/10.1177/0734242X21998730
([123]) https://ec.europa.eu/docsroom/documents/20509/ ; see also Chapter 4
([124])https://www.cece.eu/news/ecso-publications-on-the-eu-construction-2020-strategy#:~:text=The%20objectives%20are%3A%20'Stimulating%20favourable,competitiveness%20of%20EU%20construction%20enterprises'
([125]) https://ec.europa.eu/environment/eussd/pdf/SustainableBuildingsCommunication.pdf

Innovative business models could create global market opportunities of more than €600 billion by 2025 with a double-digit growth rate. ([126])

Market related issues include:

- the use and application of secondary materials imply several **economic obstacles:**
    - lack of economies of scale, unfavourable financing models, an unwillingness of the market to invest upfront in innovative technologies and materials or long pay back times are commonly voiced concerns**Error! Bookmark not defined.**
    - increased transportation, treatment, planning and operational costs of secondary materials vis-à-vis virgin materials can disincentivise the use of the secondary raw materials, in spite of a final price of recycled materials projected to be lower than for virgin materials
- transportation costs sometimes outstrip the actual treatment of demolition waste, which puts further pressure on companies and on the overall application of recycled materials
- further activities incurring costs are planning, operationalising, and acquiring and implementing new knowledge, techniques, and technologies, which supports the claim that hard- and software-based infrastructure facilitating network interaction is as important as the actual recycling and purposing technologies

Source: Technopolis Group, 2022

Summary and cross-cutting aspects

Various circular technologies demonstrate higher TRL levels, and hence need actions to increase their maturity and test them, before commercial deployment. They further need market pull under favourable framework conditions:

- BIM-based application,
- urban mining,
- off-site construction,
- use waste and advanced dry recovery,
- attrition cells,
- telematics and digital platforms.

Many of the technologies are at medium TRL and need more innovative actions such as technology validation in simulation environment with further demo in operational environment at the industry lab or a shop floor**:**

- modular design,
- recycling and recovering waste,
- magnetic density separation,
- additive and robotic manufacturing,
- AI, big data analytics,
- digital passports.

Most potential across most criteria is concentrated around the stage of design, material sourcing, recycling and repurposing and less in the stage of production (construction and deconstruction).

The greatest circularity potential, from the angle of waste minimisation, resource savings as well as longer life spans, is expected to lie in technologies employed during

([126]) https://www.rolandberger.com/en/Insights/Publications/It%E2%80%99s-time-for-construction-to-embrace-the-circular-economy.html the sourcing and design stages of the lifecycle. Especially urban mining as well as modular design and design for disassembly promise to minimise waste, with the latter expected to boost the repairability of built structures, and thereby expanding their lifecycles and use lengths by two or more times.

However, none of the technologies can be approached in isolation and the technologies themselves, without proper embedding and integration into the wider ecosystem, are considered to be ineffective. Hence, while significant potential is expected, it will not be triggered without proper ecosystem integration and actions in other parts of the value chain.

Synergies need to be created between different technologies, and complementarities harnessed where possible, with attention to technologies which create synergies, e.g. digital. A supportive and comprehensive ecosystem needs to be created in which the technologies can be embedded. The construction industry's value chain cannot be understood as a closed ecosystem, but needs to create more robust and frequent links to its immediate environments (e.g. closer integration into overall urban planning) and beyond.

More complex and energy-intensive sourcing processes, as well as front-loaded designs add a layer of complexity, which may cause long-term rebound effects. This depends very much on the application-specific context in which technologies are embedded, the resulting degree of interoperability and synergy, and the users' proficiency, to name a few important factors.

Technologies that contribute to making construction activities greener, smarter or more efficient may come at a cost, such as the need to increase the space and equipment needed per unit. In addition, high up-front costs for acquiring required equipment, material and know-how as well as potentially more time- and labour-intensive coordination efforts may counterbalance the envisioned benefits.

Furthermore, the different technologies require a considerable knowledge base that is equipped with IT and technical skills. Many companies may not have employees possessing these skills.

2.3. Assessment of circular technologies in the energy intensive industries

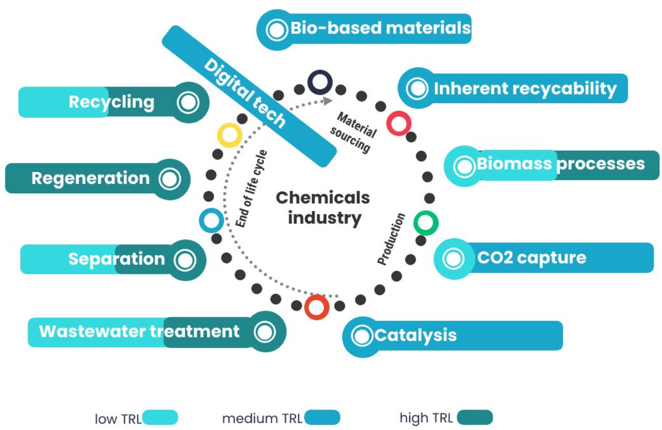
Chemicals industry

Circular technologies applied in the chemicals industry ([127]) can be grouped along the lifecycle stages of raw and secondary material sourcing (including recycling of end-of-life materials into the beginning of the chain); production and consumer interface; and digital and horizontal technologies.

([127]) It has to be stressed that it is difficult to provide an accurate assessment of the technological readiness level or potential of these technologies without considering how they are applied to a given product. This is partly why some technologies described in the subsequent paragraphs are described as having unknown or debated levels of maturity.

As circular economy technologies contribute significantly to reducing greenhouse gas emissions in energy-intensive industries ([128]), several circular technologies in the chemical industry discussed in this study are also covered in the ERA industrial technology roadmap for low-carbon technologies in energy-intensive industries, published in April 2022. For example, carbon capture and utilisation technologies focusing on producing chemicals, polymers and fuel from captured CO or CO2 molecules, use of plastic waste and biomass as alternative feedstocks in the chemical industry are addressed in the mentioned roadmap. Furthermore, process efficiency technologies, which have been discussed in the low-carbon technology roadmap, have a strong relevance both for energy and material efficiency.

Figure 2.5: Overview of main technology groups relevant for the circularity of the chemical industry



Source: Technopolis Group, 2022.

Most of the circular technologies in the chemical industry have a broad range of Technology Readiness Levels. While some existing technologies are already implemented at commercial scale (e.g. for separation technologies, CO2 capture technologies), technological development is still required to improve the environmental footprint of these operations. Often, one category of technologies includes various methods or processes, some with advanced technologies at high TRL, as well as alternative emerging technologies at low TRL.

([128]) Available at https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/era-industrial-technology-roadmap-low-carbon-technologies-energy-intensive-industries_en

Table 2.10: Summary of assessment results for circular technologies for the Chemical industry – material sourcing and end of life technologies

Technology pathways of R&I actions	TRL	Circularity potential	Economic potential	Contributing to zero-pollution	Possible negative effects
Material sourcing					
Bio-based materials of the process industries	TRL4-6	**	***	**	likely
Inherent recyclability of materials	TRL4-6	**	**	*	none
End of life (closing the loop)					
Separation technologies	TRL3-8	**	***	***	none
Regeneration of spent solvents	TRL9	**	**	**	none
Recycling technologies	TRL3-8	***	**	*	likely
* Recycling acids, alkaline, saline wastes	TRL4-6	***	***	*	none
* Thermochemical recycling of plastic waste/pyrolysis	TRL3-8	***	**	*	likely
* Depolymerisation/recycling plastic waste through leaching	TRL3-8	**	**	*	none
* Biotechnological recycling of plastic waste	TRL6	**	**	*	likely
* Recycling of plastic waste via solvolysis	TRL4-6	**	**	*	none
* Electrochemical recycling of plastic waste/plasma	TRL3-5	**	**	*	none

Source: Technopolis Group, 2022.

At the stage of raw material sourcing, two priorities stand out for their circularity potential and in R&I: bio-based materials and **inherently recyclable materials** (e.g. recycling-friendly materials) which are both at an intermediate stage of development (TRL 4-6). These technologies are key for improving the eco-design of products, and their development and use is at the heart of “safe and sustainable by design” approach. With regard to bio-based materials, competing use of agricultural land raises concerns and has to be considered, while the EU Bioeconomy policy aims at systematically building downstream value chains for a sustainable use of biomass and waste.

Recycling is naturally a huge technological development field for chemicals and will benefit from material design which anticipates this process. An important challenge for the chemical industry is to help cut down the current amount of plastic waste systemically. Various technologies are explored to tackle the challenges of plastic waste recycling, at different stages of development.

Although chemical recycling has received a lot of research attention in the last few years, mechanical recycling methods, which have higher TRLs remain absolutely necessary.

Recycling technologies that are closest to commercialisation include **thermochemical recycling for plastic waste and advanced separation technologies for plastic waste**. Several industrial projects for advanced separation are ongoing, but a lot of R&D activities are done at pilot and lab scales. Thermochemical recycling for plastic waste reduces well over 50% of waste production. Technologies with more varied levels of advancement include **electrochemical recycling of plastic waste, recycling of plastic waste via solvolysis and recycling plastic waste through leaching / depolymerisation**. Biotechnological recycling of plastic waste technologies is estimated to be at TRL 6.

Recycling technologies for acids, alkaline and saline wastes, estimated as having high circularity potential, are at an intermediate stage of development (TRL 4-6) and seem to be economically interesting. The **regeneration of spent solvents** (the process of extracting useful materials from waste or by-products solvents generated during the recovery process) is close to commercialisation (TRL 9).

Overall, recycling technologies contribute only moderately to achieving zero-pollution. In so far as recycling plants are still run on fossil fuel energies, they will have a negative impact on air pollution and contribute to rising CO2 emissions. Chemical recycling has raised strong opposition from NGOs on the grounds that hazardous waste is being used in the process. Similarly, biotechnological recycling requires enzyme engineering and there are still debates on whether there could be issues related to any resulting microplastics from this process.

Table 2.11: Summary of assessment results for circular technologies for the Chemical industry – digital technologies

Technology pathways of R&I actions	TRL	Circularity potential	Economic potential	Contributing to zero-pollution	Possible negative effects
Digital technologies					
Data collection, data sharing and data security	TRL4-7	***	***	**	likely
Coordination & management of connected processes	TRL4-6	**	***	**	none
Distributed ledger technologies	TRL4-7	***	**	*	none

Modelling and simulation tools in material design	TRL7-9	**	***	**	likely
Digital twins	TRL5-8	**	***	**	likely
Digital process development/plant engineering	TRL5-8	**	***	**	likely

Source: Technopolis Group, 2022.

The digital technologies group demonstrate the strongest results in terms of economic performance, with solid impact on circularity. Data sharing platforms and distributed ledger technologies have the highest estimated contribution to circularity, as they help improve design. Similar in the section above the estimations about improved data collection technologies to support raw material sourcing (characterisation and design for recyclability) and recycling. Almost all technologies are considered to likely lead to indirect effects.

Transversal (and mainly digital) technologies in the chemical sector have overall reached intermediate levels of development. Modelling and simulation tools, especially supporting the design stage of materials, have reached medium to medium-high maturity levels (TRL 7-9). Improved data collection technologies are also considered to be well advanced (TRL7-8). All other technologies identified (data sharing platforms, coordination and management of connected processes, digital twins, plant engineering) have very varied maturity levels, ranging from TRL 4-7.

Table 2.12: Summary of assessment results for circular technologies for the Chemical industry – production technologies

Technology pathways of R&I actions	TRL	Circularity potential	Economic potential	Contributing to zero-pollution	Possible negative effects
Production					
Biomass processes	TRL3-8	**	**	**	none
* Biomass-tolerant processes	TRL3-8	**	**	**	none
* Biomass pre-treatment processes	TRL3-8	**	**	**	none
CO2 capture	TRL3-8	**	**	**	likely
* Advanced capture and purification of CO2	TRL3-8	**	**	*	likely
* Use of CO2 and CO as a building block in polymers	TRL4-6	**	*	***	likely
Catalysis	TRL3-8	**	**	*	likely
* Photocatalysis	TRL2-3	***	***	*	none
* Electrocatalysis	TRL2-3	**	**	*	likely
* Heterogeneous catalysts	TRL3-8	**	**	*	none

* Homogeneous catalysts	TRL3-8	*	**	*	none
* AI and machine learning for discovering new catalysts	TRL4-6	*	**	*	none
Wastewater treatment	TRL3-8	**	**	**	likely
* Valorisation of solutes from wastewater treatments	TRL3-8	**	**	*	likely
* Valorisation of solids from wastewater treatments	TRL3-8	**	**	**	likely

Source: Technopolis Group, 2022.

Production

Looking at technologies in the production stage, TRL assessments are for the most part very broad and therefore partly inconclusive. It is still complex to assess the maturity level of the integration of alternative feedstocks into processes: **biomass pre-treatment processes and development of biomass-tolerant processes** are considered to be at TRL ranging from 3-8. Looking at alternative feedstock solutions, there is strong resource-saving potential if **biomass-processes use heat exchanger/evaporators**, which should be maintained by an eco-efficient cleaning technology to ensure resource savings, the sustainability of plant performance and an increase in lifecycle investment.

The **utilisation of CO2 and CO as a building block in polymers** is at a relatively intermediate state of development. Several CO2 to polymer technologies have been demonstrated at lab and pilot scale, and a first demo plant was built in Europe. A lot of R&D is being done on advanced capture and purification of CO2 looking into technologies at various levels. Advanced capture and purification levels of CO2 are also at varied stages of development (TRL 3-8). There are concerns that the utilisation of CO2 and CO as a building block in polymers may raise the same concerns as the utilisation of the first generation of biofuels (guiding feedstock to the wrong applications).

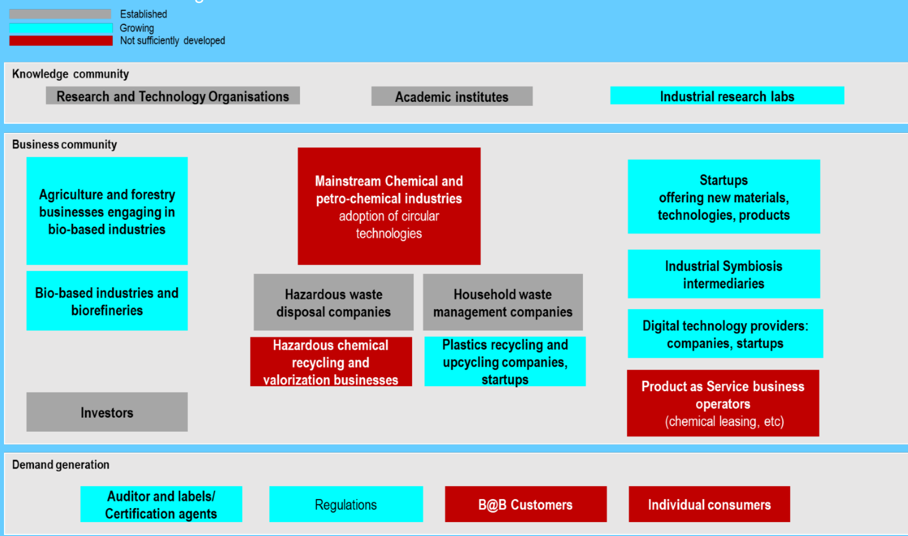
The sustainability of the production process relies significantly also on “secondary resources” such as catalysts, solvents and water. **The maturity of catalysts** ranges from low to high, depending on their type: photocalysis and electrocatalysis are at early stages (TRL2-3), while heterogenous and homogeneous catalysts are considered to have broader TRLs, ranging between 3-8. **AI and machine learning** are used to screen catalysts and identify new ones for a host of different catalytic reactions. Very varied levels of development can currently be attributed to them, ranging from very low to medium-low. Furthermore, **the current recyclability potential of catalysts is a grey area in research**.

Still in the production stage, **wastewater valorisation** is an important area of research with multiple projects at varied levels of development (TRL 3-8), making it an important contribution to resource saving. Some **improved separation technologies** are already at a commercial level of development, but new technologies on early stages are also being explored. Consequently, the TRL range of the technology is also broad (3-8).

Box 2.3 | Zoom on the chemical circular value chain

Key technology developers and owners in the chemical industry circular value chains are the **chemical and petro-chemical industries**. Further stakeholders are businesses specialising in recycling activities, which include **waste management companies** (common for consumer plastics), but also increasingly **SMEs and start-ups** that innovate plastic recycling, bio-based polymers, compostable polymers, products out of these new polymer materials. Recycling and revalorisation of chemical waste is often done by chemical companies themselves, or in collaboration with specialised **hazardous waste management and recycling companies**.

Figure 2.6: Stakeholders involved in circular chemical value chains



Source: Technopolis Group, 2022

Service-based models are often launched by the **suppliers of chemicals or SMEs and start-ups** that enter the new business area with new business models that state to help clients to reduce waste and material use, save cost and contribute to reducing their environmental footprint.

Industrial symbiosis intermediaries, such as specialised SME consultancies, industrial cluster organisation set up digital platforms to encourage exchange of secondary resources. Other type of intermediaries and often start-ups offer digital solutions such as blockchain and distributed ledger, digital product passport, integrated value chain management, data collection and digital optimisation. In production of chemical and polymers using carbon capture and utilisation (example of industrial symbiosis), the CO and CO2 suppliers are steel, cement, heat power generators, and other **fossil fuel using industries**. Further intermediary stakeholders include **investors, certification bodies** providing labels based on environmental auditing**, public and industry initiatives** facilitating collaborative activities aiming at greening the industry.

Public and industry initiatives are major drivers. European Partnerships under Horizon Europe, such as *Process4Planet* or *Circular Bio-based Europe*, and namely their members are key R&I players in promoting innovative technologies.

Recycling in the chemical industry

The most prominent circular chemical material is **recycled plastics polymers.** The global plastics market is likely to be driven by the increasing consumption of plastics in construction, automotive, medical devices, and electrical & electronics industries. Regulatory intervention to reduce the gross vehicle weight to improve fuel efficiency and ultimately reduce carbon emissions has driven automotive Original Equipment Manufacturers (OEMs) to use plastic as a substitute for metals, such as steel and aluminium, for fabricating automotive components.

Collection, sorting and recycling are widely associated with the plastic recycling chains. Despite growing practices for plastic collection and recycling, only 5% of the value of plastic packaging material retains in the economy, the rest is lost after a very short first-use. The annual bill accounts for between €70 and €105 billion.

In the EU, the potential for recycling plastic waste remains largely unexploited. Around 26 million tonnes of plastic waste are generated in Europe every year. But less than 30% of such waste is collected for recycling. From this amount, a significant share leaves the EU to be treated in third countries, where different environmental standards may apply. 70% of plastic waste is put in landfills or incinerated.

Source: Technopolis Group, 2022

Circular business models in the chemical industry

Besides technologies, there are a range of non-technological solutions that are highly relevant for the chemicals industry and needs to be mentioned. Main business models range from joint circular product development, take-back chemicals concepts or leasing of chemicals. The incentive for circular business follows a different logic notably the chemicals company is paid for the service provided instead of the quantity of substance that is consumed. The rationale for business investment is provided by the hyper growth of market for recycled materials (Accenture, 2019). The table below provides a summary of the main non-technological solutions identified in this report.

Table 2.13: Assessment of main non-technological solutions

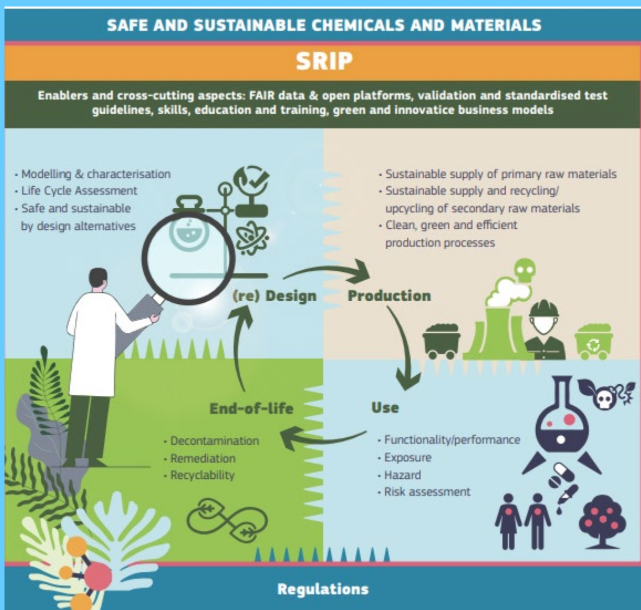
Solution	Short description
Designing for recyclability	Designing materials/products to have easier, more efficient recycling and shorter reverse cycle.
Joint circular product development	Allowing chemicals and related companies to expand their efforts to advance the circular economy by diverting waste from landfills.
Leasing of chemicals	Chemical Leasing is a service-oriented business model that shifts the focus from increasing sales volume of chemicals towards a value-added approach. The producer mainly sells the functions performed by the chemical and functional units are the main basis for payment. (Unido, 2020)
Take-back chemicals	The chemicals supplier is paid for the function of a substance rather than the quantity.
Reselling chemical byproducts	Taking chemicals waste stream from one production process and using it to make new products.
Waste capture and storage	Capturing and stocking chemical wastes without an immediate reselling opportunity with the motivation of future use or minimizing environemtal effects.
Circular chemical exchange platform	Network-driven solutions to enable the exchange of reusable chemicals or wastes

Source: Technopolis Group, 2022

Box 2.4 | The Strategic Research and Innovation Plan for Safe and Sustainable Chemicals and Materials

The Chemicals Strategy for Sustainability (CSS) announced a Strategic Research and Innovation Agenda in 2022. The ‘Strategic Research and Innovation Plan for safe and sustainable chemicals and materials’ (SRIP) delivers on this announcement and highlights current research and innovation (R&I) areas crucial for accelerating the transition to chemicals and materials that are safe and sustainable. It provides a comprehensive outlook of R&I needs for chemicals and materials across their lifecycle: 1) design phase R&I needs builds on the experiences acquired when developing the safe and sustainable by design framework for chemicals and materials; 2) R&I to achieve safe and sustainable production processes; 3) the use stage requires R&I to enable a reliable assessment of functionality, performance, safety and sustainability, including exposure monitoring and modelling as well as hazard and risk assessment; 4) end of life covers R&I for decontamination and remediation. In addition, the SRIP also outlines the key enablers and cross-cutting aspects crucial for maximising the impact of future research such as FAIR data, validation and standardisation of test methods, skills and education and new, green business models. It also announces a monitoring scheme for the SRIP implementation. The aim of the SRIP is to guide R&I funders in their decisions on investments across EU, national and private funding programmes. It is an opportunity for a more transparent communication among all relevant actors on joint R&I priorities proposed by the wider community: from academia to SMEs, large-scale industry, regulators and policymakers.

Figure 2.7: The lifecycle approach of the Strategic Research and Innovation Plan (SRIP)



Source: Strategic Research and Innovation Plan for Safe and Sustainable Chemicals and Materials

The Commission will refer to this SRIP in the Horizon Europe work programme as an overarching strategy to which Horizon Europe contributes as a means of addressing the identified challenges.

Summary and cross-cutting aspects

For many categories of circular technologies in the chemical industry, technology readiness level range is broad. This implies that further R&I efforts are still required for a substantial variety of technologies across all types, while those that have already demonstrated technical viability would need favourable framework conditions to enter to market.

Technologies demonstrating higher TRL via prototype validation (TRL6-7) or piloting pre- or commercial first of a kind production system (TRL 8-9) include:

- Several plastics separation technologies
- Recycling via thermochemical processes and depolymerisation, as well as spent solvent regeneration
- Multiple digital technologies, including data collection, modelling, and simulation
- Absorption and chemical looping-based carbon capture technologies

- Several product-oriented biotechnologies launched with the rollout of biorefineries

The market diffusion of these technologies can present benefits on short-term, should their deployment be incentivised via regulatory or special stimulus measures.

At the same time, more advanced or competing to the above technologies are at TRL 4-6 and currently subject to testing and prototyping at various labs and testing facilities of companies and research organisation. These technologies include:

- Valorisation of biobased waste and industrial CO2 and CO for production of polymers
- New recycling methods for acids, alkaline, saline, as well as recycling by solvolysis
- Development of better recyclable polymers
- AI and new digital and technologies

There is a need in continuous support for further R&D and piloting before they are mature enough for their commercialisation.

Lastly, there are many new-generation circular technologies related concepts and being developed and go through validation, including:

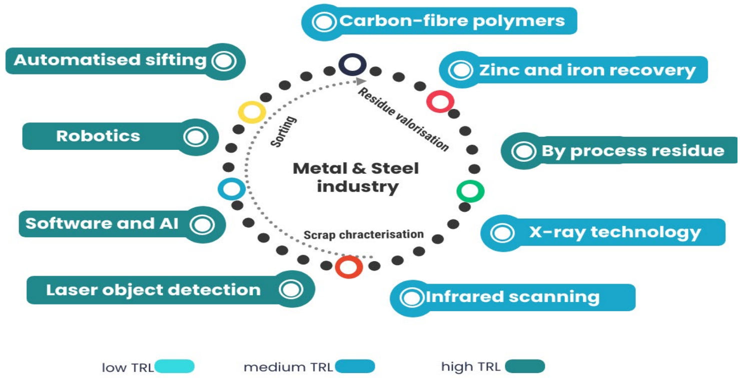
- New developments in photo- and electrocatalysis
- Improvement of the chemical recycling and polymerisation methods that are less energy-intensive, lest costly, and aimed at better quality for reuse.
- Waste and wastewater solution valorisation including for substitution of raw materials in chemicals manufacturing

Metal and Steel industry

The metal and steel industry has many opportunities for shifting to a fully circular system. Technologies addressed in this study can close loops and introduce efficiencies in production and end of life processes. These technologies also offer a significant contribution to the reduction of greenhouse gases as described in the ERA industrial technology roadmap for low-carbon technologies in energy-intensive industries ([129]). It maps already industrial symbiosis, resource efficiency and waste valorisation (as an aggregated group), therefore this roadmap analyses various waste valorisation technologies, end of life recycling and supporting technologies.

([129]) Available at https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/era-industrial-technology-roadmap-low-carbon-technologies-energy-intensive-industries_en

Figure 2.8: Overview of main technology groups relevant for the circularity of metal and steel



Source: Technopolis Group, 2022.

Almost all technologies presented contribute to **circularity, zero-pollution and resource saving to some extent.** The assessment of technologies is presented in the tables and explanations below.

Table 2.14: Summary of assessment results for circular technologies for the Metal and steel industry – residue valorisation technologies

Main circular technologies along the value chain	TRL	Circularity potential	Economic potential	Contributing to zero-pollution	Possible negative effects
Residue valorisation & content					
Carbon-fibre-reinforced polymers in EAF	TRL4-6	*	**	*	not likely
Zinc and iron recovery					
- RecoDust for Fe and Zn recovery from BOF dust	TRL4-6	*	**	*	not likely
- Leaching process for Zn recovery from BOF sludge	TRL4-6	**	**	*	not likely
- Digitalisation tools for CE focusing on monitoring	TRL4-6	***	***	**	not likely
- Induction furnace & bath injection for Zn recovery	TRL7-8	*	*	*	not likely
By process residue valorisation					
- MIDREX residue agglomeration for reuse in DR	TRL7-8	*	*	*	not likely
- Waste plastic gasification for syngas production	TRL4-6	**	*	*	not likely
- Slag utilisation strategies	TRL7-8	**	***	**	not likely
- Two-step dust recycling of EAF dust	TRL7-8	*	*	*	likely
- Reuse of waste refractories	TRL7-8	***	***	*	not likely
- Scrapyard management using sensors & machine learning	TRL4-6	***	***	*	not likely

Source: Technopolis Group

Residue valorisation and metal content recovery technologies are considered to be at an intermediary to advanced stage of development. **Zinc recovery technologies** represent strong potential as they recover a lot of minerals (e.g. zinc recovery from electric blast furnace). Several technologies can be considered to recover the metal fraction from metal oxide and the mineral fraction (as slag). **Few technologies are considered to be at the stage of commercialisation**, except for those resorting to the use of carbon-fiber-reinforced polymers in EAF, reuse of waste refractories, and scrapyard management via scrap handling/tracking using sensors and machine learning tools. For example, scrapyard management is an available product from several steel suppliers. For scrap characterisation, software for routing and inventory management is considered to hold significant promises, as is AI for detection system technology.

There are on-going development projects including IoT (advanced sensors) and machine learning (image recognition tool, correlation between trap elements in liquid steel and scrap grade and suppliers, etc.). These tools are at demonstration level (TRL 8).

Scrap technologies are key for achieving circular steel, in particular removing copper from scrap is considered important. The **ballistic magnetic separation of copper (CU)/aluminum (AL) from iron (FE)** (mainly electric motors with coils inside) technology is mature, but still insufficiently used in practice. To date, this separation was done by hand, but the technology is very relevant as CU causes metallurgical problems regarding the steel composition and to date cannot be removed in a commercially viable way in the steel mill once melted.

Similarly, **waste plastic gasification for syngas production** is a well-established technology, but not yet fully integrated in the steel process.

Other technologies for residue valorisation and metal content recovery are considered to be at more varied levels of development, such as digitalisation tools for CE focusing on monitoring (slag reuse scenarios, dynamic environmental impact analysis/online LCA, and simulation for optimisation (by-product pre-treatment).

Digitalisation tools offer significant waste minimisation potential focusing on monitoring, scrapyard management using sensors and machine learning as well as AI detection system technology. Indeed, information exchange between machines and services has huge potential and machine learning is extensively applied to optimize processes ([130]).

As concerns the resource saving potential, there is significant potential in leaching processes for Zn recovery, digitalisation tools for CE focusing and monitoring, and scrapyard management using sensors and machine learning. According to a research paper, the leaching process for Zn recovery from BOF sludge selectively extracts Zn from the sludge (obtaining a 76% leaching yield) while leaving behind most iron. The cleaned, Fe-rich residue can be fed to the BF, via the sinter plant, representing major iron cost savings ([131]). Concurrently, the leached Zn in the pregnant leach solution can be recovered as a ZnS-precipitate product, as a feed for the zinc industry ([132]). Looking

([130]) 2021, Johannes Rieger, 'Residue Valorization in the Iron and Steel Industries: Sustainable Solutions for a Cleaner and More Competitive Future Europe', *Metals*. Available at: https://www.mdpi.com/2075-4701/11/8/1202/htm

([131]) 2020, 'A novel ammoniacal leaching process to valorise Zn-rich Basic Oxygen Furnace sludges',

([132]) 2019, Harald Raupenstrauch, 'RecoDust—An Efficient Way of Processing Steel Mill Dusts'. Journal of Sustainable Metallurgy 5(11).

at induction furnace and bath injection for Zn recover from filter dust, some research work points to very good zinc and iron recovery especially producing a high-quality zinc oxide product with an average zinc content of 61% ([133]). In addition, as a reusable secondary raw material resource, the steel mill dust contains a high amount of iron and zinc which can be reemployed. In the future, RecoDust in combination with dry slag granulation will become an efficient technique for processing lower zinc-containing materials of a steel mill ([134]).

Similarly, the **valorisation of carbon fiber reinforced polymer (CFRP) waste streams seems to be extremely promising** based on the high carbon content of carbon fibers (CF), chars from CFRP and even unprocessed CFRP waste ([135]).

It should be noted however that most processes today (e.g., zinc recovery) still rely on coal. Industry is starting to move towards gas, natural gas, hydrogen and electricity to further improve the carbon footprint of technologies. Using waste plastic as a fuel in the blast furnace process is also developing.

While residue valorisation and content recovery technologies are not expected to increase the life span of products (use of carbon-fibre reinforced polymers in EAF, RecoDust for Fe an Zc recovery, Zn recovery from Hilsarna filter dust, MIDREX reside agglomeration for reuse in direct reduction), scrapyard management using sensors and machine learning however is considered to double or significantly increase the lifespan of a product.

Secondary steel production is already about 5 to 6 times more energy-efficient than current primary production routes. However, a major issue compromising circularity in steel is copper contamination ([136]). Copper contamination levels of newly available scrap constrain the extent to which secondary steel can replace virgin steel. By around 2040-2050, up to 35 Mt/year of virgin steel could be replaced by clean scrap. This would be roughly equivalent to a CO2 emission reduction of 63 Mt CO2 /year in the EU. Ecodesign requirements to facilitate dismantling, the up-coming review of the End of Life Vehicles Directive, and the Digital Product Passport may all facilitate cleaner steel cycles. These could be complemented by innovation and development of advanced copper removal technologies from steel; Eliminating inefficient end-of-life recycling practices to maximise the overall EU scrap supply while maintaining clean scrap flows; Developing integrated Direct Reduced Iron (DRI) and Electric Arc Furnace (EAF) production technologies to facilitate the blending of high shares of scrap into integrated primary and secondary steel production routes and developing EAF mini-mills to process growing quantities of steel scrap into a range of different steel products.

Regarding the water and soil pollution reduction potential of these technologies, most technologies are considered to contribute to a moderate extent. Digitisation tools for CE focusing on monitoring once again shows good or significant potential. In contrast,

([133]) 2016, Gerald Stubbe et al, 'Zinc and Iron Recovery from Filter Dust by Melt Bath Injection into an Induction Furnace'. Available at: https://www.velco.de/wp-content/uploads/2021/05/Erzmetall_Schmelzinjekt2016-1.pdf

([134]) 2020, 'A novel ammoniacal leaching process to valorise Zn-rich Basic Oxygen Furnace sludges', Available at: https://eurelco.org/2020/11/09/a-novel-ammoniacal-leaching-process-to-valorise-zn-rich-basic-oxygen-furnace-sludges/

([135]) 2020, 'End-of-Life Carbon Fiber Reinforced Polymers in Steelmaking - Accessing a C-Rich Residue Stream as Alternative Reducing Agent', Available at: https://opus4.kobv.de/opus4-bam/frontdoor/index/index/docId/51613

([136])https://www.agora-energiewende.de/en/publications/mobilising-the-circular-economy-for-energy-intensive-materials-study/

few technologies from the reside valorisation and content recovery group allow for a significant reduction of air pollution.

Table 2.15: Summary of assessment results for circular technologies for the Metal and steel industry – scrap characterisation technologies

Main circular technologies along the value chain	TRL	Circularity potential	Economic potential	Contributing to zero-pollution	Possible negative effects
Scrap characterisation					
Xray technology	TRL4-6	*	*	*	not likely
Infrared scanning	TRL4-6	*	*	*	not likely
Laser object detection (LOD)	TRL7-8	*	*	*	not likely
Software: routing, inventory management, anti-theft, doc signing	TRL4-6	***	***	*	not likely
Artificial Intelligence detection system technology	TRL4-6	***	***	**	not likely

Source: Technopolis Group

At the **end-of-life** stage, the overall maturity level of metal scrap characterisation technologies is still intermediary, while some technologies have reached a more advanced stage than others (laser object detection (LOD)). Most technologies (Xray technology, Software: routing software, inventory management, anti-theft compliance, document signing, AI detection system technology) **are already being used but more efforts are required to make them commercially viable.** Xray technology for instance is relatively advanced, with solutions currently being offered by companies such as Steinert or Tomra. Tomra has developed X-TRACT, a powerful precision x-ray sorting of aluminum, e-scrap and wood ([137]). Similarly, infrared scanning technologies are used for color detection (e.g., CU cables) and are already on the market. Infrared scanning technologies are for the most part already operating but are at varied levels of advancement regarding precision and efficiency.

([137]) https://www.tomra.com/en/solutions/waste-metal-recycling/products/x-tract

Table 2.16: Summary of assessment results for circular technologies for the Metal and steel industry – sorting technologies

Technology pathways of R&I actions	TRL	Circularity potential	Economic performance	Contributing to zero-pollution	Possible rebound effects
Sorting					
Robotic metal scrap cutting	TRL4-6	**	***	*	likely
Automatised sifting of mixed waste streams (LIBS)	TRL4-6	**	**	*	not likely

Source: Technopolis Group, 2022.

As for metal scrap collection and sorting technologies, robotic metal scrap cutting is at a medium to advanced level of maturity. Laser-induced breakdown spectroscopy (LIBS) is at a medium stage of advancement.

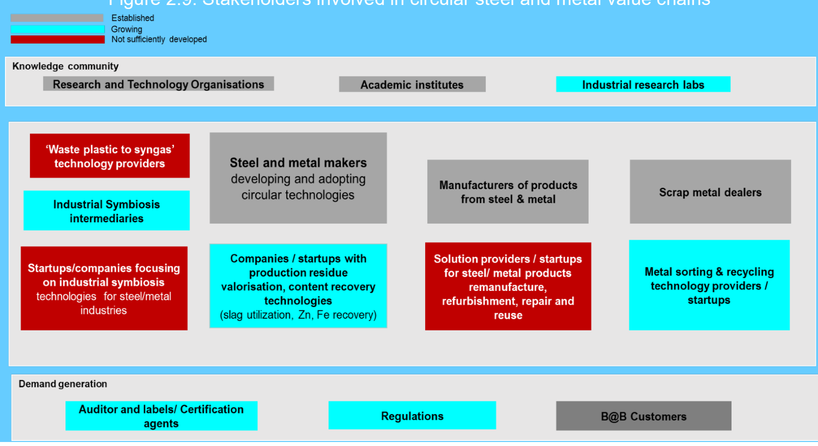
Robotic metal scrap cutting, and LIBS are both assessed positively with regard to their potential contribution to resource saving. Most scrap characterisation and also sorting technologies are considered to increase the lifespan of products by 25-50% percent.

Looking at potential long term negative effects of technologies for the metal and steel industry, there may be strong societal effects relating to the need to **adapt skills, development and education**. The increased resort to robotics will undoubtedly impact societies and communities, and a real discussion should take place on their functional, social and psychological value of robots in order for them to be sustainable. The perceptions of critical stakeholder groups about circular technologies in the steel industry should be taken into considerations. There are concerns that, although increasing the value of waste through improved sorting is important, such processes can cause products to reach **end-of-life prematurely**. Recycling must be counterbalanced by repurposing and reuse processes to ensure that products' life value and net impact is optimised.

Box 2.5 | Zoom on the metal and steel circular value chain

Key technology developers and owners in the metal and steel industry circular value chain are the **producers of the steel and metal**, which are usually large companies. These companies often have R&D capacities and resources and focus on improving and developing alternative and less polluting technololgies including circular technologies. Examples are production process residue (e.g. slag) valorisation and content (Zn, Fe) recovery, syngas use for low-carbon steel-making coupled with plastic waste-to-syngas technology. The Figure below depicts the value chain of steel and metal recycling more specifically.

Figure 2.9: Stakeholders involved in circular steel and metal value chains



Source: Technopolis Group, 2022

Specialised technology companies and **start-ups** represent another very important group of rechnology providers reinforcing circularity in the industry. There are technology companies that focus narrowly e.g. industrial symbiosis, process waste valorisaton (for slag, Zn, Fe), syngas technologies, as well as on metal scap sorting and processing.

Metal scrap dealers engage in development of advanced metal sorting and recycling technologies often in collaboration with start-ups, industry and public research organisations.

Another promising stakeholder' group is **businesses that look into the reuse and extended use** of metal product or infrastructure facilitated **by remanufacturing, refurbishment, repair and restoring**.

Industrial symbiosis intermediaries have been already cooperating with steel and metal industry by involving them in industrial symbiosis schemes. Through these schemes steel and metal manufacturers offered excess heat to other industries, supplied slag for production of concrete, as well as have started testing technologies for CO2 utilisation in chemical production.[14]

Research and academic organisation are very important players especially in developing alternative more sustainable technologies in metal production or recycling[15]. Their role is critical in studying technologies in particular in early maturity stages.

Further intermediary stakeholders include **investors, certification bodies** providing labels based on environmental auditing.

The public and industry initiatives facilitating collaborative activities have been important in facilitating greening the metal and steel industry. *Process4Planet*, the European Partnerships under Horizon Europe, their members are key R&I players in promoting innovative circular technologies.

Source: Technopolis Group, 2022

Summary and cross-cutting aspects

The maturity of circular technologies in the steel and metal industry ranges from medium to medium-high levels. This supports the observation that metal and steel industries have already been maximising recycling practices, which dictated by the minimal risk of reduced quality for the recycled material and metal products. Nonetheless, new R&D developments continue to offer new technologies and close loops not only in the metals sector, but also side stream materials of the industry.

As the assessment shows, the types of metal and steel production technologies that are already demonstrating their technical viability and entering commercialisation (TRL7-8) include:

- Valorisation of residues of zinc, slag, electric arch furnace, dust and refractory
- Laser based scrap characterisation technologies

The majority of assessed circular technologies are subject to prototyping on partial or full scale or demonstration (TRL 4-6) and thus require attraction of investment for piloting, deployment and commercialisation. Many of these technologies rely of advancements in IT, AI and machine learning, and smart management based on data processing:

- Sorting technologies are taking attention of robotics and automation R&D
- Artificial intelligence detection systems, inventories and doc signing
- Xray and infrared scanning as an alternative to more common laser technologies
- Digitalisation tools for monitoring and optimisation of processes

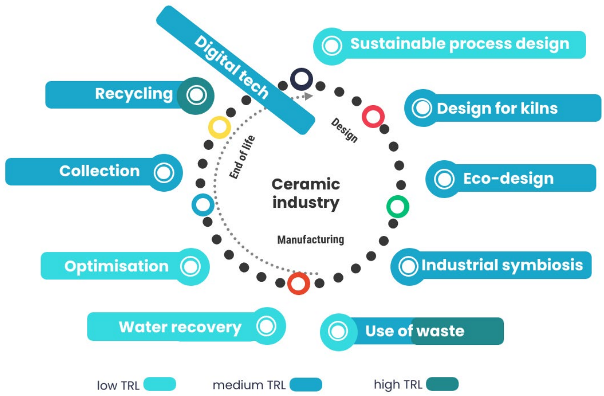
Other types of technologies being prototyped are recycling via valorisation including:

- Use of carbon-fibre-reinforced polymers in furnacing
- Novel methods for Fe and Zn recovery from dust and sludge
- Waste plastic gasification for syngas

Ceramic industry

Ceramic industry, with its largely traditional production technologies and resource and energy intensive processes, can really benefit from sustainability technologies. The circular technologies for this industry can be grouped along the lifecycle stages of i) product and process design for circularity, ii) resource-efficient manufacturing, iii) end of lifecycle, and iv) digital technologies.

Figure 2.10: Overview of main technology groups relevant for the circularity of ceramics



Source: Technopolis Group, 2022.

Table 2.17: Summary of assessment results for circular technologies for the Ceramic industry – design and manufacturing technologies

Main circular technologies along the value chain	TRL	Circularity potential	Economic potential	Contributing to zero-pollution	Possible negative effects
Sustainable process design: sustainable manufacturing process of porcelain stoneware ceramic tiles based on ceramic body dry preparation	TRL3-4	***	**	*	none
Design for resource and energy efficient kilns	TRL6-7	**	***	***	none
Ecodesign with lifecycle thinking, e.g. Reduction in products thickness, CO2 integration for improved quality	TRL4-8	***	**	**	none
Industrial symbiosis – tracking and tracing end-of-life ceramic products across value chain	TRL4-6	***	**	***	none
Use of waste					
- Use of side streams, end of life ceramic waste, industrial and inorganic waste	TRL3-4 to 7-8	***	**	*	likely

- Use of organic wastes tested as substitutes to the clay raw material (e.g. sewage sludge, agri/organic/municipalwaste)	TRL 2-3 to 4-5	**	**	*	likely
Water recovery					
- Industrial deployment of condensation and gas purification systems for water recovery and re-use	TRL3-5	**	*	*	none
- Solutions for urban wastewater (reclaimed water) use in ceramic production	TRL3-4	**	**	**	none
- Recovering and reusing of water evaporated in spray drying step of the ceramic process, for the preparation of slurries	TRL3-4	***	***	***	none
Optimisation					
- Waste heat storage and later use e.g. in drying process	TRL1-4	**	**	***	none
- Optimisation of the sintering/firing process: Liquid phase sintering, pressure assisted sintering, microwave sintering, field assisted sintering, flash sintering, spark-plasma sintering	TRL1-2 to 4-5	**	**	***	none
- Cold sintering process	TRL1-3	**	***	***	none
- Paint use minimisation via digital printing on ceramic surfaces	TRL6-7	**	*	***	likely

Source: Technopolis Group, 2022.

Technologies at the design stage in the ceramic industry include process design change as well as product design changes. **Product and process design** improvements can offer 20-50% waste savings, while new design of kilns can offer a decrease of energy consumption by 45%. Product eco-design in addition to waste minimisation can also increase the lifespan of product by 25%-100%. The maturity levels of these technologies vary from TRL 4 to 7. For example, porcelain stoneware ceramic tiles based on ceramic body dry preparation, as addressed by the P4P partnership has TRL 3-4 today, but will be driven toward TRL7 by 2030. Design for more efficient kilns is at TRL 6-7, while technologies addressing circular ecodesign of ceramic products at TRL 4-8.

Resource-efficient manufacturing has the biggest scope of using circular technologies, ranging from process optimisation via resource efficiency measures to technologies allowing industrial symbiosis and high value recycling.

Waste valorisation technologies are mostly at diverse stages of their maturity (TRL2-3 to TRL7-8). Water recovery technologies are also at TRL below 3-5 and P4P is planning to bring them to TRL7. Water monitoring technologies for ceramic industries are already demonstrated and applied (TRL 8). At the same time heat recovery technologies are at TRL 3-6. More efficient sintering technologies are still to be proven (TRL 1-3 to 4-5).

Waste and side-stream valorisation technologies offer up to 80-90% of own waste valorisation, that increase resources saving between 10 to 50%.

External waste stream valorisation technologies allow incorporation organic waste in amounts of 3-6% for municipal waste, sewage sludge, sugar industry waste, mixing with petcoke, scrap soil, mill scale; up to 9% for olive stones residues, 85% for eggshell, as well as inorganic waste incorporations of 5-6% of mill scale, pet coke, oil refinery sludge, roof tiles waste, alternative solid fuels, 7,5% of glass waste, 10% of cement – asbestos waste, 3% of aluminium electrostatic painting sludge. All these translate into traditional resource input saving and waste reduction (eg landfill) in other sectors.

All types of water efficiency technologies assessed in the study can help to reduce water use and losses by 20%. Heat recovery technologies can cut energy consumption by 40-80% and improve energy efficiency by 55-80%.

Digital printing on ceramic products can secure 80% reduction of the material due to replacement of decorative paste to ink for digital printing. By reducing time and temperatures in new approaches in sintering significant reduction of energy consumption can be achieved (e.g. cold sintering technologies rely on 200'C instead of 1000'C in traditional sintering).

All technologies scoped in this study have been offering a good contribution to circularity. Moreover, many circular technologies help in reducing greenhouse gas emissions. The ERA industrial technology roadmap for low-carbon technologies in energy-intensive industries discussed some of these technologies, e.g. waste heat recovery, energy efficient kiln design, captured carbon utilisation.

Table 2.18: Summary of assessment results for circular technologies for the Ceramic industry – end of life and digital technologies

Technological pathways of R&I actions	TRL	Circularity potential	Economic performance	Contributing to zero-pollution	Possible rebound effects
End of life					
(System for) Collection, sorting and separation of waste/ Sensor technologies	TRL3-6	***	***	***	none
Recycling of post-consumer ceramic – Take-back programme	TRL6-7	***	***	*	none
Digital technologies					
Digitalisations technologies for resource monitoring and circularity	TRL1-8	**	***	***	none
Digital product passport	TRL5-6	**	***	***	none

Source: Technopolis Group, 2022.

End of life ceramic waste collection technologies' maturity vary from TRL 3 (for sensors) to TRL 6-7 (for SMART demolition). Smart demolition and sensor technologies can increase the purity of the recycled material by 80-100%, which can promise 20-50% waste reduction.

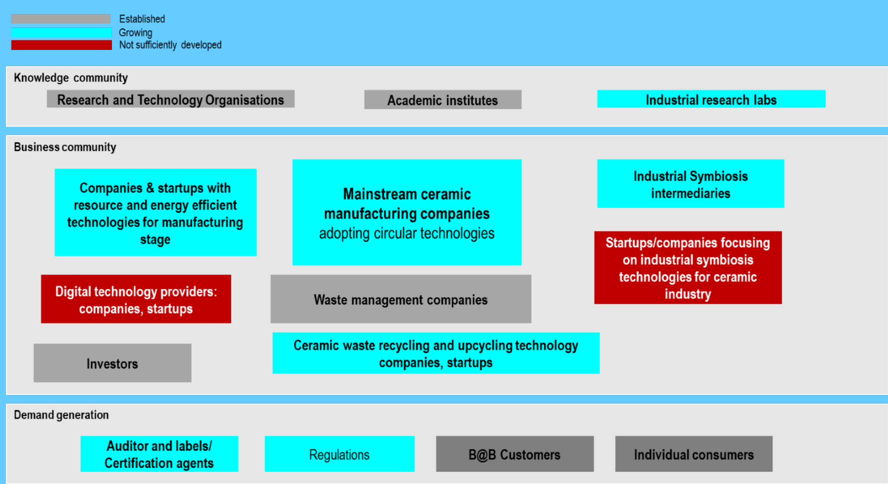
Digital technologies as a group also vary from TRL 1-3 for complex digitalised industrial plants to simpler monitoring technologies that can be at TRL7-9. **Technologies** such as the one for monitoring and optimisation of resource and energy use can offer 10-20% savings and waste minimisation. More advanced options such as fully digitalised plants can secure 10-50% of waste reduction and resource efficiency.

Box 2.6 | Zoom on the ceramics circular value chain

The ceramic industry is largely represented by medium and small-sized enterprises rooted in the long-term traditions of the European ceramic manufacturing. The traditional industrial value chain has been largely linear, connecting raw material supplies, ceramic producers, users, and end of life waste management. The key circular value chains that emerge in ceramics is on the one hand about the valorisation of secondary raw materials (waste of other industries) via industrial symbiosis and on the other hand, end of life ceramic waste diverting from landfill by engaging in waste separation, recycling and making use of it either back in ceramic or other industries.

The key stakeholders in a circular ceramic value chain are the mainstream ceramic manufacturers that develop, introduce and own circular technologies. Some have own industrial research laboratories or pursue a collaboration with public research organisations. Over the past years they have been active in investing, developing, testing and piloting resource-efficient technologies like water and energy recovering, energy efficient kilns and digital printing. Some have been exploring the possibility of creating products using waste materials from ceramic production, as well as rethinking the design of tiles by reducing the thickness of the top layer to minimum (that reduces use of energy in production) and introducing integrated lock to reduce need in adhesive materials. Ceramic manufacturers are also increasingly innovating in closing their loop via recycling of their end-of-life products[17].

Figure 2.11: Stakeholders involved in circular ceramics value chains



Source: Technopolis Group, 2022

There are **many technology providers, including established companies and new start-ups, who offer new resource and energy efficient technologies.** For example: System Ceramic (IT)[18] and SACMI (IT)[19] are the leading european process system developers for the ceramic industry. In recent years, **Industry 4.0 technology providers** helping ceramic manufacturers to achieve optimisation and resource savings with the help of the smart digital technologies.

Industrial symbiosis solutions that allow valorising waste of other industries in the ceramic manufacturing have been experimented and tested, both by industries and **researchers at academia**.[20] In case of commercialisation of these technologies there will be opportunities for circular synergies with agriculture, forestry, waste management, construction, and other companies, which will also boost the role of **industrial symbiosis intermediaries**.

End of life ceramic solution (sorting, recycling) are often offered by specialised **waste management companies** and also of a growing interest to **start ups and specialised technology companies**. Some of them go for a narrow waste specialisation and excel in their area.[21] Post demoliston ceramic product reuse became a business line for selected companies[22]

Further intermediary stakeholders include **investors, certification bodies** providing labels based on environmental auditing**, public and industry initiatives** facilitating collaborative activities aiming at greening the industry. The most prominent initiative supporting R&I of circular technologies in ceramic industry is *Process4Planet* the European public-private partnership supported under Horizon Europe. Business matchmaking platforms like TECNA and Tecnargilla [23] offer opportunities to bring in investors and technology buyers to the ceramic industry. It is also notable that over the last decades there have been numerous mergers and acquisitions in the ceramic industry[24]. This process is often accompanied with investment in modernisation and sustainability improvement in the acquired enterprises. External investment into circular technologies is seen mostly in cases of start-ups such as the *venture capital fund called 'Cottonwood Technology Fund'* (NL-US)[25].

Source: Technopolis Group, 2022

Summary and cross-cutting aspects

The assessment of circular technologies for ceramic industries has shown that the maturity levels vary significantly, being striking to see that very few have come close to commercialisation stage, while most technologies are in early prototype modelling and proof of concept stages.

Technologies that have been demonstrated TRL 6-7-8, and are closer to the market and can offer benefit via deployment in the short-run are:

- Energy and resource efficient kilns
- Selected approaches in ceramic production side stream valorisation
- Digital printing that dramatically reduced consumption of ink
- Take back programme for ceramic waste
- Selected digitalisation technologies for resource monitoring

It is notable that companies have already been actively looking into energy and digital printing technologies to minimise costs associated with production, energy and resource consumption.

A significant share of the scoped technologies forms various groups that have been subject to partial and full-scale prototyping and validation (TRL 3-5). To facilitate circularity of the ceramic industry, these technologies will play a significant role in closing the loop in the currently largely linear models in the ceramic industry related value chains. These will include investing in further progress of:

- Eco-design and lifecycle thinking focused technologies and products
- Industrial symbiosis by deploying side stream materials from other industries, as well as resource efficient manufacturing and valorisation of own side streams
- More advanced and optimised sintering processes
- Ceramic waste sorting, collection, separation technologies – largely missing in practice today

Circular technologies on a stage of basic observation, and technology conceptualisation (TRL1-2) are:

- Waste heat storage for reuse (e.g. in ceramic product drying)
- Cold sintering process, that potentially offers big energy cost savings
- Selected digitalisation technologies for resource use optimisation tailored to the industry

2.4. Conclusions

In order to assess the role of technologies, their role in the different phases of circularity and their positive effects on sustainability criteria such as pollution and greenhouse gas emission reduction are taken into consideration.

The analysis of potential technologies in the three ecosystems was pioneer work, as it could not build on consolidated existing sources for relevant technologies and the assessment of their potential.

Textile

- ✓ Textile recycling technologies, a cornerstone for circularity in this industrial ecosystem, are overall at high TRLs, and seem interesting also from an economic perspective. There is a quite clear view on technologies existing or under development and short-term impact appears possible if adequate investments are made in the scale up of new technologies and roll-out when investing in increased recycling capacities.
- ✓ R&I support can be very targeted to bring disassembly and sorting of textiles to a higher TRL, in particular to automatise the sorting and to solve the challenge of preparing composite textiles for recycling, through material blend separation technologies, which show high circular and economic potential. New technologies to reduce the use of chemicals and water pollution have emerged, and emphasis is e.g. needed to reduce the environmental impact of chemical recycling technologies.
- ✓ In order to close the loop systemically, further R&I efforts are necessary for the development of technologies related to design, durability, reuse and repair. A second hand market is developing beyond the social economy, still at early stage.
- ✓ Specific to the textile ecosystem, there is a need to research the potential of sustainable consumption behaviours, while preserving the economic viability of companies in this industrial ecosystem. Current consumption trends are not sustainable and, if consumption continues to grow at current rates, more pressure will be created in terms of material consumption and waste management in the sector.

Construction

- ✓ Technologies across the stages of design, material sourcing, recycling and repurposing technologies are able to increase circularity and are economically interesting. Technologies with the highest overall potential include urban mining, Building Information Modelling (BIM)-based applications, modular design, off-site construction, digital material passport and supporting digital technologies. Sorting and separation technologies bear important R&I challenges, including for
- ✓ Circularity does however not rely on individual technologies but needs an integrated approach which covers the lifecycle from material sourcing, building, using, repurposing, renovating and end of life.

Energy-intensive industries

- ✓ For chemicals, the R&I priorities are set out in the Strategic Research and Innovation Plan (SRIP) for Chemicals, under the Chemicals Strategy for Sustainability (CSS), which has been developed as a self-standing initiative. The SRIP for Chemicals highlights R&I areas crucial for accelerating the transition to chemicals and materials that are safe and sustainable by design.

- ✓ Steel seems to be one of the few areas where recovery and recycling have been practiced without legal requirements, simply because it seems to be cost-efficient and logistically and technologically fairly easy. Steel recycling technologies are already advanced, and the scrap steel market is expected to meet overall market demand by 2050. Several robotic technologies for metal scrap collection and sorting are already commercialised, while others are being developed. Most scrap characterisation technologies (Xray, software routing, etc.) are already being used, but more efforts are required to make them commercially viable.
- ✓ In the ceramics industry, the circularity of materials and products is mainly addressed through waste take back programmes which are ready to be piloted, while sorting and collection solutions are still at low to medium maturity stages. An important priority is process optimisation including increased material and energy efficiency. Technologies enabling industrial symbiosis offer great circularity potential, with environmental and economic benefits spreading across several industrial value chains. Reducing energy consumption is one of the highest concerns of industry, where innovating sintering processes, as well as storing and reusing waste heat are of increasing interest.

Cross-cutting technologies:

Lifecycle approach and advanced materials

- ✓ For all ecosystems, it will be crucial to incorporate the circular economy principles already in materials' design and development. This will trigger more systemic change and will affect not only the life of materials but the entire product-service value chain. This is not for the far future, a first legal framework for this is already proposed.
- ✓ Implementing the circular economy principles already in materials' design and development is also in line with other initiatives, such as the Strategic Research and Innovation Plan for chemicals (SRIP), published by the Commission in October 2022, or the Materials 2030 Manifesto, which was published by an important group of stakeholders in February 2022. This will trigger more systemic change and will affect not only the life of materials, but the entire product-service value chain. This is not for the far future, a first legal framework for is already proposed.

Digital technologies

- ✓ Digital technologies and business models play a key role in the transition of all three industrial ecosystems to the circular economy. Their use and impact often depend on their specific role and state of development in the phases of design, production and sorting/recycling.
- ✓ Examples of relevant digital technologies include the data collection and material tracking as well as waste management (all depending on the use of traceable materials, which can be separated); artificial intelligence for data analysis and design technologies; blockchain for planning and operation of buildings (depending on construction with digitised building parts); platform technologies to facilitate supply chain and customer relations; virtual and augmented reality to anticipate consumer experiences and influence sustainable consumer behaviour.
- ✓ The Commission has proposed digital product passports (DPP) in the Circular Economy Action Plan and in the Sustainable Products Initiative. They are defined as product-specific data sets, which can be electronically accessed through a data carrier to "electronically register, process and share product-

related information amongst supply chain businesses, authorities and consumers”. The DPP would provide information on the origin, composition, and repair and disassembly possibilities of a product, including how the various components can be recycled or disposed of at end of life. This information can enable the upscaling of circular economy strategies such as predictive maintenance, repair, remanufacturing and recycling. This will also inform consumers and other stakeholders of the sustainability characteristics of products and materials. The development of DPPs is currently ongoing.

INVESTMENTS IN R&D AND INNOVATION

The move towards a circular economy is an integral part of the transition pathway for the ecosystems of the textile, construction, and EII sectors. It also requires continuous long-term investment in innovative circular technologies and business models and other parts of the transformation process. Section 1 describes the estimated needs for R&D and Innovation investment in circular technologies in the three industrial sectors. Section 2 offers a review on patenting trends in technologies for the circular economy. It presents an extensive analysis of circular economy technologies for the EU in comparison to other major economies and provides insights into the performance of EU Scoreboard companies and their subsidiaries in comparison to other leading R&D investors of major economies. Section 3 presents analysis of private investments in circular technologies in the three ecosystems, where the EU position in the global context and also vis-à-vis China, South Korea, Japan, UK and US is revealed. It also analyses tech uptake of specific circular technologies, as identified by the technology assessment framework of Chapter 2 in the roadmap. Section 4 describes the EU public investments and programmes, while Section 5 provides information on the national programmes and investments of the EU Member States and Norway, including funding under the Recovery and Resilience Facility.

3.1. R&D and innovation investment needs

Overview

The transition to a circular economy requires sustained private investment into circular solutions, capable of being scaled up, that eliminate waste and pollution, keep products and materials in use and regenerate natural systems ([138]).

The assessment of technologies in Chapter 2 shows that technological solutions are at different TRLs, which highlights the need for further support for R&I investments to bring technologies close to the market.

The available estimates for R&I investment needs cover lower (1-3), medium (4-7) and higher (8-9) TRLs, bringing new technologies to the demonstration stage and first-of-a-kind installations (FOAKs). As far as possible on the basis of available estimates, this section also considers wider market deployment investment needs for the scale-up and roll-out of technologies to industrial use after the R&I phases.

R&I investments are particularly important in creating a stable demand for technology-based solutions and driving technological development. Production processes need to transform from linear to circular, which requires initial investments, changes to processes, feedstock, equipment and output, retraining of staff, and coordination within the wider value chain ([139]). In addition, soft investment needs are also highlighted. These are necessary to support social change, organisational innovation and new governance.

The overview and analysis below build on the estimates made by European partnerships and technology platforms of their investment needs and the results of a Delphi study specifically performed for this ERA industrial technology roadmap. The

([138]) https://www.weforum.org/agenda/2022/02/double-circular-economy-in-ten-years
([139]) See for example: https://www.eib.org/attachments/thematic/circular_economy_guide_en.pdf

assessment of investment needs in the textiles, construction and energy-intensive industrial ecosystems covers the period until 2030.

Textile

Commission Staff Working Document was published for consultation at the end of March 2022 to accompany the EU Strategy for Sustainable and Circular Textile ([140]) and to prepare the scenarios towards co-creation of a transition pathway for a more resilient, sustainable and digital textiles ecosystem ([141]). It highlights that it is necessary to develop technologies that use less energy and reduce waste and to invest in material and product innovation ([142]). Investments in material and product innovation are needed to ensure a pole position for the EU in future markets such as advanced sustainable bio-based textiles.

According to Euratex, significant investments will be needed to scale up ongoing R&D, create new capacity and unleash the potential of sustainable textile and recycling ([143]). The strategic research and innovation agenda of the Textile European Technology Platform (ETP) identified the following R&I and related investment needs to support the green transition (low-carbon, circular, low emission) of the textile industry:

- Set up a dedicated budget of EUR 50 million under Horizon Europe to carry out foundational empirical studies and rigorous meta-analyses of existing research into fundamental knowledge gaps and barriers to textile sustainability;
- Dedicate a budget of EUR 100 million from the Common Agricultural Policy in 2023-2030 for R&I programmes on sustainable cultivation, development of technologies and demonstration of a complete industrial processing chain for major EU-based feedstocks of natural fibres and bio-based fibres;
- Set up a EUR 50 million cascading funding programme in Horizon Europe (2023-2026) for projects on circular, bio-based and digital textile innovation for sustainability;
- Invest EUR 3 billion (equalling 1% of the estimated size of the European Regional Development Fund (ERDF) from 2023 to 2030) in regional sustainable textile research, infrastructure for education and technology transfer, collective support structures (clusters) and operational programmes;
- Set up a network of recycling hubs across Europe to bring innovative textile recycling processes and technologies for major categories of textile waste up to the scale needed for a pre-industrial pilot activity.

A study on the technical, regulatory, economic and environmental effectiveness of textile fibres recycling ([144]), published by the European Commission in 2021 ([145]),

([140]) COM (2022) 141 final.
([141]) Commission SWD (2022), 105 final, 30.3.2022.
([142]) https://ec.europa.eu/docsroom/documents/49360/attachments/1/translations/en/renditions/native
([143]) https://euratex.eu/wp-content/uploads/Recycling-Hubs-FIN-LQ.pdf
([144]) Mechanical recycling, thermal recycling and chemical recycling are given as examples for textile fibre recycling technologies.
([145])https://op.europa.eu/en/publication-detail/-/publication/739a1cca-6145-11ec-9c6c-01aa75ed71a1/language-en

shows that there is a lack of funding to support textile recycling technologies that reached a higher TRL than a demonstrated proof of concept. ([146])

The same study indicates that policy actions should, among other things, foster the development of recycling capacity and attract the necessary investments. For example, enhance traceability of materials and chemicals used in textiles; promote design for recyclability; ease access to feedstocks for textile fibre recycling; stimulate the demand for recycled fibres; set a frame with clear long-term direction. Furthermore, the study purports that initiatives need to be taken to improve the recyclability of disposed textile products over time by making sure new products entering the market are better recyclable.

Both Euratex (in 2021) and the Textile ETP's strategic R&I agenda (in 2022) have called for investments **in 'regionally based but EU-wide connected sustainable innovation and recycling hubs and a large-scale cascading funding programme for small-scale rapid innovators'**. The draft transition pathway for the textile ecosystem, prepared by the Commission, refers to the intention of some Member States to launch recycling hubs, as part of their national recovery and resilience plans (RRPs), to comply with new requirements from 2025 on the mandatory collection of textile waste. These recycling hubs are intended to collect, sort and process textile waste into secondary raw materials.

McKinsey has estimated that by 2030, EUR 6-7 billion in capital expenditure investments will be needed to scale up the textile recycling industry ([147]) along the whole value chain in the EU, including textile collection, sorting, and recycling. Similarly, the 2021 Global Fashion Agenda's report concluded that if the fashion industry invests EUR 5-6 billion in recycling technologies by 2026, as well as additional capital for collecting and storing infrastructure, the sector could become up to 80% circular ([148]). Similar assessments have been made by the European Investment Bank, calling for investments of EUR 20-50 million per recycling hub and recycling infrastructure ([149]).

Construction

The built environment is designed, created, maintained, renovated and upgraded by the construction sector. The Built4People SRIA ([150]) lists several types of R&I activities needed and the budgets assigned to them. The SRIA includes the following indications on investment needs:

- EUR 35 million budget for smart grid-ready and smart network-ready buildings, as active utility nodes in smart communities. This would be used to: (i) improve the integration of buildings into city networks, in particular water and wastewater; (ii) to encourage the local reuse of water and waste heat; (iii)

([146]) The study says that at the moment most textile products on the market are not designed to be optimally recycled and for that reason, priority should be given to initiatives that within the existing context contribute to lowering overall process cost and improving the accuracy of the input. However, there is a need to align interest and develop cooperation along the value chain from brand and retails to manufacturers, yarn and fabric suppliers, collectors and recyclers.
([147]) https://www.mckinsey.com/industries/retail/our-insights/scaling-textile-recycling-in-europe-turning-waste-into-value
([148]) https://www.environmentalleader.com/2021/11/fashion-industry-could-increase-recyclable-materials-market-share-with-new-technology-investments/
([149]) https://www.eib.org/en/stories/renewcell-textile-recycling
([150]) https://www.kowi.de/Portaldata/2/Resources/heu/coop/he-built4people-sria-2022-27.pdf

optimise the management of wastewater and rainwater to solve sanitary issues, improve the economic competitiveness of solutions and encourage standardisation); (iv) Integrate BIM with energy modelling and monitoring during the operation and maintenance phase and create simulations at building and district level to make it possible to calibrate models and define of optimal modes of management.

- EUR 75 million for reuse and recycling. This includes: (i) certified innovative, sustainable and durable construction products and systems, including strategies to reuse and recycle materials; (ii) Product labelling, according to lifecycle performance, including the CO2 footprint (with a cradle-to-cradle approach) and information on durability/service life;(iii) preventing 'hidden' ecological or social impacts, aligned with or going beyond EU Level(s) framework indicators; (iv) low-carbon and durable solutions for new construction, retrofitting, repair and reinforcing, including cultural heritage, using traditional materials that are bio-based and locally sourced, or innovative materials that are compatible with traditional materials).
- EUR 55 million for tools to facilitate a lifecycle-based approach and better integrate holistic building assessments into green public procurements. This includes, for example, building certification to stimulate the circular economy, which takes into account lifecycle assessment and human health, wellbeing and safety, and integrates the EU Level(s) framework indicators.
- EUR 70 million for reliable and robust new approaches to building the circular economy (for both technology-based and nature-based solutions).
- EUR 60 million to integrate construction and demolition waste into new constructions and industrial symbiosis. This includes: (i) demonstration through exchange platform and services of the technical and economic viability of reusing construction and demolition waste (CDW) and industrial waste (IW) at regional level (CDW/IW streams, protocols and guidelines); (ii) systems to certify and/or standardise the use of materials and construction techniques that incorporate waste.

Energy-intensive industries

The EII industrial ecosystem has great potential to reduce the number of materials it uses by deploying circular solutions.

As discussed in Chapter 2, most of the circular industrial technologies for EII still need more R&I and, therefore, more investment to reach higher TRLs. The analysis of investment needs done by the EU partnerships, Processes4Planet (P4P), offer rich insights. Moreover, the first ERA industrial technology roadmap for low-carbon technologies in EIIs describes the R&I funding needs of P4P, Clean Steel, and the SET plan. The roadmap also underlines the importance of circularity in design and production as one of the keys to reducing greenhouse gas emissions and reaching climate neutrality. ([151])

The P4P partnership, which engages 10 EII sectors, has estimated that more than EUR 35 billion of investments need to be mobilised until 2050 to develop put in place an ambitious programme of innovation. This includes the total investment in the

([151]) https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/era-industrial-technology-roadmap-low-carbon-technologies-energy-intensive-industries_en

CAPEX and OPEX projects from TRL 1 to 9, including first-of-a-kind demonstration plants. It also includes funding for non-technological activities.

Total R&I investment for the period 2020-2030 is estimated at EUR 19.8 billion, of which EUR 10.1 billion stay within the expected TRL range of Horizon Europe (i.e. TRL 4 to 8) and in non-technological activities.

P4P's SRIA (2022) has estimated the investment needs of the process industries, specifically for innovative materials, at EUR 840 million. Funding to develop recycling-friendly materials, by reducing the complexity and heterogeneity of components and developing smart connections between different materials, has been estimated at EUR 1 690 million.

In a disaggregated analysis of specific technologies, the P4P's SRIA (2022) has identified investment needs until 2030 for the following selected circular technologies and solutions under its innovation programmes, among others ([152]):

- Development of recycling-friendly materials (EUR 730 million) and smart connections between different materials (EUR 320 million).
- Chemical and medical waste and sludges and liquid waste from waste treatment (EUR 205 million), metal waste (EUR 240 million), textiles (EUR 55 million), mineral waste from construction and demolition (EUR 300 million), etc.
- Increase valorisation of solids from wastewater treatments into new materials or reuse for energy production (EUR 257.5 million).
- Fully recyclable homogeneous catalysis (EUR 129 million) and highly efficient heterogeneous catalysts (EUR 129 million).
- Demonstration of Industrial-urban symbiosis (EUR 648 million).
- Digital material design (EUR 105 million).
- Autonomous integrated supply chain management, including EUR 176 million for resource efficiency monitoring solutions.
- Digitalisation of industrial-urban symbiosis (EUR 320 million).

The roadmap of the EU Clean Steel Partnership (2020) pursues the objectives of the Partnership and realisation of the opportunities for the EU steel industry to become a global leader in clean steel technologies. Based on estimates of the steel sector's work on R&D and innovation projects that fall within the scope of the roadmap, it is estimated that around EUR 3 billion will be needed from 2021 to 2030. ([153]) However, the collaboration between steel producers is expected to produce good synergies which, compared to the company-by-company approach, would reduce the investment needed to approximately EUR 2.55 billion. This assumes that around one third of the Partnership's R&I budget for 2021-2030 will be dedicated to circular economy-oriented objectives*,* of which over half of the budget will be spent on carbon capture and utlisation technologies and the rest on recycling and other circular technologies ([154]). This R&D and innovation investment will have to be followed by more investments, which would be several times bigger, to ensure that the technologies are deployed

([152]) Carbon capture and utilisation is not included in the list here, as it is covered in the roadmap mentioned above.
([153]) Data collected by ESTEP and EUROFER. See more in ERA industrial technology roadmap for low-carbon technologies in energy intensive industries.
([154]) Interview with EU Clean Steel Partnership and ESTEP representative.

and rolled out. Several case studies of the P4P SRIA have shown that investments of around EUR 800 billion are needed to deploy the new technologies, including decarbonisation, which is 24 times higher than the EUR 34 billion estimated by the partnership to develop the technologies (TRL 1-9). The P4P sectors expect deployment investments to be in the trillions, and this rough estimate might well be too low. The P4P SRIA (2022) notes that a more accurate estimation would need more detailed analysis. ([155])

Finally, Material Economics, in its 2019 analysis of pathways for EIIs towards EU carbon neutrality by 2050 (in steel, plastics, ammonia and cement) includes a pathway focused on deploying circular economy solutions to support decarbonisation, including through increased material efficiency, recirculating high-quality materials and new sustainable materials. This scenario would require an increase in investment of at least 76%. Whereas the baseline investment in the core industrial production processes is around EUR 5.1 billion per year, this would need to increase each year, to reach its maximum in the 2030s. Thus, between 2020 and 2030 the capital investment needs would add up to around EUR 80 billion in total (for steel, cement and chemicals) or around EUR 30 billion more than the baseline (no change) scenario. By 2050, the total investment will need to be close to EUR 275 billion, which is around EUR 125 billion more than the baseline scenario. ([156])

Specific project funding, based on a Delphi survey

The assessment of investment needs has been complemented by a Delphi survey that inquired about future investment priorities in the EU ([157]). In this exercise, R&I investment needs have been assessed for each main stage of the lifecycle and each circular technology group, in particular: 1) circular materials and design for sustainability 2) recycling and repurposing; 3) circular production processes. The figures are assessments of how much funding would be needed to fill some of the existing basic gaps in research and technology development, based on specific project funding and do not take into account broader investment needs.

Textile

The consultations with experts under the Delphi exercise identified a clear need to invest in alternative, circular materials and clean production and recycling technologies.

- The experts called for up to EUR 20 million of investments in alternative material projects until 2030.
- Recycling would need up to EUR 50 million in investment, including EUR 5-10 million for research on recycled materials, EUR 10-20 million on chemical recycling and additional funding for other recycling solutions. There is a particular need for funding demonstration platforms for textile fibre recycling, estimated at EUR 1 million for each facility. Support for R&I infrastructure and sorting and recycling infrastructure is also very important.

([155]) Process4Planet, 2022 – Strategic Research and Innovation Agenda.
([156]) Material Economics (2019), Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry.
([157]) The Delphi survey was carried out between December 2021 and January 2022 to gather views on the potential of technologies and related investment needs. The survey was conducted with the ‘Calibrum’ online tool. 53 experts took part in the survey: textiles (15 experts); construction (17); chemical (9); metal/steel industry (6) and ceramics (6).

- EUR 20 million would be necessary into clean textile production technologies in the framework of supporting 3-4 R&I projects with a funding of EUR 5 million, each. Further research would also be important in ozone technologies.
- Attention should be also given to R&I in the social sciences and humanities on circular technologies and human behaviour.
- Experts also identified a need to invest EUR 50 million in research on additional artificial intelligence and on augmented and virtual reality.

Construction

The experts consulted during the Delphi exercise gave different views on how much investment is needed to bring technologies to TRL9:

- EUR 5-10 million per project is needed for investments in sourcing technologies for recycled raw material, BIM technologies and circular design, to reach TRL9 level by 2030.
- EUR 5-10 million per project is needed for investments in recycling technologies to reach TRL9 level by 2030.
- Digital twins and digital technologies need additional investments (EUR 2 million per project) to support repurposing.
- EUR 10-20 million per project is needed for investments in circular production technologies to reach TRL9 level by 2030.

Energy-intensive industries

The experts who participated in the Delphi survey identified the following specific investment needs in the EIIs, according to the lifecycle stage and circular technology group:

- Technologies in the raw material sourcing stage of the chemical industry require R&I funding mainly between EUR 2 and10 million per project, while some require higher investments (between EUR 5 and 10 million), such as in innovative materials in the process industries and inherently recyclable materials.
- In the category of circular design technologies, the experts suggested that EUR 2-5 million would be needed to advance the technology for reducing product weight and thickness. Estimates of the R&I funding needs for the circular design of processes and products ranged from EUR 0.5 million to EUR 20 million.
- The new design of more efficient kilns was said to need up to EUR 20 million, while CeramUnie estimated EUR 90 million.
- R&I on circular solutions for materials in the ceramic manufacturing process require up to EUR 10 million for each material. Some experts suggested higher amounts. For example, developing side-stream (or end-of-life) valorisation would need up to EUR 1 million, according to some views, and EUR 5-10 million according to others.
- The investment needs for R&I on integrating both organic and inorganic waste into the ceramic industry would require up to EUR 1 million, or between EUR 2 and 10 million per project, according to different views.
- In the chemicals industry and in the production stages, technologies that need significant investment include those using CO2 and CO as a building block in

polymers as well as catalyst technologies (over EUR 10 million per project per technology).

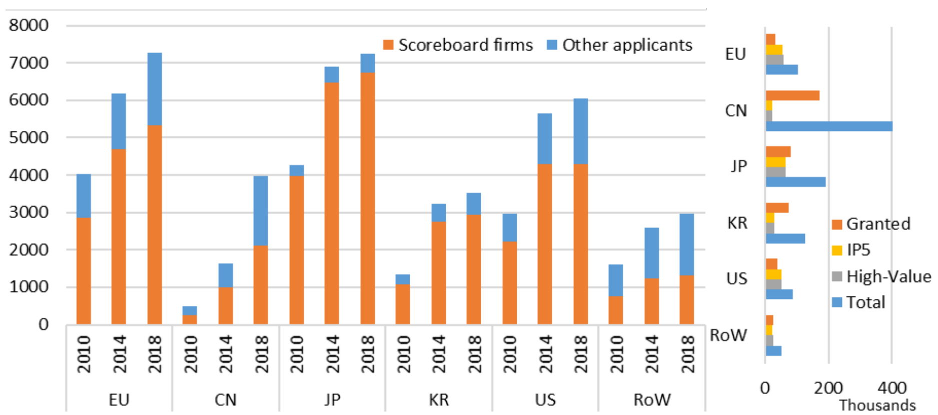
3.2. Patenting trends in technologies for the circular economy

This section first reviews the general trends in green technologies as a context to inventions in the circular economy. Then, it focuses on the analysis of circular economy technologies (CETs) ([158]), globally and in the EU. It shows how theindustrial ecosystems of this roadmap are placed in the broad spectrum of technologies related to the circular economy and describes the role and performance of large R&D investing companies as addressed in the EU Industrial R&D Investment Scoreboard.

Update on overall trends in green technologies

The global share of green inventions represents 9% share of all filings in 2018, driven by very high numbers of Chinese inventions patented domestically. Globally, green high-value inventions have a share of 10% of all high-value patent filings in 2018. At 58%, the US and the EU have the highest shares of high value patents ([159]) among green patents. Large R&D investing companies, such as those included in the EU Industrial R&D Investment Scoreboard ([160]) had a share of around 73% of green high-value inventions in 2018. The EU and the US have a lower share of large companies and a more diverse contribution to green innovation from applicants beyond the EU Industrial R&D Investment Scoreboard (Figure 3.1) ([161]). Overall, the EU is among the leaders in high-value green inventions, having caught up with Japan.

Figure 3.1: Trends in high-value green inventions: Scoreboard firms and other applicants



Note: On the left: trend of annual fillings of high-value green inventions for major economies for the years 2010, 2014 and 2018. On the right: Green inventions in the period 2010-2018: total number of inventions, high-value inventions, IP5 inventions and granted inventions for major economies.

Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

([158]) The CETs are identified through CCMTs patent classes and aggregated into industry groups relevant to CETs. Table 3.2 in Box 3.1 shows the industries that will be analysed and the concordance of codes used in the analysis.

([159]) Patents filed at several patent offices, indicating international protection.

([160])https://iri.jrc.ec.europa.eu/scoreboard/2021-eu-industrial-rd-investment-scoreboard

([161]) 'Scoreboard companies' refers to the 2022 EU Industrial R&D Investment Scoreboard, which builds its analysis on the top 2,500 R&D investors in the world.

The EU also shows the highest specialisation indices across all green technologies, except for green technologies related to IT. While ICT accounts for the largest share of green inventions, it is the automotive and othe transport industries, followed by waste, that are relevenat to the EU ([162]). The methodology for identification of green and circular technologies is discussed in the following box.

Box 3.1 | Methodology

Patenting trends are produced following the methodology developed by the JRC ([163]) to derive indicators on global inventions in clean energy technologies ([164]). Patent data are retrieved from PATSTAT 2022 Spring Edition. As data are not as complete from 2019 onwards; the analysis relies on 2018 annual figures to compare across major economies and to compute the specialisation index.

The analysis is restricted to Climate Change Mitigation Technologies (CCMTs) ([165]). CCMTs – referred to as green technologies in the context of this study - are identified through the Y02 and Y04 schemes of the Cooperative Patent Classification (CPC).

Table 3.1: Y02 and Y04 schemes of the CPC classes

CCMT	**Y scheme**	**Y02 and Y04 description**
Adaptation	Y02A	Technologies for adaptation to climate change
Buildings	Y02B	CCMTs related to buildings
CCS	Y02C	Carbon capture storage (CCS), sequestration or disposal of greenhouse gases
ICT	Y02D	CCMTs related to information and communication technology (ICT)
Energy	Y02E	Reduction of greenhouse gas emissions, related to energy generation, transmission or distribution
Production	Y02P	CCMTs in the production or processing of goods
Transport	Y02T	CCMTs related to transportation
Waste	Y02W	CCMTs related to wastewater treatment or waste management
Systems	Y04S	Systems integrating technologies related to power network operation, communication or information technologies, i.e. smart grids

The JRC methodology uses **patent families** as a proxy for **inventions**. Patent families include all documents relevant to a distinct invention, including patent applications to multiple jurisdictions as well as those following regional, national and international routes. Statistics are produced based on applicants only (as the owners of the patent and, thus, directly financing R&D activities) and considering different categories of applicants, namely companies, universities and government non-profit organisations. In case of multiple documents per invention, and when more than one applicant or technology code is associated with an application, fractional counting is used to proportion effort between applicants or technological areas, thus preventing multiple counting. An invention is considered of **high-value** when it contains patent applications to more than one office, as this entails longer processes and higher costs and thus indicates a higher expectation of the prospects in

([162]) The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.
([163]) JRC publications:
- Pasimeni, F., Fiorini, A., and Georgakaki, A. (2021). International landscape of the inventive activity on climate change mitigation technologies. A patent analysis. Energy Strategy Reviews, 36, 100677.
- Pasimeni, F. and Georgakaki, A. (2020). Patent-Based Indicators: Main Concepts and Data Availability.
- Pasimeni, F., Fiorini, A., and Georgakaki, A. (2019). Assessing private R&D spending in Europe for climate change mitigation technologies via patent data. World Patent Information, 59, 101927.
- Pasimeni, F. (2019). SQL query to increase data accuracy and completeness in PATSTAT. World Patent Information, 57, 1-7.
- Fiorini, A., Georgakaki, A., Pasimeni, F. and Tzimas, E. (2017). Monitoring R&I in Low-Carbon Energy Technologies. EUR 28446 EN, Publications Office of the European Union, Luxembourg.

([164]) SETIS Research & Innovation data: https://setis.ec.europa.eu/publications/setis-research-innovation-data
([165]) CPC classification. https://www.cooperativepatentclassification.org/cpcSchemeAndDefinitions

international markets ([166]),([167]). Within a patent family, only patent applications protected in more than one office and in one of the largest five offices are considered as **IP5 ([168])**. High value considers all countries separately, while IP5 requires at least one application to the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the National Intellectual Property Administration of the People's Republic of China (CNIPA) or the United States Patent and Trademark Office (USPTO). A **granted invention** only sums fractional counts of the patent family related to granted patent applications.

Fractional counting is also used to quantify international collaborations in patenting activity. Co-inventions are calculated based on a matrix of all combinations among co-applicants, for inventions that have been produced by at least two entities resident in two different countries. Shares of co-inventions in the same country are not considered.

The analysis of EU Scoreboard companies focuses on the companies headquartered in the EU. The portfolio of inventions of these companies includes the inventions produced by all subsidiaries, irrespective of their location. The matching of subsidiaries to applicant names in PATSTAT currently covers 60% of the Scoreboard Companies, which however account for 97% of R&I investments.

The selection of CCMTs relevant to **Circular Economy Technologies (CETs)** is done using relevant codes from the CPC classification shown in Table 2, focusing on reuse and recycling aspects of inventive activities. Patent classes are aggregated as Construction, Chemicals & Plastics, Fertilisers, Glass, Metals, Pulp & Paper, Food, Fuel from Waste, Textiles, Batteries & Fuel Cells, Electrics & Electronics, Packaging, Vehicles and Waste Water & Sludge. Chemicals & Plastics, Fertilisers, Glass, Metals and Pulp & Paper are the subgroups of EII. To facilitate the illustration of results, in certain instances we group Textiles, Batteries & Fuel Cells, Electrics & Electronics, Packaging, Vehicles and Waste Water & Sludge in the “Other” category due to low levels of patent applications in corresponding technology classes.

Table 3.1: Y02 and Y04 schemes of the CPC classes

Industry		**Technology**	
Level 1	**Level 2**	**Y02 scheme codes**	**Description**
Construc-tion	Construction	Y02W 30/58; Y02W 30/78; Y02W 30/91	Construction, demolition, wood and furniture recycling, and the use of waste
EII	Chemicals & Plastics	Y02P 20/143; Y02P 20/582; Y02P 20/584; Y02W 30/52; Y02W 30/62; Y02W 30/74	Plastics and chemicals recycling, and the use of recycled materials
	Fertilisers	Y02A 40/20; Y02W 30/40	Fertilisers of biological origin, and the use of waste or refuse in fertilisers
	Glass	Y02W 30/60	Glass recycling
	Metals	Y02P 10/20; Y02W 30/50	Reuse, recycle and recovery of metals
	Pulp & Paper	Y02W 30/64	Paper recycling
Food	Food	Y02P 60/87	Re-use of by-products of food processing for fodder production
Fuel from Waste	Fuel from Waste	Y02E 50/30	Fuel from waste, e.g. synthetic alcohol or diesel
Other	Textiles	Y02W 30/66	Disintegrating fibre-containing textile articles to obtain fibres for re-use
	Batteries & Fuel Cells	Y02W 30/84	Recycling of batteries or fuel cells
	Electrics & Electronics	Y02W 30/82	Recycling of waste of electrical or electronic equipment

([166]) Dechezleprêtre, A., et al., (2011) Invention and transfer of climate change–mitigation technologies: a global analysis. *Review of environmental economics and policy*.
([167]) Dechezleprêtre, A. et al., (2015) Invention and International Diffusion of Water Conservation and Availability Technologies. *OECD Environment Working Papers, No. 82*.
([168]) Daiko, T. et al., (2017). World top R&D investors: industrial property strategies in the digital economy, Publications Office.

	Packaging	Y02W 30/80	Packaging reuse or recycling, e.g. of multilayer packaging
	Vehicles	Y02W 30/56	Solid waste management of vehicles
	Wastewater & Sludge	Y02W 10/40	Valorisation of by-products of wastewater, sewage or sludge processing

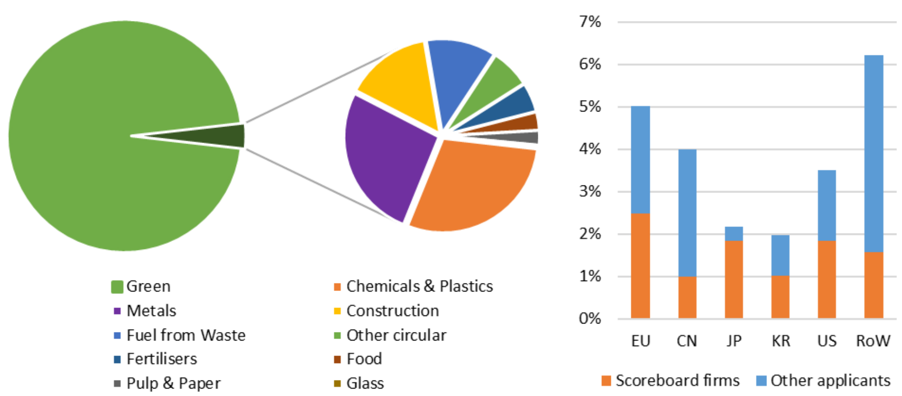
Note: Technology descriptions adapted from the Y02 scheme descriptions of the CPC.
Source: 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

Patenting trends in CETs

Global trends

Globally, patenting activity in CETs accounts for only about 4% of total green inventions between 2010 and 2019 (see, Figure 3.2). The share is the highest for the EU (5%), followed by China (4%) and the US (4%). The share of CETs in green inventions is around 2% in Japan and South Korea.

Figure 3.2: Share of CETs over green inventions in major economies (2010-2019)



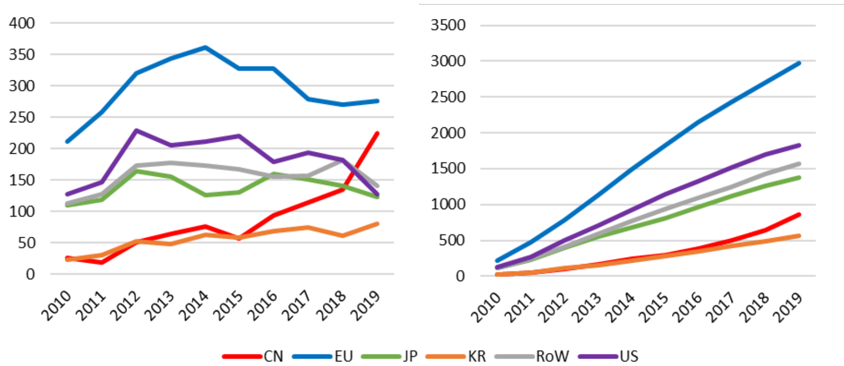
Note: On the left: Share of CETs in green inventions and the split of share by industrial categories for circular economy technologies. On the right: Share of CETs in green inventions for major economies and the split of share between the Scoreboard firms and other applicants.
Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

Between 2010 and 2019, the EU is the leader in CET inventions, both in absolute terms and as a share of overall green inventions (see, Figure 3.3). During this period, the EU's share of CETs in green inventions remains between 28% and 37%, despite a decreasing patenting trend between 2014 and 2018. The US is the second largest economy in terms of CET patenting activity, with a share fluctuating from 18% to 23%. In the US, similarly to the EU, there has been a decline in annual inventions after 2015. China had the highest growth rate over the same period; starting from a much lower level of activity, annual CET inventions more than quadrupled until 2018 and the latest figures for 2019 indicate an increase of more than seven times with respect to 2010.

Large R&D investing companies like those represented in the EU Industrial R&D Investment Scoreboard are responsible for around 50% of the CET patents in the EU, South Korea and the US, and around 25 % in China in the period 2010-2019. This is a lower share than in green technologies, overall, with a much higher share of other types of patent holders, such as the public sector, universities, or smaller companies.

Only in Japan, the share of Scoreboard companies in CET inventions remains high (around 85%).

Figure 3.3: High-value inventions in CETs in major economies (2019-2019)



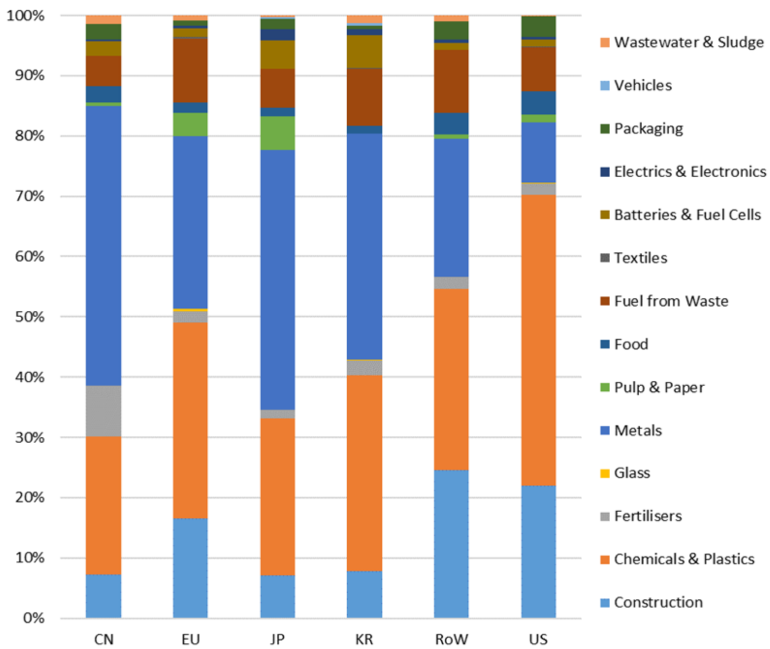
Note: On the left: Yearly high-value CET inventions. On the right: Cumulative trend of high-value CET inventions. Data not as complete for 2019.
Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

In the period 2010-2019, CET inventions are concentrated in Chemicals & Plastics (29%), Metals (27%), Construction (15%) and Fuel from Waste (12%) as shown in Figure 3.3.

Fgure 3.4 provides a breakdown of the CET patent filings of major economies by sectors. For the EU and the US, the Chemicals & Plastics category accounts for the largest share in their portfolio, with metals and construction following in the EU. The Metals category comes top in Asian economies followed by Chemicals & Plastics. Construction is the second largest category of CET inventions in the US (22%) but comes third or fourth in the portfolios of other economies.

CET inventions related to Fuel from Waste are the fourth largest category in the EU's portfolio; the EU has the highest portfolio share for this category (11%). Nothwitstanding the high share of construction patent fillings for the EU, it is behind in numbers in Asia, considering the overall high number of patents there. Figure 3.6 also shows the rather small share of patent fillings for textiles.

Figure 3.4: Industrial distribution of CET inventions in major economies (2010-2019)



Note: Industrial categories are aggregated at Level 2 categories of Table 2.
Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

Among the major economies in 2018, the EU was the one with a positive specialisation index ([169]) in most of the industrial categories for CETs except for those related to Packaging, see Table 3.3. Nine industrial categories have seen an increase in specialisation since 2010, the strongest of which is Glass, one of the EII subcategories. Among the major economies, the EU leads the specialisation in CETs related to Construction, Chemicals & Plastics, Glass, Food, Fuel from Waste, Textiles and Wastewater & Sludge. China is leading in Metals and has seen a substantial increase in specialisation in Textiles since 2010.

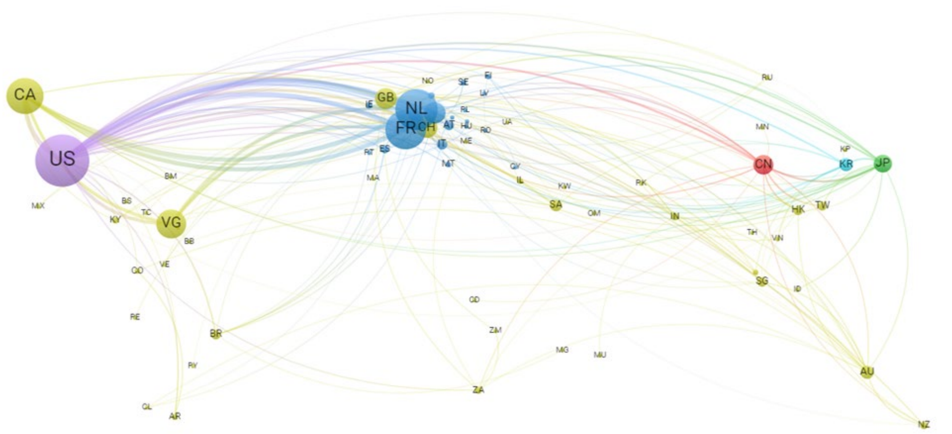
([169]) The share of CET inventions among other technologies within a country's portfolio, compared to the global average share.

Table 3.3: Specialisation index in CETs (2018)

Industry	EU Index	EU Change	CN Index	CN Change	JP Index	JP Change	KR Index	KR Change	US Index	US Change	RoC Index	RoC Change
Construction	0.6	0.1	-0.4	0.1	-0.5	0.1	-0.3	0.1	-0.1	-0.4	1.1	0.7
Chemicals & Plastics	0.6	0.3	-0.4	-0.4	-0.5	-0.2	-0.5	0.2	0.3	0.0	0.3	0.4
Fertilisers	0.3	-0.2	-0.1	-1.1	-0.7	0.0	0.3	0.7	-0.3	-0.2	1.3	0.9
Glass	4.2	3.9	-1.0	0.0			-1.0	0.0	-1.0	-0.7		
Metals	0.0	-0.1	0.4	0.2	-0.3	0.0	-0.2	0.1	-0.4	0.0	0.8	-0.3
Pulp & Paper	0.3	-0.5	-0.8	0.2	1.4	1.5	-1.0	0.0	-0.2	0.5	-1.0	-1.8
Food	0.5	0.7	0.0	-0.9	-0.8	-0.4	-0.8	0.2	0.4	-0.6	0.8	0.6
Fuel from Waste	1.3	0.6	-0.6	0.1	-0.6	-0.1	0.0	0.4	-0.2	-0.3	0.3	0.1
Textiles	1.3	0.3	0.8	1.8			1.0				-0.3	
Batteries & Fuel Cells	0.2	0.5	-0.2	-0.2	0.0	-0.7	0.8	0.7	-0.5	-0.6	0.3	1.2
Electrics & Electronics	0.6	1.1	-0.4	-3.0	1.4	0.9	-1.0	0.0	-0.9	-0.4	-1.0	-1.1
Packaging	-0.1	-0.2	-0.8	0.2	-0.6	0.0	-0.6	0.0	1.0	0.3	1.1	0.3
Vehicles			-1.0		2.1		2.3					
Wastewater & Sludge	0.6	0.1	0.2	-0.9	-0.7	-1.1	0.3	1.3	-0.9	-0.5	1.6	

Note: Specialisation index in circular economy technologies by industrial categories and major economies. For each economy, the index in 2018 is listed in the 1st column and the change with respect to 2010 is listed in the 2nd column. Data is not available for Glass, Textiles and Vehicles for all years/countries, as the codes are not widely assigned.
Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

Figure 3.5: Collaboration network in CET inventions (2010-2019)

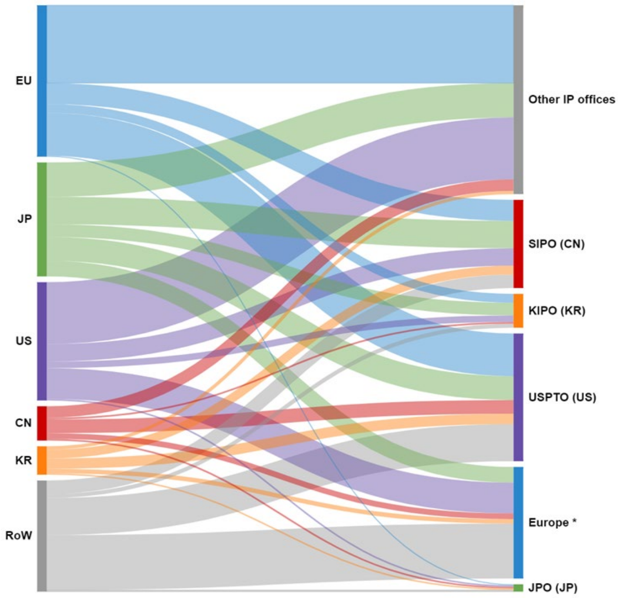


Note: Collaborations are identified through the countries of co-applicants of patents.
Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

In terms of international collaborations on CET inventions, the US has the highest number at country level in the period 2010-2019. However, the EU as a whole surpasses this (see Figure 3.5). The Netherlands and France are the leading EU countries when it comes to international collaboration, and second and third in the world, after the US. The US has the highest number of countries involved in its international alliances, with 43 in total, including 13 EU Member States. The Netherlands and France are the primary partners in US-EU CET patent applications. Patent applicants in EU Member States primarily construct alliances with US applicants, followed by other Member States. China and Japan collaborate with 18 and 20 other countries, respectively. Among EU Member States, patent applicants in France, Germany, Italy and Netherlands collaborate with counterparts in China. Applicants in Austria, Denmark, Finland, Germany, Italy and Latvia have formed alliances with counterparts in Japan.

Figure 3.6 shows that the US (23%) and the EU (20%) are the most targeted economies for international CET inventions, followed by China (16%). As with the general trend in overall green inventions, Japan attracts only a small share of international applications. The strong industry and technology base in Japan, coupled with very specific regulations, tend to make it a rather difficult and insular market for foreign technology providers. EU applicants tend to favour the US, with a share of 28% of its non-European applications, followed by China, with a share of 14%. The rest of the world (RoW) and the US applicants target European jurisdictions as their first foreign destination. Among the major economies in Asia, China and South Korea file their foreign patent applications primarily in the US, whereas Japanese applicants primarily target China.

Figure 3.6: International flow of CET inventions by major economies (2010-2019)

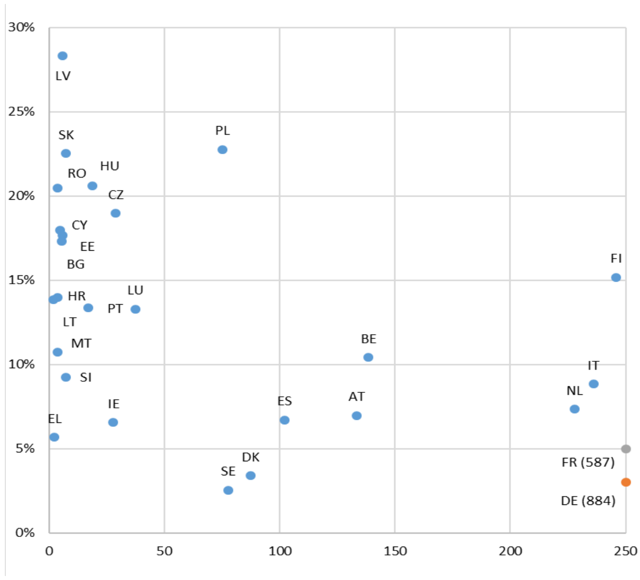


Note: Country of applicant (left) and foreign authorities targeted for protection (right).
Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.
* Europe: EPO and national IP offices of EPO members.

Trends in the EU Member States

In line with overall green invention levels, over the period 2010-2019, Germany and France have by far the highest number of CET inventions. These represent 3% and 5% of the overall green inventions produced by German and French applicants, respectively (Figure 3.7). Finland, at third rank, has the highest share of CET inventions in its green patent portfolio at 15%. Italy and the Netherlands follow next. With fewer green patents, Poland, Latvia, Slovakia, Hungary and Romania have the highest shares of CET inventions in their portfolios, more than one out of five.

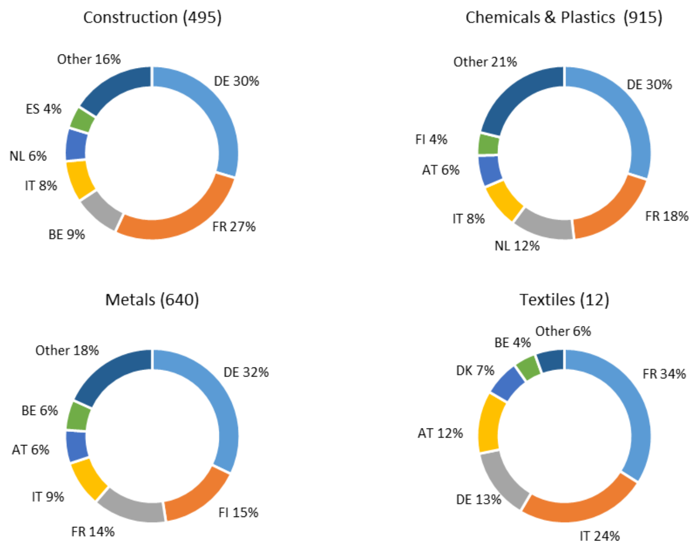
Figure 3.7: Inventive activity in CETs of the EU Member States (2010-2019)



Note: Number of CET inventions (horizontal axis) and share of CET inventions over green inventions (vertical axis).
Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

Germany and France always rank among the top five inventing countries in each of the industrial subcategories for CETs (see, Figure 3.8). Germany is first in all of the eight subcategories, followed by France except in the Metals and Pulp & Paper categories where Finland has the second highest share. Other EU Member States with high shares are the Netherlands in all categories except Metals; Italy in Construction, Chemicals & Plastics, Fertilisers, Metals and Others; Austria in Chemicals & Plastics, Metals and Pulp & Paper; Denmark in Food and Fuel from Waste; Belgium in Construction and France and Italy in Textile.

Figure 3.8: Share of CET inventions per industry and EU Member State (2010-2019)



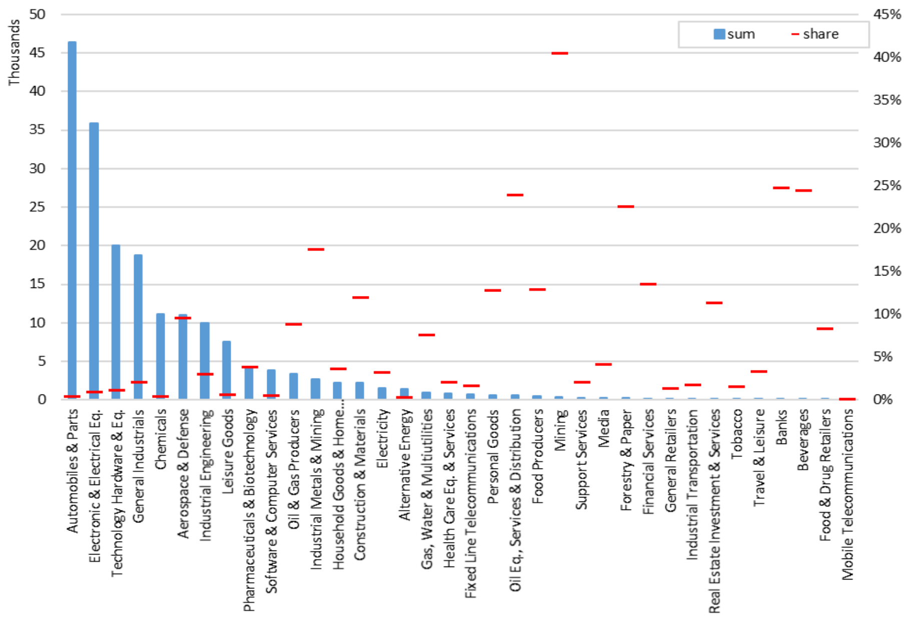
Note: Total number of CET inventions in the EU for each industrial category is given in parenthesis.
Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

The role of large R&D investors

Since 2010, the CET inventions of Scoreboard companies have accounted for 51% of the global total ([170]). Figure 3.9 presents their overall sectoral distribution. The top five sectors in absolute numbers are Automobiles & Parts, Electronic & Electrical Equipment, Technology Hardware & Equipment, General Industrials and Chemicals. In relative terms, however, the five sectors with the highest share of CET inventions are Mining, Oil Equipment, Services & Distribution, Forestry & Paper, Beverages and Industrial Metals & Mining sectors. In Beverages, the efforts in CETs are related to Food (44%), followed by Packaging (31%), metal cans, plastics and glass bottles.

([170]) The activity of subsidiary companies has been aggregated and attributed to the Scoreboard parent company. This introduces differences in the resulting performance and location (headquarters) of some companies, which are now referred to as a group and not as the subsidiaries, which may have been referenced above.

Figure 3.9: Scoreboard companies' CET invention activity by ICB sector (2010-2019)

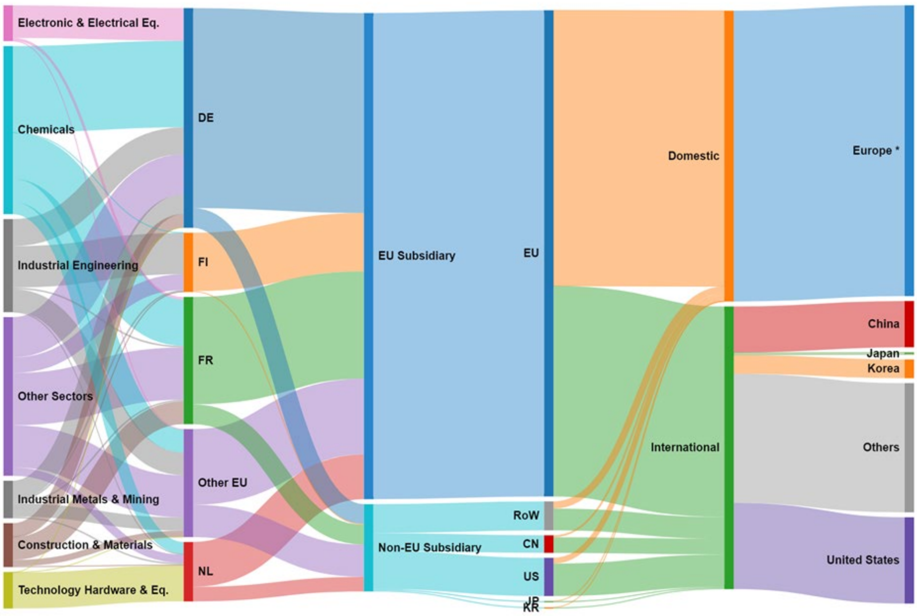


Note: Number of inventions (blue, left axis), and share in green inventions (red, right axis).
Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

EU companies active in the Chemicals sector account for about 29% of the total CET inventions produced by EU Scoreboard companies, followed by Industrial Engineering (16%) and Construction & Materials (8%). German, French, Finnish and Dutch companies have the highest number of filings among the EU Scoreboard firms, accounting for 81% of all EU Scoreboard CET inventions. The German and French companies active in CET patenting are mostly in the Chemicals sector, the Finnish in Industrial Engineering and the Dutch in Technology Hardware & Equipment.

About 85% of EU Scoreboard CET inventions are produced by EU subsidiaries (Figure 3.10). Among the inventions produced by non-EU subsidiaries of EU Scoreboard companies, 44% originate from the US, followed by 18% produced by companies located in China. Overall, 51% of CET inventions produced by EU Scoreboard companies are protected in Europe, while the rest flow to other international jurisdictions, primarily to the US at about 15%.

Figure 3.10: EU Scoreboard companies' patenting activity in circular economy technologies by ICB sector, countries of headquarter and subsidiary, and targeted jurisdiction (2010-2019)



Note: Inventions by ICB sectors (1st column), country of headquarters (2nd column), country where subsidiaries are domiciled (3rd and 4th columns) and IPO jurisdictions targeted (5th and 6th columns).
Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.
* Europe: EPO and national IP offices of EPO members.

Top Scoreboard companies in CET inventions

EU Scoreboard companies are present among the top five companies in each category (see figure 3.11). EU Scoreboard companies lead in the number of CET inventions related to Fuel from Waste, and US Scoreboard companies lead in CET inventions related to Construction and Chemicals & Plastics.

Table 3.4: Top five Scoreboard companies' CET inventions serving construction, chemicals & plastics, and metals (2010-2019)

	GLOBAL SCOREBOARD				EU SCOREBOARD			
Rank	Company	Country	inventions	Share	Company	Country	inventions	Share
Construction								
1	Halliburton	US	95	51%	Saint-Gobain	FR	30	11%
2	LafargeHolcim	CH	35	39%	BASF	DE	30	3%
3	Sika	CH	33	65%	HeidelbergCement	DE	30	51%
4	USG	US	33	82%	Weatherford International	IE	11	5%
5	Saint-Gobain	FR	30	11%	Siemens	DE	9	0%
Chemicals & Plastics								
1	Dow Chemical	US	93	19%	BASF	DE	54	5%
2	BASF	DE	54	5%	Arkema	FR	45	22%
3	Honeywell	US	47	5%	STMicroelectronics	NL	24	1%
4	Saudi Basic Industries	SA	45	16%	Solvay	BE	22	10%
5	Arkema	FR	45	22%	Siemens	DE	20	0%
Metals								
1	Sumitomo Metal Mining	JP	120	39%	Metso Outotec	FI	77	52%
2	Metso Outotec	FI	77	52%	SMS Holding	DE	44	46%
3	JFE	JP	74	35%	STMicroelectronics	NL	42	2%
4	JXTG	JP	72	23%	Siemens	DE	37	1%
5	Nippon Steel	JP	69	15%	BASF	DE	23	2%

Note: The total number of CET inventions per company is represented in blue and the share of CETs in overall green inventions per company is represented in green. Industrial categories are selected according to the total number of inventions per category.
Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

CET inventions serving the construction industry

US companies lead in CET inventions, which serve the construction industry, followed by Swiss and French companies. This is in line with the significant country-level shares of CET inventions related to the construction industry in the US and the EU. The US company Halliburton is the global leader among the Scoreboard firms in the period 2010-2019. In the EU, the top inventing companies are mostly from Germany, while Saint-Gobain from France leads in the number of inventions.

CET inventions serving the chemicals & plastics industry

Although the EU leads in CET inventions, which serve the chemicals & plastics industry, with a 29% share in total CET inventions, Dow Chemical from the US is the leading Scoreboard company. Among the EU Scoreboard firms, the CETs, which serve the chemicals & plastics account for 33% of CET inventions – the largest share together with Metals. The top inventing companies are from Germany, France, Belgium and the Netherlands; and BASF from Germany leads despite a small share for CETs, which serve the chemicals & plastics in its overall green portfolio.

CET inventions serving the metals industry

Despite the large share of Metals-related inventions in the CET inventions of all major economies, those of Japanese and EU Scoreboard firms account for 73% of total CET inventions in the period 2010-2018, with a share of 40% and 33%, respectively. The top five inventing firms are mainly from Japan, with the single exception of Metso Outotec from Finland. Other leading EU companies in CET inventions related to Metals are from Germany and the Netherlands.

3.3. Private investments in circular technologies in the three ecosystems

The first part of this section ([171]) presents an analysis of circular economy industries (CEIs) that describes, for the three ecosystems, the EU's position in the global context and compared to China, Japan, South Korea, UK and US. This is followed by a discussion of R&D&I results for CEI start-ups. The second part focuses on companies, patents, investments and collaborations, linked to specific circular technologies (CTs), as identified by the technology assessment framework in Chapter 2 of the roadmap ([172]). Tech uptake ([173]) of CTs is discussed and there is also a focus on CT start-ups. The section ends with some conclusions. The results of groundbreaking work to define indicators and data is presented in this section to provide insights into the R&I investments and the relative strengths of the EU and five other countries ([174]).

Box 3.2 | Methodology for CEI and CT-related circular technologies

The term **circular economy industries (CEIs)** is used for those companies that are linked to recycling, reuse, recovery and waste treatment technologies in the textile, construction and EII ecosystems. In April 2022, PPMI and Idea Consult analysed around 1.1 million companies, using the ORBIS, Dealroom, Technote and PATSTAT databases. **Around 81 000 companies** were linked to CEIs. The Annual Single Market Report 2021 was used as a basis for selecting relevant NACE codes (the EU's statistical classification of economic activities), since it includes a selection of these codes to define the 14 industrial ecosystems ([175]).

Methodology to identify CEI patents: first, the Commission developed a list of cooperative patent classification (CPC) codes related to recycling, repair and waste management technologies. Top keywords for each technology were derived by using the designated patent CPC codes for these technologies. Then, we developed the full set of technology keywords, which PPMI and Technote used to semantically link data between entities via text data. There were 2.2 million such keywords in total.

Circular technologies (CTs) is the term used in the circular industrial technologies roadmap, as per the technology assessment framework, developed in Chapter 2. In August-September 2022, 2.5 million companies were analysed in the ORBIS, Technote and Dealroom databases and over 45 million patents were analysed in PATSTAT. **Around 52 000 companies** were identified as linked to the CTs.

Methodology to identify CT patents: a patent was assigned to a particular technology if all the relevant keywords were found in its abstract or title. A company was assigned to a particular technology under two conditions: (i) if it owned at least one CT patent assigned to that technology; (ii) if it had at least two website URLs mentioning all the relevant keywords for the technology and had at least one circularity-related keyword among its top company keywords in Technote.

Data sources used: ORBIS is a global database of information from company financial statements. Companies from relevant CEI industries were analysed if they had (i) a turnover of at least EUR 1 million; or (ii) at least 10 employees. In total, some 1.8 million companies were

([171]) The section benefits from data and analyses of industrial R&D and innovation engagement in circular economy technologies, handled by a consortium of PPMI and IDEA Consult, under a framework contract at the Directorate-General for Research and Innovation.
([172]) The data analysis on CEIs and CTs in this section is considered a pilot, which should provide information about trends. This is derived from the first deliverable of the contract of PPMI, which as such will not be published. For the list of specific circular technologies, please see Chapter 2 and Annex.
([173]) Data relating to 'uptake' concern the costs to companies of testing and installing 'new to the company' and/or 'new to markets' technologies or processes (OSLO Manual on Innovation) and which include a strong R&D and innovation component, including technological adaptation and new local technological solutions applied to existing technical infrastructure. Data do not include 'deployment' activities where the R&D and innovation component concerns the costs of adapting installations to products and markets.
([174]) No respective data linked to circular technologies from another source could be found.
([175]) https://ec.europa.eu/info/sites/default/files/swd-annual-single-market-report-2021_en.pdf

selected. **Technote** is a large database for companies and their products and technologies. It contains data on 4.5 million companies and 70 million products and services on the market. **Dealroom** is a global provider of data on start-ups and scale-ups, and on capital that has been raised. It contains data on 2.5 million companies. **PATSTAT** is a worldwide patent statistical database, containing data on 45 million patent families.

In addition to developing the methodology as specified in box 3.2 to identify relevant companies, as well as the data on R&I investments by the private sector, which identifies relevant private companies and patents, this section is a product that represents the results of groundbreaking efforts to specify indicators and data to provide insights into R&I investment volumes and relative strengths of the EU and five other countries ([176]).

Circular economy industries' (CEIs) circular technologies

Around 7.2% of all circa 1.1 million companies in the three industrial ecosystems were identified as relevant to CEIs' technologies, worldwide. The EII ecosystem has most of the companies and also the highest share of CEI companies (13%), compared to the textiles (3,2%) and construction (2,4%) ecosystems. The EU had overall 26,443 CEI companies (32 % of total CEI companies) ([177]), which was much higher than the CEI companies identified for the US (20%) and China (4.4%). The rest of the world had 43.6 % of CEI companies. For more details, see Table 3.5.

Around 2.2% of all ca. 5.5 million patents analysed in the three ecosystems were identified as relevant to CEI technologies, worldwide. EU CEI patents came to 25,721, representing 21% of all CEI patents, see Table 3.5. The majority of the EU CEI patents were found in the EII ecosystem (20,234 patents). The EU is a circular patenting leader vis-à-vis China, Japan, South Korea, US and UK.

The median annual R&D investment in 2020 for EU CEI companies overall was lower compared to the median investment of companies in the CEI ecosystem worldwide, estimated at EUR 18.9 million per company ([178]). More specifically, the median investment of companies in the construction ecosystem worldwide stood at EUR 13.4 million, whereas EU CEI companies registered a median investment of EUR 17 million. In the worldwide textile ecosystem, the median investment came to EUR 13.4 million, whereas EU CEI companies registered only EUR 5.7 million. Finally, the median investment in the worldwide EII ecosystem was in the range of EUR 10-20 million, whereas the EU CEI companies came to EUR 12 million.

([176]) No respective data, linked to circular technologies, from another source could be found.

([177]) EU companies in the textiles represented 28% of all unique companies linked to the companies, linked to CEIs, 47% in construction ecosystem, and 31% in EII ecosystems.

([178]) The R&D&I investment data should be treated with caution, as data was available for only 6.5% of all companies in the database. Nevertheless, this points to a low share of companies, which engage in R&D & Innovation, compared to the overall sample of CEI which use such technologies.

Table 3.5: EU positioning in terms of patents, companies and investment in CEIs, 2020

Ecosystem	Number of Companies	Number of patents	Share of total CEI companies	Share of total CEI patents	Median annual R&D investment per company, 2020
Textile	1826	2767	28.8%	29.7%	EUR 5.7 million
Construction	4872	10431	47.3%	30.3%	EUR 17 million
EII	19745	20234	30.9%	23%	EUR 12 million
Total	26443	25721	32%	21%	n/a

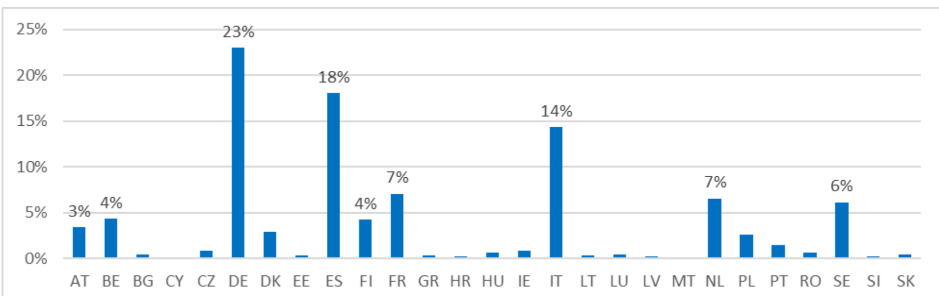
Note: R&D intensity is the ratio of firm's R&D expenditures over sales. Source: ORBIS, Technote and Dealroom by PPMI, 2020.

The analysis, based on patents and keywords, shows that a substantial share of R&D and Innovation investments in CEIs is found outside of the three ecosystems. Companies outside the ecosystem had 45% of the companies and 46% of the patents linked to the analysed technologies in the textile ecosystem, and in construction and EII, the share was about 50-55%. This applies in particular to digital technologies, e.g. artificial intelligence, big data, digital authentication and similar. The analysis also demonstrates that much of the tech uptake happened in industries outside the three ecosystems. Most of the companies that were active in CEIs but did not belong to the construction, EII or textile ecosystems, were in Telecommunications, Manufacturers of computer electronic and optical products, Manufacturers of machinery and equipment, Manufacturers of other transport equipment and engaged in Electricity gas steam and air conditioning supply. Overall, the share of companies investing in R&D and Innovation in the CEIs is found to be small and the share of CEI patents was even less.

Data for EU Member States

The figure below offers the share of relevant CEI companies by Member State (a total of 26,443 companies, including start-ups). Close to 55 % of identified EU CEI companies were located in Germany, Spain and Italy. If CEI companies from France, Sweden, Netherlands, Finland, Belgium and Austria are added, these nine countries account for ca. 86% of CEI companies in the EU. 18 Member States are home to around 14 % of all CEI companies in the EU.

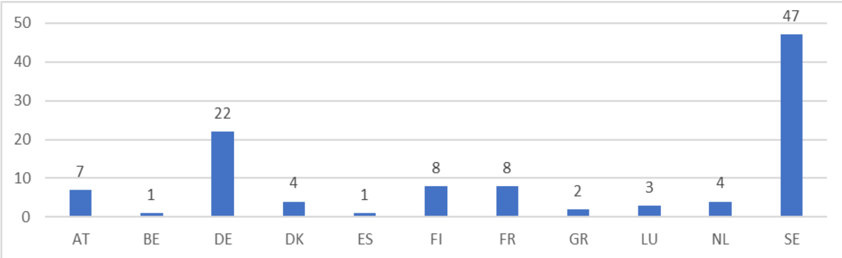
Figure 3.11: Share of CEI companies by Member State, 2020



Source: Analysis of ORBIS and Technote data by PPMI.

Figure 3.12 shows the number of large CEI companies by EU Member State for which there are R&D investment data in ORBIS. The distribution of these 107 large CEI companies that perform R&D is limited to only 11 EU Member States (headquarters). Most of these companies are located in Sweden (44%) and Germany (21%). Moreover, companies in Sweden and Germany have (on average) higher R&D investments compared to the other Member States.

Figure 3.12: Number of large CEI R&D performing companies by Member State, 2020

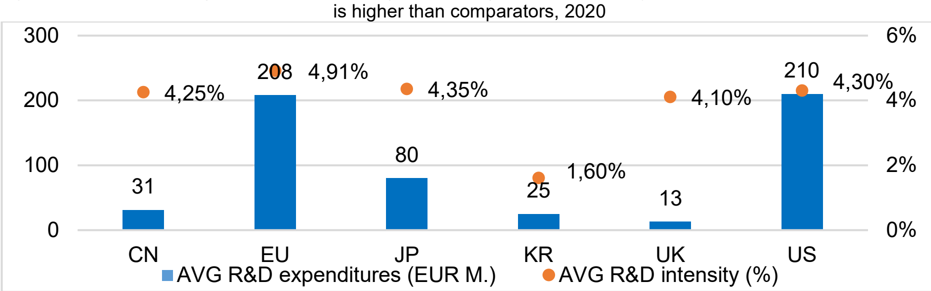


Source: ORBIS data by PPMI.

R&D expenditures and R&D intensity of large CEI companies

In 2020, the average R&D expenditures of CEI companies in the EU and US amounted to about EUR 208 million and 210 million, respectively - much higher than average R&D expenditures in Japan, China, South Korea and UK companies, see Figure 3.13. As far as the R&D intensity ([179]) of CEI companies is concerned, 2020 was a special year for EU companies, who took the lead with 4.91%, followed by Japanese companies (4.35%), US companies (4.25%), UK companies (4.10%) and South Korean companies (1.60%).

Figure 3.13: Total average R&D expenditures (EUR million) and R&D intensity of CEI companies in EU27 and US is higher than comparators, 2020



Note: The graph takes into account large companies only for which there is investment data in the Orbis database. Orbis R&D&I data covers about 300 largest spenders worldwide. This explains the relatively high R&D intensity figures observed.
Source: ORBIS data by PPMI.

As shown in Figure 3.14 (left), average R&D expenditures of large US R&D companies, linked to CEIs-related technologies, have overall been the highest throughout, even though they had a declining trend between 2015 and 2020. Large EU R&D companies engaged in CEIs-related technologies sharply increased their annual spending in 2019-2020 from EUR 114 million to EUR 208 million after years of

([179]) R&D intensity is the ratio of firm's R&D expenditures over sales.

rather stable volumes (Orbis data). Large Japanese companies, linked to CEIs-related technologies spent between EUR 66 million and 80 million during 2013-2020, while Chinese, South Korean and UK large companies spent on average between EUR 6 million and EUR 25 million over the same period. As far as R&D intensity is concerned (Figure 3.15, right), large EU companies had the highest rate in 2020 with 4.9% in R&D intensity, while they started with 2.95% of average R&D intensity in 2013.

Figure 3.14: Average R&D expenditures of CEI companies (EUR m)

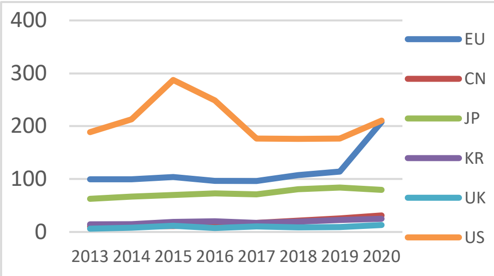
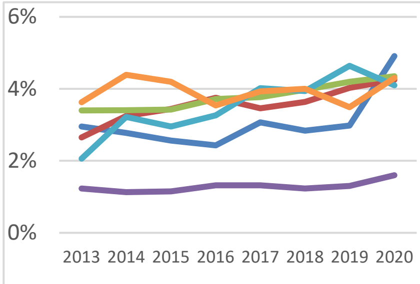


Figure 3.15: Average R&D intensity of CEI



Source: ORBIS data by PPMI.

R&D concentration of large CEI companies

The distribution of R&D expenditures in 2020 for large CEIs companies indicates that R&D investments are concentrated in few firms. The top 10% of large EU R&D investors accounted for 85.75% of total R&D investments and the top 1% for 37.10% ([180]). In comparison, R&D investments of large companies are less concentrated in the other countries compared, see Table 3.6 below.

Table 3.6: Degree of concentration for R&D investments of CEI companies, 2020

Comparators	Share of top 1%, 2020	Share of top 10%, 2020	Number of companies for which there is available data
China	29%	69%	375
EU	37%	86%	107
Japan	20%	57%	119
South Korea	18%	53%	38
United Kingdom	22%	80%	159
United States	23%	63%	49

Source: ORBIS data by PPMI.

Given the high concentration of R&D investments in large companies in the three ecosystems, they need to be analysed more closely, although they present only about half of the overall R&D investment data in the three ecosystems.

([180]) To determine the extent to which R&D expenditures are concentrated across countries, PPMI calculated the country share of total R&D expenditures for which the largest spenders (top 1% and top 10% of the companies) are responsible for, see European Commission (2018). Trends at the Frontier in Corporate R&D in the Digital Era: Facts, Prospects and Policies. https://ec.europa.eu/info/sites/default/files/economy-finance/dp120_en.pdf

CEI start-ups in the three ecosystems

18 237 existing start-ups were founded over the last decade in China, EU, Japan, South Korea, UK and US. ([181]) The share of start-ups located in China, Japan and South Korea was less than 3% in the total sample, hence for the analysis only CEI companies in the three ecosystems from EU (44%), US (42%) and UK (12%) were considered ([182]).

EU had the highest number of start-ups in textiles and EII industrial ecosystems, followed by US and UK. There were slightly more US construction start-ups (1,841) than in the EU (1,712). In fact, the share of EU start-ups vis-à-vis all EU CEI companies arrives at ca. 30%. More EU start-ups were at the stage of early growth and late growth stages than in the US, whereas the US had some more at the seed stage (4,722 US companies vis-à-vis 4,524 EU companies). For details, see Figures 3.16 and 3.17.

Figure 3.16: Number of start-ups in the textile, construction and EII ecosystems

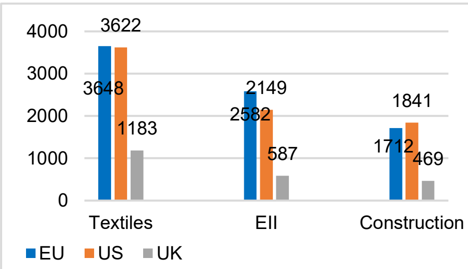
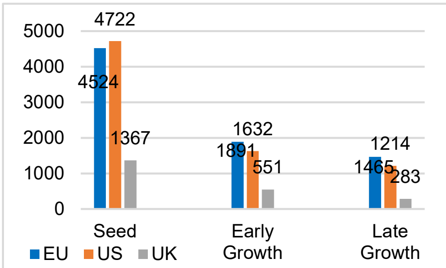


Figure 3.17: Number of start-ups at different growth stages



Note: There are three start-up stages: seed, early growth and late growth. The first one is the first phase, where the other two stages of growth are for more mature companies, which are venture-funded.
Source: Dealroom and Technote data by PPMI.

Figure 3.18 shows the geographical distribution of start-ups in the three industrial ecosystems, where EU companies are predominant compared to US and UK companies. At the same time, the number of start-ups in the three focused ecosystems was comparatively lower vis-à-vis other sectors, where ICT companies play a dominant role. Unlike large companies, the share of textile start-ups prevails over construction and EII start-ups. Furthermore, the total funding in 2020 of CEI start-ups in US was ca. 6 times higher than the funding for EU firms. UK start-ups had even less funding in 2020 compared to EU start-ups, see Figure 3.19.

([181]) The definition of a start-up is adopted from Dealroom, which has been used for access to start-up data.
([182]) PPMI performed the analysis for DG R&I.

Figure 3.18: Distribution CEI start-ups by ecosystem and by country, 2020

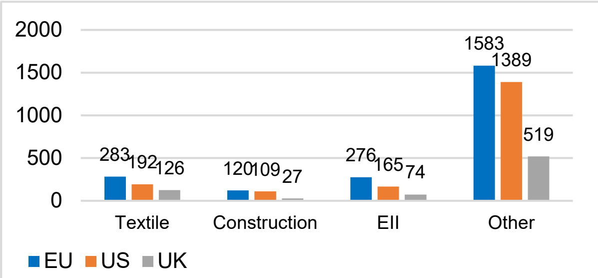
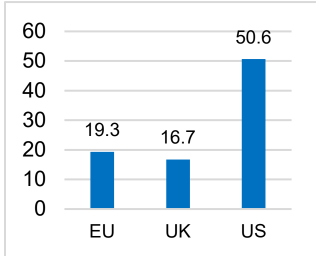


Figure 3.19: Total funding of CEI start-ups by country (EUR million), 2020



Source: Dealroom and Technote data by PPMI.

Company investments in specific circular technologies (CTs)

The 2020 data analysis, undertaken for this roadmap, found that overall, ca. 52 000 companies (2% of all) were identified as linked to CTs ([183]), of which 16 226 were EU companies (31% of CT companies).

4 671 EU CT patents were identified, which represent 11% of all CT patents. Share of collaborations, involving EU companies and median investments per company are available in the table below.

Table 3.7: EU companies engaged in CTs, patents, share in R&D collaborations and investment, 2020

Ecosystem	Companies	Patents	Share of collaborations, involving EU companies	Median annual R&D investment per company ([184])
Textile	3295	230	29%	EUR 10 million
Construction	8951	694	18%	EUR 16.8 million
EII	3980	3747	25%	EUR 21.1 million
Total:	16226	4671	n/a	n/a

Source: ORBIS, Technote and Dealroom by PPMI, 2020.

The information below for the three industrial ecosystems focuses on identifying in which technologies at higher TRL (see Chapter 2) EU companies appeared active (number and share of companies and patents, collaborations, R&D investments) and which of these technologies show a medium to high or a low-tech uptake overall. The

([183]) The following technologies were not captured, as no single patent or company could be identified for a statistical analysis, or the research did not produce satisfactory results: 1.9 Reducing waste by integrating and reusing it in the production; 2.1 Raw Material Sourcing: Urban Mining; 3.1.2 Inherent recyclability of materials; 3.1.3 Improved data collection technologies; 3.2.4 Digitalisation tools for CE focusing on monitoring; 3.1.21 Valorisation of solutes from wastewater treatments; 3.1.22 Valorisation of solids from wastewater treatments; 3.1.23 Data sharing platforms and data security; 3.1.24 Coordination & management of connected processes; 3.3.13 Mapping the water system: all pipes, valves, points of use, cross-connections and meters, monitoring & fixing any leaks; 3.3.16 Water and energy save in ceramic tile spray-drying process through recovering and reusing of water evaporated in spray drying step of the ceramic process, for the preparation of slurries; 3.3.21 Take back programme; 3.3.22 Digital monitoring for: - energy, water, materials use / optimisation of processes - pollution control.

([184]) This column indicates total investment per company, i.e. the amount includes R&D&I, infrastructure/tangible.

assumption is that areas with high uptake would be more mature and/or more attractive, so that private investments into industrial demonstrators could be encouraged to further mature, upscale and prepare deployment of these technologies. For technologies identified with low tech uptake, the proposed next step would be to gain a deeper understanding of the reasons for this and if they would deserve more attention and efforts.

Textile ecosystem

EU had 3 295 textile companies (40% of all, including start-ups), 230 patents (18% of all), 29% share of collaborations (involving EU companies), and a median R&D investment of EUR 10 million per company in 2020, see table above. As such, EU companies invested above the world and US averages. 21 CT-related technologies were observed in the textile ecosystem. Information about these specific technologies based on number of companies, patents, overall tech uptake, EU's position, including for investments and share of collaborations, involving EU companies, is available in the table below.

Looking at CTs that have higher TRLs (as identified in Chapter 2 and Annex 2), the EU had the highest investments per company in few circular technologies in this analysis. This included e.g. "using recycled materials in fabrication of fibres & yarns", "chemical recycling: textiles polymers into new polyester products" and "chemical recycling: cellulosic waste of cotton to viscose or lyocell". The share of collaborations, involving EU companies was high (between 38% and 43%). These technologies showed overall high/medium tech uptake ([185]), except for the "chemical recycling: textiles polymers into new polyester products", which had overall low-tech uptake.

In "design for sustainability", identified as circular technology with high potential, the overall tech uptake appeared medium/high. The EU share of companies stood at 40% of all companies, while the share of patents was 15 % (overall, 3 536 companies and 123 patents related to this technology were identified). The investment levels for this technology had medium values for EU companies.

Similarly, in plasma technologies and pigments - "recycling dye/pigments in waste water of dyeing processes" (overall, medium tech uptake) and "reduce chemicals with plasma technologies" (overall, low/medium tech uptake), EU companies had 31% and 33% share of total companies and 14% and 17% of overall patents. There was, however, a low share of collaborations, involving EU companies (16% and 6 %, respectively). The investment levels were lowest for the former technology and medium value for the latter.

In sorting technologies, e.g. "automated fibre sorting using near-infrared technologies", the EU appeared to have 5 companies active (50% of all), while there were no patents and no available information on collaborations and investments related to this technology, which is found as having low tech uptake.

As far as digital technologies are concerned, e.g. the "digital technologies: collaborative consumption business models" is identified as high tech uptake. The EU companies had 40% share (1 112 companies) and 17 % of the patents (161 patents), whereas the median R&D investment per company stood at medium level (EUR 22.6

([185]) See definition for "tech uptake" at the beginning of section 3.3.

million). Similarly, EU companies were well represented in the "digital authentication/passport for textile products/materials technology" – 40 % of companies, 19% of the patents, whereas the median investments were the highest – EUR 10 million per EU company.

"Material blend separation technologies for chemical polymers", identified as one of the needed technologies which is at medium TRL, had a medium/high overall tech uptake. EU companies had medium values of shares of companies, patents, collaborations and median investments in these technologies. Another similar technology, "tailored clothing selection via augmented/virtual reality technology", however, had low tech uptake and EU companies, patents and median investments had medium values.

There are, however, several other textile CTs, identified as low-tech uptake, where the shares of EU based companies were the lowest – e.g. "compressed carbon dioxide as a solvent in dyeing process"; "adding pigments to recycled textiles (electrochemically)"; "reduce water and chemicals with ozone technologies"; "fabric optimisation at the garment design stage; and "re-thinking the traditional apparel cut & sew approach". See table below for details.

Table 3.8: Technology uptake of selected relevant textile CETs and EU positioning

CIRCULAR TECHNOLOGIES AND BUSINESS MODELS	**TECHNOLOGY UPTAKE IN THE ECOSYSTEM (ALL REGIONS)**			**EU POSITIONING**			
	Total no. of patents*	**Total no. of companies***	**Overall level of tech uptake***	**EU share of companies***	**EU share of patents***	**EU-median investment per company, EUR mil****	**Share of collaborations involving EU companies***
Fabrication of fibres from secondary bio-based raw materials	203	2005	Medium / high	40%	17%	13,7	39%
Using recycled materials in fabrication of fibres & yarns	97	2511	Medium / high	43%	20%	11	38%
Design for sustainability (durability & disassembly)	123	3536	Medium / high	40%	15%	11,9	26%
Compressed carbon dioxide as a solvent in dyeing process	12	133	Low	27%	8%	25,1	32%
Adding pigments to recycled textile (electrochemically)	15	135	Low	27%	19%	77,6	37%
Recycling dye/ pigments in waste water of dyeing processes	14	632	Medium	31%	14%	14,3	16%
Reduce chemicals with plasma technologies	84	139	Low/ medium	33%	17%	30	6%
Reduce water & chemicals with	76	307	Medium	28%	19%	26	52%

CIRCULAR TECHNOLOGIES AND BUSINESS MODELS	TECHNOLOGY UPTAKE IN THE ECOSYSTEM (ALL REGIONS)				EU POSITIONING		
	Total no. of patents*	Total no. of companies*	Overall level of tech uptake*	EU share of companies*	EU share of patents*	EU-median investment per company, EUR mil**	Share of collaborations involving EU companies*
ozone technologies							
Fabric optimisation at the garment design stage	12	271	Low/ medium	29%	23%	13,7	26%
Re-thinking the traditional apparel cut & sew approach	10	150	Low	29%	30%	8,2	N/A
Sustainable packaging schemes in retails of textile products	3	2460	High	39%	0%	10	34%
Digital technologies: coll-aborative consumption business models	161	1112	High	43%	17%	22,6	29%
Tailored clothing selection via augmented/ virtual reality	30	143	Low	37%	13%	14,5	22%
Clothing plastic microfiber release reduction for households	12	384	Low/ medium	36%	23%	18,3	47%
Material blend separation technologies for chemical polymers	113	1127	Medium / high	35%	15%	18,1	34%
Automated fibre sorting using near-infrared tech	1	10	Low	50%	0%	N/A	N/A
Post-consumer recycling by adding cellulose-based fibres	23	226	Low/ medium	47%	33%	11,2	N/A
Regeneration of used textile materials into yarn	2	46	Low	61%	0%	26,1	N/A
Chemical recycling: textiles polymers into new polyester products	3	60	Low	46%	0%	14,7	N/A
Chemical recycling: cellulosic waste of cotton to viscose or lyocell	35	843	Medium	49%	23%	14,5	43%
Digital authentication/ passport for textile products/ materials	246	968	Medium / high	40%	19%	10	20%

Notes: * - data in these columns are coloured based on the distribution of values within each column. Maximum values in each column are coloured in green, while the lowest values are highlighted in red. ** - data in these columns are coloured based on the positioning of EU relative to the US and world values. Green colour indicates that the EU's value was the highest of the three. Red means that the EU's value was the lowest. Yellow means that the EU had the middle value.
Source: prepared by PPMI, using Technote, Orbis, Dealroom and PATSTAT data.

Construction ecosystem

In this analysis, the EU was represented by 8 951 construction companies (31% of all CT companies), 694 patents (11% of all), an 18% share of collaborations involving EU companies, and a median investment of EUR 16.8 million per company, see table 3.8 above. As such, EU companies invested more than US companies (EUR 14.6 million) but less than the world average (EUR 23.2 million), mainly due to the very high concentration of R&D investment in Asia by fewer but larger companies.

Among CTs at higher TRLs, "BIM-compatible plug-ins and applications/4D BIM" show high tech uptake. The EU had the highest investments (EUR 25.6 million per company) for this technology, the highest number of companies (36% of all), a medium value of share of collaborations involving EU companies (31%) and a lower share of patents (7% of total). For "Digital platforms and marketplaces" technologies, the EU had the lowest median investment (EUR 13.7 million per company) and the share of EU companies and patents was low too (13% and 8%, respectively). The share of collaborations, involving EU companies, however, was the highest – 33%. EU companies had the highest median investment (EUR 14.4 million) per company in medium level of tech uptake, like "Advanced dry recovery". The share of collaborations, involving EU companies, was the highest in this technology (36%), but at the same time the EU share of companies was low (10% of total), similar to the EU share of patents (7%).

The median investments of EU companies were lowest in some low-tech uptake technologies, like "Heating air classification systems" and in "Near infrared spectroscopy" but also in some digital technologies, like "Big data and analytics", "Artificial intelligence", and "Blockchain technology", which were found to be with high tech uptake. However, EU companies had the highest median investments in the "Augmented and virtual reality" technology, which was identified with high tech uptake. (see table below for more details).

Table 3.9: Technology uptake of selected relevant construction CETs and EU positioning

CIRCULAR TECHNOLOGIES AND BUSINESS MODELS	TECHNOLOGY UPTAKE IN THE ECOSYSTEM (ALL REGIONS)				EU POSITIONING		
	Total no of patents*	Total no of companies*	Overall level of tech uptake	EU share of companies*	EU share of patents*	EU median investment per company, EUR million*	Share of collaborations involving EU companies
BIM-compatible plug-ins and applications/4D BIM	375	7019	High	36%	7%	25,6	31%

CIRCULAR TECHNOLOGIES AND BUSINESS MODELS	TECHNOLOGY UPTAKE IN THE ECOSYSTEM (ALL REGIONS)				EU POSITIONING		
	Total no of patents*	Total no of companies*	Overall level of tech uptake	EU share of companies*	EU share of patents*	EU median investment per company, EUR million*	Share of collaborations involving EU companies
Modular Design & design for Disassembly of buildings	1383	10245	High	31%	14%	16,8	24%
Additive and robotic manufacturing	1333	6966	High	37%	18%	17,4	29%
Digital Platforms and market places	13	4827	High	13%	8%	13,7	33%
Digital Twins	1957	1454	High	29%	6%	16,9	28%
Advanced Dry Recovery	29	1195	Medium	10%	7%	14,4	36%
Heating Air Classification System	0	96	Low	2%	N/A	43,9	N/A
Attrition Cells Scrubbers	13	36	Low	33%	8%	N/A	0%
Gravity Column	24	37	Low	0%	4%	400	6%
Magnetic Density Separation	2	12	Low	0%	0%	N/A	N/A
Near-infrared spectroscopy	5	19	Low	0%	20%	9	N/A
Big data and analytics	739	3879	High	28%	6%	13,7	25%
Artificial intelligence	145	2565	High	34%	20%	12	38%
Blockchain technology	76	1492	High	38%	32%	10,1	6%
Augmented and virtual reality	219	1677	High	28%	9%	24,5	30%

Notes: * - data in these columns are coloured based on the distribution of values within each column. Maximum values in each column are coloured in green, whilethe lowest values are highlighted in red. ** - data in these columns are coloured based on the relative positioning of the EU relative to the US and World values. Green colour indicates that the EU's value was the highest of the three. Red means that the EU's value was the lowest. Yellow means that the Eu had the middle value.

Source: prepared by the team using Technote, Orbis, Dealroom and PATSTAT data.

EII ecosystem

The EU had 3 980 EII companies (27% of all), 3 737 patents (11% of all), a 25% share of collaborations involving EU companies, and a median R&D investment of EUR 21.1 million per company. As such, the investment was higher than for the US (EUR 13.8 million), but below the world average of EUR 24.5 million. In Japan, China and South Korea, investments were much larger (exceeded EUR 100 million per company) and concentrated in a smaller number of companies. In addition, China and Japan owned very significant shares of patents related to CTs, 40% and 25% of the world total, respectively.

In high tech uptake technology, like "improved separation technologies", EU companies had the highest median investment (EUR 16.4 million) and the level of collaborations stood at 23%, while the EU share of companies and patents was low – 21% and 5%, respectively.

Median EU company investment was the highest or median value in variety of EII CTs. For example, for technologies with highest circularity potential, like processes of recycling acids, alkaline, saline wastes, thermochemical recycling of plastic waste/pyrolysis and bio-based processes. It was also highest in other high or medium tech uptake technologies, like homogeneous catalysts, improved separation technologies, and reduction of product thickness.

Highest EU investments were also found in low-tech uptake technologies like electrocatalysis, stag utilisation strategies, scrapyard management using sensors & machine learning and pyrometallurgical processes, among other.

With some minor exceptions, like the digital printing in ceramic surfaces (56% of total), heterogeneous catalysts (37%) and pyrometallurgical processes (36%), patenting was overall low in EU EII specific circular technologies CTs in international comparison.

EU EII CTs had the lowest median investments in digital technologies, like digital process development/plant engineering, digital printing on ceramic surfaces and AI and machine learning for discovering new catalysts.

The overall share of collaborations, involving EU companies, had median values (around 25%), with the exception of innovative materials of the process industries (55% share) and regeneration of spent solvents (49%). More details are available in the table below.

Table 3.10: Technology uptake of selected relevant EII CETs and EU positioning

CIRCULAR TECHNOLOGIES AND BUSINESS MODELS	**OVERALL TECHNOLOGY UPTAKE (ALL REGIONS)**				**EU POSITIONING**		
	Total no. of patents*	**Total no. of companies***	**Overall level of tech uptake**	**EU share of companies***	**EU share of patents***	**EU median investment per company, EUR million****	**Share of collaborations involving EU companies***
Innovative materials of the process industries	84	122	Low/ medium	13%	5%	41,2	55%
Regeneration of spent solvents	18	56	Low	13%	11%	24	49%

CIRCULAR TECHNOLOGIES AND BUSINESS MODELS	OVERALL TECHNOLOGY UPTAKE (ALL REGIONS)				EU POSITIONING		
	Total no. of patents*	Total no. of companies*	Overall level of tech uptake	EU share of companies*	EU share of patents*	EU median investment per company, EUR million**	Share of collaborations involving EU companies*
Recycling acids, alkaline, saline wastes	547	768	Medium /high	14%	6%	21	24%
Thermochemical recycling for plastic waste	150	521	Medium	25%	12%	15	29%
Biotechnological recycling of plastic waste	54	4004	High	33%	7%	7,7	25%
Biomass-tolerant processes	154	155	Low/ medium	24%	8%	48	25%
Biomass pre-treatment processes	764	1226	Medium / high	40%	14%	20	38%
Use of CO2 and CO as a building block in polymers	105	185	Low/ medium	24%	19%	15,5	10%
Photocatalysis	913	535	Medium	27%	6%	25,5	37%
Electrocatalysis	129	103	Low	8%	4%	80,4	14%
Heterogeneous catalysts	726	379	Medium	27%	37%	22,8	30%
Homogeneous catalysts	238	224	Medium	24%	20%	32,6	27%
AI and machine learning for discovering new catalysts	11	117	Low	30%	10%	4,6	17%
Improved separation technologies	3293	3481	High	21%	5%	16,4	23%
Digital process develop-ment/ plant engineering	17	74	Low	13%	6%	20	N/A
Use of carbon-fibre-reinforced polymers in EAF	277	494	Medium	17%	21%	48,3	20%
Slag utilization strategies	46	60	Low	8%	4%	974,2	43%
Scrapyard management using sensors & machine learning	7	40	Low	25%	0%	150	N/A
Pyrometallurgical processes	97	159	Low	29%	39%	83,4	35%
Hydrometallurgical Residue Treatment	422	431	Medium	24%	19%	20	41%
Reduction in products thickness	779	739	Medium / high	18%	7%	68,6	19%
Re-use of waste into secondary materials	97	1284	Medium / high	36%	9%	20	17%
Reuse of water - Systemic solutions	21	257	Low/ Medium	31%	5%	131,9	20%

CIRCULAR TECHNOLOGIES AND BUSINESS MODELS	OVERALL TECHNOLOGY UPTAKE (ALL REGIONS)			EU POSITIONING			
	Total no. of patents*	Total no. of companies*	Overall level of tech uptake	EU share of companies*	EU share of patents*	EU median investment per company, EUR million**	Share of collaborations involving EU companies*
for urban waste water (reclaimed water) use into the process industry							
Store and later use the waste heat for the drying process	27	168	Low	25%	7%	735,5	7%
Digital printing on ceramic surfaces	9	119	Low	50%	56%	25,5	12%
Efficient system for collection, sorting and separation of waste (post-consumer ceramic, etc). Sensor based separation technologies	0	26	Low	20%	N/A	150	17%
Fully digitalised production plant to optimise resource consumption (water,energy, raw materials…) in a systemic way	>23000	3085	High	19%	N/A	30	24%

Notes: * - data in these columns are coloured based on the distribution of values within each column. Maximum values in each column are coloured in green, whilethe lowest values are highlighted in red. ** - data in these columns are coloured based on the relative positioning of the EU relative to the US and World values. Green colour indicates that the EU's value was the highest of the three. Red means that the EU's value was the lowest. Yellow means that the Eu had the middle value.
Source: Prepared by PPMI using Technote, Orbis, Dealroom and PATSTAT data.

Start-ups in CTs

Data for CT-related start-ups in the EU, US and UK were collected from the Dealroom and Technote databases. ([186]) In CTs related to the textile ecosystem, the EU had 42% of start-ups but only 23% of the capital raised. In construction, the corresponding figures were 41% and 20%, and for the EII ecosystem they were 41% and 19%. While the US had a similar number of start-ups as the EU in a majority of technologies, it raised significantly more capital and had more highly funded start-ups (i.e. start-ups raising at least EUR 100 million).

As far as the number of start-ups is concerned, the EU has more start-ups than the US in 38 of 82 CT categories, while the US leads in numbers in 42 categories, the UK in two. ([187]) In terms of total investments in start-ups, the US leads in 61 categories, even by far in categories where the EU has more start-ups, such as in 'Using recycled materials in fabrication of fibres & yarns', 'Design for sustainability (durability and disassembly)' 'Digital technologies: collaborative consumption business models'

([186]) Chinese, Korean and Japanese start-ups represented less than 2% of the dataset and for that reason were not analysed.
([187]) The list of technologies is available in Annex 2 and discussed in Chapter 2 of the roadmap.

(textiles), ‘BIM-compatible plug-ins and applications/4D BIM’, ‘Additive and robotic manufacturing’ (construction), or ‘Biomass pre-treatment processes’ (EII-chemicals), and in key digital technologies such as Digital Twins, AI and Blockchain (see Table 3.11 below).

The US is clearly ahead in numbers of start-ups as well as investments in digital technologies such as Digital Platforms and market places, Big data and analytics, ‘AI and machine learning for discovering new catalysts’ and ‘fully digitalised production plant to optimise resource consumption (water, energy, raw materials) in a systemic way’. The same applies however also to ‘material blend separation technologies for chemical polymers’, ‘recycling acids, alkaline, saline wastes’, ‘recycling plastic waste through leaching/depolymerisation’ (low numbers), ‘biotechnological recycling of plastic waste’, ‘advanced separation technologies for plastic waste’, ‘improved separation technologies’ (EU and US not far apart in number of start-ups).

There are several areas, where the EU has fewer start-ups but overall higher investments, notably in ‘recycling dye/pigments in wastewater of dyeing processes’ (low numbers), ‘digital authentication/passport for textile products/materials’, ‘augmented and virtual reality’, ‘electrochemical recycling of plastic waste’. In terms of both number of start-ups and investments, the EU is ahead in ‘sustainable packaging schemes in retails of textile products’.

Table 3.11: Number of start-ups and total investments in selected CETs in EU, US and UK, 2020

TECHNOLOGY	No. of EU start-ups	No. of US start-ups	No. of UK start-ups	Total EU Investment, mil. EUR	Total US investment, mil. EUR	Total UK investment, mil. EUR
Using recycled materials in fabrication of fibres & yarns	312	239	134	189,6	880,1	110,6
Design for sustainability (durability and disassembly)	413	392	177	259,7	4849,5	164,7
Recycling dye/pigments in waste water of dyeing processes	81	97	43	61,8	41,5	57,2
Reduce chemicals with plasma technologies	12	10	3	0,2	45,8	0
Sustainable packaging schemes in retails of textile products	328	315	192	1366,8	748,6	250,7
Digital technologies: collaborative consumption business models	164	109	44	114,8	336,4	65,2
Material blend separation technologies for chemical polymers	127	145	63	130,3	4258,5	86,6
Digital authentication/passport for textile products/materials	117	130	44	2482,5	366,9	134,6
BIM-compatible plug-ins and applications/4D BIM	399	202	131	103,1	439,2	123,5
Modular Design & design for Disassembly of buildings	1019	990	280	1764,5	4493,3	377,2
Additive and robotic manufacturing	917	758	229	1567,8	7338,9	384,5
Digital Platforms and marketplaces	515	1323	306	1152,1	7001,8	624,7
Digital Twins	228	151	52	192	1127,6	132,5

TECHNOLOGY	No. of EU start-ups	No. of US start-ups	No. of UK start-ups	Total EU Investment, mil. EUR	Total US investment, mil. EUR	Total UK investment, mil. EUR
Big data and analytics	725	907	314	2197	11917,8	1895,6
Artificial intelligence	587	514	177	959,7	4197,1	435,9
Blockchain technology	346	298	115	323,3	1748	469
Augmented and virtual reality	216	224	80	2486	461,9	124,1
Recycling acids, alkaline, saline wastes	61	88	12	77,1	786,9	16
Recycling plastic waste through leaching/depolymerisation	39	65	18	112,3	299,2	22,7
Biotechnological recycling of plastic waste	443	583	340	158,9	1562,1	423
Electrochemical recycling of plastic waste	159	220	111	1265,3	437,9	83,1
Advanced separation technologies for plastic waste	136	141	44	146,7	457,6	181,3
Biomass pre-treatment processes	185	114	27	226,3	869,1	35,4
AI and machine learning for discovering new catalysts	23	34	7	130,5	136,5	4,9
Improved separation technologies	338	345	58	182,8	654,1	75
Fully digitalised production plant to optimise resource consumption (water, energy, raw materials…) in a systemic way	374	576	57	460,2	13372,8	3,1

Notes: The selection on technologies has been identified based on presence of at least 20 companies and more than EUR 40 million of total investment. * - data in these columns are coloured based on the distribution of values within each column. Maximum values in each column are coloured in green, whilethe lowest values are highlighted in red. ** - data in these columns are coloured based on the relative positioning of the EU relative to the US and World values. Green colour indicates that the EU's value was the highest of the three. Red means that the EU's value was the lowest. Yellow means that the Eu had the middle value.
Source: Dealroom and Technote data by PPMI.

Box 3.3 | Technologies developed by circular industrial tech start-ups

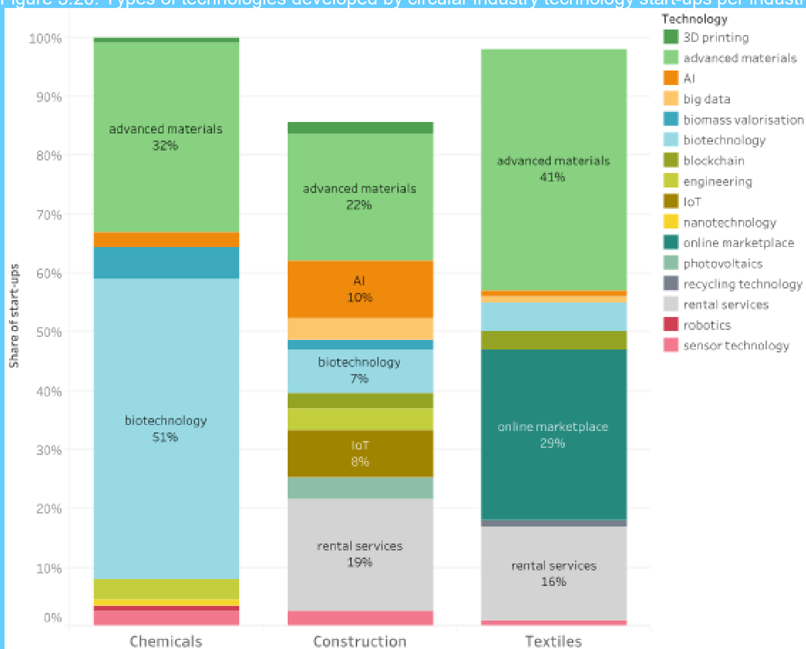
An analysis provided by Technopolis Group, based on consulting two databases (Eutopia and Cruncbase), highlights the types of technologies that circular industry technology start-ups develop the most often per industry. The analysis reveals that online platforms related digital technologies (45%) and advanced materials (41%) are the most common types within the **Textile** sector. Although in a lower presence, biotechnology is at the core of the business model of 5% of the circular start-ups.

Regarding the **Chemicals** sector, 51% of the start-ups develop biotechnology-based solutions and techniques that facilitate circularity. The second most common technology within start-ups focusing on the chemical industry is advanced materials (32%).

Finally, the results show more diversity of technologies among the start-ups operating within the **Construction** sector. Advanced materials are the most common technology developed by 22% of the start-ups. Some other common technologies are Artificial Intelligence (10%), Internet of Things (9%) and Biotechnology (7%).

For the broader analysis and the metholodogy used for collecting this data, please consult Annex 3 – SME Survey, of this roadmap.

Figure 3.20: Types of technologies developed by circular industry technology start-ups per industry



Source: Technopolis Group, based on Eutopia and Crunchbase

3.4. EU public investments and programmes

With the aim of helping EU industries to transition to a circular economy, the Commission supports circular technologies through grants and financial instruments (investment through loans and equity via the European Investment Bank (EIB), the European Investment Fund (EIF) or national promotional banks).

A major tool at EU level to boost R&I is the 2021-2027 Framework Programme for research and innovation, Horizon Europe. With a budget of EUR 95.5 billion, it accounts for almost 10% of public funding for R&I in Europe and is the largest

European research and innovation programme so far. Within Horizon Europe, six partnerships with industry (Processes4Planet, Clean Steel, Made in Europe, Circular bio-based Europe, Built4people and AI, Data & Robotics) play a major role in the funding of R&I in green industrial technologies. The European Innovation Council funds breakthrough green technologies, and the European Institute of Innovation and Technology brings together green innovators and organisations. Other EU programmes, initiatives and funds also support green technologies, such as the EU LIFE programme and the Innovation Fund.

InvestEU, the EU's investment programme for 2021-2027, is mobilising private investment in R&I and green technologies. The EU’s cohesion policy is also investing more than EUR 56 billion in R&I between 2021 and 2027, with a particular emphasis on the less developed regions. ([188])

EU centrally managed funds

Horizon 2020/Horizon Europe

The circular economy gained importance during the lifetime of Horizon 2020 from 2014 to 2020. The work programmes 2016-17 and 2018-20 introduced the concept of “focus areas” where the main objective shifted from researching technologies to bringing new technology-based products to the market. Pulling together relevant topics from different parts of the programme, overall almost EUR 700 million were allocated to the focus area *Industry 2020 in the circular economy* in 2016-17, and EUR 1044 million were allocated in 2018-2020 to the focus area *Circular Economy* ([189]).

In Horizon 2020 (2014-2020), industrial R&I on circularity was funded mainly under the following headings:

- Industrial Leadership: Innovation in SMEs; LEITs for manufacturing; LEIT for materials;
- Societal challenge 2: Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the bioeconomy; and societal challenge 5: Climate action, environment, resource efficiency and raw materials.

According to the Tracking of Research Results search engine ([190]) based on information from the CORDIS ([191]) database of projects, EU-funded projects under Industrial Leadership and societal challenges 2 and 5 include:

- 117 projects with a total EU contribution of EUR 780 million which correspond to “circular” and “industry”.
- 5 projects with a total EU contribution of EUR 37 million which correspond to “circular” and “textile industry”.
- 4 projects with a total EU contribution of EUR 35 million which correspond to “circular” and “construction” and “building sector”.

([188]) SRIP report 2022
([189]) Opportunities and challenges in targeted funding of Research and Innovation - Publications Office of the EU (europa.eu)
([190]) Tracking of Research Results is an EC search engine in the making, which retrieves data on EU-funded projects
([191]) The Community Research and Development Information Service (CORDIS) is the European Commission's primary source of results from the projects funded by the EU's framework programmes for research and innovation, from FP1 to Horizon Europe.

- 31 projects with a total EU contribution of EUR 242 million which correspond to “circular” and “energy-intensive industries”.

In Horizon Europe (2021-2027), circularity in industry is funded mainly under the following clusters within Pillar II: Global challenges & European industrial competitiveness: Cluster 4 (Digital, Industry and Space), Cluster 5 (Climate, Energy and Mobility) and Cluster 6 (Food, Bioeconomy, Natural Resources, Agriculture and Environment).

Horizon Europe is starting to fund projects that are relevant to this roadmap such as CISUTAC ([192]), which will support the transition to a circular and sustainable textile sector.

Box 3.4 | Analysis of circular projects under EU research framework programmes

Methodology

The European Commission services have used a text mining analysis to determine a shortlist of projects under Horizon 2020, Horizon Europe and the Research Fund for Coal and Steel (RFCS) that are relevant for circularity.

The method consisted in using a list of keywords corresponding to the technologies flagged as relevant to the three ecosystems. The text mining search has been executed into the database of the above-mentioned funding programmes, more specifically into the title and the abstract of the projects. A relevance score was calculated based on the matching of these keywords with the text and the projects above a certain threshold were shortlisted.

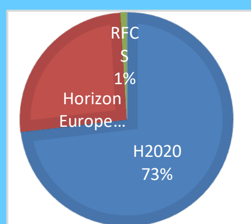
The result is a list of 830 such relevant projects in total: 627 under H2020, 180 under Horizon Europe, 23 under RFCS.

This list is neither accurate nor exhaustive but based on this methodology it is a good sample of EU-funded projects involving circular technologies and can serve as a proxy for analysing the order of magnitude and diversity of such projects.

Analysis of projects

The projects selected under that methodology amount to EUR 3.68 billion total costs (of which 3.09 billion requested EC contribution):

- Total costs EUR 2.74 billion (respectively 2.26) under Horizon 2020
- Total EUR 893 million (respectively 802) under Horizon Europe
- Total EUR 45 million (respectively 28) under the RFCS



438 projects will end after 2023, the rest has ended in 2022 or before.

Sector	Number of projects	Total costs (in million EUR)
Chemicals	125	289
Construction	89	501
Ceramics	48	249

([192]) https://circulareconomy.europa.eu/platform/fr/node/6932

Steel	31	150
Cement	8	22
Textile	7	8
Multi-sector	524	2 463

The top 10 projects ranked by total cost are as follows:

Project acronym	Total costs	Requested EC contribution	Sector (keyword match)	Technology (keyword match)
M-ERA.NET3	45 454 545 €	15 000 000 €	Construction	Advanced materials
PYROCO2	43 887 818 €	39 999 561 €	Chemicals	CCUS
AI4CSM	41 748 115 €	11 885 321 €	not attributed	Digitalisation
ACT	38 507 311 €	11 889 929 €	not attributed	CCUS
LEILAC2	34 675 725 €	15 994 730 €	not attributed	CCUS
IMOCO4.E	30 951 318 €	9 072 997 €	Construction	Digitalisation
RecHycle	28 419 720 €	6 226 743 €	Steel	not attributed
Plastics2Olefins	28 208 659 €	18 084 895 €	not attributed	Recycling
PROBONO	25 182 074 €	20 158 489 €	Construction	Energy performance
INITIATE	23 148 256 €	21 296 571 €	not attributed	Industrial symbiosis

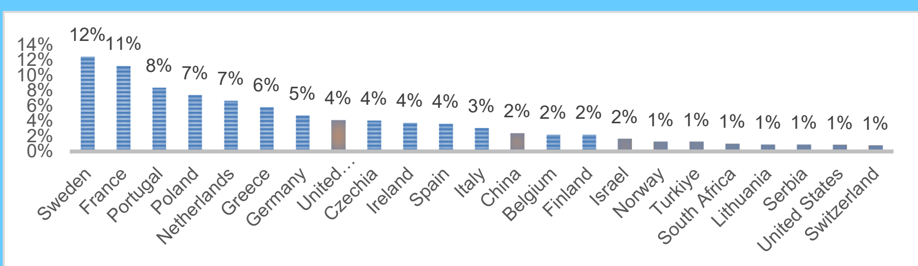
Most of these top funded projects are cross-sectoral and there seems to be an interest for CCUS among all circular technologies.

When it comes to the origin of the funding under Horizon, the list includes 25 projects funded under SPIRE, 1 under Clean steel, 31 under the EIC.

Analysis of participants

There were 4 508 distinct participants under these projects. Each project counts from 1 to 58 participants.

Based on the data available, see below the ranking for top countries represented. The figures refer to the proportion of participants from these countries, over all projects. The non-EU countries are in grey.



A number of participants are involved in many projects. See below the list of top participants:

Participant name	Country	Number of projects
FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	DE	100
COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	FR	51
FUNDACION TECNALIA RESEARCH & INNOVATION	ES	49
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	FR	49
TECHNISCHE UNIVERSITEIT DELFT	NL	41
POLITECNICO DI MILANO	IT	40
SINTEF AS	NO	39
NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO	NL	39
Teknologian tutkimuskeskus VTT Oy	FI	38
AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS	ES	38

We can see that the top participants are all research organisations or universities.

Based on the available data, the proportion of participants that are research organisations/academic sector, is 42% of all participants. The share of SMEs among all participants is 33%; and 2% of participants belong to both categories.

Horizon partnerships

Horizon Europe supports a number of R&I partnerships with industry, which develop and scale-up circular technologies in some key areas and industries.

Processes4Planet (P4P)

Processes4Planet is a Horizon Europe partnership with an overall budget of EUR 2.6 billion, EUR 1.3 billion from Horizon Europe and EUR 1.3 billion from private partners. The private sector partners are represented by A.SPIRE, with brings together more than 150 members. P4P is the successor to the Horizon 2020 SPIRE Partnership, which ran between 2014 and 2020.

P4P's ambition is to make European energy-intensive process industries circular and climate-neutral by 2050 and improve their global competitiveness. The partnership works on emerging technologies and on the scaling up of already developed technologies.

The partnership has funded and is funding circular technologies in the EIIs (such as residue valorisation, heat recovery, recycling of plastic waste or AI). Here are some examples of key projects under the former partnership:

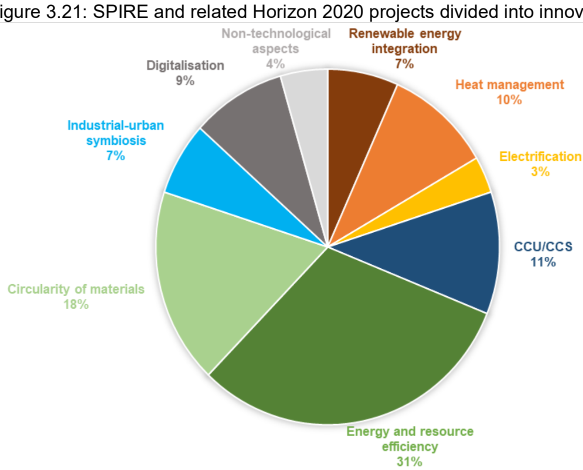
Horizon 2020 SPIRE partnership (2014-2020) and circular technologies ([193]):

- RESLAG (2015-2019) turned waste from the steel industry into valuable low-cost feedstock for energy-intensive industry (EU grant: EUR 8 million).
- The Indus3Es project (2015-2020) developed an innovative absorption heat transformer to efficiently recover and revalorise around 50% of low-temperature waste heat, increase the quality of the waste source at the required temperature and reuse it again in industrial processes (EU grant: EUR 3.8 million).
- iCAREPLAST (2018-2022) developed integrated catalytic recycling of plastic residues into added-value chemicals (EU grant: EUR 6.5 million).
- FUDIPO (2016-2021) worked on integrating artificial intelligence into several critical process industries on a wide scale to achieve radical improvements in energy and resource efficiency (EU grant: EUR 5.7 million).

Figure 3.21 on SPIRE and related Horizon 2020 projects show that:

- 18% of projects covered circularity of materials
- 7% covered industrial symbiosis
- 31% covered energy and resource efficiency

Figure 3.21: SPIRE and related Horizon 2020 projects divided into innovation categories



Source: Data from SPIRE and related Horizon 2020 projects collected by the European Health and Digital Executive Agency (HaDEA), 2022.

([193]) https://www.aspire2050.eu/projects/our-spire-projects

Processes4Planet (2021-2027) and circular technologies:

Processes4Planet has an indicative budget of EUR 204 million[194] for circular technologies projects, including Hubs for Circularity (H4C), under the 2021-22 work programme for Cluster 4 (Digital, industry and space)[195].

Hubs for Circularity (H4C) are first-of-a-kind, flagship demonstrator plants of (near) commercial size that put industrial symbiosis and/or urban industrial symbiosis into practice. The aim is to collectively achieve and demonstrate at scale, a leap towards circularity and carbon neutrality in the use of resources (feedstock, energy and water) in a profitable way. H4C are key instruments with a regional dimension that aim to accelerate the industrial transition by exploiting synergies between EU programmes and other funding/loan sources. Industry has set out the development process for 25 hubs by 2027. Under the 2021-22 work programme, the focus has been on launching many projects on electrification, hydrogen, conversion of CO2, waste reduction and new circular value chains.

Calls for proposal under the 2023-24 work programme ([196]) will propose EUR 223 million ([197]) in funding for Processes4Planet's circularity-oriented projects.

Clean Steel partnership

Building on the work already carried out under Horizon 2020, in 2021 the Commission launched the new Clean Steel partnership to specifically support the transformation of the steel industry into a carbon-neutral and circular sector. The EU is contributing EUR 700 million to the Clean Steel partnership through Horizon Europe and the Research Fund for Coal and Steel.

([194]) HORIZON-CL4-2021-TWIN-TRANSITION-01-14: Deploying industrial-urban symbiosis solutions for the utilisation of energy, water, industrial waste and by-products at regional scale (Processes4Planet Partnership): indicative budget: EUR 28 million; HORIZON-CL4-2021-TWIN-TRANSITION-01-16: Hubs for Circularity European Community of Practice (ECoP) platform (Processes4Planet Partnership) (CSA): EUR 2 million; HORIZON-CL4-2021-TWIN-TRANSITION-01-17: Plastic waste as a circular carbon feedstock for industry (Processes4Planet Partnership) (IA): 39 million; HORIZON-CL4-2022-TWIN-TRANSITION-01-10: Circular flows for solid waste in urban environment (Processes4Planet Partnership) (IA): EUR 42.5 million; HORIZON-CL4-2022-TWIN-TRANSITION-01-11: Valorisation of CO/CO2 streams into added-value products of market interest (Processes4Planet Partnership) (IA): EUR 42.5 million; HORIZON-CL4-2021-RESILIENCE-01-01: Ensuring circularity of composite materials (Processes4Planet Partnership) (RIA): indicative budget: EUR 24.7 million; HORIZON-CL4-2022-RESILIENCE-01-01: Circular and low emission value chains through digitalisation (Processes4Planet Partnership) (RIA): indicative budget: EUR 25.3 million

([195]) https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-7-digital-industry-and-space_horizon-2021-2022_en.pdf

([196]) Available at Horizon Europe work programmes (europa.eu)

([197]) HORIZON-CL4-2023-TWIN-TRANSITION-01-36: Modelling industry transition to climate neutrality, sustainability and circularity (Processes4Planet partnership) (RIA): indicative budget: EUR13 million; HORIZON-CL4-2023-TWIN-TRANSITION-01-37: Hubs for circularity for near zero emissions regions applying industrial symbiosis and cooperative approach to heavy industrialized clusters and surrounding ecosystems (Processes4Planet partnership) (IA): indicative budget: EUR40 million; HORIZON-CL4-2023-TWIN-TRANSITION-01-40: Sustainable and efficient industrial water consumption: through energy and solute recovery (Processes4Planet partnership) (RIA): indicative budget: EUR30 million; HORIZON-CL4-2023-TWIN-TRANSITION-01-42: Circular economy in process industries: Upcycling large volumes of secondary resources (Processes4Planet partnership) (RIA): indicative budget: EUR30 million; HORIZON-CL4-2024-TWIN-TRANSITION-01-35: Turning CO2 emissions from the process industry to feedstock (Processes4Planet partnership) (IA): indicative budget: EUR40 million; HORIZON-CL4-2024-TWIN-TRANSITION-01-38: Hubs for circularity for industrialised urban peripheral areas (Processes4Planet partnership) (IA): indicative budget EUR40 million; HORIZON-CL4-2024-TWIN-TRANSITION-01-41: Breakthroughs to improve process industry resource efficiency (Processes4Planet partnership) (RIA): indicative budget: EUR30 million.

The indicative budget of the Clean Steel partnership for circular technologies in the 2021-22 Work Programme 2021-22 (Cluster 4) is EUR 28 million ([198]).

Calls for proposal under the 2023-24 work programme will propose EUR 12 million ([199]) in funding for Clean Steel's circularity-oriented projects.

Made in Europe

Made in Europe is a Horizon Europe public-private partnership running from 2021 to 2027 with a budget of EUR 1.8 billion in total.

The European Factories of the Future Research Association (EFFRA) represents the private side in the partnership. Made in Europe is the successor of the Factories of the Future Partnership which ran under the Horizon 2020 programme.

The partnership funds circular technologies in the manufacturing industry, which includes the textile and energy-intensive industry sectors.

Factories of the Future Partnership and circular technologies (2014-2020)

Relevant projects funded by the partnership included those on circular technologies to manage energy-efficient manufacturing systems and on manufacturing platforms, such as:

- ECOFACT (2020-2024) aims to enable manufacturing industries to optimise the energy performance of their production systems in line with their relevant production constraints (time and resources). At the same time, the project introduces a novel green marketing concept of the energy and environmental signature of manufactured products from a lifecycle perspective (EU grant: EUR 9.9 million).
- DigiPrime (2020-2023) is developing a new concept, a circular economy digital platform to tackle the uneven spread of information asymmetry among stakeholders in value chains. The aim is to develop new circular business models across different sectors, based on the data-enhanced recovery and reuse of functions and materials from high value-added post-use products (EU grant: EUR 16 million).
- KYKLOS 4.0 (2020-2023) aims to show how cyber-physical systems, product lifecycle management, lifecycle assessment, augmented reality, and artificial intelligence technologies and methods are able to transform circular manufacturing (EU grant: EUR 16 million).

([198]) HORIZON-CL4-2021-TWIN-TRANSITION-01-19: Improvement of the yield of the iron and steel making (Clean Steel Partnership) (IA): indicative budget: EUR 14 million; HORIZON-CL4-2022-TWIN-TRANSITION-01-13: Raw material preparation for clean steel production (Clean Steel Partnership) (IA): indicative budget: EUR 14 million.

([199]) HORIZON-CL4-2023-TWIN-TRANSITION-01-45: Circular economy solutions for the valorisation of low-quality scrap streams, materials recirculation with high recycling rate, and residue valorisation for long term goal towards zero waste (Clean Steel Partnership) (RIA).

Made in Europe and circular technologies (2021-2027)

Under the 2021-22 work programme (Cluster 4), Made in Europe has an indicative budget of up to EUR 87 million ([200]) for circular technologies projects.

The calls for proposal of the 2023-24 work programme will have an indicative budget of EUR 147 million ([201]) for Made in Europe's circularity-oriented projects.

European Partnership for a Circular Bio-based Europe

The Circular Bio-based Europe Joint Undertaking (CBE JU) is a EUR 2 billion partnership (joint-undertaking) between the EU and the Bio-based Industries Consortium (BIC), established under Council regulation (EU) 2021/2085 of 19 November 2021. CBE JU operating under the rules of Horizon Europe, for the 2021-2031 period. The partnership is building on the success of its predecessor, the Bio-based Industries Joint Undertaking (BBI JU) and funds projects to develop competitive circular bio-based industries. The objective of the initiative is to make a major contribution to reaching the EU's climate targets by 2030, pave the way for climate neutrality by 2050 and increase the sustainability and circularity of production and consumption systems in line with the European Green Deal.

It aims to develop and expand the sustainable sourcing and conversion of biomass into bio-based products. It will do this by focusing on multiscale biorefinery processing and applying circular economy approaches such as using biological waste from agriculture, industry and cities. It also aims to deploy bio-based innovation on regional scales to help revival of rural and economically marginal areas.

The partnership funds circular technologies in the textile and energy-intensive sectors (chemicals) using bio-based materials as substitutes and through industrial symbiosis.

Since 2014, the CBE JU and its predecessor (BBI JU) have funded more than 140 projects, including projects on circular technologies such as: ([202])

Textiles (technologies such as making fibres from secondary bio-based raw materials):

([200]) HORIZON-CL4-2021-TWIN-TRANSITION-01-02: Zero-defect manufacturing towards zero-waste (Made in Europe Partnership) (IA): indicative budget: EUR 27 million; HORIZON-CL4-2021-TWIN-TRANSITION-01-05: Manufacturing technologies for bio-based materials (Made in Europe Partnership) (RIA): indicative budget: EUR 20 million; HORIZON-CL4-2021-TWIN-TRANSITION-01-07: Artificial Intelligence for sustainable, agile manufacturing (AI, Data and Robotics - Made in Europe Partnerships) (IA): indicative budget: EUR 18 million; HORIZON-CL4-2022-TWIN-TRANSITION-01-07: Digital tools to support the engineering of a Circular Economy (Made in Europe Partnership) (RIA): indicative budget: EUR 22 million.

([201]) HORIZON-CL4-2023-TWIN-TRANSITION-01-02: High-precision OR complex product manufacturing – potentially including the use of photonics (Made in Europe and Photonics Partnerships) (IA): indicative budget: EUR48 million; HORIZON-CL4-2023-TWIN-TRANSITION-01-04: Factory-level and value chain approaches for remanufacturing (Made in Europe Partnership) (IA): indicative budget: EUR 38 million; HORIZON-CL4-2024-TWIN-TRANSITION-01-05: Technologies/solutions to support circularity for manufacturing (Made in Europe Partnership) (RIA): indicative budget: EUR 36 million; HORIZON-CL4-2024-TWIN-TRANSITION-01-01: Bio-intelligent manufacturing industries (Made in Europe Partnership) (RIA): indicative budget: EUR 25 million

([202]) https://www.bbi.europa.eu/projects ([202]) https://www.bbi.europa.eu/projects

- the GLAUKOS project (2020-2024) is developing bio-based textile fibres and textile coatings – with a particular focus on fishing gear and clothing (EU grant: EUR 4 million)

Chemicals (technologies such as use of bio-based raw materials and biotechnological recycling of plastic waste):

- AFTERBIOCHEM (2020-2024), on anaerobic fermentation and esterification of biomass to produce fine chemicals (EU grant: EUR 20 million)

In June 2022 the CBE JU published its first call for project proposals under the Horizon Europe programme. A total of EUR 120 million was dedicated to improving competitive circular bio-based industries in Europe across 12 topics ([203]), of which EUR 74 million is dedicated to calls relevant to this roadmap ([204]). The second CBE JU call (2023, EUR 215.5 million) is under preparation, and is expected to be published by Q4 2022 and open in Q1 2023.

Built4People: People-centric sustainable built environment

The vision of the new Built4People partnership is to develop high-quality, low-carbon, energy and resource-efficient built environments that drive the transition towards sustainability. The partnership brings together participants across the entire value chain and will develop sector-specific innovation clusters across the EU.

The partnership will receive over EUR 8 billion from Horizon Europe. The total commitments, including those from private partners and from Member States, amount to around EUR 22 billion.

The partnership funds circular technologies in the construction sector.

The indicative budget of Built4People for circular technologies projects in the 2021-2022 work programme (Cluster 5: Climate, Energy and Mobility) ([205]) is EUR 56 million ([206]).

([203]) https://www.cbe.europa.eu/news/eu120-million-available-advancing-europes-circular-bioeconomy

([204]) HORIZON-JU-CBE-2022-IA-03 Cost-effective production routes towards bio-based alternatives to fossil-based chemical building blocks – EUR 12 million; HORIZON-JU-CBE-2022-IA-04 Co-processing of mixed bio-based waste streams – EUR 12 million; HORIZON-JU-CBE-2022-IAFlag-01 Maximum valorisation of sustainably sourced bio-based feedstock in multi-product, zero-waste, zero-pollution biorefinery – EUR 14 million; HORIZON-JU-CBE-2022-R-01 High performance bio-based polymers for market applications with stringent requirements – EUR 9 million; HORIZON-JU-CBE-2022-R-02 Bio-based coatings, barriers, binders, and adhesives – EUR 9 million; HORIZON-JU-CBE-2022-R-03 Circular-by-design bio-based materials to improve the circularity of complex structures – EUR 9 million; HORIZON-JU-CBE-2022-R-05 Sustainable fibres biorefineries feedstock – EUR 9 million

([205]) https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-8-climate-energy-and-mobility_horizon-2021-2022_en.pdf

([206]) HORIZON-CL5-2021-D4-02-02: Cost-effective, sustainable multi-functional and/or prefabricated holistic renovation packages, integrating RES and including re -used and recycled materials (Built4People): indicative budget: EUR 22 million; HORIZON-CL5-2021-D4-02-03: Strengthening European coordination and exchange for innovation uptake towards sustainability, quality, circularity and social inclusion in the built environment as a contribution to the new European Bauhaus (Built4People): indicative budget: EUR 1 million; HORIZON-CL5-2022-D4-02-01: Designs, materials and solutions to improve resilience, preparedness & responsiveness of the built environment for climate adaptation (Built4People): indicative budget: EUR 15 million; HORIZON-CL5-

The calls for proposal under the 2023-24 work programme will propose indicative funding of EUR 54 million ([207]) for Built4People's circularity-oriented projects.

European Partnership on Artificial Intelligence, Data and Robotics

With the aim of delivering the greatest benefit for Europe from AI, data and robotics, this partnership will drive innovation, acceptance and uptake of these technologies. The partnership will boost new markets and applications and attract investment to create technical, economic and societal value for businesses and people, while protecting the environment.

The Commission plans to invest EUR 1.3 billion in this partnership, an amount to be matched by industry, for a total of EUR 2.6 billion in funding by 2030.

The partnership funds digital circular technologies across sectors.

The indicative budget for the partnership's projects on circular technologies in the 2021-22 work programme (Cluster 4) is up to EUR 45 million ([208]).

Calls for proposal under the 2023-24 work programme will have an indicative budget of EUR 60 million ([209]) to fund circularity-oriented projects in the fields of AI, data and robotics.

European Innovation Council (EIC)

The EIC has been set up under Horizon Europe with a budget of EUR 10.1 billion. It supports game-changing innovations throughout the lifecycle from early-stage research to proof of concept, technology transfer, and the financing and scale-up of start-ups and SMEs.

A unique feature of the EIC is that it provides funding for individual companies (mainly start-ups and SMEs) through both grants and investments. The investments currently take the form of direct equity or quasi-equity investments and are managed by the EIC Fund.

2022-D4-02-05: More sustainable buildings with reduced embodied energy / carbon, high life -cycle performance and reduced life-cycle costs (Built4People): indicative budget: EUR 18 million.

([207]) HORIZON-CL5-2023-D4-02-01: Innovative uses of lifecycle data for the management of buildings and buildings portfolios (Built4People Partnership): indicative budget: EUR 10 million; HORIZON-CL5-2023-D4-02-03: Demonstrate built-environment decarbonisation pathways through bottom-up technological, social and policy innovation for adaptive integrated sustainable renovation solutions (Built4People Partnership): indicative budget: EUR 12 million; HORIZON-CL5-2024-D4-02-01: Industrialisation of sustainable and circular deep renovation workflows (Built4People Partnership): indicative budget: EUR 16 million; HORIZON-CL5-2024-D4-02-03: BIM-based processes and digital twins for facilitating and optimising circular energy renovation (Built4People Partnership): indicative budget: EUR 8 million; HORIZON-CL5-2024-D4-02-04: Design for adaptability, re-use and deconstruction of buildings, in line with the principles of circular economy (Built4People Partnership): indicative budget: EUR 8 million.

([208]) HORIZON-CL4-2021-DIGITAL-EMERGING-01-09: AI, Data and Robotics for the Green Deal (AI, Data and Robotics Partnership) (IA): indicative budget: EUR 27 million; HORIZON-CL4-2021-TWIN-TRANSITION-01-07: Artificial Intelligence for sustainable, agile manufacturing (AI, Data and Robotics - Made in Europe Partnerships): indicative budget: EUR 18 million.

([209]) HORIZON-CL4-2024-DIGITAL-EMERGING-01-04: Industrial leadership in AI, Data and Robotics boosting competitiveness and the green transition (AI Data and Robotics Partnership): indicative budget: EUR 60 million.

The EIC pilot phase was launched in 2018, incorporating existing instruments under the Horizon 2020 programme, in particular the SME instrument and the Future and Emerging Technologies programme. ([210])

The EIC pilot (2018-2020), together with the existing instruments, has supported circular technologies in the construction, textile and EIIs sectors, including:

<u>Construction</u> (technologies such as recycling and recovering waste and digital platforms):

- The Madaster project (Netherlands, 2017-2019) developed an ICT platform to precisely document and store material-related information on products. This innovative solution specifically focuses on the construction sector with the ambition to eliminate waste.
- TRACK4REUSE (France, 2020-2022) is setting new waste traceability standards for the green demolition and construction industry.
- Re-create (Israel, 2020-2022) is developing regenerative construction materials and products to help transform the building industry into a circular economy sector.
- Honext (Spain, 2018-2021) brings a new life to industrial waste used in construction applications.

<u>Textile</u> (technologies such as post-consumer recycling by adding cellulose-based fibres, and digital solutions):

- Colorifix (UK, 2020-2022) offers a revolutionary dyeing process to help the textile industry reduce its environmental impact.
- H2COLOR-AUX (Portugal, 2020-2022) is developing an innovative polymer particle used in textile dying which massively reduces water and energy consumption.
- NewNormal (Finland, 2019-2021) has developed a low-cost process to produce cellulose-based fibre from textile waste.
- Smartex (Portugal, 2020-2021) has created a device to detect defects in textile production.

<u>EIIs</u> (technologies such as: recycling of plastic waste, and recovery solutions):

Steel:

- ReStoRE (Italy, 2019-2022) is developing a proper solution for integrated refractory and steel recovery.

Chemicals/plastics:

- PLASTDEINK (Spain, 2019-2021) has developed a water-based process for the delaminating and deinking of surface printed plastic to reintroduce the plastic into other applications.

([210]) https://eic.ec.europa.eu/about-european-innovation-council_en

Horizontal (blockchain technologies):

- CirculariseSource (Netherlands, 2020-2022) offers a blockchain-based transparency solution to provide absolute proof of the circular economy, sustainability and recycling practices of manufacturers at any stage of the supply chain.

From 2021 to 2027, the EIC is offering three funding schemes through its annual programme:

- The EIC Pathfinder (worth EUR 343 million in 2023) provides grants of up to EUR 3-4 million for early stage research on breakthrough technologies;
- The EIC Transition (worth EUR 128.3 million in 2023) provides grants of up to EUR 2.5 million for technology maturation from proof of concept to validation;
- The EIC Accelerator (worth EUR 1.13 billion in 2023) provides grants of up to EUR 2.5 million, combined with equity investments of up to EUR 15 million, to develop and scale up deep-tech or disruptive innovations.

Most funding is awarded through open calls with no predefined thematic priorities (EIC Open). The EIC Open funding is designed to support any technologies and innovations that cut across different scientific, technological, sectoral and application fields or represent novel combinations. The challenge driven approach (EIC Challenges) provides funding to address specific technological and innovation breakthroughs. These challenges take into account EU priorities for transitioning to a green, digital and healthy society, including the development of green/circular technologies.

The 2023 EIC work programme sets out an updated set of EIC Challenges. Over half a billion euro is made available for start-ups to develop future technologies that will contribute to EU objectives, including environment friendly construction ([211]).

For 2023:

- The EIC Pathfinder Challenges (EUR 163.5 million) include Architecture, Engineering and Construction digitalisation for a novel triad of design, fabrication, and materials.

- The EIC Transition Challenges (EUR 60.50 million) include Environmental intelligence.

- The EIC Accelerator Challenges (EUR 523.5 million) include the New European Bauhaus and Architecture, Engineering and Construction digitalisation for decarbonisation (EUR 65 million) and Energy storage (EUR 100 million).

([211]) EIC work programme 2023 https://eic.ec.europa.eu/eic-2023-work-programme_en

For 2022:

- The EIC Transition Challenges (EUR 60.5 million) included Green digital devices for the future and Process and system integration of clean energy technologies.

- The EIC Accelerator Challenges (EUR 536.9 million) included Technologies for Open Strategic Autonomy and Technologies for 'Fit for 55' ([212]).

In 2021, the EIC started to fund relevant projects via the EIC Accelerator Challenge, like:

- Super Dryer (Finland, 2022-2024) is developing breakthrough clean fibre dryers to cut emissions in clothes recycling.

European Institute of Innovation and Technology (EIT)

The EIT is an EU body that aims to improve Europe's ability to innovate. The EIT is an integral part of Horizon Europe, with a budget of EUR 3 billion for 2021-2027. Bringing together more than 2900 partners, the EIT is Europe's largest innovation ecosystem and connects many innovators and research organisations.

The EIT supports the development of dynamic, long-term European partnerships between leading companies, research labs and higher education. These partnerships are called EIT Knowledge and Innovation Communities (KICs) and each is dedicated to finding solutions to a specific challenge. The KICs that support green/circular technologies are the EIT Climate-KIC, EIT Raw Material and EIT Manufacturing.

Besides the KICs, the EIT has also established the Regional Innovation Scheme, for EU Member States with a lower innovation performance ([213]) and non-EU Horizon Europe associated countries. Under this scheme EIT KICs disseminate knowledge and promote broader participation in their projects across Europe.

The EIT has funded many circular economy projects. These are summarised in an online tool ([214]) that presents EIT circular economy initiatives.

EIT Manufacturing

One of the four flagships ([215]) of EIT Manufacturing is called "Low Environmental Footprint Systems & Circular Economy for Green Manufacturing". The calls for proposals are currently following the flagships and attracting proposals in that area. The portfolio strategy will ensure that EIT Manufacturing funds a minimum number of innovation projects in that area. In 2023, EIT Manufacturing will launch a new programme focused on lower TRL solutions developed by start-up companies in green manufacturing.

([212]) EIC work programme 2022 https://eic.ec.europa.eu/about-european-innovation-council_en
([213]) Based on the European Innovation Scoreboard, https://ec.europa.eu/info/research-and-innovation/statistics/performance-indicators/european-innovation-scoreboard_en
([214]) https://kumu.io/ckicsj/eit-cross-kic-circular-economy-initiatives-wp1
([215]) https://www.eitmanufacturing.eu/what-we-do/focus-areas-flagships/

Missions

EU Missions are a new feature of Horizon Europe. They are a new way to create effective solutions to some of our greatest challenges. They have ambitious goals and will deliver results by 2030.

EU Missions are a coordinated effort by the Commission to pool the necessary resources in terms of funding programmes, policies and regulations, as well as other activities.

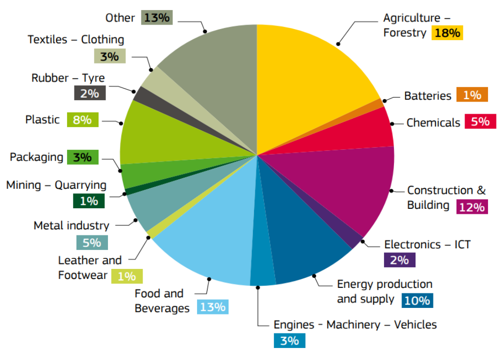
Green/circular technologies fall under two missions: Adaptation to climate change and Climate-neutral & smart cities (for the construction sector). The budget for circular industrial projects is up to EUR 45 million ([216]), under the 2021-22 work programmes for EU missions ([217]).

LIFE programme

LIFE is the EU's funding instrument for the environment and climate action. During the 2014–2020 programming period, over EUR 945 million was invested in projects supporting the circular economy, of which the EU contributed more than EUR 366 million in over 215 projects.

As shown in Figure 3.22, 3% of LIFE circular economy projects from 2014 to 2020 were in the textiles - clothing sector and 12% in the construction & building sector. For EIIs, 5% of LIFE circular economy projects were in chemicals and 5% in metal industry.

Figure 3.22: LIFE circular economy projects by sectors (2014-2020) ([218])



Source: Factsheet "LIFE and the circular economy" by the European Climate, Infrastructure and Environment Executive Agency (CINEA), 2021

([216]) HORIZON-MISS-2022-CLIMA-01-04: Transformation of regional economic systems for climate resilience and sustainability: estimated budget: EUR 6 million; HORIZON-MISS-2021-CIT-01-02: Collaborative local governance models to accelerate the emblematic transformation of urban environment and contribute to the New European Bauhaus initiative and the objectives of the European Green Deal: indicative budget: EUR 2 million; HORIZON-MISS-2021-CIT-02-01: Urban planning and design for just, sustainable, resilient and climate-neutral cities by 2030: indicative budget: EUR 35 million.

([217]) https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-12-missions_horizon-2021-2022_en.pdf

([218]) https://cinea.ec.europa.eu/publications/disrupting-linear-model-life-and-circular-economy_en

Over the years, LIFE has helped many projects to enter the market. Some projects have come up with cutting-edge technologies, while others have focused on developing consumer products. Examples include PolyStyrene Loop ([219]): from 2017 to 2021, LIFE invested EUR 2.7 million in this project to collect polystyrene waste from demolition sites and return it to a usable condition.

For 2021-2027, the EU has increased funding for the LIFE programme to EUR 5.4 billion. LIFE has several new sub-programmes, including Circular economy and quality of life for which EUR 1.3 billion has been earmarked. ([220])

The Circular economy and quality of life sub-programme aims at facilitating the transition toward a sustainable, circular, toxic-free, energy-efficient and climate-resilient economy. It also aims to protect, restore and improve the quality of the environment, either through direct interventions or by supporting the integration of those objectives into other policies.

One of the priority topics in the sub-programme is to co-finance projects on the recovery of resources from waste. This covers innovative solutions to develop value added recycled materials, components or products; and business and consumption models or solutions to support value chains, which aim to reduce or prevent the use and waste of resources.

The sub-programme mostly provides action grants for projects that implement innovative and best practice solutions in these areas through the 'standard action projects'. It also covers the implementation, monitoring and evaluation of EU environmental policy and law through the 'strategic integrated projects'. The Commission will continue to look for solutions that are ready to be implemented in close-to-market conditions, at industrial or commercial scale, while a project is running. ([221])

Innovation Fund

The Innovation Fund supports the commercial demonstration of innovative low-carbon technologies, aiming to bring to market industrial solutions to decarbonise Europe. It plays a unique role due to its size and focus on the last steps in the roll-out of innovative clean technologies.

The Innovation Fund will provide around EUR 38 billion ([222]) of support from 2020 to 2030, financed from the auctioning of EU Emissions Trading System allowances. It targets in particular EIIs, including products that can replace carbon-intensive products. The projects can support the application of circular economy and energy efficiency principles in EIIs at various levels, for example by recycling material residues, using heat that would otherwise be lost or supporting the replacement of fossil fuels.

([219]) Examples of finalised close-to-market LIFE projects (europa.eu)
([220]) https://cinea.ec.europa.eu/publications/disrupting-linear-model-life-and-circular-economy_en
([221]) https://cinea.ec.europa.eu/programmes/life/circular-economy-and-quality-life_en
([222]) Depending on carbon price, the volume is estimated using EUR 75 / tCO2 as carbon price

These are some examples of circular projects in EIIs:

- Second large-scale call: pre-selected for a grant in July 2022:

    - the IONFibre project in Finland, which will produce a new fibre from pulp to replace polyester in textile applications;
    - the PULSE project in Finland, which will deploy a first-of-a-kind proprietary technology enabling the processing of large quantities of liquefied plastics waste into drop-in petrochemical feeds that can replace virgin fossil feeds;
    - the Carbon2Business project in Germany, which will deploy a second generation oxyfuel carbon capture process at Holcim's Lägerdorf cement plant, capturing over 1 million tonnes of carbon dioxide equivalent annually and providing it as a raw material for further processing into synthetic methanol;
    - Project Air in Sweden, which will create a first-of-a-kind, large-scale, commercial and sustainable methanol plant using a carbon capture and utilisation process to convert CO2, residue streams, renewable hydrogen and biogas to methanol.

- First large-scale call:

    - The ECOPLANTA project in Spain, which will use non-recyclable materials rejected by sorting centres to produce circular chemicals and advanced biofuels.

The Innovation Fund's first two large-scale calls generated a lot of interest from businesses and received applications that by far exceed the available budget of each call, which created a lot of competition between projects. This clearly shows the strong and varied roster of projects that the Fund can support in its next calls. A third call for large-scale projects was launched on 4 November 2022 with an increased budget of EUR 3 billion.

The EU also launched four small-scale calls for smaller innovative clean-tech projects under the Innovation Fund, including circular projects.

InvestEU / European Fund for Strategic Investments (EFSI)

InvestEU is the EU's investment programme for 2021-2027, which builds on the EFSI which ran from 2014 to 2020. It brings together under one roof all of the EU's financial instruments available to support investment, including InnovFin.

It provides long-term funding by mobilising private investment in line with EU policies. The InvestEU guarantee amounts to EUR 26.2 billion. The InvestEU Fund is market driven but supports four 'policy windows' which are areas that represent important policy priorities: Sustainable infrastructure (EUR 9.9 billion); Research, innovation and digitisation (EUR 6.6 billion); SMEs (EUR 6.9 billion); and Social investment and skills (EUR 2.8 billion).

The overall investment to be mobilised on this basis is estimated at more than EUR 372 billion, of which 30% will contribute to climate objectives. The major novelty is that the guarantee can be used by the EIB Group and also by national promotional banks and institutions (NPBIs) and other international financial institutions, such as the

European Bank for Reconstruction and Development, the Council of Europe Development Bank or the Nordic Investment Bank. ([223])

The improved implementation of InvestEU through NPBIs might yield opportunities for synergies with national funds channelled by the same banks.

EFSI and circular technologies 2014-2020

EFSI had nine general objectives: Research, development and innovation; Energy; Transport; Smaller companies; Digital, Environment and resource efficiency; Social infrastructure; and, since the extended EFSI, Bioeconomy and Regional development. R&I in circular technologies can be considered as part of the Environment and resource efficiency objective and/or the Research, development and innovation objective.

By 31 December 2021:

- 72 EFSI operations, with a total amount of EUR 4.5 billion of EFSI approved financing and EUR 17.1 billion of investments (including private partners investments) had been tagged as part of the Environment and resource efficiency objective;

- 219 EFSI operations, with a total amount of EUR 12.7 billion of EFSI approved financing and EUR 50.7 billion of investments had been tagged as part of the Research, development and innovation objective;

- 6.1% of investments fell under the Environment and resource efficiency objective and 18% under the Research, development and innovation objective. ([224])

These are some examples of projects relating to circular technologies:

- The PANARIA SUSTAINABLE CERAMICS project finances the purchase of new cutting-edge technologies and investment in research and development for innovative products and processes (Italy/Portugal – EUR 50 million loan agreement);

- The ARVEDI RDI & ADVANCED MANUFACTURING TECHNOLOGY project encompasses (i) research, development and innovation activities; (ii) new advanced manufacturing technology downstream in steel processing lines; (iii) various circular economy measures; (iv) renewable electricity generation in several of its manufacturing facilities. The project runs from 2020 to 2023 (Italy - EUR 110 million loan agreement);

- The DIGITAL INTEGRATED TEXTILE MANUFACTURING project finances Vandewiele's research, development and innovation programme, focusing on digitally integrated solutions for textile manufacturing (2020-2023), with the aim of developing more efficient and high-tech and high value-added textile

([223]) https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_1045
([224]) EFSI 2021 Operational report

production machinery (Belgium, France, Germany, Italy and Sweden – EUR 100 million loan agreement).

InnovFin 2014-2021

InnovFin was an initiative launched by the EIB Group in cooperation with the European Commission under Horizon 2020. InnovFin aimed to facilitate and accelerate access to finance for innovative projects, which by their nature are riskier and harder to assess than traditional investments, and therefore often face difficulties accessing finance ([225]).

A few projects related to circular technologies were supported such as:

- RENEWCELL TEXTILE RECYCLING DEMO PLANT (EDP) - financing of a first full-scale commercial plant to recycle waste textiles into high-quality biodegradable pulp from which new textiles and subsequently clothes can be produced (Sweden - EUR 30 million loan agreement).

InvestEU and circular technologies 2021-2027

The Sustainable infrastructure and Research, innovation and digitisation windows of the InvestEU fund can finance sustainable industrial applications and new environmentally sustainable technologies such as circular technologies.

The Guarantee Agreement with the EIB Group was signed in March 2022 and the financial products are now on the market. The Green Transition thematic product (a joint product across the Sustainable infrastructure and Research, innovation and digitisation windows) includes a section on circular economy. This product provides an EU guarantee of EUR 948 million to the EIB Group. Eligibility and policy checks have been made for proposed operations but none have been signed yet. In addition, the General debt product under the Research, innovation and digitisation window (over EUR 3 billion in EU guarantee), also includes the circular economy as one of the main priorities.

The EIB also finances research and development of circular technologies from its own resources. In 2021, EUR 27.6 billion ([226]) of EIB investments went to climate action and environmental sustainability projects. As the EU's 'climate bank', the EIB pledged to increase its climate funding to 50% by 2025, i.e. to approximately EUR 30 billion per year.

EU Taxonomy

The EU's sustainable finance taxonomy will be essential to direct private investment towards sustainable economic activities and improve financing conditions for investing in the transition to a circular economy and other environmental objectives.

Based on the work of the Sustainable Finance Platform of experts, the Commission is considering the adoption of technical screening criteria to determine, among other things, what constitutes a substantial contribution to the circular economy.

([225]) InnovFin EU Finance for innovators (eib.org)
([226]) https://www.eib.org/en/about/priorities/climate-action/index.htm

Decentralised funds

Promoting innovation is a central feature of the cohesion policy programmes for 2021-2027, where at least EUR 56 billion are earmarked for innovation and research. Smart specialisation strategies aim to mobilise the innovation potential of all EU regions.

Within the cohesion policy programmes, the European Regional Development Fund (ERDF), with a budget of EUR 215.2 billion, funds economic cohesion, including research and innovation and the circular economy.

Mapping ERDF projects (2014-2020) in circular economy

The ERDF aims to improve economic and social cohesion in the EU by correcting inequalities between its regions. Some of the key priority areas for ERDF investment are research and innovation and the transition to a low-carbon economy.

In the programming period 2014-2020, around EUR 22.9 billion of the ERDF (Table 3.12) was used to support projects related to the development or adoption of circular economy technologies and more eco-friendly business models (12% of total ERDF). Circular economy projects associated with the development or adoption of technologies to support a more efficient use of resources (e.g. waste reduction, reuse of by-products and resource optimisation) represented 67% of total ERDF circular economy projects (EUR 15.4 billion).

Table 3.12: ERDF projects in the circular economy, 2014-2020 (EUR amount of funding), by categories

Category	EU funds	%	Total
Circular economy (CE)	EUR 22 894 079 300	12%	(% Total ERDF)
Technology	EUR 15 451 148 625	67%	(% Total CE)
Research and & innovation	EUR 3 301 948 009	14%	(% Total CE)
Interregional collaboration (Interreg)	EUR 1 174 239 392	5%	(% Total CE)
Sectors or project-related activities			
Textile	EUR 641 726 403	3%	(% Total CE)
Construction	EUR 12 939 234 723	57%	(% Total CE)
Energy-intensive industries	EUR 1 076 834 881	5%	(% Total CE)

Source: JRC-B7, TEDAM.
Note: Analysis performed using Bachtrögler et al. (2021) database and text analysis techniques to identify projects in the circular economy and by specific industries. The total corresponds to the sum of the regional amounts, excluding projects without Nuts 2 level localisation and located in extra-regions. For more details, see Marques Santos, Conte and Ojala (2022).

Around 57% of ERDF projects on the circular economy (EUR 12.9 billion) were concentrated in projects related to construction activities or investments (Table 3.10). This refers to investments targeted mainly on energy efficiency and renovating buildings, i.e. associated to the concept of green building design or to extend the life of a building. ERDF circular economy projects in the textile industry (EUR 641 million) and EIIs (EUR 1 billion) were mainly associated with technologies to improve resource efficiency and use more eco-friendly materials in production (Table 3.13).

On average, ERDF projects on the circular economy were bigger than non-circular economy projects (Table 3.13). However, when analysing the size of R&I or interregional collaboration projects, circular economy projects were slightly smaller on average than non-circular economy projects (Table 3.13).

Table 3.13: Average amount of EU funding for ERDF projects in the circular economy and non-circular economy, by category

Categories	Circular economy	Non-circular economy
Total ERDF (EU funding)	EUR 548 095	EUR 336 432
Total R&I (EU funding)	EUR 222 748	EUR 247 194
Total interregional collaboration (EU funding)	EUR 222 057	EUR 248 366
Total in the three selected industries (EU funding)	EUR 713 987	EUR 619 033

Source: JRC-B7, TEDAM.
Note: Interregional collaboration refers to Interreg projects. For more details, see Marques Santos, A. Conte, A. and Ojala, T. (2022). “Mapping Circular Economy projects funded by ERDF in 2014-2020”, Territorial Development Insights Series, JRC132160, European Commission.

ERDF projects in the textile, construction and EII sectors are more than twice more likely to be associated with the circular economy than the average (17% versus 7%) (Table 3.14).

Table 3.14: Circular economy ERDF projects as a share of the total, by sector and typology

Sectors	All types	Only R&I	Only interregional collaboration
All sectors	7%	34%	12%
Textile, construction and EII sectors	17%	22%	10%
Textile sector	12%	46%	23%
Construction sector	16%	16%	9%
EII	17%	45%	7%

Source: JRC-B7, TEDAM.
Note: For more details, see Marques Santos, Conte and Ojala (2022).

R&I activities account for 14% of ERDF circular economy projects (EUR 3.3 billion), and interregional collaboration projects for around 5% of the total (EUR 1.2 billion) (Table 3.12). R&I activities in ERDF circular economy projects are more likely to happen in the textile sector or EIIs than in construction, and interregional collaboration projects are more common in the textile industry (Table 3.14).

Regions in eastern European countries and Greece have the highest amount of ERDF per capita spent on circular economy projects (Figure 3.23). This geographical distribution, however, correlates strongly with the ERDF’s allocation of funds to these countries and regions.

The share of circular economy ERDF projects as a percentage of all ERDF projects (Figure 3.24) shows which regions are concentrating or specialising in the circular economy. In addition to regions in eastern European countries and Greece, some regions in Belgium, Germany, the Netherlands, Austria, Finland and the United Kingdom reported a share of circular economy projects (measured by the amount of EU funding awarded) above 22%.

Figure 3.23: ERDF circular economy projects, EU funds (EUR) per capita, 2014-2020

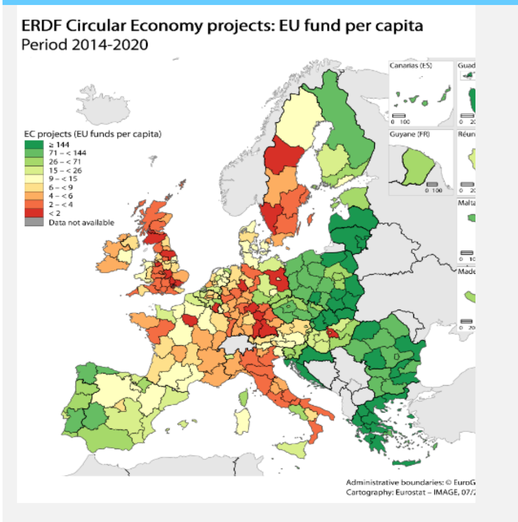
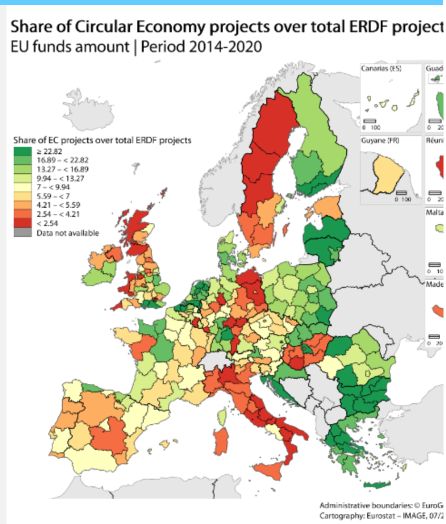


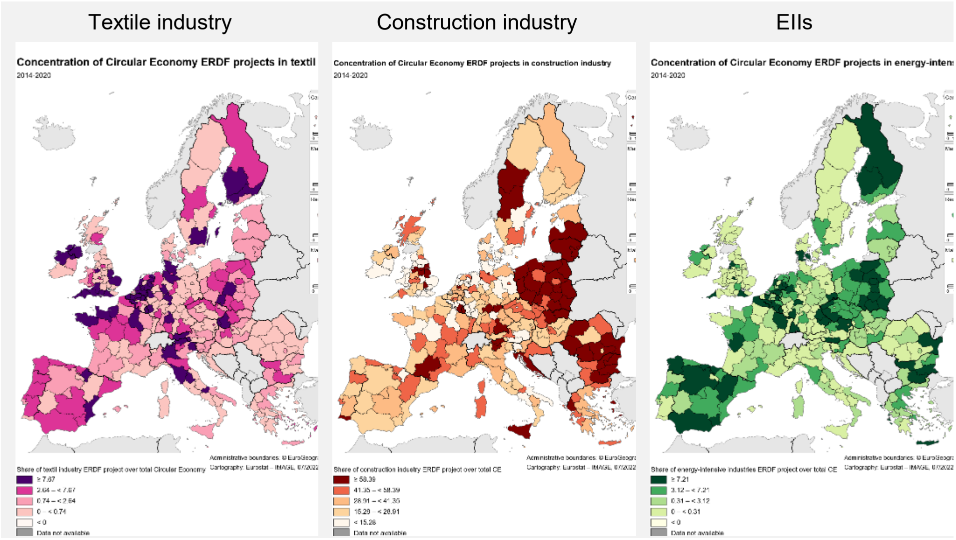
Figure 3.24: Share of circular economy projects as a percentage of all ERDF projects (% EU funds), 2014-2020



Source: JRC-B7, TEDAM.
Note: Analysis performed using Bachtrögler et al. (2021) database and text analysis techniques to identify projects in the circular economy. For more details, see Marques Santos, Conte and Ojala (2022).

A higher concentration of circular economy projects in the textile industry (Figure 3.25 - left) is observed in some regions of Belgium, Ireland, Spain, France, Italy, the Netherlands and the United Kingdom. Some regions of Germany and of eastern European countries had a higher concentration of circular projects in the construction industry (Figure 3.25 - centre). EIIs with ERDF projects in the circular economy (Figure 3.25 - right) showed a higher concentration in some regions of Belgium, Germany, France, Austria, Poland and the United Kingdom.

Figure 3.25: Concentration of circular economy ERDF projects by industries, 2014-2020



Source: JRC-B7, TEDAM.
Note: Analysis performed using Bachtrögler et al. (2021) database and text analysis techniques to identify projects in the circular economy and by specific industries. For more details, see Marques Santos, Conte and Ojala (2022).

ERDF (2021-2027)

Based on their prosperity, all regions and Member States concentrate support from the ERDF on a more competitive and smarter Europe (policy objective 1), as well as the greener, low-carbon transition towards a net zero carbon economy and resilient Europe (policy objective 2), through the practice known as 'thematic concentration'.

Operations under the ERDF are also expected to contribute 30% of the overall budget to climate objectives.

The various cohesion policy programmes set out the funding opportunities for all Member States and regions until 2027. Member States run the programmes, via managing authorities. These provide information on the programmes, select projects and help to implement them.

Based on the available draft programmes ([227]), the following ERDF-relevant spending areas are covered:

- R&I on the circular economy - 10 Member States (AT, CZ, DE, DK, FI, IT, LT, NL, SE) with a total projected EU investment of EUR 339 million;
- Support for resource efficiency in SMEs and Support for resource efficiency in large enterprises - 8 Member States (AT, CZ, DE, DK, EL, FI, IT, SE) with a total projected EU investment of EUR 1.02 billion;
- R&I on the circular economy, Support for resource efficiency in SMEs and Support for resource efficiency in large enterprises - 10 Member States (AT, CZ, DE, DK, FI, IT, LT, NL, SE) with a total projected EU investment of EUR 1.4 billion.

([227]) not all Member States had submitted one yet at the end of September 2022

Interregional Innovation Investments instrument

Under the ERDF, the Commission is financing the Interregional Innovation Investments (3I) instrument with a budget of EUR 570 million for 2021-2027 ([228]).

The 3I instrument aims to support interregional portfolios of companies' investments bringing innovation to the market at high technology readiness levels (TRL 6-9) and reshaping EU interregional value chains.

It funds interregional innovation investments projects under shared smart specialisation priorities in the following thematic areas: green transition, digital transition and smart manufacturing.

Partnerships for Regional Innovation

In May 2022, the Commission and the European Committee of the Regions launched the Partnerships for Regional Innovation, as part of the new Innovation Agenda for Europe. It aspires to become a strategic framework for innovation-driven territorial transformation, linking EU priorities with national plans and place-based opportunities and challenges. A pilot phase involves 74 territorial entities who have volunteered to co-develop the approach. It aims in particular to address the fragmentation of funding instruments and policies for territories (cohesion policy, Recovery and Resilience Plans, Horizon Europe) ([229]).

Synergies

Horizon Europe, LIFE and ERDF are complementary in their approaches to funding circular technology projects.

The regulatory framework for 2021-2027 allows for more synergies between EU centrally managed funds such as Horizon Europe and LIFE, and cohesion funds such as ERDF that are managed jointly by national managing authorities and the EU.

A new guidance document ([230]) was published in July 2022 to explain to national managing authorities the new opportunities for synergies between Horizon Europe and the ERDF. Relevant mechanisms include the Seal of Excellence, transfer, cumulative funding, co-funded and institutionalised Horizon Partnerships, teaming, and upstream/downstream synergies including missions.

The Seal of Excellence is a quality label awarded by the Commission to a proposal that has been submitted to a competitive call for proposals under an EU instrument and judged to comply with the minimum quality requirements of that EU instrument, but which could not be funded due to budgetary constraints. The Seal of Excellence indicates that a project might be a good candidate for support from other EU or national sources of funding. A Seal of Excellence under Horizon Europe recognises the value of the proposal and helps other funding bodies take advantage of the Horizon Europe

([228]) https://ec.europa.eu/regional_policy/en/newsroom/news/2021/11/24-11-2021-commission-launches-the-eur570-million-interregional-innovation-investment-instrument
([229]) https://op.europa.eu/en/publication-detail/-/publication/5e5b1298-d58b-11ec-a95f-01aa75ed71a1
([230]) https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/synergies-guidance-out-2022-07-06_en

evaluation process. It can, for example, be awarded to proposals submitted under the EIC Accelerator and EIC Transition schemes. This allows Member States and regions to identify and benefit from a pipeline of excellent research and innovation project proposals in their territory ([231]).

New developments under Horizon Europe include the EIC 'Fast Track' scheme that provides a preferential treatment for proposals that result from existing Horizon Europe or Horizon 2020 projects; and the EIC pilot 'Plug-in' scheme that applies to applications that result from existing national or regional programmes certified by the Commission.

Coordination and support actions (CSAs) are being developed in the context of synergies between Horizon Europe and the Innovation Fund.

The Innovation Fund aims to ensure synergies with other investment support instruments, such as InvestEU or other relevant EU funding programmes, such as Horizon Europe. It is possible to combine funding from InvestEU and the Innovation Fund for a specific project. Projects that receive financing from the Innovation Fund can also get support from national or regional programmes.

A bonus is provided for in the LIFE award process to promote the continuation of projects funded under other programmes, including Horizon Europe.

Synergies are also in place between Horizon partnerships, such as common calls between Made in Europe and AI, Data and Robotics.

Member States can also choose to channel a part of their ERDF funds to the InvestEU guarantee, to benefit from favourable investment conditions. EU countries can also use InvestEU as a tool to implement their recovery and resilience plans under the Recovery and Resilience Facility if they so wish.

3.5. National public investments and programmes

This section provides an overview of circular economy national strategies, programmes and action plans of EU Member States and Norway. It also offers information on public investments and highlights recent national circular economy programmes in selected countries, whereas the annex adds information about the other countries in focus ([232]).

EU Member States have adopted diverse circular economy plans, strategies and roadmaps in recent years with the objective to foster circularity and the green transition of industrial ecosystems. **Today, most EU countries have a dedicated circular economy national plan or roadmap, or at least a relevant study has been developed** (e.g. the OECD report on Slovakia, the World Bank report on Croatia, the

([231]) Draft COMMISSION NOTICE Synergies between Horizon Europe and ERDF programmes, 5 July 2022, C(2022) 4747 final

([232]) This section is based on a review of national programmes, presented at the Circular Economy Platform https://circulareconomy.europa.eu/platform/ complemented by desk research, prepared by TECHNOPOLIS for the Commission. It relies also on a review of the national reform programmes and recovery and resilience funds, provided by Technopolis Group, with background and input from experts from the Commission. Finally, representatives of Member States under the ERA industrial technology roadmap subgroup provided comments and suggestions through workshops that were organised by the Prosperity Directorate of DG Research & Innovation of the European Commission on 11 July 2022 and 21 September 2022. Several representatives of Member States provided also written inputs of national investments and programmes.

analysis for Romania by the ‘Ernest Lupan’ Institute for Research in circular Economy and Environment, etc.).

The recent surge in circular strategies is also a result of new EU policies such as the European Green Deal and legislation such as the EU waste package that asks Member States to work towards ambitious recycling and landfill-reduction targets, put in place mandatory waste prevention measures and implement stronger rules on separated waste collection. Circular economy considerations are also part of most of the national Waste Management Plans that must be prepared in line with the Waste Framework Directive (e.g. in the case of Croatia, Hungary, Ireland, and Romania, the waste management plan includes objectives related to promoting the circular economy).

Some of the national reform programmes and national recovery and resilience plans (RRPs) also include a dimension on the circular economy (e.g. the Austrian national reform programme or the RRP of Slovenia). The Recovery and Resilience Facility (RRF) sets each Member State a climate target of devoting at least 37% of their total allocation to the green transition, including the circular economy. According to the analysis of the European Commission (2022), 13% of the RRF’s budget has been allocated to the objective of biodiversity, circular economy, sustainable water and pollution prevention ([233]).

The circular economy received particular attention in 2018 when several Member States each published a dedicated strategy. Since 2021, many strategies have been updated and new roadmaps have been put in place. Although these circular economy action plans are recent, some of the previously launched national environmental strategies (e.g. Estonia’s 2007-2013 national environmental action plan) already included circular economy related actions such as promoting resource efficiency and reducing the use of materials use. The figure below provides an overview of when EU Member States launched their first circular economy action plan, strategy or roadmap.

Figure 3.26: Year each Member State launched a national circular economy strategy, roadmap or action plan economy

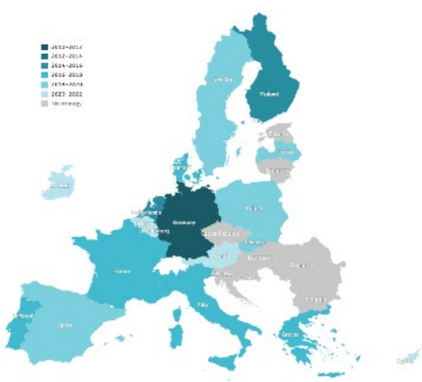
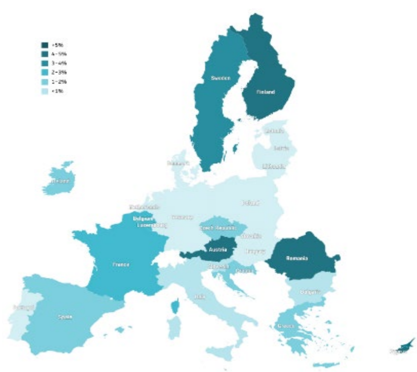


Figure 3.27: Percentage of national recovery and resilience plan funds dedicated to the circular



Source: Technopolis Group
Note: Belgium has created its circular strategies at regional level.

([233]) Report on the implementation of the Recovery and Resiliencex` Facility COM (2022) of 1 March 2022.

The rationale behind the national strategies is in most cases both ecological (addressing societal development goals) and economic, such as to save resources and reduce material dependencies. Some strategies also aim at increasing resilience and addressing social challenges. The strategies and roadmaps identify various common priority areas. The content of the action plans addresses, on the one hand, sustainable consumption and service models and, on the other hand, waste management and recycling.

The national public funds into the circular economy vary in terms of volume and period of investment. High investments are found in Spain (EUR 1 529 million) for 2021-2023; France (EUR 570 million) for 2021-2025; Finland (EUR 342.5 million) for 2021- 2026; Netherlands (EUR 217.5 million) for 2020, see Table 3.16. Medium investments between EUR 13 million and EUR 120 million are available in countries, like Belgium, Austria, Sweden, Denmark and Cyprus ([234]). As far as, RRP budgets are concerned, Italy has a huge budget of EUR 5.27 billion under the "Circular economy and sustainable agriculture". Austria, Sweden, Czechia, Bulgaria and Slovenia have also dedicated RRP funding for circular economy with the range between EUR 48 million and EUR 350 million.

The circular economy funding covers actions related to awareness raising, cooperation partnerships and pilot projects in most cases. Additional investment to finance research and innovation of circular technology development comes from national R&D programmes. Funding is also allocated to infrastructure development such as recycling hubs or waste management that are covered by national or regional economic development programmes and often linked to waste management schemes.

Table 3.15: National public Investments of EU Member States and Norway for circular economy

Country	National budget for circular economy	Source	RRP budget for circular economy	Source
Austria	EUR 82 million (2021-2023)	https://www.ffg.at/2-ausschreibung-fti-kreislaufwirtschaft	EUR 350 million	
Belgium	EUR 120 million (2021-2022)	https://vlaanderen-circulair.be https://circulareconomy.europa.eu/platform/sites/default/files/resume_de_la_politique_wallonne_en_v1_1.pdf	EUR 198 m (promotion of recycling and reuse, eco-design projects, innovation in resource-handling and waste processing	https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility/belgiums-recovery-and-resilience-plan_en#green-transition
Bulgaria	x		EUR 92.3 million	
Croatia	EUR 673 million	Waste management plan of Croatia (2017-2022) management_plan_	EUR 542 m supporting businesses for green	https://ec.europa.eu/info/business-economy-

([234]) Providing estimates how much has been invested into the circular economy by the public sector needs a common framework what is considered as a circular economy related expenditure and what is not. Current national policy documents have a diverse understanding when indicating the budget earmarked for the circular shift.

		of_the_republic_of_croatia_for_the_period_2017-2022.pdf (gov.hr)	transition and energy efficiency	euro/recovery-coronavirus/recovery-and-resilience-facility/croatias-recovery-and-resilience-plan_en
Cyprus	EUR 13 million		EUR 64 million	https://ec.europa.eu/info/sites/default/files/2021_07_20_cy_rrp_fico.pdf
Czechia	x		EUR 141 million	
Denmark	EUR 17 million (2022-2030)		No funds for CE per se	
Estonia	EUR 900 000	https://www.kik.ee/en/grants/circular-economy-pilot-projects	EUR 220 million (green transition in business - development and uptake of green technologies, increased low-carbon and climate-neutral R&I capabilities and resource efficiency, support for modernisation in business models and improved skills needed for the green transition)	https://ec.europa.eu/info/sites/default/files/factsheet-estonia_en.pdf
Finland	EUR 342.5 million (2021-2026)		No financing for circular economy	
France	EUR 570 million (2021-2027)		EUR 414,5 million - measures on biodiversity and circular economy	https://ec.europa.eu/info/sites/default/files/2021_07_02_fr_rrp_fico.pdf
Germany	x		No funds for CE per se	
Greece	x		No funds for CE per se	
Hungary	x		x	
Ireland	x		No funds for CE per se	
Italy	EUR 62.8 million	co-financed by the Cohesion Fund	EUR 5.27 billion	
Latvia	x		No funds for CE per se	
Lithuania	x		EUR 337.8 million	https://finmin.lrv.lt/uploads/finmin/documents/files/Naujos%20kartos%20Lietuva%20planas.pdf
Luxembourg	x		No funds for CE per se	
Malta	x		EUR 78 million (Comp 1: Addressing	https://eufunds.gov.mt/en/Op

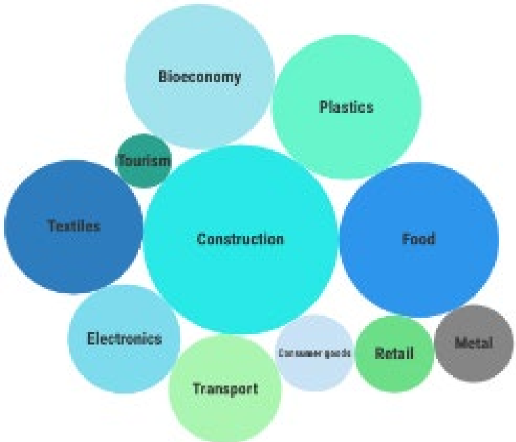
			climate neutrality through enhanced energy efficiency, clean energy and a circular economy)	erational%20Programmes/Documents/Malta%27s%20Recovery%20%20Resiliance%20Plan%20-%20July%202021.pdf
Netherlands	EUR 217.5 million (2020)		No funds specifically dedicated to CE; some projects on sustainable food system will be supported	https://ec.europa.eu/commission/presscorner/detail/en/ip_22_5397
Poland	x		No financing for circular economy per se	
Portugal	x		EUR 800 million greening of industry	https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility/portugals-recovery-and-resilience-plan_en
Romania	x		EUR 440 million (improving waste management)	https://ec.europa.eu/info/sites/default/files/2021_10_12_ro_rrp_financial_counsellors_working_party_fico_slides.pdf
Slovakia	x		Envisaged funding (EUR 368 million) on decarbonisation of industry	https://ec.europa.eu/info/sites/default/files/2021_06_28_sk_rrp_fico_0.pdf
Slovenia	x		EUR 48 m	
Spain	EUR 1 529 million (2021-2023)		EUR 2,091 million (Preservation of coastal areas and water resources)	https://planderecuperacion.gob.es/plan-espanol-de-recuperacion-transformacion-y-resiliencia
Sweden	EUR 27.2 million (2021-2023)		EUR 286 million	
Norway	x		x	x

Source: Desk research by Technopolis Group and written contributions from countries to DG Research and Innovation

Although the national strategies concern the overall economy, some countries prioritised certain sectors that should focus on circular economy actions such as

Denmark, Finland, Ireland, Netherlands, Poland, Portugal, Slovenia, Spain and Sweden. The industries most often addressed are construction, agri-food and the bioeconomy, textile, plastics and transport.

Figure 3.28: Sectors most often targeted in the national circular economy strategies and roadmaps



Source: Technopolis Group analysis.

Digitalisation is part of several national strategies and continues to be a major driving force that benefits the circular economy (e.g., the cases of Austria and Estonia). Table 3.16 provides an overview of the most recent circular economy strategies, actions plans, and roadmaps produced by Member States.

Table 3.16: Overview of current circular economy strategies and action plans at EU Member State level

Country	Strategies	Country	Strategies
Austria	National circular economy strategy, 2021	**Italy**	Towards a model of the circular economy for Italy - Overview and strategic framework
Belgium	At regional level: Circular Flanders, Circular Wallonia, Circular Brussels, 2021	**Latvia**	National action plan for the transition to the circular economy 2020-2027
Bulgaria	Bulgaria is to adopt a circular economy strategy, 2022	**Lithuania**	A circular economy strategy is under development (2022)
Croatia	Word Bank Report	**Luxembourg**	Circular Economy Strategy Luxembourg, 2021
Cyprus	Cyprus action plan for the transition to a circular economy (2021)	**Malta**	The circular economy strategic vision 2020-2030

Czechia	National circular economy strategic network for Czechia: Circular Czechia 2040 (under development)	**Netherlands**	Government-wide programme for a Dutch circular economy by 2050
Denmark	Action plan for the circular economy, 2021	**Poland**	Roadmap for the transition to the circular economy, 2019
Estonia	A national circular economy strategy and action plan is under development (2022)	**Portugal**	Circular economy action plan, 2017
Finland	Strategic programme for the circular economy, 2021; Finnish roadmap to a circular economy, 2016-2025	**Romania**	IRCEM (Institute for research in circular economy and the environment) project to prepare Romania's strategy for the transition to a circular economy (ROCES) 2020-2030
France	Law against waste and for a circular economy, 2020; Circular economy roadmap, 2018	**Slovenia**	Roadmap towards the circular economy
Germany	Circular economy roadmap, 2021; Circular economy Act	**Slovakia**	OECD review: Closing the loop in the Slovak Republic, A Roadmap Towards Circularity for Competitiveness, Eco-innovation and Sustainability
Greece	National action plan on the circular economy, 2018	**Spain**	España Circular 2030 (2020)
Hungary	A circular economy strategy is in preparation (2022)	**Sweden**	The Swedish strategy for the circular economy accelerates the transition to sustainability
Ireland	Whole of government circular economy strategy, 2022-2023		

Source: Technopolis Group.

Some Member States are more advanced than others in terms of national circular economy investments and programmes (see Box 3.5). To access information on other Member States and Norway, see Annex 4.

Box 3.5 | Highlights from recent national circular economy programmes

Austria

According to the Federal Ministry of Environment, Austria aims to become climate-neutral by 2040. The Austrian national climate and energy strategy envisages a 36% reduction in GHG emissions by 2030 compared to 2005 in sectors not subject to the EU emissions trading system (2018).

The ministry has begun to implement the national circular economy strategy, which was prepared in 2021. The strategy's overriding goals are to reduce material consumption, increase resource and energy efficiency, replace primary raw materials by secondary raw materials, replace fossil raw materials by biogenic raw materials, and achieve a largely fossil-free and climate-neutral production. The massive reduction in greenhouse gases (to 45%) that is necessary can only be achieved through changes in the production of basic materials and material goods. The focus areas of the strategy include construction and building infrastructure, mobility, waste management, biomass, textiles and clothing, plastics and packaging and electrical and electronic equipment. In 2022 and 2023, the ministry will spend EUR 60 million on applied research, internships, studies and innovative public procurement that are relevant for circular economy.

The RTI Circular Economy Initiative is a multiannual programme that supports research, technology development and innovation in the circular economy. Initiatives that have received support include projects aiming to transform the linear economic system to a circular one with new technological approaches and innovative solutions; projects that serve to intensify product use, innovations that optimise the use of resources and projects to develop innovative solutions that close material cycles.

EUR 10 million has been allocated to the RTI initiative's first call published in 2021 and EUR 12 million for the second call published in 2022. These calls support the development of innovative technologies and systemic innovations that take into account the entire lifecycle of goods and help create the circular economy.

Finland

Finland has a comprehensive set of programmes in place to encourage the shift to the circular economy. These comprise measures in the fields of research, innovation, market development, regulations and tax incentives, sustainable procurement, education, and dissemination. As a result of cooperation between different stakeholders, including the ministries of the environment and of economic affairs and several research institutes, Finland adopted its latest strategic programme for the circular economy in April 2021. This strategy envisions that Finland's '*economic success is founded on a carbon-neutral circular economy society*' and sets out the objectives, indicators, measures and resource allocation needed to achieve a systemic transition to a circular economy by 2035. The Finnish strategy is the result of a long reflection and experimenting with different approaches since 2016. Initiatives have taken place in the fields of research, development and innovation, and in ecosystem development, which have been complemented by demonstrations and investments in industrial facilities.

Finland's strategic programme for the circular economy has set the following budget allocations: EUR 2.3 million for the promotion of the circular economy by the Ministry of the Environment and EUR 3 million by the Ministry of Economic Affairs and Employment in 2020-22. In 2020-21, the Ministry of Economic Affairs and Employment allocated EUR 38 million for future investments in the circular economy and sustainable growth. It is expected that EUR 200-250 million will be spent on research, development and innovation. Ecosystem activities to promote a low-carbon circular economy and investments in demonstrations and facilities will be mainly paid for from the EU recovery instrument's funding in 2021-2026. EUR 9.2 million has been allocate in 2022is to finance operating models supporting public procurement, industrial symbioses, ecosystem development, regional circular economy activities and product design. EUR 14 million in appropriations per year in 2023 and 2024, and EUR 12 million in 2025 will continue to fund these initiatives. EUR 1.7 million has been provided for the implementation of one-off measures (working on different scenarios, drawing up sector plans, promoting the recycling markets and reporting on financial management) in 2022, and EUR 0.5 million in 2023.

Netherlands

The Dutch government published its first circular economy strategy in September 2016 with the interim goal of halving the use of primary raw materials by 2030. The strategy prioritised five areas: biomass and food, plastics, the manufacturing industry, the construction sector and consumer goods.

Following the selection of the five priority sectors highlighted in the government programme for 2050, and the Raw Material Agreement in 2017, the Dutch government published separate transition agendas for each of the five sectors, to set out government interventions to accelerate the transition to the circular economy. These interventions broadly fit under the following categories: legalisation and regulations, intelligent market incentives, financing, knowledge and innovation, and international cooperation.

The Dutch government presented a comprehensive circular economy implementation programme for 2019 to 2023, which includes concrete action plans and projects. The measures in this programme are divided according to the same five topics in the previous policy documents. The programme introduces 10 cross-cutting themes: (i) extended producer responsibility; (ii) legislation and regulation; (iii) circular design; (iv) circular procurement; (v) market stimuli; (vi) funding instruments; (vii) monitoring, knowledge, innovation, behaviour and communication, education and the labour market; international efforts; (x) the Netherlands Circular Accelerator. An assessment of the programme's progress is made every year and the results and recommendations are published. These reports can lead to updates in the implementation programme. So far, two updates have already been made, in 2020 and 2021.

In addition, the National Science Agency research programme annually allocates funds for academic-industry collaborative R&I projects, with a budget of EUR 0.5 to 10 million per project. Many projects that have been funded address circular economy innovations in various industries, as well as interdisciplinary topics and social, behavioural and business aspects.

Slovenia

Slovenia has proposed bold circular economy objectives in various key national documents such as Vision for Slovenia in 2050, the Slovenian development strategy 2030, Slovenia's smart specialisation strategy and its climate strategy. It developed a dedicated national roadmap towards the circular economy ([235]) in 2018 (among the first in central Europe) that sets Slovenia on the path to become a circular economy front-runner. Following a multi-stakeholder consultation, Slovenia identified four priority areas: the food system, forests, manufacturing industry and transport. The roadmap adopted a system approach and takes action according to several dimensions including entrepreneurship, policy and education. The roadmap was based on various inputs and discussions conducted during meetings in each region of Slovenia, interactive workshops, a review of good practices and structured interviews with key stakeholders from government departments, the economy, interest groups and experts from individual fields.

National measures aim at fostering education, capacity building, business innovation and disseminating good practices. Slovenia promotes innovative policy initiatives of transformative change (236). For example, the Slovenia Innovation Hub, in cooperation with the Ljubljana Technology Park, provides training and coaching for circular economy minded start-ups. Slovenia has been implementing waste management measures and was recognised for its efforts in separate waste collection.

An interesting element of the Slovenian Roadmap is that it introduces the Circular Triangle, a model that unites the following elements – Circular Economy (business models), Circular Change (government policies) and Circular Culture (citizens), three interdependent aspects that are at the core of systemic change from a linear to a circular economy.

Slovenia collaborates with the EIT Climate-KIC and participates in the Deep Demonstrations of Circular, Regenerative Economies programme launched in 2021. The project aims to introduce circularity by

([235])https://circulareconomy.europa.eu/platform/sites/default/files/roadmap_towards_the_circular_economy_in_slovenia.pdf
([236]) https://circulareconomy.leeds.ac.uk/wp-content/uploads/sites/35/2021/04/Circular-Slovenia_final.pdf

activating a coordinated portfolio of innovation actions in key economic sectors and selected value chains.

Slovenia's national recovery and resilience plan has a component to promote the circular economy through financial investments and regulatory reforms. The 'circular economy' component sets out measures to promote material productivity, eco-innovation, and the link to waste management. It supports schemes with around EUR 48 million of grants, or nearly 2% of the total budget of Slovenia's national recovery and resilience plan ([237]).

Sweden

In 2020, the Swedish Ministry of the Environment and the Ministry of Enterprise and Innovation published the Swedish government's strategy for a transition to the circular economy post-pandemic. This strategy sets out four focus areas: (i) circular economy through sustainable production and product design; (ii) circular economy through sustainable ways of consuming and using materials, products and services; (iii) circular economy through non-toxic and circular material cycles; and (iv) circular economy as a driving force for the business sector and other players through measures to promote innovation and circular business models.

Following the strategy, in January 2022 the Swedish government announced an action plan for the transition to Circular Economy. This action plan builds on the four focus areas and presents the policy instruments and measures that the Swedish government intends to use in order to achieve the environmental goals in the 2030 agenda. The action plan states that the government plans to develop specific national strategies for electrification, water, and the bioeconomy.

As the head of the Swedish national plastics coordination, the Environmental Protection Agency has prepared a roadmap to provide an overall picture of the common priorities and needs for Sweden's transition to the sustainable use of plastics. The roadmap was developed in line with the Swedish circular economy action plan for 2021-25 and is supposed to be revised and updated by the end of this period.

In Sweden's 2021 budget bill, circular economy objectives received a dedicated line of investment of EUR 14 million for 2021, EUR 13 million for 2022 and EUR 12 million for 2023.

3.6. Conclusions

- ✓ As regards identified R&I and infrastructure investment needs, estimations for the textile sector seem to converge in the order of EUR 5 to 7 billion to increase circularity for textiles by 2030 and to scale up the textile recycling industry along the whole value chain, including textile collection, sorting, and recycling in the EU. Focused on the fashion industry, the sector could become as high as 80% circular.

- ✓ For energy-intensive industries, the Processes4Planet (P4P) partnership estimated specific investment needs into specific technologies for the circularity of the involved sectors at around EUR 3.6 billion until 2030, through the Partnership's projects pipeline.

- ✓ For construction, the Built 4 People partnership estimates a comparatively small amount of EUR 300 million of R&I investments, needed for the Partnership's projects pipeline, on topics such as smart network-ready buildings, for reuse and recycling, for a lifecycle-based approach and better integrated holistic building assessments, for new approaches to building the

([237]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021SC0184 circular economy and to integrate construction and demolition waste into new constructions and industrial symbiosis.

- ✓ Green tech patents overall represent 9% of all patents. The EU has the second biggest share of high value green patents within its portfolio (slightly behind the US) and shows the highest specialisation.

- ✓ In circular economy related patenting, the EU is the worldwide leader, in total numbers and in the share of worldwide patents (2018). The chemicals, metals and construction sectors account for the highest shares of inventions. China ranked first in terms of the growth rate of circular economy technology (CET) patents, compared eg to a decrease of annual high-value inventions in the EU after 2015. The EU and US were the most targeted economies for international inventions in circular economy patents (2010-2018).

- ✓ The share of circular economy related patents as part of green inventions is small. In 2018, circular economy technologies represented just 4% of overall green inventions, and 5% for the EU.

- ✓ Global large R&D investing companies have a share of about 51% of patents which warrants a deeper understanding of the role of smaller companies, the research sector and start-ups in developing new solutions and helping them to adapt and create markets for circular materials, products and services.

- ✓ For the three industrial ecosystems together, around 81000 companies were identified as active in the circular economy and technologies overall, representing 7.2% of all companies (including start-ups). The EU has the highest share (32%) of companies worldwide, compared for example to the US (20%) and China (4.4%). EU based companies held 21% of all patents worldwide for the circular economy and related technologies in general, the majority of them in the EII ecosystem.

- ✓ Focusing on the circular technologies (CTs) identified in this roadmap, about 52 thousand companies were found, representing 2 % of all companies, of which 16,226 were based in the EU, which represented 31% of all circular technologies' (CTs) companies worldwide. In the specific areas of CT (identified in this roadmap), EU companies accounted overall for 11 % of all patents.

- ✓ In the EU, 86% of CEI companies are located in 9 Member States, with Germany, Spain and Italy at the top, followed by France, Sweden, Netherlands, Finland, Belgium and Austria. Large R&D investing CEI companies were found in only 11 Member States and most of these companies were located in Sweden (44%) and Germany (21%).

- ✓ The analysis showed that only a fraction of companies invests in R&D. On this basis, this roadmap presents investment data as proxy indicators for industrial R&D engagement (median investments1), together with patents and involvement in R&D collaboration. Data on R&D investments can be found only for large companies, based on reporting requirements, and without possibility to attribute annual investments to specific technologies. The available data show a high concentration of investments, as in the EU the top

10% of large R&D investors accounted for 86% of total R&D investments and the top 1% for 37%.

- ✓ Based on the best available data collected for this analysis, it seems that EU companies in the construction ecosystem are particularly strong in established technologies, while overall less active in technologies at R&D stage which are the focus of this roadmap. In construction, the patent share of EU companies in CEI was significantly higher than the one in CTs, and the median annual R&D investments for CTs were lower than those for CEI (2020 data). In textiles and EII, EU companies appear more engaged in newer technologies and development, as the median R&D investments per company are higher for CT-related companies than for companies in the CEI context, in textiles even quite significantly.

- ✓ In the international context, however, EU is challenged: In the specific CTs in the EII ecosystem as well as in the construction ecosystem, EU company investments were higher than for the US but below the worldwide median, due to high R&D investments by companies in Asia. Only in the textile ecosystem, EU companies invested above the world and US averages.

- ✓ EU textile companies had the highest investments per company (compared to US and UK, while together with low patenting activity) in certain CTs at higher TRLs related to recycling, the lowest shares in CTs which showed overall low tech uptake2 (e.g. “compressed carbon dioxide as a solvent in dyeing process” or “adding pigments to recycled textiles (electrochemically)”. EU textile companies were well represented in “Digital technologies: collaborative consumption business models” and “Digital authentication/passport for textile products/materials technology” where median investments were medium and highest, respectively. Unlike textile companies, EU construction companies had the lowest median investment and the share of EU companies and patents was low too in “Digital platforms and market places”, but also for “Big data and analytics”, “Artificial intelligence”, and “Blockchain technology”. Similarly, EU EII CETs had also lowest median investments in digital technologies, like digital process development/plant engineering, digital printing on ceramic surfaces and AI and machine learning for discovering new catalysts.

- ✓ In construction, EU companies showed the highest investments in technologies with high tech uptake, such as “BIM-compatible plug-ins and applications/4D BIM”, whereas they had medium investment in medium level of tech uptake technologies, like “Advanced dry recovery”. Construction is the industrial ecosystem where industries outside the ecosystem account for most of the technology related activities and patents, notably because of the high importance of digital technologies.

- ✓ In the EII industrial ecosystem, a smaller share of EU EII companies (among companies from other countries) had the highest median investment in high tech uptake technology, like “Improved separation technologies” and the level of collaborations stood at 23 %, – 21 % and 5 %, respectively. There was medium level of investment in a number of CTs with highest circularity potential, like processes of recycling acids, alkaline, saline wastes, thermochemical recycling of plastic waste/pyrolysis and bio-based processes. Investment was also highest in other high or medium tech uptake technologies, like homogeneous catalysts, improved separation technologies, and reduction of product thickness. Highest investments were also found in low tech uptake technologies, like electrocatalysis, stag utilisation strategies, scrapyard management using sensors & machine learning and pyrometallurgical processes, among other.

- ✓ While the overall number of start-ups related to circular economy and technologies in the three industrial ecosystems was overall lower compared to other sectors, across the three ecosystems, the share of EU based start-ups internationally was the highest at 44%, followed by the US 42% and the UK 12%. China, Japan and South Korea have less than 3 % in the total sample. The EU has the highest number of CEI start-ups in textiles and EII industrial ecosystems, followed by US and UK. There were slightly more US construction start-ups (1,841) than in the EU (1,712).

- ✓ More EU start-ups are at the stage of early growth and late growth stages than in the US, whereas the US has some more at the seed stage (4,722 US companies vis-à-vis 4,524 EU companies). The total funding of CEI start-ups in 2020 in the US was about 2.5 times higher than the funding for EU firms.

- ✓ While linked to circular technologies the US had a similar number of start-ups as the EU, in a majority of technologies it raised significantly more capital and had more highly funded start-ups (i.e. start-ups raising at least EUR 100 million), overall and also in most of the specific circular economy technologies. In CTs related to the textile ecosystem, EU had 42% of start-ups but only 23% of the capital raised. In construction, the corresponding figures were 41% and 20%, while for EII ecosystem they were 41% and 19%.

- ✓ EU programmes and financial instruments include support for the development and uptake of circular industrial technologies for 2021-2027: Horizon Europe (especially EU Partnerships, EIC, specific actions in Horizon Europe Clusters 4, 5 and 6), LIFE (Circular economy and quality of life: EUR 1.3b), the Innovation Fund, InvestEU (Green Transition thematic product (EUR 948 million including R&I) and General debt product (over EUR 3 billion under the R&I&D Window). Based on the available programmes of Member States, EUR 1.4 billion of ERDF is to be invested in circular projects.

- ✓ European partnerships under Horizon Europe like Processes4Planet, the Circular Bio-based Europe Joint Undertaking and Made in Europe play a key role in developing circular industrial technologies and business models driving systemic change with solutions for the full lifecycle of products.

- ✓ A clear innovation pipeline for major technologies seems to be missing. There is no continuous support from early development to uptake of circular technology projects. Support and activities are scattered across different initiatives and programmes, with no apparent link.

- ✓ Public investments into the circular economy are concentrated in few EU Member States (Spain, France, Finland and Netherlands are in the lead.). Most of the Central and Eastern European Member States have no dedicated circular economy strategy, national roadmap or action plan.

- ✓ On average, about 3 % of the overall budget of Recovery and Resilience Plans (RRPs) is dedicated to the circular economy. Austria, Finland and Romania have dedicated over 5%, while Sweden plans to channel between 3-4%. The rest of the Member States have investments that are less than 3% of overall RRP funding.

- ✓ Although the national strategies concern the overall circular economy, some Member States prioritised certain sectors (e.g. Denmark, Finland, Ireland, Netherlands, Poland, Portugal, Slovenia, Spain, and Sweden). Industries most often addressed are construction, agri-food and the bioeconomy, textiles, plastic and transport. Although textiles and construction are highlighted in the national strategies of some Member States, there is no information on the related activities.

FRAMEWORK CONDITIONS

The challenge of moving towards circularity goes beyond the availability of technology[238]. After outlining the results of a business survey of technology developers, this chapter summarises the main framework conditions for the development and uptake of circularity technologies and business models: regulations, non-regulatory barriers including valorisation, standards and technology infrastructures.

4.1. Challenges and barriers for R&D investments in circularity: survey results

A business survey ([239]) of start-up firms that develop circular industrial technologies, explored the main barriers that hinder R&D activities. Figure 4.1 below offers a detailed breakdown of the challenges identified, on a scale from 1 (small challenge) to 5 (big challenge). **'**Lack of appropriate sources of finance' was the biggest challenge for 44% of the respondents and the second biggest challenge for 36%. This finding reflects the issue of access to funding being a common barrier to technology start-ups. Investors might be also risk-averse and less willing to back up technology projects with high economic risks.

'Insufficient flexibility of regulations or standards' was selected as the biggest challenge by 25% of respondents and as the second-biggest challenge by 20% of the respondents. More than half of the respondents give the following challenges a grade higher than 3 out of 5 in the above-mentioned scale:

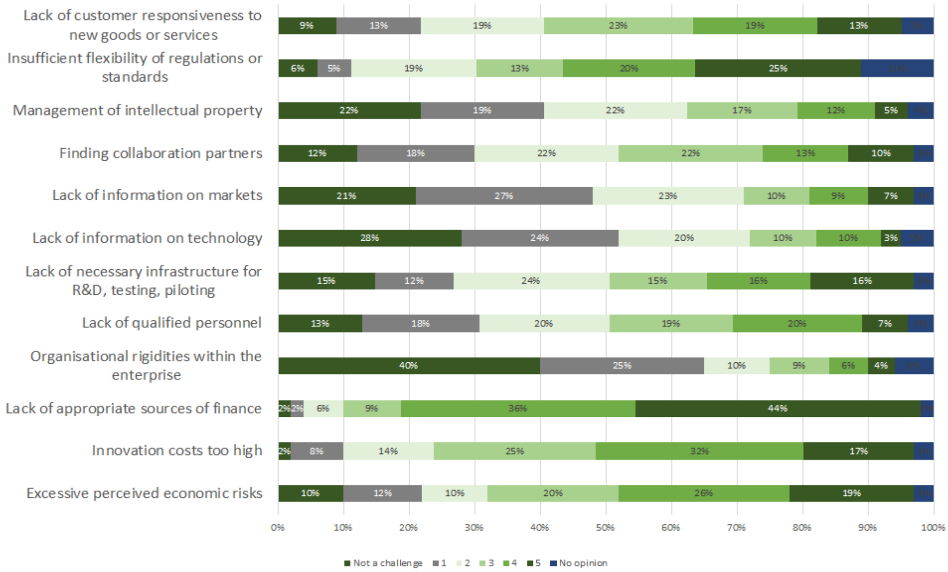
- excessive perceived economic risks;
- innovation costs too high;
- lack of customer responsiveness to news goods or services.

These findings highlight the need for more effective cost management strategies for circular innovation as well as reflect the prevailing market barriers to commercialising circular industrial technologies. These challenges are interlinked with the issue of regulations and standards, which are rated as major barriers by the respondents since better regulations could enable a more favourable economic environment for new circular products and services.

40% of respondents do not consider 'Organisational rigidities within the enterprise' a challenge for their R&D activities. The lack of information on technology is considered a small challenge or not a challenge at all by 54% and 48% of the respondents, respectively. The 'Management of intellectual property' has been considered as a small challenge or no challenge at all by 41% of the respondents.

([238]) European Commission (2018), Research & Innovation Projects relevant to the Circular Economy Strategy, CALLS 2016 – 2017, HORIZON 2020. https://circulareconomy.europa.eu/platform/sites/default/files/h2020_projects_circular_economy_2016-2017.pdf
([239]) Organised in preparation of this roadmap, run between 30 October and 15 December 2021 – see Annex.

Figure 4.1. Evaluation of challenges hindering R&D activities



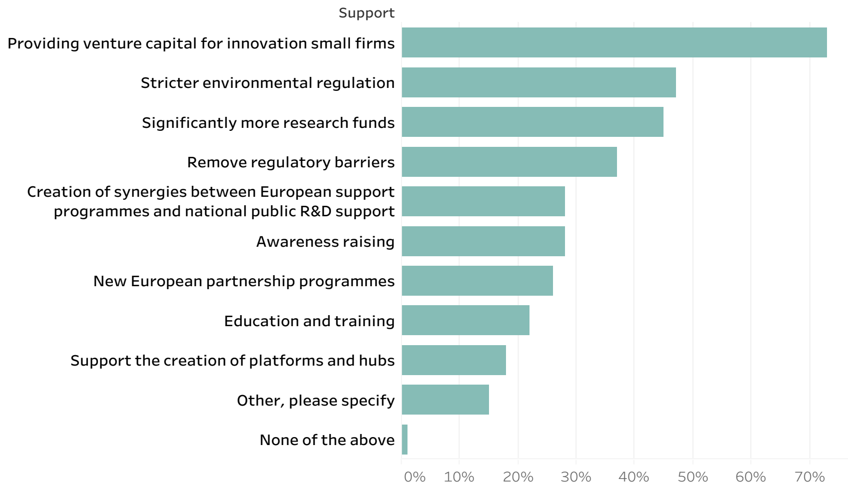
Source: Survey on technology developers, developed by the European Commission, 2021, conducted on 140 firms, between October and December 2021.

Respondents also had the opportunity to highlight other challenges they have encountered, such as:

- lack of funding when moving from proof of technology to proof of business;
- in an EU context, the challenge of accessing public funding at national and EU level;
- national market barriers of low visibility;
- lack of adoption of innovation by market players;
- no clear EU laws on waste management.

The survey asked circular technology start-ups about how EU policy could better support the development of sustainable technologies and solutions. **'Providing venture capital for innovation small firms'** was the most voted support measure by respondents (73%). The second most voted options were, **'stricter environmental regulation'** and **'significantly more research funds',** chosen by 47% and 45% of the respondents, respectively. The next most positive support measure, voted by 37% of the respondents, was removing regulatory barriers.

Figure 4.2 Respondents' opinion on EU policies as a support to developing sustainable technologies and solutions



Source: Survey on technology developers, developed by the European Commission (2021), conducted between October and December 2021 involving 140 respondents.

The results suggest that next to funding, analysed above in Chapter 3, companies consider the flexibility of regulation and standards, removing regulatory barriers that hamper circular technologies, and more widespread use of business models as key factors for the development of R&D activities. Start-ups expect to benefit particularly strongly from the pull factor provided by stricter environmental regulation.

4.2. EU regulatory framework conditions

As one of the main components of the European Green Deal, the European Commission adopted the new **circular economy action plan (CEAP) ([240])** in March 2020. The CEAP aims to ensure that the regulatory framework is streamlined and fit for purpose to achieve a sustainable future, and that new opportunities from the transition are maximised. The plan sets out initiatives that, among other things, facilitate the uptake of circular practices, products and technologies across industries and service sectors. It recognises the role of circular technologies in that they deliver '*material savings throughout value chains and production processes, generate extra value and unlock economic opportunities*.'

The two EU legislative packages on the circular economy proposed by the European Commission in March and November 2022 implement important parts of the action plan delivering substantial pillars for a favourable regulatory framework for a circular economy.

Another key policy initiative that determines the regulatory landscape is **the EU action plan 'Towards a Zero Pollution for Air, Water and Soil' ([241])** It sets out a vision for the EU that by 2050 air, water and soil pollution should be reduced to levels no longer considered harmful to health and natural ecosystems, respecting our planetary boundaries. While mainstreaming pollution prevention, the plan targets a significant reduction of total waste generation and a 50% reduction of residual municipal waste

([240]) COM (2020) 98 final; https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
([241]) COM (2021) 400 final; https://environment.ec.europa.eu/strategy/zero-pollution-action-plan_en

by 2030. In addition, it intends to revise measures that address pollution from large industrial installations to ensure consistency with circular economy policies.

Main EU regulations relevant for all industrial ecosystems

The set of EU waste related regulations ([242]), including the Waste Framework Directive ([243]), Directives on packaging waste ([244]), end-of-life cars, batteries, electronics ([245]), and landfill waste ([246]) (all updated in 2018) have become an important driver for closing the loops in the EU economies. In addition, other waste related regulations are currently being revised, taking into account the ambitions of the CEAP such as addressing packaging waste ([247]) and preventing international shipment of waste ([248]). Furthermore, over 2022-2023, the European Commission is to work on a targeted revision of the Waste Framework Directive. Considering the ongoing efforts across the EU to implement the '2018 waste package' and the waste related regulations (listed above), the Commission has set out the scope of the policy initiative for the targeted amendment of the Waste Framework Directive for 2023 ([249]). All these regulatory measures create, push and pull forces for circular waste management practices and recycling, bringing waste streams back in the loop as a secondary resource. They have set (or plan to set) mandatory targets for certain types of industrial waste reuse, recycling, and other methods of material recovery e.g. for construction and demolition waste, textile waste, commercial waste, non-hazardous industrial waste, and other waste streams ([250]).

The **Industrial Emissions Directive (IED)** ([251]) has been one of the most important pieces of environmental legislation that regulates pollutant emissions and thus promotes clean technologies. The IED aims to reduce harmful industrial emissions in the EU, setting out the requirements, which industrial installations need to fulfil based on the application of best available techniques (BATs) in different sectors ([252]). The Directive applies to large installations of the chemicals, metals and ceramics sectors, as well as cement and textile production. It sets out limit values for atmospheric pollutants and emissions to water and soil through this reference document. In line with the zero pollution action plan and the CEAP, the Commission proposal of April 2022 to revise the IED broadens the scope of the Directive to increase the investments

([242]) https://environment.ec.europa.eu/topics/waste-and-recycling_en

([243]) Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste

([244]) Directive 94/62/EC and amending it Directive (EU) 2018/852; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:l21207

([245]) Directive (EU) 2018/849 amending Directives 2000/53/EC on end-of-life vehicles, 2006/66/EC on batteries and accumulators and waste batteries and accumulators, and 2012/19/EU on waste electrical and electronic equipment

([246]) Landfill Directive – Directive 1999/31/EC, amended by Directive (EU) 2018/850.

([247]) https://environment.ec.europa.eu/topics/waste-and-recycling/packaging-waste_en

([248]) https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_5918

([249]) The 2023 revision of the Waste Framework Directive (2018/851) focuses on facilitating waste prevention and reuse over waste recovery and disposal. The aim is to improve waste management by reducing waste generation including through reusing products or components, reducing mixed waste and increasing preparation for reuse or recycling of waste by improving separate collection. Textile waste is one of the important focus areas of this initiative. It will also assess the feasibility of setting food waste reduction targets.

([250]) Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste

([251]) Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control), OJ L 334, 17.12.2010, p. 17.

([252]) IED is accompanied with the EU Regulation on reporting of environmental data from industrial installations and establishing an Industrial Emissions Portal facilitates (E-PRTR Regulation), that faciliate monitoring of pollution-reduction efforts by enhancing publicly available information on the actual performance of installations.

in new, cleaner technologies that also improve energy use, resource efficiency and water reuse ([253]). Notably in the last few years, driven by the circular economy agenda, relevant technical stakeholders and the European Commission Joint Research Centre have supported the incorporation of more circular technologies into the list of BATs certified under the IED for preventing industrial pollution. The revised rules provide the establishing an Innovation Centre for Industrial Transformation and Emissions (INCITE), monitoring emerging techniques for emission reduction, including through circularity.

As set out in the CEAP, the **Sustainable Product Initiative ([254])** of 30 March 2022 put forward several legislative proposals that aim to make products placed on the EU market more sustainable. This initiative affects all industrial ecosystems. The Commission proposal for a new **regulation on ecodesign for sustainable products** ([255]) is the cornerstone for the EU's approach to more environmentally sustainable and circular products. It will set a wide range of requirements, including on i) product durability, ii) reusability, iii) upgradability and reparability, iv) substances that inhibit circularity, v) energy and resource efficiency, vi) recycled content, vii) remanufacturing and recycling, viii) carbon and environmental footprints, and ix) information requirements, including a digital product passport. It is based on – and will replace – the current Ecodesign Directive 2009/125/EC, which has led to improvements of energy-related products for over a decade. The proposed new legislation has a significant implication for technological development, as all changes promoted by this legislation will require a massive uptake of technical, digital, and artificial intelligence solutions, as well as reinventing managerial, logistical, and customer relationship practices that themselves need to rely on new, smart and cleaner technologies.

Along with the Ecodesign Regulation, and to complement the proliferation of circular products, the Commission adopted a proposal for a **Directive on Empowering Consumers for the Green Transition** (March 2022) ([256]). It is also preparing **legislation on green claims for products ([257])**, which will provide a more harmonised approach for providing reliable environmental information, increasing simplification and reducing administrative burdens, especially for SMEs. These instruments aim to ensure consumers get adequate information on a product's environmental performance, e.g. durability and reparability before purchase. In addition, it will strengthen consumer protection against untrustworthy or false environmental claims and premature obsolescence practices. While these legislative acts do not address technology directly, they help create a favourable environment for circular products and technologies offering these products.

The Commission is now also proposing a **review** of the **Directive on packaging and packaging waste to increase the essential requirements for packaging and establish EU-wide measures and targets for preventing packaging waste** ([258]). This proposal aims at fully harmonising rules on packaging while tackling negative impacts on the environment and health from packaging and packaging waste. It also aims at ensuring i) the free movement of packaging and packaged goods, ii) a market for secondary raw materials that works effectively, iii) support for compliance with

([253]) COM(2022) 156 final
([254]) https://ec.europa.eu/growth/industry/sustainability/sustainable-product-policy-ecodesign_en
([255]) COM (2022) 142 final.
([256]) COM (2022) 143 final.
([257]) https://ec.europa.eu/environment/eussd/smgp/initiative_on_green_claims.htm; adopted on 30 November 2022.
([258]) Adopted on 30 November 2022.

recycling targets for packaging as well as iv) a reduction in the generation of packaging waste, including by reducing (over)packaging.

In doing this, the new rules aim at spurring innovation, rewarding frontrunners, and helping level the playing field on the EU market. The revision will help provide long-term investment certainty, with the first new obligations on industry expected in the second half of the decade.

All of the above legislation adds to the regulatory framework for the development and uptake of circular industrial technologies and business models in the three industrial ecosystems. Table 4.1 provides an overview of the relevant regulations for the three EU industrial ecosystems covered by this industrial technology roadmap.

Table 4.1. Overview of key strategies and regulations relevant for the industry ecosystems

	Strategies	Regulations
Cross-cutting	European Green Deal Circular economy action plan (CEAP) Zero pollution action plan (ZPAP)	Industrial Emissions Directive Sustainable Products Initiative and Ecodesign regulation Set of EU waste regulations Energy Efficiency Directive
Textile	EU ecolabel criteria for textile products	EU strategy for sustainable and circular textiles Textile Regulation ((EU) No 1007/2011)
Construction	Strategy for a sustainable built environment Level(s) - European framework for sustainable buildings	Construction Products Regulation Energy Performance of Buildings Directive
Energy intensive industries	EU Chemicals Strategy for Sustainability 'Towards Competitive and Clean European steel' strategy	Plastics related set of regulations EU Fertilising Product Regulation REACH: Registration, Evaluation, and Authorisation and Restriction of Chemicals

The main sector-specific regulations or parts of regulations relevant for the circular economy are elaborated on further in the sections below.

Sector-oriented policies and regulations

Textile

In textile production, a range of EU policy instruments are already in place and others are expected to come into force that aim to promote not just sustainable production, but sustainable consumption.

Most recently, the **EU strategy for sustainable and circular textiles** was launched in March 2022. The strategy aims to create a greener, more competitive sector that is more resistant to global shocks. The Commission's 2030 Vision for Textiles is that all textile products placed on the EU market are durable, repairable and recyclable, made of recycled fibres, and free of hazardous substances. It envisions that the textile sector becoming stronger and taking responsibility for their products along the value chain with sufficient capacities for recycling and with minimal incineration and landfilling ([259]). Under the new Ecodesign for Sustainable Products Regulation, the Commission is expected to introduce binding design requirements to i) improve textile quality; ii) improve durability, reusability, reparability, and fibre-to-fibre recyclability, iii) increase mandatory recycled fibre content, iv) minimise and track the presence of substances of concern and v) reduce the adverse impacts on climate and the environment

In addition, the setting of reuse and recycling targets for textiles (among other materials) will be considered by the Commission by 31 December 2024, as stated in the **Waste Framework Directive** (as amended by Directive (EU) 2018/851). EU Member States have a legal obligation to introduce separate collection of waste textiles by 2025.

Among the existing measures, a key regulation in the textile industry has been **Regulation (EU) No 1007/2011** on textile fibre names and the marketing of the fibre composition of textile products**. This legislation** requires textile products sold in the EU to carry a label clearly identifying the fibre composition and indicating any non-textile parts of animal origin. Although its main objective was not driven by environmental considerations, the information about composition helps customers make more responsible decisions, and textile tagging can help in the sorting and recycling processes at the end of the lifecycle. Regarding pollution control and saving resources, the BAT Reference Document for the Tanning of Hides and Skins ([260]) has been regulating practices related to tanning processes in the EU since 2013.

Relevant for the EU textile industrial ecosystem, **Regulation (EC) No 1907/2006** ([261]) concerning registration, evaluation, and authorisation of chemicals (the **REACH Regulation**), requires those involved in the textile market to register substances used during the textile production processes in Europe. Moreover, the Commission has also developed voluntary schemes such as the **EU ecolabel criteria for textile products** ([262]) and the EU green public procurement criteria for textile products and services ([263]), which include detailed criteria for environmentally sustainable textile products.

⇒ In 2022, the Commission published the final draft of the revised **BAT Reference Document for the Textile Industry**, as part of the implementation of the Industrial Emissions Directive. While the BAT document for the textile industry covers mature techniques already available

---

([259]) COM(2022) 141 final.
([260]) https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/TAN_Published_def.pdf
([261]) Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.
([262]) Commission Decision 2014/350/EU of 5 June 2014 establishing the ecological criteria for the award of the EU Ecolabel for textile products (OJ L 174, 13.6.2014, p. 45–83).
([263]) EU green public procurement criteria for textiles products and services, SWD (2017) 231 final.

on the market, this roadmap could constitute a building block for the upcoming Innovation Centre for Industrial Transformation and Emissions (INCITE), planned for under the revision of the Industrial Emissions Directive.

Construction

The EU has established a comprehensive legislative and regulatory framework for the construction industry, and recently strengthened efforts to step up green construction. In March 2020, under the Circular Economy Action Plan the Commission committed itself to launch a new **strategy for a sustainable built environment ([264])**. This strategy will aim to ensure consistency across the relevant policy areas such as climate, energy and resource efficiency, management of construction and demolition waste, accessibility, digitalisation and skills.

The New European Bauhaus initiative ([265]) aims to integrate sustainability with social inclusion and aesthetics. It addresses the sustainable built environment, among other objectives. The design phase of the initiative was launched in 2021. The New European Bauhaus is expected to help implement the 'Fit for 55' legislative package by supporting new innovative ideas for energy efficiency of buildings, sustainable infrastructure and integration of renewable energy and nature-based solutions.

Moreover, the Commission launched the revision of the **Construction Product Regulation,** and the proposal was adopted in March 2022. The revision aims to address the sustainability performance of construction products, including the possible introduction of recycled content requirements for certain construction products, taking into account their safety and functionality. According to the revised Regulation, the manufacturers will have to deliver environmental information about the lifecycle of their products. They will also have to respond to several obligations such as giving preference to recyclable/recycled materials, complying with the minimum recycled content obligations, publishing instructions in product databases for use and repair of the products, and designing products facilitating reuse, remanufacturing and recycling ([266]).

Regarding the objective to boost energy performance of buildings, the EU has established a legislative framework that includes the **Energy Performance of Buildings Directive** (Directive 2010/31/EU) and the **Energy Efficiency Directive** (Directive 2012/27/EU), both amended in 2018 and 2019, as part of the **Clean energy for all Europeans** package. Although this legislation is related to energy and not the circular economy *per se*, it is expected to result in reduced resource and material consumption within the industrial ecosystem.

For assessing and reporting on the sustainability performance of buildings, the Commission has developed a voluntary scheme called **Levels ([267])** that applies circular economy principles to the built environment. The scheme has established a

([264]) https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-strategy-for-a-sustainable-built-environment
([265]) COM (2021) 573 final.
([266]) REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL laying down harmonised conditions for the marketing of construction products, amending Regulation (EU) 2019/1020 and repealing Regulation (EU) 305/2011.
([267]) https://environment.ec.europa.eu/topics/circular-economy/levels_en

common language of indicators, which creates a shared framework to understand sustainability performance in buildings.

Energy-intensive industries

In March 2020, the European Commission adopted the **EU chemicals strategy for sustainability**: **towards a toxic-free environment** ([268]). Under the European Green deal, the EU promotes a shift from chemical-by-chemical regulation to addressing chemical pollution broadly in the *zero pollution action plan* and its chemicals strategy. The strategy sets out actions promoting the safe and sustainable design of chemicals, non-toxic material cycles, the greening and digitalising of chemicals production, and innovative industrial production. It supports, among other things i) new technologies and innovation that can replace legacy substances in waste streams, ii) chemical recycling with positive environmental performance from a lifecycle perspective and iii) new business models offering chemicals as a service. The 'safe and sustainable by design' concept will be promoted through a Commission proposal for a Council recommendation and developed further in a strategic research and innovation plan for advanced materials.

Focused on environmental and health protection, the **REACH** ([269]) Regulation came into effect in 2007 and regulates the use of certain hazardous substances in products made and sold in the EU. Under the 2020 strategy, the Commission published the **REACH Restrictions Roadmap**, which aims to prioritise the substances that will be introduced under the REACH Regulation ([270]). It is of great importance and support for the EU's zero pollution targets, while the implication for the circularity under REACH is a challenge: the Regulation can control secondary material (waste) and often block it from being integrated into the production loop, while it prevents the hazardous substances that waste could contain. To enable a favourable environment for circular solutions, careful alignment is needed between EU rules on chemical safety and on those on waste recycling/reuse ([271]).

Most recently, in July 2022, the **EU Fertilising Product Regulation ([272])** entered into force for all Member States. This Regulation will open up the market for new and innovative organic fertilisers that will promote the increased use of recycled nutrients. This would further help the development of the circular economy and allow for a more resource-efficient general use of nutrients, while reducing EU dependency on nutrients from non-EU countries.

Plastics related regulations are very relevant for the circular economy overall and for energy-intensive industries more specifically. While the **Packaging and Packaging**

([268]) COM (2020) 667 final.
([269]) Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.
([270]) SWD (2022) 128 final.
([271]) Joonas Alaranta, Topi Turunen, 'How to Reach a Safe Circular Economy? - Perspectives on Reconciling the Waste, Product and Chemicals Regulation', Journal of Environmental Law, Volume 33, Issue 1, March 2021, Pages 113–136, https://doi.org/10.1093/jel/eqaa016.
([272]) Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003.

Waste Directive (PPWD) ([273]**)** and the **Single Use Plastics Directive (**[274]**)** promote reusability, recyclability, uptake for recycled material, and design for circularity, the presence of hazardous chemical substances in plastics, the circular organic polymer materials will be addressed in the **EU legislative initiative on promoting bio-based, biodegradable and compostable plastics (**[275]**),** currently being prepared.

The Commission's new **policy framework for bio-based, biodegradable and compostable plastics (**[276]**)** aims to clarify the role these plastics can play in delivering on the Commission's commitments for a carbon neutral and circular economy. It will help improve the understanding of the environmental impacts of these plastics over their full lifecycle as well as the applications that are likely to be the most appropriate to deliver genuine environmental benefits as compared to conventional plastics.

Addressing the steel industry, the Commission published the **'Towards Competitive and Clean European steel' strategy** ([277]) in 2021. It sets key objectives for circular steel: i) increased circularity through the electric arc furnace route, ii) circular-by-design approaches, iii) improved scraping and sorting processes, iv) product design, v) quality and safety of secondary materials, and vi) digitalisation as an enabler for green and circular steel. In addition, the Commission will also support the deployment of clean steel technologies with the **European industrial strategy** ([278]) and the **EU Emissions Trading System Innovation Fund** ([279]).

The ceramics industry's sustainability performance in the context of the circular economy is addressed by the **IED**, **REACH**, directives on ceramic articles intended to come into contact with foodstuffs ([280]) and the **PPWD.** Expert discussions related to the IED and BATs are currently considering the integration of circular technologies for the ceramic industry. Health and environmental safety is relevant to REACH and food safety rules when waste materials are integrated into the production loop. With the ongoing revision of the PPWD, the Commission is considering to further define reusable packaging with the expectation that these rules also apply to ceramic packaging ([281]).

Industry feedback on regulations

Beyond the business survey on framework conditions for developing the circular industrial technologies mentioned above, an additional stakeholder consultation at a dedicated workshop brought up a number of specific regulatory issues for industry.

([273]) European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste, OJ L 365, 31.12.1994, p. 10-23. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:01994L0062-20150526
([274]) https://eur-lex.europa.eu/eli/dir/2019/904/oj
([275]) https://environment.ec.europa.eu/topics/plastics/bio-based-biodegradable-and-compostable-plastics_en
([276]) Adopted on 30 November 2022.
([277]) SWD (2021) 353 final.
([278]) https://ec.europa.eu/growth/industry/strategy_en
([279]) Commission Delegated Regulation (EU) 2021/1204 of 10 May 2021 amending Delegated Regulation (EU) 2019/856 as regards the application and selection procedures under the Innovation Fund.
([280]) Commission Directive 2005/31/EC of 29 April 2005 amending Council Directive 84/500/EEC as regards a declaration of compliance and performance criteria of the analytical method for ceramic articles intended to come into contact with foodstuffs (Text with EEA relevance).
([281]) Response to a question from the European Parliament (Question reference: E-000828/2022) Answer given by Mr Sinkevičius on behalf of the European Commission. Available at: https://www.europarl.europa.eu/doceo/document/E-9-2022-000828-ASW_EN.html

- **Permissions and authorisations** to roll out new waste recycling and circular technologies at an industrial scale were identified as barriers due to the strict requirements and the long time it takes to obtain the permission needed under the waste regulation. Industry suggested relevant demonstration projects at industrial scale should be subject only to authorisation requirements for innovation demonstration to speed up the process.

- Stakeholders agreed on the need to step up the **naming and classification of waste** as well as the definition of waste as a secondary raw material. This issue was highlighted in particular by the stakeholders from the ceramic and construction sectors.

- **Differences between national regulations** make the transition towards the circular economy uneven across Member States given the different levels of ambition among countries.

- The stakeholders agreed on the need for more **guidance on how to apply new regulations**. For instance, representatives from the textile sector were uncertain about how to approach upcoming regulations. Companies pointed out that they would benefit from specific training sessions to better understand the implications of new regulations. In particular, start-ups face specific difficulties in complying with new regulations.

- The **low availability of raw materials** such as bio-derived materials and the high prices are hindering more wide-scale uptake of circular raw materials. While the fuel industry is incentivised and supported by various EU directives to use bio-based materials, stakeholders representing the chemical industry highlighted the absence of this type of regulation in their field.

- One specific example of a barrier was given in the context of the steel industry regarding carbon capture and utilisation (CCU) technologies, in particular, the focus on recycling CO_2 for fuel generation. It was suggested that a review of the delegated act on renewable fuels of non-biological origin under the Renewable Energy Directive in terms of its impacts on market deployment would be welcome. To install CCU technology, current rules require a 70% carbon footprint reduction compared to fossils and the use of green electricity. **These conditions were considered to restrict the full market potential** of this technology.

<u>Expected impact of regulations on the circular economy</u>

As seen from the review of the EU regulations above, most of them have recently been adopted or are currently being revised or developed under the CEAP, the ZPAP, and as part of the European Green Deal commitments. **This new generation of regulatory instruments has a stronger focus and a more comprehensive intervention approach with respect to the circular economy. However the impact of these regulations on the transition to circular practices and the uptake of technology remain to be seen in the coming years.**

When looking into the impacts of *earlier regulations,* the evidence shows **different outcomes and impacts** across various types of technologies and industries.

The 2020 evaluation of the **IED (**[282]**)** reported that its impacts on the circular economy were harder to assess. It reported that there is very little information available on the impact the IED may have had in addressing aspects that do not involve emissions such as energy, water and material use, and waste generation. It suggested that the BAT reference document (BREF) process does not systematically include BATs on circular economy areas of resource use, hazardous chemicals use and industrial symbiosis ([283]). The 2021 Impact Assessment concerning the IED revision ([284]) ([285]) had identified shortcomings in addressing resource efficiency or the circular economy. It highlighted the following challenges.

- Provisions on resource-efficient techniques are interpreted and implemented differently across EU Member States.
- BAT conclusions focus primarily on end-of-pipe emissions and, to a lesser extent, on waste generation, rather than on resource consumption per unit of output.
- BATs do not systematically take into account (upstream or downstream) value chain issues that could be addressed by the IED operator. The study suggested that the knowledge of and insights about the environmental effects that occur beyond the installation boundaries as a result of the choices made by a plant's operator might be very limited.
- BAT conclusions do not offer sufficient information to unlock the potential for supporting industrial symbiosis, which would create more resource-efficient value chains.
- Some resource efficiency related information (e.g. production levels, process or product specifications, or the resource use per unit produced) is considered by industry to be confidential business information, which does not allow for an assessment of the extent to which industries have become circular.

Notably, the IED revision ([286]) proposed by the Commission in 2022 has a much stronger focus on addressing the circular economy and on aligning the IED with EU circular economy polices and plans. It suggests widening the Directive's scope, encouraging the development of new technologies, improving resource and energy efficiency, and promoting water reuse, waste prevention and greater circularity. It sets out that the industry '…*permits should establish, where possible, mandatory environmental performance limit values on consumption and resource efficiency levels, including on the use of water, energy and recycled materials, based on the environmental performance levels associated with the best available techniques*…' ([287]).

([282]) SWD (2020)181.
([283]) Assessment in this area was hampered by commercial confidentiality, the reference character of any performance levels established in the BAT conclusions, and other economic incentives already in place.
([284]) Ricardo, VITO, Wood, E3Modelling (2021) Assessment of options for the revision of the Industrial Emissions Directive, Final Report, available at https://circabc.europa.eu/ui/group/06f33a94-9829-4eee-b187-21bb783a0fbf/library/8b3ba7eb-0b4d-4a4d-a6ac-7b8fc0fdfd79?p=1&n=10&sort=modified_DESC.
([285]) SWD (2022) 111final.
([286]) COM (2022) 156 final.
([287]) COM (2022) 156 final, p 26.

Regarding the **EU waste legislation,** it has been evaluated over recent years where implication on the circular economy among many categories of impacts has been assessed ([288]). Studies did not explicitly analyse the technology uptake, but the achievements gained in recycling and material recovery are clearly the results of technological and technical solutions rolled out in Member States. It was shown that the PWWD had already led to increased rates in the recycling of packaging waste (50% to 80%) in most of the Member States over 10 years ago ([289]). Notably, their targets were achieved because the main efforts were focussed on collecting and treating institutional, commercial and industrial packaging waste.

When looking into the relevance of the industrial ecosystems subject to this roadmap, the EU steel industry currently benefits from recycling rates of 85.5% for steel packaging and 76% for aluminium beverage cans ([290]), while the rate of recycling for plastic packaging in the chemical sector is still 32.5% (against energy recovery at 42.6% and landfilling at 24.9%) ([291]). In 2019, thanks to shredding and other technologies, the targets under the Directive on end-of-life of vehicles for recycling (80%) and recovery (85%) were exceeded, reaching 89.6% and 95.1%, respectively. Some 51% of portable batteries sold in the EU were collected for recycling, but not all EU Member States reached the target of 45% and a higher level of material recovery was not always met ([292]). All of these figures have implications for the steel, metals and chemicals industries. At the same time, all evaluation studies conclude that a circular economy concept with its special emphasis on (i) product design for recycling, durability and reparability, (ii) extended producer responsibility with its own collection schemes, (iii) prevention, recycling and recovery as a dominating objective still needs to get better deployment in waste management practices in all industrial ecosystems and related value chains.

2017 **REACH evaluation ([293])** investigated among other things, whether the regulation encouraged R&D and innovation. This relationship proved to be very complex: there were clear signals that REACH promotes substitution of toxic substances by safer and new ones and it was also emphasised how substitution contributes to innovation and a green economy. However, there was little clear evidence that chemical legislation in general terms, is in itself a stimulus to more fundamental development of alternative technologies, new business models and non-chemical solutions, as innovation is predominantly market driven.

A further note on chemical regulation is on the **interface between EU waste and chemical rules** that has been attracting policy attention due to tension between the Waste Regulation, the REACH Regulation and the **Regulation (EC) No 1272/2008** on classification, labelling and packaging of substances and mixtures ([294]). Waste legislation pursuing the circular economy agenda aims to increase the recovery of materials, while product and chemicals legislation sets out restrictions to protect human health and the environment from the substances of concern that these

([288]) The studies included the 2014 *ex post* evaluation of selected waste-related directives – the PWWD, the Directive on end-of-live vehicles and the Batteries Directive (SWD (2014) 209 final), as well as separate studies of the last two Directives from 2021 (SWD (2021) 61 final) and 2019 (SWD (2019) 1300 final).
([289]) SWD(2014) 209 final.
([290]) https://www.metalpackagingeurope.org/sustainability
([291]) https://www.europarl.europa.eu/news/en/headlines/society/20181212STO21610/plastic-waste-and-recycling-in-the-eu-facts-and-figures , based on Eurostat data.
([292]) https://ec.europa.eu/info/news/commission-publishes-evaluation-eu-batteries-directive-2019-apr-09-0_en
([293]) SWD (2018) 58 final
([294]) COM (2018) 32 final.

recovered materials may contain. Achieving a sustainable circular economy requires a level playing field between waste-based and virgin raw materials in order to enable waste-based materials to be used while taking into account their potential impacts on human health and the environment. The experts suggest that in the longer term, the aim should be to erase the border between waste and chemicals regulation and create a single regime for regulating materials and their flow ([295]). Technological solutions can also be important as they provide possibilities for more advanced solutions in the form of circular product design for easy and safe recovering, recycling and remanufacturing.

Summary of main conclusions

- Single market rules, which provide harmonised legal requirements to be observed in the lifecycle of products from the EU industrial ecosystems for textiles, construction and energy-intensive industries (e.g. for production, waste, emissions or recycling of materials), are gradually evolving.
- The Green Deal has strongly accelerated this evolution since the circular economy and zero pollution action plans. Beyond the traditional waste-related regulations, the new legislation will start covering more comprehensively all phases of the lifecycle of relevant products, which will increase the need for innovative industrial technologies and business models.
- These needs will have to be addressed through accelerated development of innovative circular industrial technologies and business models.
- At the same time, the new harmonised rules are expected to help create a better level playing field with reduced regulatory barriers between Member States.
- Targeted information exchange and best practices could help implement the new ambitious policies in the Member States, in particular in those for whom the proposed targets will be particularly challenging.
- Industry, in particular small companies and start-ups will benefit from information and advice which will help them innovate and bring their business operations in line with the future performance requirements.

4.3. Non-regulatory framework conditions

Technological progress is not only incentivised by regulations and political objectives. A favourable environment for developing innovative circular technologies and business models also depends on i) framework conditions like the availability of skills and relevant infrastructure, ii) behavioural changes by consumers and businesses, iii) the valorisation of research and innovation results, and iv) a common

([295]) Joonas Alaranta, Topi Turunen, (2021) How to Reach a Safe Circular Economy? — Perspectives on Reconciling the Waste, Product and Chemicals Regulation, Journal of Environmental Law, Volume 33, Issue 1, March 2021, Pages 113–136, https://doi.org/10.1093/jel/eqaa016 .

understanding between researchers and industry about the characteristics of new circular technologies through standards.

The areas of concern raised by the stakeholders during the workshop on non-regulatory framework conditions included: skills (e.g. lifelong learning), data sharing, SMEs, policy incentives, and lifecycle perspective during the whole value chain.

Focus on human capital: skills and consumer behaviour

A highly skilled, knowledgeable, entrepreneurial, and motivated workforce is one of the core factors for securing a dynamic, innovative and economically sustainable economy. Research, development and innovation is driven by industry and the research community. This includes large companies, SMEs, start-ups, universities, research organisations and labs under public and private mandates as well as technology infrastructures.

The transition to the circular economy will depend to a large extent on the knowledge and skills available at these organisations and on newly educated and skilled graduates supplied by educational institutions. Under the Circle Economy initiative ([296]), the belief is put forward that future jobs in the circular economy are likely to include a combination of more traditional skills, e.g. manual, and more novel circular skills, e.g. those in modular design and the analysis of material compositions. Soft skills for collaborating across sectors and service-related skills will be just as important as hard skills for programming, operating and repairing equipment.

Another important ingredient in making circularity work is consumer and business behaviour. Establishing a circular economy in the EU calls for a wide-scale transformation of production and consumption systems. Production systems respond to and shape consumer demand through the products offered and how they are marketed. Informed consumer choices can potentially shape decisions made by producers upstream and downstream in product supply chains ([297]).

Valorisation of R&I results for innovative circular technologies and business models

Boosting knowledge valorisation is essential for rapidly delivering new solutions to global challenges and opportunities created for the green and digital transformation of industry. Leveraging the full value of intellectual assets generated by R&I activities requires organisations to carry out such activities to manage a wide range of intellectual assets, from those that can be legally protected (patents, copyrights, trademarks, etc.) to others that could be used in valorisation activities (data, know-how, prototypes, processes, practices, technologies, inventions, software, etc.).

Knowledge valorisation involves creating value from knowledge by linking different areas and sectors. It transforms data and research results for the greening of industry into sustainable products and solutions that benefit society.

([296]) Circle Economy (2022), The Circularity Gap Report 2022.
([297]) European Environmental Agency: Enabling consumer choices for a circular economy — European Environment Agency (europa.eu)

On 9 August 2022, the European Commission adopted a proposal for a Council Recommendation on the guiding principles for knowledge valorisation (COM(2022)391 final) ([298]) to i) increase social and economic value from knowledge and ii) transform data and research results into sustainable products and solutions. The recommendation will align policy principles and measures for national, regional and local policy makers to maximise the transformation of R&I results into solutions that benefit society. To help implement the guiding principles and in line with ERA Action 7 ([299]), the Commission is developing, together with a wide range of stakeholders, codes of practice on the smart use of intellectual assets and on standardisation for researchers.

Codes of practice on the smart use of intellectual assets and on standardisation for researchers

Improving access to and the sharing of intellectual assets, as envisaged in the EU intellectual property action plan ([300]), is key to accelerating the uptake of innovative solutions which can help complete the ongoing green transition and reach the goals of the CEAP. Europe is one of the main global innovators in the field of plastics circularity ([301]).

The code of practice on the smart use of intellectual assets provides guidance for those involved in research and innovation (R&I) to successfully manage their assets with a view to increasing the socio-economic impact of research results and innovative technologies and accelerating the use of knowledge, therefore giving R&I players a competitive market advantage. The code encourages those in the R&I ecosystem to adopt an intellectual assets management strategy that identifies the environmental and societal impact of its practices and that includes sustainability provisions.

([298]) Developing guiding principles for knowledge valorisation was proposed in the Commission Communication on ‘A new ERA for Research and Innovation’ of September 2020 and included in the ERA policy agenda for 2022-2024 endorsed by Council Conclusions on the Future governance of the ERA in November 2021. The guiding principles were co-created with the ERA Forum subgroup composed of nationally nominated experts.

([299]) The new ERA Policy Agenda, annexed to the Council conclusions on the ERA governance, sets out 20 concrete ERA actions for the period 2022-2024 to contribute to the priority areas defined in the Pact for Research and Innovation. Action 7 is ‘Upgrade EU guidance for a better knowledge valorisation’.

([300]) Communication ‘Making the most of the EU’s innovative potential - An intellectual property action plan to support the EU’s recovery and resilience’ COM/2020/760

([301]) See Chapter 3 above and Patents for tomorrow’s plastics (epo.org)

Box 4.1 | Intellectual assets that help in the transition to a circular European economy

The network NETVAL runs the portal Knowledge Share, which gives easy access to information about patents and technologies developed at universities and public research bodies in Italy. It aims to enable the interaction between university technology transfer offices, academic researchers and industry partners. It has a dedicated webpage on patent information on zero waste and recycling technologies.

The VTT LaunchPad is an in-house business incubator that aims to create fundable spin-off companies built on technologies developed by the researchers working at the VTT Technical Research Centre of Finland. To be accepted into the VTT LaunchPad, the business idea must 1) be based on VTT's IP rights that can be spun off, 2) show market potential and be scalable, 3) benefit the customer and society, 4) be built on a demonstrated technology, and 5) be run by a team that can be formed for a fundable spin-off venture. VTT recently supported a new company in revolutionising circular plastics recycling through a process that can affordably convert most of the world's waste plastics back to usable virgin grade materials an infinite number of times.

The **EU Knowledge Valorisation Platform (**[302]**)** provides an interactive space for stakeholders for cross-border peer learning, sharing best practices ([303]), co-creating further guidance and staying connected to EU developments in knowledge valorisation. The platform stimulates cooperation across borders and sectors by involving all relevant players, from academia and industry to public policy makers and civil society. Developers of circular industrial technologies and business models and other interested parties can benefit from teaming up with universities and research organisations in their outreach and valorisation activities to learn about newly developed technologies and open up new business opportunities.

Box 4.2 | Best practice examples from the EU knowledge valorisation platform that promote dissemination and uptake of new technologies and models for circularity

Circular business support management is provided by the University of Applied Science in The Hague, Netherlands. In cooperation with potential users, it develops a sustainable protocol for (facility) professionals to stimulate sustainable behaviour and reduce raw material flows in facility management.

Standardisation for innovative circular technologies

With the 2022 EU standardisation strategy ([304]), the Commission has laid the basis for a stronger use of standards to address societal needs and strengthen the competitiveness of EU industry. The strategy underlines the importance of Horizon Europe and its partnerships, such as joint undertakings, as well as the ERA industrial technology roadmaps, to anticipate standardisation needs and link strategic priorities with pre-normative research.

European standardisation priorities are now carried out by a new Chief Standardisation Officer, who is supported by an EU excellence hub on standards composed of Commission departments. As part of the EU standardisation strategy,

([302]) Knowledge Valorisation Platform | European Commission (europa.eu)
([303]) Repository of best practice examples is available on the Knowledge Valorisation Platform, which is continuously open for submissions of new best practice examples.
([304]) An EU strategy on standardisation setting global standards in support of a resilient, green and digital EU single market; COM (2022) 31 final.

the Commission is also developing better tools for anticipating future standardisation needs in key policy areas.

Standards allow a common language to be used in the different steps of the circular economy process: avoid waste, reuse, remanufacture, refurbish, maintain, recycle. Each step includes a lifecycle approach. At each step, **standards are required to ensure that the process to implement circularity** will be safe and efficient in the way a product is 'collected' and 're-worked' to extend or renew its use.

Some of these standards are usually developed for processes and geared towards general use (e.g. the International Standards Organisation (ISO) or CEN), while others are more geared towards the electrical component (Cenelec, or International Electrotechnical Commission (IEC)). However, they are often interconnected to ensure full convenience, safety and security.

As outlined above in Chapter 4.1, for instance, the Sustainable Products Initiative ([305]) establishes a legal framework, so all products produced or placed on the EU market **stay in line with technical standards** for sustainability. It aims to make products fit for a climate-neutral, resource-efficient and circular economy, reduce waste and **ensure that the performance** of frontrunners in sustainability progressively becomes the norm.

In addition, **standards in circularity** as part of the Green Deal are promoted by the new **ESG** (environmental, social, and governance) and **UN Sustainable Development Goals** (**SDGs**) criteria. They are also promoted by the **EU Sustainable Finance Taxonomy** ([306]), as they all require standards and labels to ensure the greenness of the actions, where circularity is the key milestone. This taxonomy highlights three groups of sustainable activities: 'low-carbon' activities, which are environmentally sustainable; activities 'in transition' towards a zero-emission economy; and 'enabling' activities, which allow those in the first two categories to deliver low-carbon performances or significant reductions in emissions ([307]).

([305]) https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12567-Sustainable-products-initiative/public-consultation_en
([306]) https://knowledge4policy.ec.europa.eu/publication/sustainable-finance-teg-final-report-eu-taxonomy_en
([307]) CEN-CENELEC Industry Advisory Forum (2021), Circularity standards & related Product Data standards.

Box 4.3 | How standards are developed

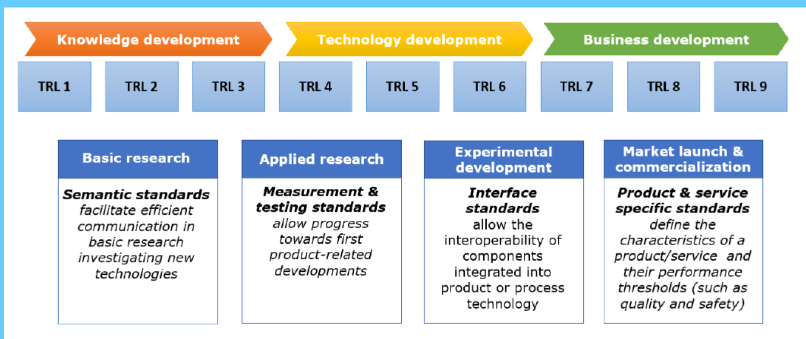
A standard is a formal, voluntary document that sets out the specifications for terminology, products, systems, processes or services. Standards can help make different parts of an infrastructure work together or systematise processes, e.g. energy efficiency or waste reduction. Standards can lift barriers to the uptake of green technologies and materials, by specifying tests, or providing robust definitions that avoid misleading environmental claims. It is important that scientists can communicate and exchange their research results by using agreed vocabulary, definitions and units. It is essential to undertake repeatable measurements and comparable experiments.

To be suitable for providing the basis for a standard, a research outcome needs to be applicable to, and be of use for, one or more established groups of stakeholders: researchers, industry and/or regulators. Transferring research results into one or more standards can have a significant impact on how industry and other researchers use these results subsequently, by making clear not only what the research outcomes are but also how to implement them.

For the rapidly emerging innovations, this warrants intensive efforts to strengthen the use of research standards in the knowledge development phase and to ensure the further development of standards for business development. A strong and coherent approach for the wide-scale development of such standards can significantly help improve the framework conditions for innovation driving the circular economy.

Although standards become more important when an innovation matures (and thus reaches a higher TRL), they can support all development stages, as shown in the figure below.

Figure 4.3. Type of standards dominant in different phases of the innovation chain and TRLs



Standards, in contrast to patents, are accessible to everyone at low cost and are more likely to be broadly implemented because all (interested) stakeholders have reached a consensus. Furthermore, standardisation is a cooperation and transfer process because it represents a common platform for different players with diverse backgrounds, i.e. research, industry, public administration, and social interest groups, e.g. consumers. Typically, many different groups and organisations develop and publish standards in a cooperative manner, using various degrees of consensus in their preparation and approval.

Formal standards are standards that are approved or adopted by national, regional or international standards bodies, while informal standards are published by other standards development organisations. At the European level, standards are developed by the European standardisation organisations officially recognised under Regulation (EU) No 1025/2012 on European standardisation: the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardisation (CENELEC) and the European Telecommunications Standards Institute (ETSI).

Due to the level of transparency and public involvement, national standards take on average 18 months to develop. For European and international standards, the time needed for development increases to more than 2 years. This is because national standardisation bodies have to develop a position in their mirror committees that vote at national level to support a European or international standard.

Standardisation activities in research projects usually focus on creating pre-standards (such as the CEN/CENELEC Workshop Agreements (CWAs)). In most cases, a pre-standard is a public, freely available document that describes products, systems or services by defining characteristics and requirements. A pre-standard is characterised by the fact that, compared with a standard, it reflects the consensus of interested parties and is not developed based on the national delegation principle. In contrast to a standard, the pre-standard is developed in a workshop (temporary committee) with advice from a standardisation organisation. After the committee adopts the pre-standard, the standardisation organisation publishes it.

Standardisation use cases as examples for valorisation of research results in circular technologies and business models

Some Member States and third countries are also driving a common understanding of circular and sustainable economies:

- The voluntary standard XP X30-901, developed by the French national standardisation body AFNOR, proposes a matrix ([308]) covering the seven areas of action of the circular economy: i) sustainable procurement, ii) ecodesign, iii) industrial symbiosis, iv) functional economy, v) responsible consumption, vi) extension of service life, and vii) the effective management of materials and products at the end of their lifecycle.

- Together with the German Federal Ministry for the Environment, German standardisation bodies DIN, DKE and VDI announced the German Standardisation Roadmap Circular Economy ([309]) scheduled for January 2023. It aims to provide an overview of the current state of standardisation in the field, describe the requirements and challenges, and identify possible specific needs for action for future standards and specifications.

- In 2017, British Standards, the UK's national standardisation body published the first practical framework and guidance (BS 8001) of its kind for organisations to implement the principles of the circular economy ([310]). With its universal character, guidance can be applied to any organisation, regardless of location, size, sector and type. It provides practical ways to secure smaller 'quick-wins', right through to helping organisations rethink more thoroughly how their resources are managed to improve financial, environmental and social benefits.

The ISO and the IEC are key to developing international standards. They have created technical committees (TCs) to address circularity issues.

- ISO/TC 323 *Circular Economy* aims to cover all aspects of a circular economy including public procurement, production and distribution, end of life as well as wider areas such as behavioural change in society, and assessment, e.g. some kind of circularity footprint or index. Currently six standards are being developed.

- IEC/TC 111 *Environmental standardisation for electrical and electronic products and systems* prepares key cross-cutting standards that ensure electrical and electrotechnical products are designed with the environment in mind, taking into account the circular economy perspective.

- The *Circular Economy Topic Group* (CE-TG) within the *Strategic Advisory Body on Environment* (SABE) advises on and coordinates all CEN and CENELEC standardisation activities related to circular economy ([311]). CE-TG was founded in 2020 and is mainly tasked with coordinating ongoing and new

---

([308]) https://circulareconomy.europa.eu/platform/sites/default/files/circular_economy_and_voluntary_standard.pdf
([309]) https://www.din.de/en/innovation-and-research/circular-economy/standardisation-roadmap-circular-economy
([310]) https://www.bsigroup.com/en-GB/standards/benefits-of-using-standards/becoming-more-sustainable-with-standards/BS8001-Circular-Economy/
([311]) https://www.cencenelec.eu/areas-of-work/cen-cenelec-topics/environment-and-sustainability/environment/

standardisation activities in the field of circular economy. It does **not develop standards**. Instead, it develops guides or other documents/tools intended to support the CEN and CENELEC standardisation community in implementing circular economics in their standards. As of 2021, SABE CE-TG recognises 210 standards or initiatives relevant to the circular economy and 25 CEN and CENELEC TCs with standards that support the circular economy, in the fields of plastics, electronics, batteries, textiles and construction.

The rolling plan for ICT standardisation ([312]) focuses on ICT standardisation actions that can support EU policies. It is the result of an annual discussion involving a wide range of interested parties as represented in the European multi-stakeholder platform on ICT standardisation. Standardisation actions identified in this document are complementary to other instruments, in particular the annual EU work programme for European standardisation. A specific chapter is dedicated to the circular economy ([313]), and includes a summary on relevant policy and legislation, a set of requested standardisation actions, as well as an overview of ongoing standardisation activities in the area.

Box 4.4. Horizon 2020 success stories on standards linked to circularity

The ECOBULK project (Horizon 2020 project funded under Grant Agreement 730456) focused on demonstrating that reusing, upgrading, refurbishing, and recycling composite products in the automotive industry is possible, profitable, sustainable and appealing.

ECOBULK submitted and proposed two CWAs based on the work carried out specifically for design for circularity and composite recovery in the automotive industry:

- CWA17806:2021: Design Circular Framework Setting. Composite recovery design solutions in the automotive industry. This document sets out a circular design approach with the aim of delivering long-lasting and modular products in the automotive industry that will i) be easy to upgrade, refurbish and reuse, ii) be aligned with the EU's new regulations and iii) help step up the transition to a circular economy.

- CWA17807:2021: Dismantling methods and protocols in a Circular Economy Framework. Composite recovery in the automotive industry. This pre-normative document presents the strategies and technologies for collection and material recovery (plastics, foam, glass, fibres from vehicle parts) for (re-) manufacturing, in addition to parts that are already being recycled.

The recovery and valorisation of bio-waste are the focus of several EU-funded projects, such as VALUEWASTE (Horizon 2020 project funded under Grant Agreement 818312), which proposes an integrated system for urban bio-waste valorisation which would lead to key strategic products being produced for the EU.

The results of the project are feeding into the CEN Workshop on key factors for the successful implementation of urban bio-waste selective collection schemes (KEY-BIOWASTE). The primary objective of this new CEN workshop is to propose ways for cities to improve the quality of the selectively collected bio-waste, enabling robust bio-waste valorisation processes to be developed.

([312]) https://joinup.ec.europa.eu/collection/rolling-plan-ict-standardisation/rolling-plan-2022
([313]) https://joinup.ec.europa.eu/collection/rolling-plan-ict-standardisation/circular-economy-0

Current standards supporting circularity in energy-intensive industries

Steel manufacturing

Recent studies have investigated potential technological solutions to separate copper from steel scrap – which is essential to making steel recyclable - using a combination of techniques including improved physical separation, vacuum distillation, slagging, and solid scrap pre-treatments. However, significant work is still needed in this area ([314]).

To support the responsible sourcing and production of steel and to maximise the contribution steel can make towards achieving a sustainable society, the **Responsible Steel standard** was developed and published in 2019. This standard is applicable globally to all types of steel production, including basic oxygen furnace (BOF) steelmaking and electric arc furnace (EAF) steelmaking. It includes requirements that address, for example, the sourcing of raw materials for producing steel, which has significant social and/or environmental impacts. Such raw materials include mined materials, refined metals for alloys and coatings, and pre- and post-consumer scrap metal for recycling ([315]).

Waste electrical and electronic equipment is an important source of metals, including rare metals. This aspect has received great attention along with the discussion of strategic autonomy and critical raw materials. The **Waste Electrical and Electronic Equipment (WEEE) Directive (2012/19/EU**) refers to certain standards series ([316]).

The standard EN 50614:2020 outlines the requirements for preparing the reuse of waste electrical and electronic equipment and the technical specification TS 50625-5 provides guidance of the end-processing of WEEE fractions for copper and precious metals. The EN 50574 standards series specify collection, logistics & treatment requirements for end-of-life household appliances containing volatile fluorocarbons or volatile hydrocarbons.

Although the WEEE Directive contains some requirements to be fulfilled by treatment operators, most of these are not very specific and they do not contain as much detail as the general treatment standard EN 50625-1 coupled with its accompanying technical specification on depollution TS 50625-3-1. In addition, there are more specific treatment standards: EN 50625-2-1 (lamps), EN 50625-2-2 (CRTs and FPDs), EN 50625-2-3 (heat-exchange equipment) and EN 50625-2-4 (for photovoltaic panels), each of which has its own associated technical specification – TS 50625-3-2, TS 50625-3-3, TS 50625-3-4 and TS 50625-3-5, respectively.

The technical specification, TS 50625-4, sets out requirements for collecting WEEE and the logistics associated with transporting that WEEE to a treatment facility.

([314]) Finding the Most Efficient Way to Remove Residual Copper from Steel Scrap, 2019. Daehn et al., Metallurgical and Materials Transactions B Vol 50B, 1225-1240.
([315]) Responsible Steel Standard Version 1.0, 2019.
([316]) https://www.tic-council.org/application/files/7416/3844/4691/Presentation_Implementing_the_Circular_Economy_Action_Plan_-_How_to_avoid_greenwashing_draft.pdf

Chemical industry

Circularity in plastics

Several of the standardisation activities may be promoted by the Circular Plastics Alliance ([317]), which brings together stakeholders from industry, academia and public authorities, covering the full plastics value chains in the EU, to boost the EU market for recycled plastics to 10 million tonnes by 2025 (+150% compared to 2016).

In the field of plastics, the **European technical committee for plastics (CEN/TC 249)** set up various working groups relevant for circular technologies:

- WG 11 Plastics recycling
- WG 26 Agricultural plastic products Use, removal, collection & recycling
- WG 13 Wood Plastics Composites (WPC)
- WG 24 Environmental aspects
- WG 9 Bio-based and biodegradable plastics.

CEN/TC 249/WG 11 'Plastics recycling', the committee develops standards for the characterisation of plastics recyclable polymers (PVC, PET, PP, etc.) and wastes. Furthermore, there are also work programmes on sampling and testing methods. The recently established **WG 26 'Agricultural plastic products - Design-for-recycling, use, removal, collection and recycling'** will develop standards on design for recycling of products made of plastics and used in the agricultural production process.

Furthermore, over the next 3 years, CEN/TC 249 will develop standards mandated through the upcoming **Standardisation Request on 'Plastics recycling and recycled plastics'**. These standards will address quality grades for sorted plastics wastes, characterisation of recyclable polymers, and quality characteristics for integrating plastic recyclable polymers into products, as well as design for recycling of agricultural, construction, packaging, and automotive plastic products.

Deliverables already achieved under CEN/TC 249 support the circular economy by addressing recycled plastics. These include ([318]):

- Sample preparation (CEN/TS 16011:2013), and sampling procedures for testing plastics waste and recyclates (CEN/TS 16010:2013);
- Standards on characterisation of polystyrene (EN 15342:2007), polyethylene (EN 15344:2007), polypropylene (EN 15345:2007), poly-vinyl chloride (EN 15346:2014), polyethylene terephthalate (EN 15348:2014) recyclates and plastics wastes (EN 15347:2007);
- EN 15343:2007, which deals with traceability, assessment of conformity and recycled content; and
- CEN/TS 16861:2015, which deals with the determination of selected marker compounds in food grade recycled polyethylene terephthalate (PET).

([317]) https://ec.europa.eu/growth/industry/policy/circular-plastics-alliance_en
([318]) https://www.cencenelec.eu/media/CEN-CENELEC/News/Publications/standardisation_circular_economy_closing_the_loop.pdf

Circularity in secondary cells and batteries

The technical committee of CENELEC for secondary cells and batteries (CLC/TC 21X) develops European standards for electric vehicle batteries. This technical committee will soon be involved in the standardisation of the 'second life' lithium-ion batteries. CLC/TC 21X and its international counterpart, IEC/TC 21, contribute to circular technologies by standardising technical performances associated with qualification tests of cells, modules, and batteries and the safety risk consideration for their 'second life' after their use in electric vehicles.

Box 4.5 | Circular business models for solar power, batteries and photovoltaics

CIRCUSOL experts joined the Working Group that developed standard IEC 63330 related to the requirements for repurposing secondary batteries. They contributed with a sorting method, the development of which was based on CIRCUSOL research. CIRCUSOL experts also joined the Belgian mirror group for battery standards, BEC-CEB TC21, and the 'CEN/CLC eM-CG – ad hoc group batteries'.

The battery normalisation plan is supporting the new European Battery Regulation. Thanks to contributions from CIRCUSOL, a specific working item for developing a particular standard complements the agenda.

CIRCUSOL drafted a technical report as a work item in IEC TC82 (solar photovoltaic energy systems) as a first step towards developing standards for PV reuse. The work item project team has been appointed and is led by a CIRCUSOL consortium member (CIRCUSOL – H2020 #776680).

Standards supporting circularity in construction industry

Many **technical committees** worldwide are enthusiastic about the circular economy in the construction sector ([319]). Standardisation in this field is still in its early stages. Therefore, harmonisation and rapid adoption are prerequisites to trigger this virtuous circle.

<u>Construction and demolition waste</u>

The EU met the target for construction and demolition waste (CDW) set by the Waste Framework Directive ([320]), but some Member States still have to improve their recovery performance to meet it. Currently, the recovery-rate indicator includes backfilling, which is below recycling according to the waste hierarchy. Therefore, this indicator must be updated to reflect the actual amount of recycled or reused materials. **Standard methods for measuring CDW generation and recovery performance** across the EU must be developed to prevent Member States from interpreting the definitions of recycling and backfilling differently ([321]). Similarly, Member States should

([319]) ISO 20887:2020 'Sustainability in buildings and civil engineering works – Design for disassembly and adaptability – Principles, requirements and guidance'.
([320]) Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.
([321]) Paola Villoria Sáez, Mohamed Osmani; A diagnosis of construction and demolition waste generation and recovery practice in the European Union, (2019). Journal of Cleaner Production.

harmonise the inconsistent definitions of waste and secondary raw material, which sometimes differ even between regions in the same country.

Concrete

Options for circularity in the concrete industry include the reuse of concrete components, the use of concrete waste as aggregates for fresh concrete and the reuse of cement paste into cement, concrete or binders ([322]).

The use of recycled aggregates for producing fresh concrete is a well-known technology, extensively tested on a small scale, but it is struggling to be taken up in the market. One of the main hurdles is the mistrust of secondary raw materials for construction, which are often considered second-class products. The valorisation of the supply chain of recycled aggregates requires standards that set transparent procedures, available to the public authorities and the public in general, especially for public procurement. The **lack of a harmonised definition for backfilling in the Waste Framework Directive** results in Member States having different interpretations and inconsistent definitions of what is waste and what is a secondary raw material. This presents an obstacle to activating this virtuous circle.

Feeding materials (including CDW) into cement kilns is not straightforward from a chemical ([323]) and a standardisation ([324]) point of view. CDW is not set out under **current standards** as an additional constituent to clinker in cement (**EN 197-1:2011** and **EN 197-5:2021)** or to cement in concrete (**EN 206:2013+A2:2021**). Yet, the use of CDW for cement production remains the topic of further research and (demonstration) testing ([325]) also in industry ([326]). The use of upcycled fillers from other industrial processes (ground blast furnace aggregates, slag, silica fume, and fly ash) is widespread and is a good example of **industrial symbiosis**, especially for manufacturing high-performance concrete.

Construction

In November 2020, the Subcommittee on the **circular economy in the construction sector (CEN/TC 350/SC 1)** was established with the following remit:

([322]) Giorgi S. et al. Drivers and barriers towards circular economy in the building sector: Stakeholder interviews and analysis of five European countries policies and practices, Journal of Cleaner Production, https://doi.org/10.1016/j.jclepro.2022.130395.

([323]) JRC (2013), Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide - Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control).

([324]) VEEP, D7.6 Report on the contribution to the Standardisation system, 31 March 2021, https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5db493d7a&appId=PPGMS

([325]) VEEP, Cost-Effective Recycling of CDW in High Added Value Energy Efficient Prefabricated Concrete Components for Massive Retrofitting of our Built Environment, H2020 project nr: 723582, https://cordis.europa.eu/project/id/723582; BNB, Beton naar hoogwaardig beton, 2014 - 2020 INTERREG V-A Belgium - The Netherlands (Vlaanderen - Nederland), https://keep.eu/projects/19326/Beton-naar-hoogwaardig-beto-EN / ; RECEMENT, RE-generating (raw) materials and end-of-life products for re-use in CEMENT/Concre, ERA-MIN-2018_77, https://www.era-learn.eu/network-information/networks/era-min-2/era-min-joint-call-2018/re-generating-raw-materials-and-end-of-life-products-for-re-use-in-cement-concrete

([326]) https://www.holcim.com/who-we-are/our-stories/net-zero-emissions-decarbonated-alternative-raw-materials ; https://www.heidelbergcement.com/en/pr-16-05-2022

- specifying circular principles, guidelines, and requirements to facilitate the transition to a more sustainable circular economy, including tools and processes to achieve this;

- covering design to deconstruction and end-of-life scenarios in all stages of current and subsequent lifecycles, which applies to new and existing construction works (buildings and civil engineering works), including their products, materials and components.

The Subcommittee deals with technical issues on circularity, as well as environmental, economic and social challenges. This work will take into account **CEN/TC 350 (sustainability of construction works)** standards and consider the work of existing committees on subjects that may support the circular economy in the construction sector, e.g. ISO/TC 323 'Circular economy' and **CEN-CLC/JTC 10 'Material efficiency aspects for products in scope of Ecodesign legislation'**, which includes European Commission initiatives.

There are currently two working groups under CEN/TC 350/SC 1 ([327]), one focusing on **'framework, principles and definitions'**, and the other on **'gap analysis, conclusions and recommendations'.** General standards on circularity can be applied to the ceramic manufacturing sector to measure circularity performance and provide information to consumers. Some examples are:

- Environmental labels and declarations – Type I environmental labelling ISO 14024:2018
- Environmental labels and declarations – Self declared environmental claims (Type II environmental labelling) ISO 14021:2016
- Environmental labels and declarations – Type III environmental declarations ISO 14025:2006
- Environmental management – Eco-efficiency assessment of product systems ISO 14045:2012
- Environmental management – Water footprint ISO 14046:2014
- Environmental management – Material flow cost accounting ISO 14052:2017.

<u>Material efficiency</u>

Between 2019 and 2020, the CEN-CENELEC Joint Technical Committee 10 **on material efficiency** published a series of eight standards ([328]) that provide the general principles to consider when addressing material efficiency in energy-related products. These cross-cutting guidance documents focus on durability, remanufacture, repair,

([327]) https://standards.cencenelec.eu/dyn/www/f?p=205:7:0::::FSP_ORG_ID:2868394&cs=1E483B462A3001B254B70E3969CA6730E

([328]) 'General method for the assessment of the durability of energy-related products' EN 45552:2020; 'General method for the assessment of the ability to remanufacture energy-related products' EN 45553:2020; 'General methods for the assessment of the ability to repair, reuse and upgrade energy-related products' EN 45554:2020; 'General methods for assessing the recyclability and recoverability of energy-related products' EN 45555:2019; 'General method for assessing the proportion of reused components in energy-related products' EN 45556:2019; 'General method for assessing the proportion of recycled material content in energy-related products' EN 45557:2020; 'General method to declare the use of critical raw materials in energy-related products' EN 45558:2019; and 'Methods for providing information relating to material efficiency aspects of energy-related products' EN 45559:2019.

recyclability, reused components, recycled content, critical raw materials and information ([329]).

([329]) https://www.iec.ch/blog/european-standards-circular-economy?msclkid=ff211b6ba9ed11ecabac1ba981ddd0b9

Standards supporting circularity in textile industry

Several of EU's standardisation activities in the circular textile sector may be promoted through the **EU strategy for textiles**, which strengthens the sector's competitiveness, innovation, and boosts the EU market for textile reuse ([330]).

Several of CEN's technical committees are already developing standards on circularity in the textile industry:

- CEN/TC 248/WG 39 – Circular Economy for textile products and the textile chain ([331]);
- CEN/TC 248/WG 37 – Microplastics from textile sources which is developing the test methods regarding microplastics;
- CEN/TC 466 – Circularity and recyclability of fishing gear and aquaculture equipment ([332]) working on a Datasheet and requirements for environmental and circular fishing gear.

The following ISO technical committees are relevant as well:

- ISO/TC 38 – Textiles ([333])
- ISO/TC 323 – Circular economy ([334]).

There are the below working groups:

- ISO/TC 323/WG 1 – Terminology, principles, frameworks and management system standard
- ISO/TC 323/WG 2 – Practical approaches to develop and implement Circular Economy
- ISO/TC 323/WG 3 – Measuring and assessing circularity
- ISO/TC 323/WG 4 – Circular Economy in practice: experience feedback
- ISO/TC 323/WG 5 – Product circularity data sheet

Furthermore, in the context of the planned delegated act implementing the proposed regulation on ecodesign for sustainable products for textiles, standardisation requests could be issued to CEN on the basis of Article 10 of Regulation (EU) 1025/2012 on European standardisation, in view of European harmonised standards possibly being adopted subsequently under that Delegated Act. These standards can then underpin the testing and compliance schemes for the various ecodesign requirements, in line with predetermined parameter requirements.

([330]) https://ec.europa.eu/growth/industry/sustainability/textiles_en
([331]) https://standards.cencenelec.eu/dyn/www/f?p=205:22:0::::FSP_ORG_ID,FSP_LANG_ID:2922255,25&cs=107C9E56F42A03A3BCB4F2ED884FF50D4
([332])https://standards.cencenelec.eu/dyn/www/f?p=205:29:0::::FSP_ORG_ID,FSP_LANG_ID:2847769,25&cs=16D375D3CF5571D59BC8548F00F2A7662#1
([333]) https://www.iso.org/committee/48148.html
([334]) https://www.iso.org/committee/7203984.html

Box 4.6 | Traceability system - using interoperability improves transparency and promotes circularity on textile and clothing

TRICK, funded by EU's Horizon 2020 research and innovation programme, puts the digitised circular fashion economy into practice with a consortium of more than 29 partners through blockchain data traceability. It supports the adoption, tracing and demonstration of sustainable approaches in the textile industry by means of i) an innovative and circular product information management system based on blockchain and ii) its ability to provide stakeholders with all the relevant data needed to implement practices that help prevent waste and help in making informed choices on purchases.

TRICK provides affordable and standardised solutions to move SMEs closer to circular economy. In a recent policy brief, the project explains on how standards can help set up and manage sustainable SME supply chains ( ), which has been reported in the joint publication from the World Trade Organization and World Customs Organization publications (TRICK – H2020 #958352).

Approach to anticipate standardisation needs for circular technologies

The previous section focused on listing the progress made in standardisation in areas covered by the three industrial ecosystems addressed in this roadmap. This section attempts to set out an approach to anticipate standardisation gaps for innovative technologies, including in circular industries. The hypothesis is based on the observation that standardisation and regulatory actions peak on a timeline after a novel technology has noted a sharp increase in publications, start-ups, and patent registrations. Creating and comparing timelines of key events for specific technologies makes it possible to anticipate the moment when standardisation for a given technology will take place ([335]).

Standardisation needs arise continuously from new technologies, advancements of existing technologies or the transfer of a technology to a different field. Therefore, setting up an approach that surveys developments helps in anticipating standardisation needs, as promoted by the EU standardisation strategy. To achieve this, it is necessary to monitor the scientific literature that could provide indications on where the focus of public research is put, but it is equally important to monitor patents as an indicator for private sector research focus.

Several tools are available for the monitoring of the scientific publications. However, most of these tools are keyword driven, which makes it necessary to know in advance what one is looking for. However, the 'Technology and Innovation Monitoring' (TIM) tool, used for text mining and analysis that applies semantic algorithms to identify the keywords associated with the scientific publications deposited in Elsevier's database SCOPUS, could provide information on the most active or the newest topics by means of applying statistical calculations.

The following analysis applies a new methodology (see Box 4.7) to identify standardisation needs in the area of circular industrial technologies and business models.

([335]) Useful in this context is also the 'Innovation Radar' (https://www.innoradar.eu/), which includes since recently also an option to spot standardisation activities.

Box 4.7 | Methodology used under this roadmap for circular industrial technologies

In Chapter 2, this roadmap provided a list of relevant technologies that could advance the circularity of the three industrial ecosystems in focus, from which a list of keywords can be formulated.

As mentioned above, our working hypothesis is that technologies link with standardisation activities in a sequential timeline. We assume that the selected technology first emerges in scientific publications, followed by R&I activities in spin-off companies, followed by patents until they also appear in regulatory texts and finally as European standards. Using the JRC TIM tool, we evaluated and assessed publications related to the keywords (1).

We further analysed patent data linked to the keywords (2), which provide insight of whether these technologies have gained access to the market. This has provided options related to geographical area and time. In addition, we assessed EU legislative texts (3) through a search of the EUR-Lex database in relation to standards linked to the selected keywords.

The search continues in standardisation documents (4) (ISO/CEN/CENELEC standards database) and results are finally tested on time scale and spatial scale (5).

Results also included a semantic text analysis, which could assess if certain technologies are related to specific clusters that are planned or not planned. This is important to verify if, for example, in a given domain certain technologies were not captured in the list of initial keywords.

Text mining searches were conducted by extracting the keywords from the table corresponding to each of the industries. The table below shows the terms/keywords used and the final search prepared with them to analyse the available scientific information and the patents associated for each of the selected industries.

Table 4.1. List of keywords describing selected emerging circular technology fields and search function

Ceramics	
Sustainable manufacturing based on ceramic body dry preparation Ecodesign with life cycle thinking Reduction in product thickness Industrial symbiosis – use of waste from other industries Use of industrial and inorganic wastes as substitutes for raw materials Energy efficient kilns	Water efficiency – water recovery/reuse Heat recovery Optimisation of the sintering/firing process Cold sintering Resource use minimisation Efficient collection, sorting and separation of waste Reuse of waste
Search: *ceramic AND (sustainable OR 'energy efficient' OR ecodesign OR reuse OR 'reuse' OR 'industrial symbiosis' OR (waste OR water OR heat AND (recycling OR 'reuse' OR recovery)) OR 'cold sintering' OR "resource minimisation")*	
Steel	
Carbon-fibre-reinforced polymers Decodust for fe and zn recovery from BDF dust Leaching process for zn recovery from BDF sludge Zn recovery from hisarna filter dust Induction furnace and bath injection for zn recovery Midrex residue agglomeration for reuse in DR Waste plastic gasification for syngas production	Slag utilisation strategies Two-step dust recycling of EAF dust Reuse of waste refractories X ray technology Laser object detection Robotic metal scrap cutting LIBS for automatised sifting of mixed waste streams
Search: *steel AND (reinforced OR recovery OR reuse OR recycled OR 'laser detection' OR 'robotic metal scrap cutting' OR 'LIBS for automatised' OR decodust OR 'zn recovery' OR 'zinc recovery' OR 'iron recovery')*	
Chemical	
Innovative materials Inherent recyclability of materials Regeneration of spent solvents Recycling acids, alkaline, saline wastes Thermochemical recycling for plastic waste Recycling waste plastic waste through leaching/ depolymerisation Biotechnological recycling of plastic waste Recycling of plastic waste via solvolysis Electrochemical recycling of plastic waste	Biomass-tolerant processes Biomass pre-treatment process Photocatalysis Electrocatalysis Heterogeneous catalysts Homogeneous catalysts Improved separation techniques Valorisation of solutes from wastewater treatment Valorisation of solids from wastewater treatment
Search: *chemical AND industry AND (innovative OR regeneration OR recyclability OR recycling OR valorisation OR leaching OR depolymerisation OR solvolysis OR electrochemical OR catalysis) AND (materials OR solvents OR acids OR alkaline OR waste OR plastic OR biomass)*	
Construction	
Urban mining Bim-compatible plug-ins and applications Off-site construction Additive and robotic manufacturing Use of waste (combustion, liquified, stabilised, vitrified or mineral) Recycling and recovering waste from other ells Construction materials - digital passports Advance dry recovery	Heating air classification system Attrition cells/scrubbers Gravity column Magnetic density separation Near-infrared – construction Big data and analytics Block chain technology Augmented and virtual reality
Search: *construction AND industry AND ('urban mining' OR bim-compatible OR ((additive AND (robot OR manufacturing OR 'off-shore')) OR 'recycling waste' OR 'digital-passport' OR (advance AND dry AND recovery) OR 'near-infrared' OR 'big data' OR 'block chain' OR 'augmented reality' OR (attrition AND (cells OR scrubber))))*	
Textile	
Secondary bio-based raw materials Recycle fibres & yarns Sustainable fibres & yarns Compressed CO_2 as solvent in dyeing process Adding pigments to recycled textiles (electrochemistry) Recycling dye/pigments from waste water Plasma technologies to reduce chemicals Ozone technologies to reduce water and reuse waste Sustainable packaging for textile products Tailored clothing using augmented/virtual reality	Chemical polymers – material blend separation Near-infrared technologies for fibre sorting Cellulose-base fibres for recycling Regeneration of textiles into yarn Chemical recycling of textile polymers Chemical recycling of cellulose waste Concerning the replacement of raw materials with recycled materials Optimisation at the garment design – artificial intelligence Convert cellulosic waste of cotton to viscose/lyocell Clothing plastic microfiber release reduction
Search: *(((textile AND (fibres OR yarns) AND ('bio-based' OR recycling OR sustainable OR 'cellulose-base' OR regeneration OR viscose OR lyocell))) OR ((textile AND ('near-infrared' OR ((ozone OR plasma) AND technologies) OR virtual reality OR 'compressed CO_2' OR electrochemistry OR 'sustainable packing'))) OR ((textile AND (recycling OR reducing OR regeneration) AND (chemical OR solvent OR pigments OR dyes OR water OR microfiber OR waste))))*	

Box 4.8 | Defining alternative keywords

To make sure the selected keywords are the most recent and suitable to describe the technology sector, it would be useful to test alternative keywords that may explain a particular emerging context more in-depth. This is important for verifying if, for example, certain technologies were not captured in the list of initial keywords. The JRC TIM tool allows people to identify additional keywords in either scientific publications or patents that are related to those selected by the experts, allowing the scope to be broadened if necessary. The alternative keywords are created from the list of keywords defined (**author keywords**) or are extracted by TIM using semantic algorithms (**automatic keywords**), among the documents identified as relevant to each topic. To determine regulatory or standards gaps, it could also be more useful to identify keywords that have recently been added or those whose use is increasing compared to previously. TIM allows data to be analysed when mathematic statistics are provided for the application of an **activeness indicator** that will show those topics which have been the focus of more research or which are newly appearing.

Table 4.2. Alternative keywords defined in the publications (author keywords) or are extracted by TIM using semantic algorithms (automatic keywords) and alternative keywords defined with the TIM activeness indicator, based on semantic analysis of pooled articles of specific technology clusters

	Ceramics	Steel	Chemicals	Construction	Textile
Author keywords	Ceramics Finite element Wears Total hip Ceramic membrane Sintering Alumina Coatings Friction Arthroplasty Corrosion Thick film Sol gel Pzt Tribology Spark plasma	Re cycling Scrap Steel Electric arc furnace Hot metal Steel scrap Dusting Steelmaking Slagging Metalation Scrap metal Stainless steel Bof Cast iron Material flow	Re cycling Waste Leaching Adsorption Wastewater Catalysis Biomass Catalyst Heavy metal Ionic liquid Life cycle Waste management Heterogeneous catalysis Fly ash	Urbanisation Construction industry Sustainable development Land use Cities Housing Urban planning Low carbon Smart city Life cycle Re cycling Architecture Agglomeration	Textiles Re cycling Dyeing Wastewater Adsorption Cotton Wastewater Fiber Textile waste Azo dye Textile effluent Fibre Bio degradable Decolorisation Yarns Reactive dye
Automatic keywords	Alumina Coatings Optimisation Total hip Sintering Polyethylene Wears Tiles Ceramic membrane Process parameter Ceramic composites Tribology	Scrap Steel Furnace Slagging Electric arc furnace Steel scrap Smelting Melting Scrap metal Hot metal Scrap steel Metal scrap Pouring Re cycling Molten steel	Chemical industry Waste Preparation methods Technical field Leaching Industrial production Raw materials By product Washing Wastewater Filtration Sludge Environmental protection	Construction industry Urban development Construction Urban planning Urban environments Land use Real estate Construct state Sustainable development	Re cycling Waste Preparation Leaching Raw materials By product Washing Industrial waste Wastewater Filtration Catalyst Sludge
Author keywords (activeness)	Microstructures Metal matrix composite Wear behaviour Metal ceramic Silicon carbide Prostheses Wear rate Kilns Finite element Hardening Agglomeration Functionally graded Moulds Cofire New materials Corrosion Protective coating	Circular economy Scrap dissolution Metal scrap Laser induced breakdown spectroscopy Scrap steel Scrap melting Steel making Induction furnace Heat transfer Coefficient Precipitation Bathing Oxygen concentration Carbon Basic oxygen furnace Dioxins	Decolourisation Aluminium dross Electrochemical methods Molecular imprinting Clinoptilolite Self healing Natural zeolite Rubber Thermal properties Absorptive capacity Bentonite Waste electrical/electronic 3d printing Magnetisation Flame retardant Porous material Tensile strength	Cloud computing Rural revitalisation Metalation Metropolitan region Economic growth Environmental justice Construction management Urban mining Emission inventory Pm2 5 Green building Smart city Construction and demolition waste Remote sensing	Waste tire Washability Re pair Sustainable material Sound absorption coefficient Synergistic effect Organic pollutants Lean manufacturing Blended fabric Biological activity Chromium vi Catalytic Biological oxygen demand Zno nanoparticles Collagen

(1) Scientific publications

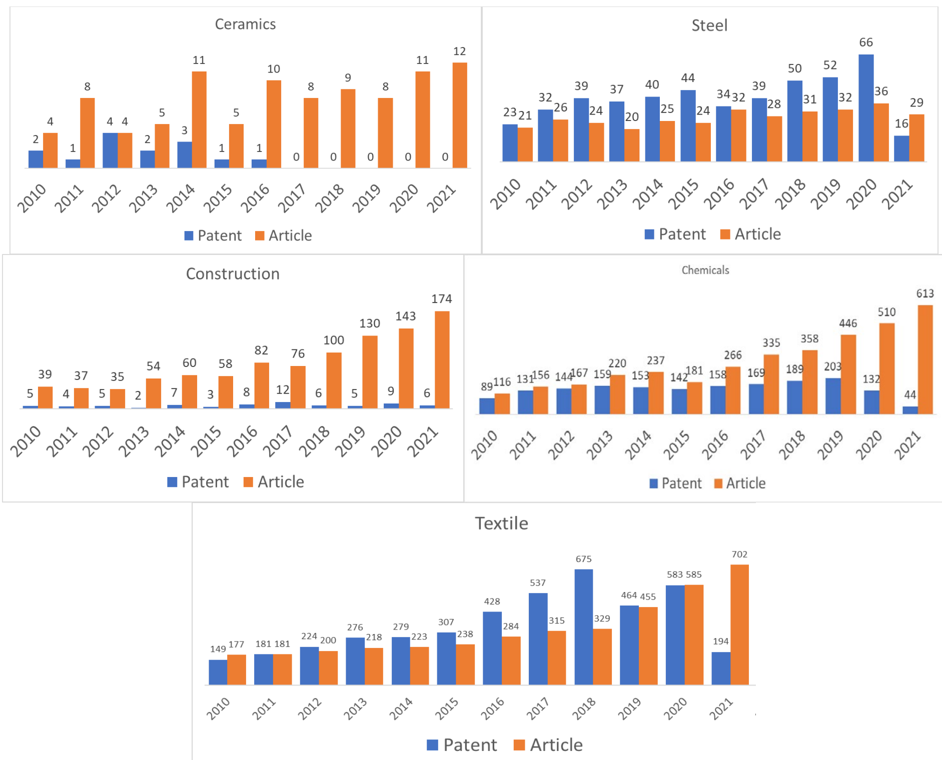
The searches were launched using the JRC TIM tool that allows for the quick identification and analysis of scientific publications and patents. The results are shown in the table below. Textile and chemicals are those industries where most research actions seems to have occurred.

Table 4.3. Number of SCOPUS indexed peer review publications, conference proceedings and patents per technology field when using keywords from Table 4.1.

	Ceramics	Steel	Chemicals	Construction	Textile
Journal articles	194	597	4,725	1,237	6,116
Conference proceedings	66	253	1,309	701	866
Patents	32	911	4,262	262	5,287

The results of the SCOPUS-indexed publication harvest and the registered patents associated with the circular technology keywords were plotted over a timeline of 10 years. While publications are generally increasing with time, we observed a curve in patents activity. Interestingly, publications on circular technologies dominated in the ceramics, chemicals and construction sectors, while patent applications dominated in sectors such as steel and textile.

Figure 4.2. Number of journal articles and number of patent registrations per technology field over the past 10 years when using keywords from Table 1



(2) Patents

Patents are good indicators of technological advances and private investment. The table below shows the top patent family classifications for each of the five industries. Patent families are a collection of patent applications covering the same or similar technical content. The applications in a family are related to each other through priority claims. The European Patent Office uses an automated process to build patent families based on applications' priority claims. The analysis of the patents could bring additional understanding of the future needs for standardisation.

Table 4.4. Patent families resulted from the search based on the circular technology keywords

Ceramics	Y10T: technical subjects covered by former us classification C04B: lime, magnesia; slag; cements; compositions thereof; artificial stone ; ceramics C23C: coating metallic material; coating material with metallic material; surface trea H01L: semiconductor devices; electric solid state devices not otherwise provided for B23K: soldering or unsoldering; welding; cladding or plating by soldering or welding; Y02P: climate change mitigation technologies in the production or processing of goods
Steel	Y02P: climate change mitigation technologies in the production or processing of goods C21C: processing of pig-iron; treatment in molten state of ferrous alloys C22C: alloys C22B: production and refining of metals ; pretreatment of raw materials F27D: details or accessories of furnaces, kilns, ovens, or retorts, in so far as they F27B: furnaces, kilns, ovens, or retorts in general; open sintering or like apparatus C21D: modifying the physical structure of ferrous metals; general devices for heat tre B22D: casting of metals; casting of other substances by the same processes or devices C21B: manufacture of iron or steel Y02W: climate change mitigation technologies related to wastewater treatment or waste B02C: crushing, pulverising, or disintegrating in general; milling grain B23Q: details, components, or accessories for machine tools; machine tools in general B23P: other working of metal; combined operations; universal machine tools B22C: foundry moulding Y02E: reduction of greenhouse gases [ghg] emission, related to energy generation, tran... B30B: presses in general B24B: machines, devices, or processes for grinding or polishing ; dressing or conditio...
Chemicals	Y02P: climate change mitigation technologies in the production or processing of goods C02F: treatment of water, waste water, sewage, or sludge C07C: acyclic or carbocyclic compounds Y02E: reduction of greenhouse gases [ghg] emission, related to energy generation, tran... B01J: chemical or physical processes; their relevant apparatus Y02W: climate change mitigation technologies related to wastewater treatment or waste ... B01D: separation C07D: heterocyclic compounds C01B: non-metallic elements; compounds thereof; {metalloids or compounds thereof not ... C22B: production and refining of metals ; pretreatment of raw materials H01M: processes or means C01P: indexing scheme relating to structural and physical aspects of solid inorganic c... Y02A: null C01G: compounds containing metals not covered by subclasses c01d or c01f C04B: lime, magnesia; slag; cements; compositions thereof; artificial stone ; ceramics... C01F: compounds of the metals beryllium, magnesium, aluminium, calcium, strontium, bar... C01D: compounds of alkali metals, i.e. lithium, sodium, potassium, rubidium, caesium, ...
Construction	G06Q: data processing systems or methods, specially adapted for administrative, commer... Y02A: null Y02W: climate change mitigation technologies related to wastewater treatment or waste ... C04B: lime, magnesia; slag; cements; compositions thereof; artificial stone ; ceramics... Y02P: climate change mitigation technologies in the production or processing of goods C02F: treatment of water, waste water, sewage, or sludge E02D: foundations; excavations, embankments ; underground or underwater structure B09B: disposal of solid waste A01G: horticulture; cultivation of vegetables, flowers, rice, fruit, vines, hops or se...

Textile	D06B: treating textile materials by liquids, gases or vapours
	D06M: treatment, not provided for elsewhere in class d06, of fibres, threads, yarns, f...
	D06P: dyeing or printing textiles; dyeing leather, furs, or solid macromolecular subst...
	D10B: indexing scheme associated with sublasses of section d, relating to textiles
	D02G: crimping or curling fibres, filaments, threads, or yarns; yarns or threads
	Y02W: climate change mitigation technologies related to wastewater treatment or waste ...
	D03D: woven fabrics; methods of weaving; looms
	D01F: chemical features in the manufacture of artificial filaments, threads, fibres, b...
	C02F: treatment of water, waste water, sewage, or sludge
	D06C: finishing, dressing, tentering or stretching textile fabrics
	B01D: separation
	B32B: layered products, i.e. products built-up of strata of flat or non-flat
	D06L: bleaching; bleaching leather or furs
	Y02P: climate change mitigation technologies in the production or processing of goods
	C08G: macromolecular compounds obtained otherwise than by reactions only involving uns...
	D04B: knitting
	D01D: mechanical methods or apparatus in the manufacture of artificial filaments, thre...

Table 4.5. shows the geographic or spatial distribution of publications on circular technologies in selected sectors. While journal articles were distributed evenly although with United States and China in the lead, followed by several European countries, China, Korea and Russia dominated in patent applications in most sectors, except in ceramics.

Table 4.5. Geographic or spatial distribution of the publications and patents on circular technologies in industrial sectors of ceramics, steel, chemicals, construction and textile

	Ceramics	Steel	Chemicals	Construction	Textile
Journal articles	UK Germany Spain Australia USA	USA Russia China Germany Japan	China USA India Germany UK	China USA UK Australia Russia	China India USA Germany UK
Patents	UK Germany Russia USA Netherlands	China Russia Japan South Korea Ukraine Germany	China Russia South Korea Japan USA	China South Korea USA Russia Japan	China South Korea Russia Japan USA

Figure 4.3. Geographic analysis of publications using TIM and employing circular technologies keywords from the steel sector. Most active regions were China, Russia and Japan.

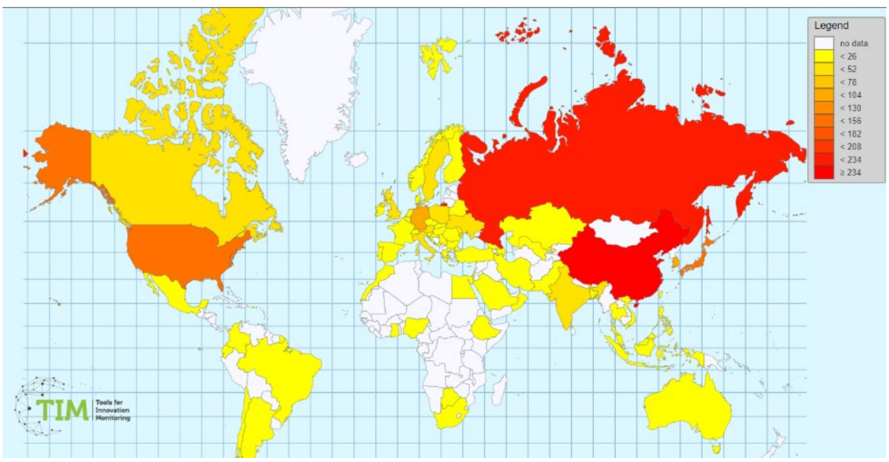
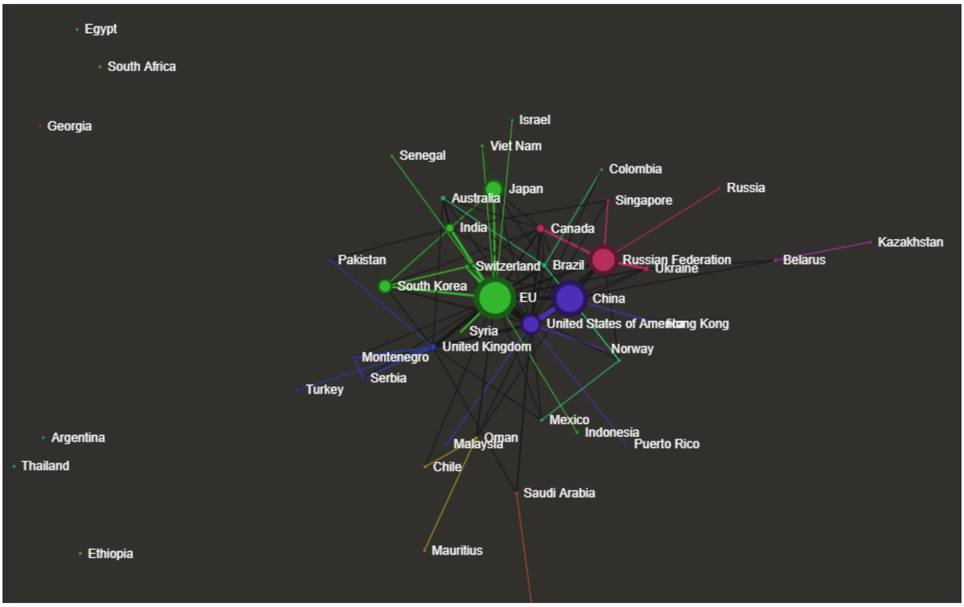


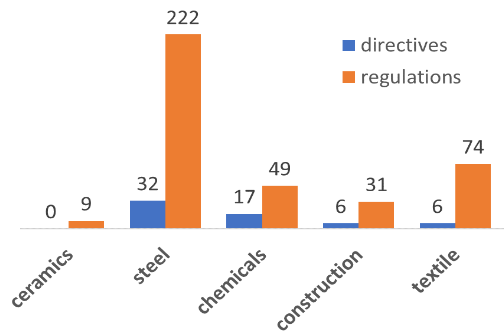
Figure 4.4. Cluster and relationship analysis of publications using TIM and employing circular technologies keywords from the steel sector. TIM application detected three dominant clusters led Europe, China and Russia, respectively



(3) Regulatory texts

In order to analyse the regulatory context, we used the keywords already selected. Searches were carried out in the EUROLEX database to identify existing directives and regulations. Multiple searches were carried out to combine ‘ceramic industry’, ‘steel industry’, etc. with each of the pre-identified keywords. To reduce the number of false positives, we applied proximity indicators in such a way that two keywords (or group of keywords) could not exceed a maximum of 40 words.

Figure 4.5. Appearance of keywords in directives and regulations of the 5 technology domains



	Ceramics	Steel	Chemicals	Construction	Textile
Directives	--	16 (iron recovery) 1 (recovery) 12 (recycled) 2 (reuse) 1 (zn recovery)	7 (biomass) 6 (recycl*) 4 (regeneat*)	2 (off-shore) 4 (recycling)	3 (recycl*) 1 (regenerat*) 2 (sustainable)
Regulations	7 (efficient) 2 (recover*)	193 (iron recovery) 28 (recovery) 1 (reuse)	13 (biomass) 34 (recycl*) 2 (regenerat*)	1 (off-shore) 30 (recycling)	2 (bio-base*) 25 (recycl*) 2 (regenerat*) 45 (sustainable)

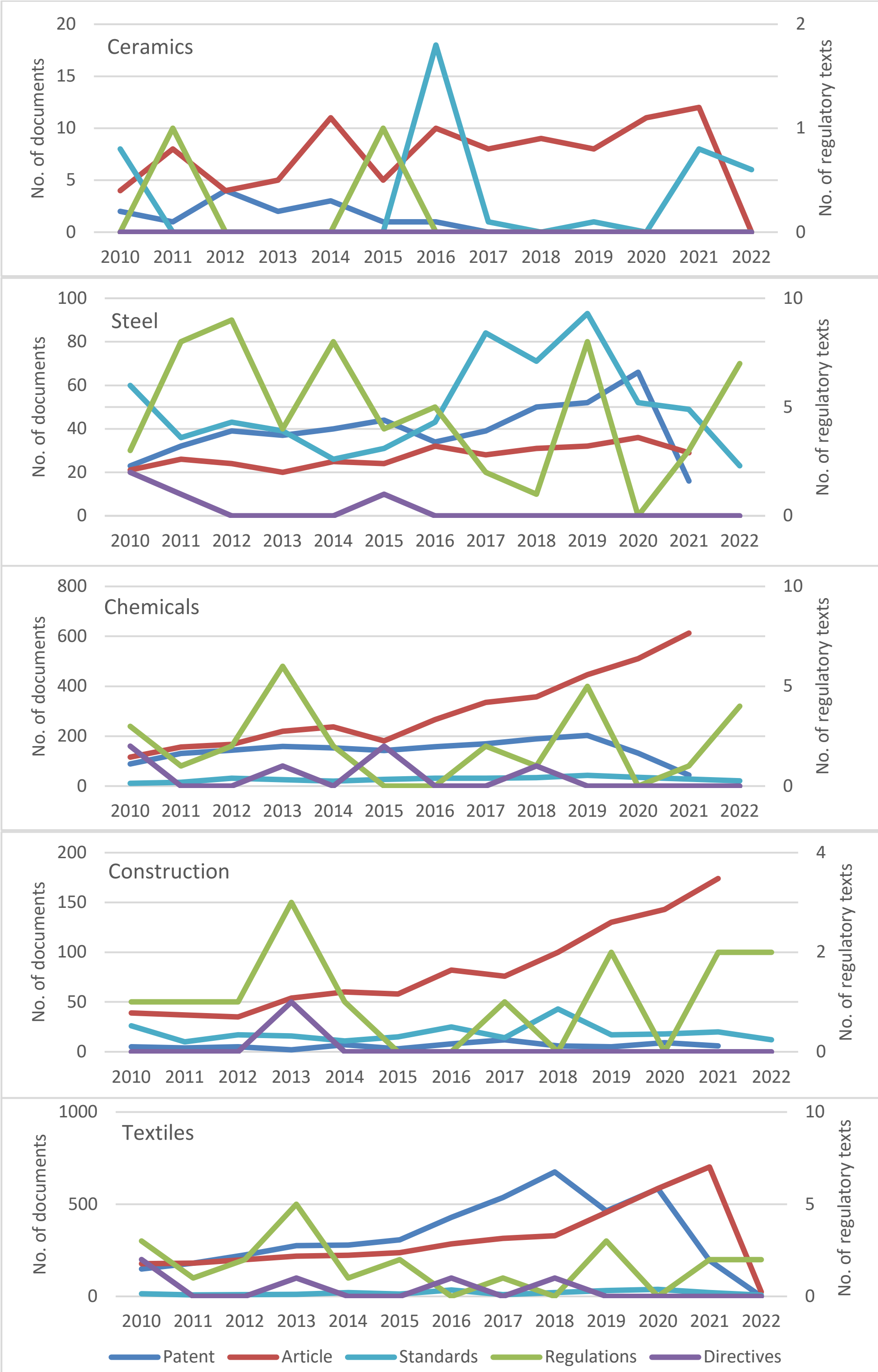
Standards

A datamining exercise in the complete standards database of CEN-CENELEC, which also includes adopted standards from the ISO and the IEC resulted in the identification of 65 standards that linked to the keywords that have been provided by the experts for circular technologies since 2010. Standards were distributed relatively evenly over the years. Some sectors such as steel and chemicals produce more standards than others.

Table 4.7. Number of standards in technology domains of ceramics, steel, chemicals, construction and textile resulting from a datamining exercise of the abstracts of the CEN-CENELEC database, when using keywords from Table 4.2

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Ceramics	8	0	0	0	0	0	18	1	0	1	0	8	6
Steel	60	36	43	39	26	31	43	84	71	93	52	49	23
Chemicals	11	15	32	26	20	27	32	31	34	43	35	28	21
Construction	26	10	17	16	11	15	25	14	43	17	18	20	12
Textiles	15	8	9	11	21	12	35	10	20	32	38	20	7

Figure 4.6. Number of patent registrations, journal articles, standards (y axis), regulations (z axis) and directives (z axis) in the field of ceramics, steel, chemicals, construction and textile over the past 10 years



In all five domains, publications, such as those covering conference proceedings and scientific journal articles increased over the last 10 years in a linear manner. Patents, standards, regulations and directives remained at a relatively constant level, except in a few years when there were elevated numbers. In the case of ceramics, steel and construction, an elevated number of regulations went along with a subsequent elevation in standard publication. With certain margin of safety, we can conclude that regulatory texts play a role for increased standardisation. It is possible that a call for action for a harmonised standard has led to these developments.

At least in the chemicals, construction and textiles domain, regulations and directives have similar patterns and peaks. Patent registration was inconsistent. We observed a linear increase of patents only in the case of textiles, chemicals and steel.

To summarise, it is not possible to conclude that increased research, scientific publications and patenting in the circular technologies domains of energy-intensive industries (ceramics, chemicals and steel), construction and textile, result in increased standardisation. Further research is needed to how to predict standardisation needs in those fields.

The role of infrastructures in enabling circularity

Europe has a rich and diverse landscape of infrastructures, integrating EU-wide large-scale research infrastructures with complementary national, mid- and small-sized **research infrastructures (RIs)** and **technology infrastructures (TIs).** The latter have been supported by initiatives such as pilot lines, testing and experimentation facilities, digital innovation hubs, and open innovation testbeds, which have an impact on various R&I fields and industrial sectors.

Infrastructures (physical or digital) support 'excellent science' (the first pillar of Horizon Europe), underpin the creation of new knowledge and innovations, applied research and provide solutions for the twin transition by supporting development of new materials, products and processes. They also address the needs of numerical simulations of products and production processes in the green and digital transitions, but also in view of the use of renewable energy. The same infrastructure can carry out multiple roles in innovation cycles and in ecosystems.

This section focuses on the role and impact of RIs and TIs in enabling circularity in the three industrial ecosystems and provides examples of relevant infrastructures to illustrate their role and activities.

Role of research infrastructures

The development of advanced technologies, which would provide new tools to reduce waste, recycle materials and enable circular production, requires increased efforts by all players in the research and innovation landscape. The development of **new breakthrough technologies,** as well as **scaling up of some innovative technologies** in particular require the **RIs' support** ([336]).

([336]) Over the past two decades, the European Strategy Forum on Research Infrastructures (ESFRI), a body composed of national representatives and the European Commission, has radically transformed the availability of state-of-the-art facilities for researchers by promoting common investments in regional, national and European levels, *Impact of RIs on circularity in textiles and construction (337)*

RIs can significantly contribute to a better design of products and a better insight into the lifecycle of materials and systems, and the development of breakthrough technologies as well as scaling up some innovative technologies. A deep scientific understanding of, e.g. material properties and production-process characteristics is crucial for reaching a higher degree of circularity. For the most part, the basic research required for this is situated in the broad field of materials science and engineering for upscaling to products, elements and structures. Among the RIs, this is to a great extent catered for by analytical research facilities, which offer specialised techniques among other probes, powerful beams of photons, electrons, neutrons, protons, laser light and ions, each of which has specific advantages.

Table 4.8. Examples of recent research for relevant circular economy target areas of textile and construction

Textile	Construction
• Textiles with added value. Incorporation of nanoparticles into textile materials via extrusion or by applying an atmospheric pressure plasma jet. The goal is to produce textiles with better UV protection (UPF50+), increase antimicrobial activity and to explore biodegradation of such materials incorporated with nanoparticles. A low mitigation rate of nanoparticles is necessary for applications. Biodegradability of the materials will be tested according to standardised method EN ISO 11721-2:2000 which examines the resistance of materials to microorganisms in soil (soil burial test) in a controlled environment. (Lasers) • Investigations of materials with nanofibers (polymer nanotextiles, polymer and composite nanofibers) put into operation with ionising radiation for electronic and sensoric applications, and smart, waterproof, self-cleaning and durable textiles. (Ions) • Use of MeV TOF-SIMS for the chemical (organic) characterisation of the different coatings used in the textile industry. (Ions)	• Studies on cement, e.g. on the hydration of alite, the main component of the ubiquitous Portland cement, or the development of a new methodology to produce better additives for concrete technology (photons) • In situ studies on concrete, with recent research aiming for low CO_2 content cements and the recycling of waste materials into cements (photons) • Investigation of wood and pulp-based building materials, e.g. transparent wood, flame-resistant wood (photons) • PIXE/RBS analysis of the cement and limestone for conservation purposes (ions) • Monitoring the impregnation of wood by functional monomers to produce green and recyclable material for buildings and furniture (lasers) • Green technologies (laser ablation cleaning) of building surfaces (e.g. graffiti removal) (lasers) • Monitoring and sorting of building demolition waste with mobile sensors (e.g. LIBS) and assessment of their reusability (critical raw materials) (lasers) • In situ determination of water / moisture transport in different building materials (e.g. wood, concrete, masonry etc.) using neutron imaging; neutron imaging investigations of corrosion processes in opaque media, e.g. steel rebars in concrete (neutrons) • Carbon-neutral building materials, and fire stability of building materials (neutrons) • Neutron stress/strain studies on engineering materials, including studies on material lifetimes and failure mechanisms (neutrons).

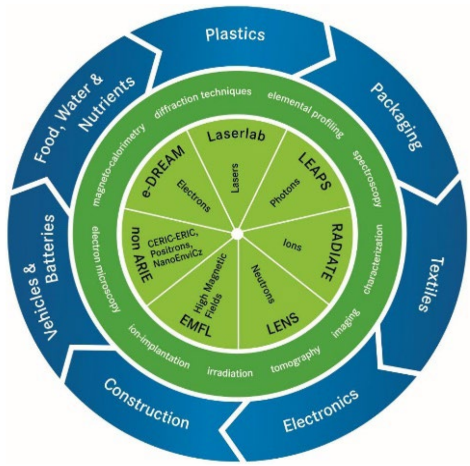
reinforcing Europe's global leadership in this field. Europe now has at its disposal a rich landscape of RIs covering all scientific domains, with at present over 55 European Research Infrastructures mobilising close to EUR 20 billion worth of common investments.

(337) The Governing body of the European Forum provided written input for research infrastructures on September 30 2022.

Source: European Strategy Forum for Research Infrastructures for DG RTD, 30 September 2022.

A number of analytical research infrastructures in Europe have formed a consortium called ReMade@ARI ([338]) to pool their offers. Since September 2022, ReMade@ARI's activities, which serve the broad community of users in the field of circular economy research, have been supported with an EU grant. ReMade@ARI will be the central hub for all sectors and research areas in which new materials for a circular economy will be developed. A landscape analysis of activities that are already ongoing indicated that these facilities are often already strongly involved in research on topics identified in the circular economy action plan as the most relevant areas.

Figure 4.9: ReMADe@ARI platform



Source: HZDR/ Werkstatt, with permission, written input from ESFRI, 30 September 2022.

Most of the physical research infrastructures, in particular the analytical facilities, have developed significant digital in-house capabilities that support users in managing and analysing the rapidly increasing amount of experimental data. Furthermore, there are dedicated digital research infrastructures, such as the Partnership for Advanced Computing in Europe (PRACE) that offers world class computing and data management resources to researchers.

While research infrastructures with their services support the development of circular industrial technologies, increasingly they are making efforts to reduce the environmental impact of their own operation.

The recent upgrade of the European Synchrotron Radiation Facility (ESRF) in Grenoble, France has shown that it is possible to increase the performance of the machine by 100%, while reducing the energy consumption by 20%. The 'LUMI' CSC supercomputer, located in the town of Kajaani, Finland, is one of the recently acquired supercomputers of the Euro High Performance Computing Joint Undertaking (EuroHPC JU). Energy supply for LUMI is 100% hydropower, while its waste heat will

([338]) https://leaps-initiative.eu/remadeari-project/?utm_source=rss&utm_medium=rss&utm_campaign=remadeari-project

produce 20% of the heat needed for houses in the district, resulting in a net negative carbon footprint of 13 500 tonnes of CO_2 equivalent per year.

Box 4.9. Example of RIs collaborating with industry ([339]) - PRACE SUPPORTS PARTNERSHIPS WITH INDUSTRY

Since the inception of its open R&D offer, PRACE (the partnership for advanced computing in Europe) has supported collaboration and technology & knowledge transfer between academia and industry. Through implementing projects supported by the European Commission, PRACE is proposing high-value services for code enabling, training, and user support to industry, allowing companies to benefit from the expertise gathered by PRACE partners. PRACE launched a specific (successful) initiative called SHAPE (SME HPC adoption programme in Europe) to help European SMEs use high performance computing (HPC) and advanced numerical simulation, in order to demonstrate that HPC enables SMEs to become more innovative and competitive. PRACE set up an industrial advisory committee composed of high-level representatives from major European industrial sectors to advise the RI on developing new services to support wider usage of HPC and data services by industry. In addition, a user forum provides feedback on the effectiveness of the services and suggests how these services could be further developed. There are several examples of investment by industry: (i) PRACE is running a PCP [pre-commercial procurement] on HPC on the provision of R&D services that seek solutions for whole-system design for energy efficient HPC; (ii) PRACE works together with industries to enable their codes and improve their competiveness; and (iii) as mentioned above, the SHAPE initiative supports the implementation of complete projects, including computation, for SMEs around Europe, where the SMEs 'invest' their engineers and experts to co-develop the projects.

Role of technology infrastructures

Technology infrastructures ([340]) are essential for the **European R&D and innovation ecosystem.** They are also a **key element in the development of local and regional innovation ecosystems, as partners of civil society, industry and SMEs.** TIs carry out research and innovation between low and high TRLs, answering the needs of industry as their main driver and customers (incl. SMEs and start-ups) ([341]). They deliver a wide range of technological and non-technological services offering pilot lines, testing and experimentation facilities, digital innovation hubs, open innovation testbeds, demonstration sites, living labs, etc. TIs are mostly created, managed, maintained and upgraded by research and technology organisations (RTOs) and technical universities (TUs), but can be also hosted by large industry.

([339]) Cited from: ESFRI Scripta Volume III: Innovation-oriented cooperation of Research Infrastructures, 2018, https://www.esfri.eu/latest-esfri-news/esfri-scripta-volume-iii-now-published-innovation-oriented-cooperation-research

([340]) Technology infrastructures are facilities, equipment, capabilities and support services required to develop, test and scale up technology to advance from validation in a laboratory to higher TRLs prior to competitive market entry. They can have public, semi-public or private status. Their users are mainly industrial players, including SMEs, which seek support to develop and integrate innovative technologies towards commercialisation of new products, processes and services, while ensuring feasibility and regulatory compliance (Commission staff working document, 2019).

([341]) Viscido, S., Taucer, F., Grande, S. and Jenet, A., Towards the Implementation of an EU Strategy for Technology Infrastructures, European Commission, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-46502-7, doi:10.2760/761184, JRC128007.

Box 4.10. Open innovation test beds (OITBs) as part of the landscape

OITBs ([342]) are defined as tools to scale up advanced materials to prototypes in industrial environments. OITBs are single-entry points and platforms providing common access to physical facilities, capabilities and services required for developing, testing and upscaling of nanotech and advanced materials. The project portfolio ([343]) funded by Horizon 2020 and Horizon Europe to support the development of OITBs includes activities related to technology infrastructures in various industrial sectors including for advanced materials, nanotechnologies, medical technologies, nanomedicine, energy technologies and hydrogen. By June 2022, EUR 285 m had been granted for 25 OITBS, mainly for bringing nanotechnologies and materials to further maturity and helping SMEs and enterprises to bring materials from laboratory validation to prototyping in a real industrial environment (in TRLs 4 -7). As a part of their services, OITBs provide also 'non-technological services' in other areas, which are related to standardisation, regulation and defining of protocols, environment and safety issues, etc. They also provide business services to find the right market for innovative materials and developed technologies, and guidance on funding possibilities including private capital for SMEs and start-ups.

The requirements of OITBs have also moved from technology-oriented description to more purpose-oriented description (change in approach and some criteria). For example, hubs for circularity combine circular technologies and low-carbon technologies, industrial symbiosis with urban environment to produce heat, etc. In the 2021-2022 Horizon Europe work programme there was a new field of OITB for climate neutral and circular innovative materials technologies with a budget of EUR 35 m in which hydrogen research and technologies, for example, in scaling up electrolysis OITB could be a right tool, as in the new OITB on Electrolysis materials ([344]) CLEANHYBRO (presented as one of the examples in the high-level conference in June), more than 70% of the consortium are industrial partners, key material manufacturers, electrolyser manufacturers, etc. RTOs and universities, participating in OITBs have pilot lines for manufacturing and testing. One of the real life showcases could be innovative materials, component and cell stack development with updated pilot lines allowing characterisation of materials and cells and stack for different electrolysis technologies with required protocols and demonstrations with external users to see how OITB platform works. The one-stop-shop platform and the single-entry point concepts have been implemented so far in RIs and OITBs for potential users to identify which infrastructures can best answer their needs, and to facilitate the access for all users to the services provided by the infrastructure ([345]).

At the high-level conference on *Europe's Green and Digital Transition: The Role of Technology Infrastructures in the new Pact for Research and Innovation* ([346]), TIs were considered essential for European companies when developing innovative materials, components, processes and services. In addition, they were considered essential for protocols, recyclability, sustainability, lowering energy consumption, minimising the use of critical materials, accelerating access to market, the permitting process and social adaptation of new technologies. TIs can support diverse skills for technology transfer and resilient services as well as activities to strengthen and interconnect local innovation ecosystems. Clear and transparent access conditions with a harmonised

([342]) https://cordis.europa.eu/article/id/436434-open-innovation-test-beds-to-accelerate-european-innovation

([343]) Horizon 2020 under Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing (NMBP) Work Programme 2018-2020, now continuing under Horizon Europe, Pillar II, clusters 4 and 5.

([344]) CLEANHYPRO - Open Innovation Test Bed for Electrolysis Materials for Clean Hydrogen Production initiative, (28 partners from 11 countries, coordinated by Tecnalia). HORIZON-CL4-2022-RESILIENCE-01-20 (grant agreement signature expecting date: 01/11/2022).

([345]) Viscido, S., Taucer, F., Grande, S. and Jenet, A., Towards the Implementation of an EU Strategy for Technology Infrastructures, European Commission, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-46502-7, doi:10.2760/761184, JRC128007.

([346]) A high-level conference 'Europe's Green and Digital Transition: The Role of Technology Infrastructures in the new Pact for Research and Innovation' 23 June 2022, co-organised together with the European Commission, CEA, EARTO and French Presidency Council: https://www.earto.eu/joint-ec-pfeu-cea-earto-event-on-technology-infrastructures-on-23-june-2022-recording-presentations-available/

approach and a flexibility that recognise the different types of users and levels of access to attract users are needed and are considered one of the key challenges.

Furthermore, to illustrate common and specific features of the TIs across Europe, the European Association of Research and Technology Organisations (EARTO) published the *Case Studies on Technology Infrastructures* in May 2022 ([347]). Nine cases studies are presented in various fields, focused around activities, technology fields, services-delivery models, users, and role of the TI. Moreover, the following key recommendations were made to policy makers: i) promote collaboration between TIs at EU level; ii) provide regulatory and funding support; iii) provide support for small infrastructures; iv) ensure shared and coordinated access to education and training; v) provide relief from administrative burden related to State aid rules; vi) share practical approaches to engaging with (local) stakeholders; vii) increase coordination and collaboration between pilot facilities; viii) improve users' awareness of the facilities available and ix) avoid overlapping investments in Europe.

As an example of recent national inventories, a report on the mapping of national and international tech infra capacity in Sweden is being prepared ([348]) to strengthen national innovation capacity and capability through the increased use of tech infrastructure capacity in Sweden and internationally.

Impact of TIs on circularity in textile, construction and energy-intensive industries

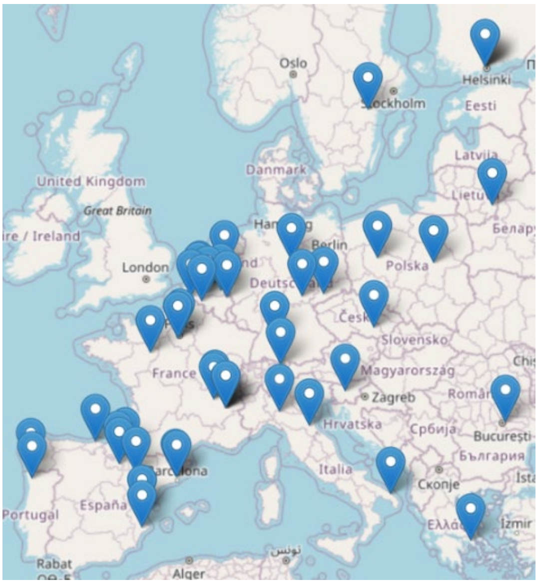
This part builds on the results of a virtual workshop on 'The Role of TIs in the circularity of industrial ecosystems' ([349]), organised by the Commission as a part of the **consultation process of the ERA Action 12 ([350]) under the ERA policy agenda**. Most of the discussion was related to i) experience with and views on TIs for the textile and construction industrial ecosystems, ii) mapping of TIs, their services and access for different users, and iii) aspects of funding.

Geographical spread of TIs in the textile and construction sectors

The mapping of specific TIs or technologies in the textiles sector, more specifically for circularity, is not available. The European technology platform for the Future of Textiles and Clothing ([351]) can be considered a source of information. Those involved in this sector would know what TIs are active in Europe. In some cases, TIs operate at local level addressing local users, but there is potential to go beyond, e.g. addressing needs across Europe, while some TIs have an even more international presence. Nevertheless, a search ([352]) on the web-portal of the Advanced

([347]) Case Studies on Technology Infrastructures, EARTO, May 2022 https://www.earto.eu/wp-content/uploads/EARTO-Case-Studies-on-Technology-Infrastructures-Final.pdf
([348]) Project INIT – Mapping of testbeds with potential for internationalisation, financed by Vinnova, Sweden's innovation agency. Report expected to be published in November 2023. More information on the project: https://www.vinnova.se/en/p/mapping-of-testbeds-with-potential-for-internationalisation-init/
([349]) On 26 September, an online workshop on 'The Role of TIs in the circularity of industrial ecosystems' was organised by the Commission in partnership with EARTO and CESAER.
([350]) ERA Action 12 on "Accelerate the green/digital transition of Europe's key industrial ecosystems" has attracted 21 Member States, 3 Associated Countries and 7 key stakeholder organisations, who committed to collaborate with the European Commission in the framework of the ERA Policy Agenda 2022-2024.
([351]) The platform is based in Brussels, and it represents all textile stakeholders that are interested in R&I. They have a large membership list – EURATEX, TEXTRANET, EU-TEXTILE 2030 and NETFAS are full members. They have also 12 associated members and 8 networking members. More info at: https://textile-platform.eu
INESCTEC very well-known lab for textiles https://www.inesctec.pt/en/projects/stvgodigital40#about
([352]) Source: Technopolis for DG Research and Innovation

Figure 4.10: Location of Technology Centres that are active in the textile industry



Technologies for Industry (353) project shows that **91 technology centres can be identified as being involved in activities relevant to the textiles industry**, out of which 71 are active in advanced materials and 50 in environmental technologies such as recycling. These organisations, such as TU Wien, The European Centre for Innovative Textiles (CETI), VITO or BOKU, support key textile technology agendas. They also often work in collaboration with industrial partners. For instance, researchers from the University of Ulm collaborate with Otto Garne, a yarn producer to create recycled yarn products. TU Wien is specialised in research on recycling technology and fibre innovation, while the Institute for Environmental Biotechnology of BOKU focuses on exploiting enzymes as biocatalysts for biomaterials processing within recycling applications. CETI is a non-profit organisation dedicated to prototyping innovative textile materials and products through both private and collaborative R&D projects. New research is going on, particularly in the field of chemical recycling of polyester, thermochemical recycling and disassembly technologies.

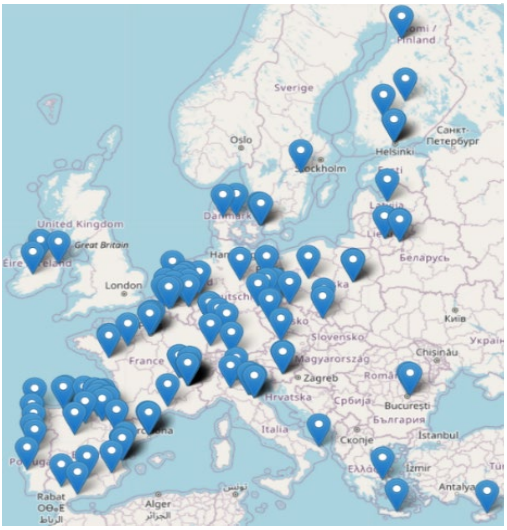
The field of construction has a large number of facilities for testing materials. Most of them are local or linked to regional ecosystems and as such are difficult to map across Europe. There are ecosystems built around public authorities, which may have links to TIs. In this area, national authorities are responsible for testing materials, and therefore TIs are linked to governmental entities (e.g. BAM). In addition, there are virtual ecosystems (like the one tested by JRC-ISPRA) and networks of projects, which covers testing facilities and TIs.

The European Construction Technology Platform ECTP (354) could be considered a possible source used to map existing TIs in this sector. Furthermore, the EU Horizon 2020 project METABUILDING (355) (with its Open Innovation Platform that includes match-making services), and the three ongoing Horizon 2020 open innovation testbed projects on 'Materials for the Building Envelope' (called MEZeroE (356), 'iclimabuilt' (357) and 'METABUILDING LABS' (358)) are networks of testing facilities and innovation service providers that are streamlining the access to pilot buildings and

(353) https://ati.ec.europa.eu/ , https://ati.ec.europa.eu/technology-centre/mapping
(354) The ECTP has 140 members: https://www.ectp.org. The next evolution in sustainable building technologies (NEST) from EMPA was mentioned also as an example in the field of construction: https://www.empa.ch/web/nest/aboutnest.
(355) This is connected with the ECTP. For more information on the METABUILDING project, see: https://cordis.europa.eu/project/id/873964
(356) More information on MEZeroE: https://cordis.europa.eu/project/id/101079859
(357) More information on iclimabuilt: https://cordis.europa.eu/project/id/952886/es
(358) More information on METABUILDING LABS: https://cordis.europa.eu/project/id/953193

living labs. All facilities within these projects together cover a substantial number of TIs around Europe and could be instrumental for mapping purposes.

Figure 4.11: Location of technology centres that are active in the construction industry



140 research and technology centres can be identified as active in the construction field in Europe ([359]). Of these, 80 are researching environmental materials, which involves researching their potential for recycling, resource efficiency, reducing the environmental impact of materials or CO_2 capture and utilisation. Many of the centres also advance research on digital solutions for the construction industry: 11 centres focus on augmented and virtual reality; 19 on artificial intelligence; 19 on big data; 12 on blockchain; 12 on cloud services; 23 on internet of things (IoT); and 11 on robotics. Frequently, research and technology centres form partnerships with private and public partners. For instance, the *Circular Building Living Lab*, led by VITO, BBRI, Hasselt University, Vrije Universiteit Brussel and OVAM, develops policy and practical recommendations to boost the construction industry's transition towards the circular economy ([360]).

Overall, research is primarily concerned with material sciences, recycling and recovery solutions, manufacturing technologies, automation, digital solutions as well as new managerial and organisational approaches to construction.

Services, type of users, cooperation with industry and SMEs:

- In the field of textiles, a small company or entrepreneur can find it a challenge to test a new product or circular solution if no TI exists. The company would have to find out how and where to test each step of the process (e.g. by asking their standard suppliers who may not be prepared to test, or asking different RTOs), with the intrinsic difficulties of small samples, which may become quite expensive and lead to a long process. In addition, the lessons, knowledge and know-how become fragmented and are distributed among the parties involved. With the support of a TI (e.g. ReImagine Textiles), the company staff acquire the know-how on the new process, and is does not become fragmented among different suppliers.

- In textiles, TIs also offer non-technological services related to productivity or the implementation of digital tools, business incubation, financing for innovation and consultancy on business models. Services can cover many areas including training, mentoring and creating innovations. The importance

([359]) https://ati.ec.europa.eu/technology-centre/mapping?search=&sectors%5B%5D=5765
([360]) https://www.sciencedirect.com/science/article/pii/S0959652622000415

of standards needs to be considered as well. Therefore, these infrastructures can be also considered ‘hubs’ and they have dedicated platforms to attract users.

- In the construction sector, virtual ecosystems and networks of projects are active, besides the services provided by national authorities responsible for the testing of materials.

- In both sectors, the collaboration with SMEs often starts informally, requiring mentoring and more specialised staff in TIs. Transaction costs are much higher for cooperating with SMEs than with large companies, due to the specific type of services, plus more services are needed involving specialised staff in order to work with SMEs. The EIC pathfinder scheme and EIC accelerator programmes were mentioned as tools that can provide more services to SMEs.

Accessibility:

- In both the textile and construction fields: There is a variety of user groups with different access modes. With regard to technical universities (TUs), it is necessary to differentiate facilities at departmental level from facilities at interinstitutional level. TIs at departmental level in TUs are much more difficult to access for SMEs than those at institutional or interinstitutional level. In TUs, TIs are used by students and industry, under different and often competing conditions: on the one hand, they offer services to academia at zero cost, while on the other, they offer services to industry on a market basis, the latter contributing to the financial sustainability of TIs.

- In both fields: The market conform access is provided to private users, IP protection mechanisms are in place and access is granted along different modes. In addition, it was recognised that in the field of construction, SMEs do not have the resources to pay. Furthermore, in this sector they are really low tech, so it is extremely important for them to have access to TIs.

Challenges identified by TI providers:

- Hosting high-class, well-functioning TIs requires dedicated and significant resources, interdisciplinary and complex technological competencies and complementary non-technological expertise and highly skilled staff to operate them and to develop services ([361]).

- TIs in TUs are used for multiple purposes covering the entire spectrum of activities of the universities’ missions and strategies ranging from teaching, collaboration with industry to PhD research. On the one hand, they offer services to academia at zero cost, and on the other, they offer access to industry on a market basis, the latter contributing to the financial sustainability of TIs.

([361]) European Commission, Joint Research Centre, Viscido, S., Taucer, F., Grande, S., et al., Towards the implementation of an EU strategy for technology infrastructures, Publications Office of the European Union, 2022 https://data.europa.eu/doi/10.2760/4834

- In textiles, one of the challenges for TIs could be that implementing the circular economy is not only about the technologies they use. It is also about how to produce and take in used materials that are closer to the market risk.

- It is not easy to find the right programme under Horizon Europe for funding TIs. There is support for TIs under the EU framework programme, e.g. support for microelectronics and the development of open innovation test beds, while Horizon Europe does not have a dedicated programme for TIs or, for example, for supporting test beds for textiles. For the textile sector, the absence of dedicated topics and funded projects for TIs was highlighted, particularly when compared to the possibilities for supporting RIs.

- Digital Europe was identified as the programme that offered the most possibilities for funding TIs. It supports testing and experimentation facilities for artificial intelligence as well as digital innovation hubs.

- Possible funding to cover the construction costs of TIs could from the European Regional Development Fund (ERDF). A call from the Basque region was mentioned as one example of a regional call whereby the ERDF could be a source of funding for TIs and cooperation. From the regional perspective, public investments are expected to promote private investments.

- In many cases, the resources come from national funding sources or from the organisation's own budget. It was concluded that large infrastructures need national funding, while small or specific infrastructures can be built with their own funding or with the help of regions. Industry does not tend to invest in the construction phase; they pay for services they get, while SMEs do not necessarily have the resources to pay for them. Therefore, cooperation with SMEs often takes the form of collaborative research contracts rather than services provided.

Obstacles identified for the green transition:

- In the field of textiles, it was mentioned that e-textiles in particular are difficult to handle at the end of their lifecycle. Therefore, sustainability and ecodesign approaches must be included to ensure the end of the lifecycle of these complex products is supervised.

- In the field of construction, circular technologies are lagging behind and the fragmentation of the market and technologies poses challenges. For example, there are challenges related to reducing the consumption of concrete and its reuse. The different approaches in regulations and strategies followed by Member States can be an obstacle for harmonisation and ensuring common approaches at European level.

- Also design of adaptability of buildings is also lagging behind. This is due to fragmentation in the EU construction sector compared to, e.g. the US, where regulations are more harmonised. We have markets with different rules and levels of adaptability, different possibilities for the uptake of circularity, and different rules for reducing concrete waste and demolition waste.

- Concrete should not be the only focus. Components (e.g. windows) are becoming increasingly complex with a broad mix of materials. Innovation on these products should start with an approach based more on eco-design, favouring their repair, reuse and recycling. In addition, new innovative production processes for more sustainable materials should be also targeted to lower the construction footprint along the whole value chain. Furthermore, aside from concrete, most construction raw materials (e.g. commodity plastics are mostly coming from outside Europe (45% production from Asia) could be sourced from bio-based raw materials instead of petrol-based materials, improving EU resilience by reducing international trade dependence.

- In addition, testing in this area of the circular economy is different, because the lifecycle of constructions and buildings is longer. The European building stock is very old and there is now a strong momentum for 'feedstock' for testing circularity.

- State aid rules and access conditions can create obstacles or barriers for cooperation and deployment across the EU if Member States implement them differently.

Impact:

- In the field of textiles, the impact related to the accumulation of knowledge was considered, e.g. by centralising knowledge in one laboratory rather than separate laboratories to create necessary interaction between different experts.

- In the field of construction, networking becomes increasingly important. RIs and TIs are relevant in the creation of networks as SMEs are more scattered in this field. The METABUILDING project's network was mentioned as an example of targeted support for SMEs. In the construction sector, TIs play a specific role for demonstrators, where they are crucial, providing the know-how and the experimentation facilities. TIs can de-risk implementation at higher TRL levels. The implementation of business models and standards for the full circularity is also lagging behind, hindering access to the market for the new products (e.g. carbonite). TIs have a role here. To prepare the market in order to overcome barriers to upscaling, the new products from recycling, reuse, etc. will need several years in testing in buildings/pilots. Here, digitalisation (simulations, digital twins, etc.) could be a huge support. TIs in the demonstration phase are 'crucial' and, among many other positive effects, they increase the trust in the new products and services. While this is valid for all sectors, in the construction sector (which is very conservative) trust is critical.

- Closer cooperation between RTOs, universities and industries was deemed important. TIs are important for regaining technological leadership and industrial competitiveness. Deep demonstration is an important step before incentivising deployment.

Box 4.11 | Examples of relevant infrastructures

1 - Example of the tool, software and simulation codes developed on generic digital infrastructure

Energy systems: better dimensioning for optimised production planning ([362])

CEA-Liten recently developed a system to control heat and power production and supply systems more effectively. In field tests in Grenoble, France, mathematical models that closely represent these energy systems were used to improve production planning in order to lower costs and lessen environmental impacts.

Multi-energy grids that include both production and storage will be one of the hallmarks of the energy transition. The integration of renewable energy will depend on these new energy systems. One challenge that must be overcome is how to manage these systems for better production planning. For this to happen, the best possible dimensioning of the systems must be done during the design phase. This is currently carried out using mathematical models that integrate sometimes difficult trade-offs between conflicting priorities like how quickly calculations can be completed, how accurate the indicators are, and how complex the model is.

CEA-Liten came up with a new method for dimensioning and managing energy systems that could help. The approach was tested on the electricity, heating, and domestic hot water networks serving 23 buildings in Grenoble's Cambridge neighbourhood. The study integrated a gas boiler, the use of domestic heating oil, solar thermal panels, a heat pump, and heat storage. The electricity component of the study was limited to the grid. CEA-Liten's PERSEE software, which includes several different methods, was used to represent the neighbourhood's energy system in operation hour by hour, year-round.

The next step was to determine to what extent the approach allows models that are more representative of the imperatives of short-term system operations to be used while optimising year-round operation to leverage seasonal impacts on heating – all without jeopardising the feasibility of the simulation with overly complex models. When conventional methods based on simplified models are used, production and storage systems tend to appear under-dimensioned due to suboptimal operation. This is characterised by an excessive use of more polluting fossil-based energy sources (like domestic heating oil in this study). CEA-Liten's new method allows the system to be managed almost as efficiently as if demand for the entire year were known in advance, for a difference of 1% to 2%. It also proved to be highly adaptable if actual demand does not align with the forecasts. The method works so well because operating constraints were maintained, but not simplified, and the means for energy production in the system were optimised to reduce the use of fossil fuels.

2 - TI example in the field of EII

CEA-Liten Hydrogen Production & Storage Platform ([363]), located in Grenoble, France.

Key figures of the TI:
- EUR 6 million investment in equipment
- 700 sq. m of facilities and a 120 sq. m outdoor testing area

The Hydrogen Production and Storage Platform supports the **development of hydrogen as an energy** source. The main focus is the solid oxide electrolyser/fuel cell (SOEC/SOFC), a **low-cost**, high-yield, **reversible hydrogen technology**. In co-electrolyser (co-SOEC) mode, the cell can turn water vapour and CO_2 into H2/CO syngas, which can then be transformed into chemical molecules of

([362]) https://liten.cea.fr/cea-tech/liten/english/Pages/Medias/News/Smart-Grid/energy-systems-better-dimensioning-for-optimized-production-planning.aspx The content of the section (box 1) is from the CEA-Liten website. All reproduction rights are reserved.
([363]) Liten - Hydrogen Production & Storage Platform (cea.fr)

interest; it can also **operate in (SOFC) mode to produce electricity and heat from a variety of carbon- or nitrogen-based fuels**.

CEA-Liten leverages the Platform's resources to develop and test demonstrators of significant sizes at various scales, from cell (where the electrochemical reaction occurs), to multiple cell stack, to module, and, finally, to system. The Hydrogen Production and Storage Platform contains the following features.

A SOEC/SOFC stack pilot line that covers all process steps: i) preparing and implementing the contact layer and seal using chemicals, tape casting, and robotic seal assembly; ii) mechanical techniques like laser engraving; and iii) crucial quality inspections of each component before the stacks are assembled. The line also handles packaging and stack performance testing. The total production capacity is 1-2 stacks per week. The equipment is flexible enough to use to develop new generations of stacks and can also be used to improve the reliability of manufacturing processes.

A performance and durability testing area is used to **characterise** single SOEC/SOFC components, cells, stacks, modules, and systems in conditions representative of the target applications. **Performance and durability** testing can be done in **SOEC**, **SOFC**, **reversible** (rSOC), and **co-electrolyser** (co-SOEC) modes. Durability tests are carried out over several thousand hours. The platform's other research instruments include chromatography and electrochemical impedance spectroscopy to provide deeper insights into the objects being investigated.

The platform also has state-of-the-art facilities for developing hydrogen storage technologies:

• Pressurised gas storage: Hydrogen is compressed to 700 bars in tanks. This type of storage can be used on board a fuel cell-powered car.
• Hydrogen can also be stored in its liquid state, which maximises the amount of fuel that can be stored in a small volume. At atmospheric pressure, hydrogen is liquefied at -253 °C. This means it can be stored in a cryogenic tank at low pressure. Liquid hydrogen storage, currently limited to space and aeronautics applications, is the subject of substantial research and development.
• In chemical storage, a liquid organic hydrogen carrier is used. These organic compounds are able to absorb and release hydrogen through chemical reactions. Research on chemical storage, an alternative to pressurised gas or liquid storage, is also very active.

3 - RI example in the field of textile

Textiles HUB (TH) – Politecnico di Milano ([364]) - **the Interdepartmental Laboratory on Textile materials and Polymers** at POLIMI, in Italy.

The TH HUB includes several departments - Architecture, Built Environment and Construction Engineering, Chemistry and Material Engineering, Design, Civil and Environmental Engineering, Energy).

TH infrastructure aims at strengthening the dual development of the fields of textiles and construction, promoting research and pilot projects where the cross fertilisation and collaboration between stakeholders of both application fields' is the key factor for accelerating the innovation processes.

Key resources: The HUB gathers more than 60 researchers and scientists and more than 10 scientific research fields collaborating to share updated knowledge, and test facilities and lifecycle-assessment evaluation tools and methods on the innovative application of textiles and polymers in the architecture, interior design, nautical, aero-spatial and automotive sectors.

Since July 2017, the HUB has been part of the POLIMI multi-site Testing Laboratory accredited by ACCREDIA (the Italian National Accreditation Body) by ILAC Mutual Recognition Agreements as Branch G of the LAB N°1275, as regards the biaxial and uniaxial testing of the mechanical tensile

([364])http://www.textilearchitecture.polimi.it/;https://www.polimi.it/en/scientific-research/research-at-the-politecnico/laboratories/interdepartmental-laboratories/textiles-hub-interdepartmental-textiles-and-polymers-research-laboratory strength of fabrics, coated fabrics and polymeric films. It currently follows five standard methods: i) UNI EN 17117-1:2019; ii) MSAJ/M-02-1995; iii) ISO527-3:1995 and ISO527-1:2012; iv_) UNI EN ISO 13934-1:2013 method 1; and v) UNI EN ISO 1421:2017 method 1.

Services provided by the HUB: TH provides services to the whole value chain of designers-to-builders of membrane structures, as well as to producers and manufacturers of polymers, fabrics and coated-textiles, such as:

• the characterisation of mechanical behaviour of technical textiles membranes, composites and lightweight components by a biaxial/uniaxial rig;
• the measurement of UV-VISNIR optical and spectral properties of translucent materials;
• the rain noise acoustic tests for lightweight systems;
• the FT-IR spectrophotometer with modules;
• the double ventilated climatic chamber;
• tools and spaces where to build-up and test prototypes and 1:1 demonstrators for unconventional textile-based membrane structures and lightweight structures.

The HUB is working on improving experimental research in the field of textiles, helped by intense collaboration activity in the setting of a harmonised standard for the structural design of membranes for construction.

HUB activities/exercises: TH has recently launched two round-robin exercises with colleagues from the universities of Essen, Newcastle, and Brussels to increase the knowledge of the structural behaviour of innovative textile materials, through the comparative evaluation of the mechanical test results obtained from the different biaxial traction machines. TH has been also consolidating new relationships with the technical universities of Stuttgart and Kassel and Aachen, where research groups on ultra-light materials are active through mutual involvement in research and doctoral programmes concerning bio-based fabric structures and biodegradable knitted textiles. The 100% polymeric nature of the current products of the 'membrane architecture' must urgently deal with the problem of environmental sustainability.

At the urban level: TH has been working in the form of an open innovation test bed in the following workshops organised during collaborative projects that had been financed and which are still ongoing in the form of active collaboration with non-profit organisations made up of members of the public.

The HUB's innovative vision: TH's innovative vision lies in developing – involving experiments in the POLIMI laboratories – a new kit of membranous products. This is expected to be achieved thanks to a double industrial symbiosis, involving two supply chains that currently generate large quantities of under-used waste: a) organic waste of vegetables produced in agriculture and not used for the food chain or for producing seeds for oil; b) textile waste of mixed polymers, currently not valued within the sorting-reuse-refashion-upcycling chain of post-consumer fashion textiles and which are sent for uncontrolled disposal in developing countries. In the last 2 years, TH lab has been supporting start-ups in the development of i) new yarns and fabrics starting from the virtuous use of agricultural production wastes, ii) 3D printing and robotic fabrication of bio-polymeric fabrics, and iii) integration of graphene into PES and PET yarns and tapes for novel smart textile products.

Expected impact: TH is addressing the issue of environmental sustainability of textile architecture by promoting the green innovation of tensile membrane structures through a paradigm shift implemented through two challenging, interrelated and combined multidisciplinary research paths, aimed at increasing circularity.

Role of the HUB in circularity: TH is taking part in a regional-based platform for circularity in the architectural engineering and construction sector: https://www.remanufacturingforaec.polimi.it/en/. TH's main role here is to study and promote the circularity of the textile sector and the sustainable reuse and recycling of textile materials. The TH lab was a partner of the above-mentioned circularity platform. It was created within Re-NetTA Research, an interdepartmental research team led by POLIMI. The lab aims to produce new organisational models and tools for regenerating and reusing short-term components from the renovation of tertiary building. The general objective is to activate circular regenerative processes based on re-production and reuse strategies and reduce waste production from renewal actions carried out on short-term cycles (i.e. temporary pavilions, exhibitions, fairs, temporary stands, fit-out of offices, screens, tapestries, and branded textile-based objects).

4 - TI example in the field of textile

Reimagine Textile ([365]) and the Fablab site in Mataró, Spain (an area with a high concentration of textile companies). It was created in 2013, and is co-owned by Eurecat (RTO) and Tecnocampus Mataró-Maresme foundation (50% -50%).

Funding of the TI: Establishment – 25% own RTO funding and 75% public funding from the regional ERDF PECT programme. Current sources of funding are private, by co-funding of the TI's projects and services: i) annual subscription fees such as subscription services of RT Passport for Start-Ups and Tech radar, access to FabLab and training for SMEs; ii) direct project contracts for SMEs accelerator, R&D and Tech transfer; iii) monthly fees partially co-funded for start-ups in the incubator programme; iv) business council sponsorship based on annual fee provided by the companies in the council so they can participate in the strategic plans and dedicated tech radar.

Role of the TI in cooperation: The activities and services focus on business innovation by offering experimentation laboratories, technological support, competitive intelligence and training. The TI brings together textile technology, innovation, talent, new business models, new skills, design and digitalisation.

Technology-related services: Creative labs (to test innovations and assess the technical viability and feasibility), providing advanced prototyping laboratory and technological diagnosis to companies to improve productivity, and implementing digital tools to increase efficiency. Entrepreneurs or companies can test the processes from the yarn to the product and to the end-of-life possibilities all at the same place, supported by experts.

Non-technological services: Competitive intelligence service including analytical information and trends in the textile sector, entrepreneurship programme, business incubation, corporate accelerator, mentoring, consultation on new business models and financing and organisation of networking events. For training, the TI provides a high-level specialisation programme (masters, postgraduates and specialisation courses) and posts job offers from companies in the textile sector through a dedicated 'job board'.

Impact of the TI: in 2018-2020: i) 30 validated technology roadmaps for companies, ii) 31 spin-offs created through the TI in total, with around 63 jobs created, iii) more than 75 Fablab users, iv) more than 14 000 users in a dedicated Web platform, v) more than 150 attendants in thematic workshops that were organised, and vi) 13 tours organised at the facilities.

Dissemination of the TI: It was disseminated through the network of dissemination collaborators, umbrella organisations and sectoral and SME associations PIMEC, TEXFOR and AEQCT.

Success story of the TI: Infinite Athletic converts used tennis racket strings into fully recyclable tennis shirts. This is an example of where the TI produced a satisfactory result and had a positive impact on entrepreneurs, who benefited from the Reimagine Textile Incubator and fab lab services.

Key impact and environmental relevance of the innovation: This is the first instance ever of a company recycling racket strings. Approximately 60 tonnes per year are wasted in Spain and about 400 tonnes in Europe. Infinite Athletic produced in their first batch 1 000 units from 100% polyester monofilament that makes clothes highly durable. By recycling and adding colour during the extrusion of the yarn, water consumption is reduced by 80%, energy consumption by 60% and CO_2 emissions by 70%, when compared to a conventional polyester.

5 - TI example in the field of construction

Name of the innovation: Carbonaide ([366]). This is an innovative technology that uses carbon dioxide to manufacture negative emissions concrete. Created by VTT (VTT Technical Research Centre of

([365]) https://reimaginetextile.com/, https://infiniteathletic.com/
([366]) VTT's Carbonaide technology for manufacturing carbon. For more information: https://www.vttresearch.com/en/news-and-ideas/carbonaide-aims-carbon-negative-concrete-technology

Finland) by using its material performance technology infrastructure to i) understand why cement-like materials fail and mechanisms age, ii) quantify material performance, and iii) predict component and structural behaviour in operations that develop sustainable material solutions for an extended lifespan and improved operational efficiency.

Technology: The Carbonaide technology is a new process that allows CO_2 to be used during the manufacturing of pre-cast concrete and the mineralised CO_2 to be further valorised. The technology transforms gaseous CO_2 into solid carbonates during the concrete hardening process. The innovation consists of a process unit (1 or 2 containers) and a CO_2 storage unit. It has the potential to further valorise bound CO_2 in the carbon offset markets. This process unit is easily integrated into existing production plants. It has the potential to change the concrete industry from a CO_2 intensive industry into a carbon sink industry.

The process has been successfully piloted, and the first objects using this technology have been carried out by Rakennusbetoni- ja Elementti Oy from Hollola, with the construction company Skanska. Rakennusbetoni- ja Elementti Oy has used the technology to manufacture carbon negative yard paving, which was installed at Skanska's construction site in the autumn of 2022. The aim of this project between these companies is to pilot carbon negative construction and to collect data on the behaviour of the materials. The active follow-up of the pilot and its results will provide the basis for preparing industrial production.

Funding: Carbonaide benefited from ERDF support. The method for commercialisation was studied with funding from Business Finland. VTT's own contribution to the technology's development was 100%. The technology has proven to be effective and economically viable.

Key impact and environmental relevance of the innovation: Currently 6-8% of global CO_2 emissions originate from the concrete sector. Due to accelerating urbanisation, the share is expected to rise drastically. One irreplaceable component of concrete is cement, which is mainly responsible for high CO_2 emissions due to its chemical nature. The cement industry is one of the two largest producers of CO_2, creating up to 8% of man-made emissions of CO_2 worldwide, of which 50% is from the chemical process and 40% from burning fuel. The main environmental benefit of the Carbonaide technology is that it converts gaseous CO_2 into mineralised carbonates. In addition, less cement is needed for the similar properties of this concrete, which improves the economic and resource efficiency of the production process.

When the technology is fully deployed worldwide, it will be capable of binding each year 0.82 Gigatons of CO_2 permanently. The anticipated impact on the climate overall is a reduction of approximately 1.4 Gigatons of CO_2 emissions. For comparison, the EU produced 2.54 Gigatons of CO_2 emissions in 2020.

The global market of concrete products and components is growing fast and amounts to approximately 370 billion US dollars annually. This offers great market potential for Carbonaide's technology. The solution also has a market in the carbon dioxide emission trade.

The innovation contributes to meeting the following UN Sustainable Development Goals (SDGs): 13 - Climate change, 11—Sustainable cities and communities, and 12 - Responsible consumption and production. In addition, it will specifically contribute to meeting the following sub goals under SDG 12: 12.2 'By 2030, achieve the sustainable management and efficient use of natural resources' and 12.5 'By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse'.

Commercialisation of the innovation: Carbonaide is ready for commercialisation and to be scaled up for industrial production. The commercial spin-off is advancing with the support of the VTT LaunchPad business incubator. The full-scale manufacturing of the new pre-cast concrete products is expected in 2 years. Carbonaide's business idea is to receive carbon dioxide from the emissions trading platforms, and to use it for the benefit of the technology. Thus, binding carbon dioxide opens another market for the company. Carbonaide's vision is to have 100 units of the production device installed in the global market by 2030. The goal is to bind approximately 500 megatons of carbon dioxide annually by 2050, which corresponds to 10–20% of the concrete market.

4.4. Conclusions

- ✓ Legislation provides direction towards circularity but a few circular binding targets.

- ✓ Single Market rules, which provide harmonised legal requirements to be observed in the lifecycle of products in textiles, construction and energy-intensive industries (e.g. for production, waste, emissions or recycling of materials) are evolving.

- ✓ The Green Deal has further accelerated this development since the action plan for a Circular Economy was adopted. As the proposals for new legislation start covering all phases of the lifecycle of relevant products and is doing so more and more comprehensively, the need for innovative industrial technologies and business models is increasing in order to meet the upcoming e.g. eco-design and circularity requirements.

- ✓ The announcement and development of more ambitious and more comprehensive rules at EU-level in 2019/2020 as well as target dates for recovery of electrical and electronic equipment coincide with a sharp increase in R&I investment into relevant technologies.

- ✓ The new harmonised rules are expected to contribute to a better level playing field with reduced regulatory barriers between Member States.

- ✓ The EU has developed useful tools to help valorising excellent research and innovation results in the area of circular technologies and business models.

- ✓ Good use of tools like the EU Knowledge Valorisation Platform could help better interlinking R&I results for circular solutions, which are addressing various parts of the product lifecycle.

- ✓ Standards are an important tool for knowledge valorisation of R&I results. New tools under the 2022 EU Standardisation Strategy can significantly boost the development of important future standards for circular industries, based on input from research and innovation. A new 'standardisation booster' supports researchers under Horizon 2020 and Horizon Europe to test the relevance of their R&I results for standardisation and a Code of Practice for researchers on standardisation has the potential to strengthens the link between standardisation and research and innovation.

- ✓ Standards for circular industrial technologies appear to be already existing under energy-intensive industries, for steel and ceramics, but to lag for the chemicals, textile and construction ecosystems.

- ✓ The analysis shows that a number of industrial standards for circularity at EU and national level are developing, but without any strategic approach for covering the main parts of full product lifecycles or value chains. In addition, relevant digital standards are usually developed separately, which makes it more difficult to make best use of digital technologies for the circular economy. Applied to circular industrial technologies and business models, the new methodology for anticipating future standardisation needs, shows that in the case of ceramics, steel and construction significant new regulation triggered subsequent elevation in publication of standards. This could be due to calls for harmonised standards under that legislation. At the same time, it is not possible to conclude that increased research, scientific publications and patenting in the circular technologies domains of energy-intensive industries (ceramics, chemicals and steel), construction and textile, would have resulted in increased standardisation.

- ✓ For the rapidly emerging innovations for circular industrial technologies and business models, the importance of research standards from low to high TRL-levels warrants intensive efforts to strengthen standards as of the phase of knowledge development. Further research is needed on how to predict standardisation needs for circularity in such sectors with higher certainty.

- ✓ Research and technology infrastructures are important cooperation partners and service providers to industry, including SMEs, for technology and product/service development. Existing infrastructures cover in particular the textile and construction industrial ecosystems through technological facilities and services.

- ✓ There is no European-wide strategy to link research and technology infrastructures or give them a specific strategic role as enablers of circularity in the transformation of the textile and construction industrial ecosystems. Research infrastructures offer high-tech specific facilities whose use could be specifically considered for example in chemicals and materials design and development.

BIBLIOGRAPHY

- Arrigo (2021). Digital platforms in fashion rental: a business model analysis, Journal of Fashion Marketing and Management: An International Journal Vol. 26 No. 1, 2022 pp. 1-20 Emerald Publishing Limited 1361-2026 DOI 10.1108/JFMM-03-2020-0044
- Bio-based industries consortium (2022). Strategic Research and Innovation Agenda (SRIA) for the Circular Bio-based Europe Joint Undertaking (CBE JU)
- Damayanti,D. Wulandari, L.A. Bagaskoro, A.; Rianjanu, A.; Wu, H.-S.(2021). Possibility Routes for Textile Recycling Technology. Polymers 2021, 13,3834. https://doi.org/10.3390/ polym13213834
- Daňo, F., Drábik, P., Hanuláková, E. (2020). Circular business models in textiles and apparel sector in Slovakia, https://doi.org/10.18267/j.cebr.226
- Changing Markets Foundation (2017). Dirty fashion. https://changingmarkets.org/portfolio/dirty-fashion/
- Circle Economy (2021), information from the website of The Circle Economy: https://publish.circle-economy.com/high_value_reuse_textile_recycling
- CSIL (2021). Data on the EU Textile Ecosystem and its Competitiveness
- ECOS (2021). Durable, repairable and mainstream - How ecodesign can make our textiles circular, https://ecostandard.org/wp-content/uploads/2021/04/ECOS-REPORT-HOW-ECODESIGN-CAN-MAKE-OUR-TEXTILES-CIRCULAR.pdf
- EEA (2022). Textiles and the environment: the role of design in Europe's circular economy https://www.eea.europa.eu/publications/textiles-and-the-environment-the
- EEA (2019). Textiles in Europe's circular economy
- EFRA (2021). Made in Europe, the manufacturing partnership in Horizon Europe – Strategic Research and Innovation Agenda (SRIA). Available at: https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_rtd_he-partnership-made-in-europe.pdf
- Ellen MacArthur Foundation (2021). Circular business models: redefining growth for a thriving fashion industry (2021).
- Ellen MacArthur Foundation (2017). A new textiles economy: Redesigning fashion's future. https://ellenmacarthurfoundation.org/a-new-textiles-economy
- Ellen MacArthur Foundation (2015) Towards a Circular Economy: Business Rationale for an Accelerated Transition
- Euratex (2022). Facts & Key Figures
- Euratex (2021). Facts & Key Figures
- Eurostat (2021). Annual enterprise statistics for special aggregates of activities (NACE Rev. 2) (sbs_na_sca_r2)
- European Commission (2022). Annual Single Market Report. BRUSSELS, 22.2.2022, SWD(2022) 40 final, https://ec.europa.eu/docsroom/documents/48877/attachments/2/translations/en/renditions/native
- European Commission (2021). Study on the technical, regulatory, economic and environmental effectiveness of textile fibres recycling
- European Commission (2021). Annual Single Market Report
- European Commission (2021). Advanced Technologies for Industry – sectoral watch. Technological trends in the machinery industry.
- European Commission (2021). EU strategy for textiles. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=PI_COM:Ares(2021)67453
- European Commission (2020). A new Circular Economy Action Plan For a cleaner and more competitive Europe. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

- European Commission (2020). Advanced Technologies for Industry – Sectoral Watch. Technological trends in the textiles industry.
- European Commission (2019). 'Dying Without Water''. https://ec.europa.eu/environment/ecoap/about-eco-innovation/experts-interviews/tintura-senza-acqua_en
- European Commission (2019). JRC science for policy report: Best Available Techniques (BAT) Reference Document for the Textiles Industry (Draft report). https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/TXT_bref_D1_1.pdf
- European Commission (2008). Waste Framework Directive. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008L0098-20180705
- Fashion for Good (2019). Polybags in the Fashion Industry
- Fashion for Good (2019a). The future of circular fashion: Assessing the viability of circular business models
- Fibersort (2020). Overcoming barriers for long-term implementation, Interreg
- GFA and McKinsey & Company (2021). Scaling circularity, https://globalfashionagenda.org/news-article/scaling-circularity-a-policy-perspective/
- Gizem Celep, Gamze D. Tetik and Fulya Yilmaz (2022). Limitations of Textile Recycling: The Reason behind the Development of Alternative Sustainable Fibers, DOI: 10.5772/intechopen.105118
- Jakob Hildebrandt, Daniela Thrän, Alberto Bezama (2021). The circularity of potential bio-textile production routes: Comparing lifecycle impacts of bio-based materials used within the manufacturing of selected leather substitutes, Journal of Cleaner Production, Volume 287
- JRC (2021). Circular economy perspectives in the EU textile sector, Joint Research Centre Technical Report
- Maxwell, D., et al. (2015). State of the apparel sector report: Water, GLASA
- McBride, S. (2017). Bricks-and-mortar shops bet on startup tech to bring back customers, Bloomberg Businessweek, February 2017
- Pal, S. & Sandberg, E. (2017). Sustainable value creation through new industrial supplyChains in apparel and fashion. In the 17th World Textile Conference of Association – of Universities for Textile (AUTEXT)-Shaping of the Future
- Resortecs (2021). A comparative Lifecycle Assessment of disassembly & recycling methods in closed-loop denim production
- Sarmadi, M. (2013). Advantages and Disadvantages of Plasma Treatment of Textile Materials. 21st International Symposium on Plasma Chemistry (ISPC 21)
- Tencel (2021). information from the website of Tencel: http://www.lenzing-fibers.com/en/tencel
- Textile ETP (European Technology Platform) (2022). Textile ETP (European Technology Platform) (2016). Towards a 4th Industrial Revolution of Textiles and Clothing.
- Textile ETP (European Technology Platform) (2016). Towards a 4th Industrial Revolution of Textiles and Clothing. http://www.technofashionworld.com/files/2016/11/TextileETP_SIRA_public-version.pdf
- Zille, A., Oliveira, F.R. and Souto, A.P. (2015), Plasma Treatment in Textile Industry. Plasma Process. Polym., 12: 98-131. https://doi.org/10.1002/ppap.201400052
- https://ellenmacarthurfoundation.org/a-new-textiles-economy
- https://textileexchange.org/2025-recycled-polyester-challenge/
- https://www.alliedmarketresearch.com/recycle-textile-market
- https://www.cbi.eu/market-information/apparel/recycled-fashion/market-potential
- https://www.ecolabelindex.com/ecolabels/?st=category,textiles

- https://www.nweurope.eu/media/9655/2020305-fibersort-51-final-case-studies-report.pdf
- https://www.mckinsey.com/industries/retail/our-insights/scaling-textile-recycling-in-europe-turning-waste-into-value
- https://www.trendwatching.com/innovation-of-the-day/waste-to-yarn-to-clothing-brightfiber-brings-cleaner-fashion-home
- Akinade, O. et al., (2019). Design for deconstruction using a circular economy approach: barriers and strategies for improvement. Production Planning & Control, pp. 1-12. Available at: https://www.tandfonline.com/doi/full/10.1080/09537287.2019.1695006
- Benachio, G. L. F., et al. (2021). "Interactions between Lean Construction Principles and Circular Economy Practices for the Construction Industry." Journal of Construction Engineering and Management 147(7). Available at: https://ascelibrary.org/doi/full/10.1061/%28ASCE%29CO.1943-7862.0002082
- Brandão, R., et al. (2021). "Reverse supply chain conceptual model for construction and demolition waste." Waste Management & Research: The Journal for a Sustainable Circular Economy 39(11): 1341-1355. Available at: https://journals.sagepub.com/doi/full/10.1177/0734242X21998730
- CECE (2018). ECSO publication on the EU Construction 2020 strategy. Available at: https://www.cece.eu/news/ecso-publications-on-the-eu-construction-2020-strategy#:~:text=The%20objectives%20are%3A%20'Stimulating%20favourable,competitiveness%20of%20EU%20construction%20enterprises'.
- Çetin, S., de Wolf, C. & Bocken, N., (2021). Circular Digital Built Environment: An Emerging Framework. Sustainability, Volume 13. Available at: https://www.mdpi.com/2071-1050/13/11/6348
- Digiplace Project (n.d.). Available at: https://digiplaceproject.eu/
- EEA (2021). Construction and demolition waste: challenges and opportunities in a circular economy. Available at: https://www.eea.europa.eu/publications/construction-and-demolition-waste-challenges
- EEA (2010). SOER2010 Material resources and waste — SOER 2010 thematic assessment
- EUR_Lex (2020). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662
- EUR-Lex (2008). DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on waste and repealing certain Directives. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098
- European Aluminium Association (2014). Specific EAA position on the EU Packaging and Packaging Waste Directive (summary). Available at: https://european-aluminium.eu/media/1354/201404_specific-position-on-the-eu-packaging-waste_europeanaluminium.pdf
- European Commission (2014). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS ON RESOURCE EFFICIENCY OPPORTUNITIES IN THE BUILDING SECTOR. Available at: https://ec.europa.eu/environment/eussd/pdf/SustainableBuildingsCommunication.pdf

- European Commission (2016). EU Construction and Demolition Waste Management Protocol. Available at: https://ec.europa.eu/docsroom/documents/20509/
- European Commission (2021). Annual Single Market Report
- European Commission (2022). Annual Single Market Report
- European Commission (2022). Built4People Partnership Strategic Research & Innovation Agenda 2021-2027. Available at: https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_rtd_he-partnerships-built4people-agenda.pdf
- European Commission (2022). Green Deal: New proposals to make sustainable products the norm and boost Europe's resource independence. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2013
- European Commission (2022). Partnership Fiche: Built4People. Available at: https://ec.europa.eu/research-and-innovation/sites/default/files/bmr-2022/ec_rtd_bmr-2022-built4people-fiche.pdf.
- European Commission (2022). Scenarios for the transition pathway for a resilient, greener and more digital construction ecosystem. Available at: https://single-market-economy.ec.europa.eu/consultations/scenarios-transition-pathway-resilient-greener-and-more-digital-construction-ecosystem_en
- Eurostat (2018). Circular Economy Indicators, Recovery rate of construction and demolition waste
- Eurostat, Annual enterprise statistics by size class for special aggregates of activities (NACE Rev. 2) (sbs_sc_sca_r2)
- Fraunhofer IPK (2020). Digital Twin Readiness Assessment. Available at: https://www.ipk.fraunhofer.de/en/media/studies/digital-twin-readiness-assessment.html
- Interreg Europe (2022). Collection and recycling of construction and demolition waste: Key learnings. Available at: https://www.interregeurope.eu/find-policy-solutions/webinar/collection-and-recycling-of-construction-and-demolition-waste-key-learnings
- Kakkos, E., Heisel, F., Hebel, D. & Hischier, R. (2020). Towards Urban Mining – Estimating the Potential Environmental Benefits by Applying an Alternative Construction Practice. A Case Study from Switzerland. Available at: https://www.mdpi.com/2071-1050/12/12/5041
- Schober, K.S. (2021). How circular economy can drive greater sustainability and new business opportunities in construction. Available at: https://www.rolandberger.com/en/Insights/Publications/It%E2%80%99s-time-for-construction-to-embrace-the-circular-economy.html
- Tebbatt Adams, K., Thorpe, T., Osmani, M. & Thornback, J., (2017). Circular Economy in Construction: Current Awareness, Challenges and Enablers. Waste and Resource Management, 170(1). Available at: https://www.icevirtuallibrary.com/doi/10.1680/jwarm.16.00011
- Wijewickrama, M., Rameezdeen, R. & Chileshe, N., (2021). Information brokerage for circular economy in the construction industry: A systematic literature review. Journal of Cleaner Production, Volume 312, pp. 1-13. Available at: https://find.library.unisa.edu.au/primo-explore/fulldisplay?vid=ROR&context=L&lang=en_US&id=9916530311501831
- Yao, F. et al., (2020). Evaluating the Environmental Impact of Construction within the Industrialised Building Process: A Monetisation and Building Information Modelling Approach. International Journal of Environmental Research and Public Health, Volume 17.. Available at: https://www.mdpi.com/1660-4601/17/22/839
- Beldek, T., et al. (2016). "Green supply chain management for construction waste: case study for turkey." International Journal of Sustainable Development and Planning 11(5): 771-780. Available at:

https://www.researchgate.net/publication/341776287_Green_supply_chain_management_for_construction_waste_Case_study_for_Turkey
- Giorgi, S., et al. (2022). "Drivers and barriers towards circular economy in the building sector: Stakeholder interviews and analysis of five European countries policies and practices." Journal of Cleaner Production 336: 130395. Available at: https://www.sciencedirect.com/science/article/pii/S0959652622000415
- European Circular Economy Stakeholder Platform (2022). Circular Buildings and Infrastructure. Available at: https://hollandcircularhotspot.nl/wp-content/uploads/2022/03/circular_buildings_and_infrastructure_brochure.pdf
- Krook, J., Cleall, P. Rosendal, R., Carvalho, T. (2018). Mining the European Anthroposphere (MINEA)Working Group 2: Resource potential of waste from landfills. Available at: https://zenodo.org/record/3768961#.Y25A6naUdPZ
- Leonardo (2018)/ Construction waste as a value chain. Available at: https://leonard.vinci.com/en/construction-waste-as-a-value-chain/
- Cutaia, L., Altamura, P., Ceruti, F., Cellulare, M., Corrado, S., De Marco, E., Luciano, A., Carollo, F. C., A (2022). European Circular Economy Stakeholder Platform. Leadership Group on Construction and Infrastructure: A two-year stakeholders' consultation on the construction and infrastructure value chains. Output Paper of the activities coordinated by ENEA in 2020-2021. Available at: https://circulareconomy.europa.eu/platform/sites/default/files/ct_ci_value_chains_and_market_output_paper_final.pdf
- Zhao, X. (2021). Stakeholder-Associated Factors Influencing Construction and Demolition Waste Management: A Systematic Review. Buildings 11(4): 149. Available at: https://www.researchgate.net/publication/350597816_Stakeholder-Associated_Factors_Influencing_Construction_and_Demolition_Waste_Management_A_Systematic_Review
- https://www.eea.europa.eu/publications/construction-and-demolition-waste-challenges
- https://www.interregeurope.eu/find-policy-solutions/webinar/collection-and-recycling-of-construction-and-demolition-waste-key-learnings
- https://european-aluminium.eu/media/1354/201404_specific-position-on-the-eu-packaging-waste_europeanaluminium.pdf
- Accenture (2021), Taking the European chemical industry into the circular economy. Available at: https://www.accenture.com/_acnmedia/pdf-45/accenture-cefic-report-exec-summary.pdf
- Charles Bodar et al, 'Risk management of hazardous substances in a circular economy'. Journal of Environmental Management Volume 212, 15 April 2018, Pages 108-114 Available at: https://www.sciencedirect.com/science/article/pii/S0301479718301154
- CT de Mello Soares et al. 'Recycling of multi-material multilayer plastic packaging: Current trends and future scenarios'. Resources, Conservation and Recycling Volume 176, January 2022, 105905 Available at: https://www.sciencedirect.com/science/article/pii/S0921344921005140
- Deloitte (2020), Chemistry 4.0, growth through innovation in a transforming world. Available at: https://www2.deloitte.com/content/dam/Deloitte/global/Documents/consumer-industrial-products/gx-chemistry%204.0-full-report.pdf
- EFRA (2021), Made in Europe, the manufacturing partnership in Horizon Europe – Strategic Research and Innovation Agenda (SRIA). Available at: https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_rtd_he-partnership-made-in-europe.pdf
- European Commission (2020). Draft proposal for a European Partnership under Horizon Europe. European Partnership for a Ciruclario bio-based Europe: sustainable innovation for new local value from bio-waste and biomass (CBE).

Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/11903-European-Partnership-for-a-circular-bio-based-Europe-Horizon-Europe-programme-_en
- European Commission (2020). Chemicals Strategy for Sustainability, Towards a Toxic-Free Environment. Available at: https://echa.europa.eu/hot-topics/chemicals-strategy-for-sustainability
- European Commission (2020). Advanced technologies for industry, sectoral watch. Technological trends in the chemical industry. Available at: https://ati.ec.europa.eu/reports/Sectoral-Watch
- European Commission (2021). Masterplan for a Competitive Transformation of EU Energy-intensive Industries Enabling a Climate-neutral,Circular Economy by 2050. Available at: https://op.europa.eu/en/publication-detail/-/publication/be308ba7-14da-11ea-8c1f-01aa75ed71a1/language-en
- European Commission (2020). European Industrial Strategy
- European Commission (2019). Circular Economy Action Plan, https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
- European Commission (2020). Chemicals Strategy for Sustainability towards a toxic-free environment, Brussels, 14.10.2020, COM(2020) 667 final, https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf
- Ladu, L., Quitzow, R, ‘Bio-Based Economy: Policy Framework and Foresight Thinking’. In: Morone, P., Papendiek, F., Tartiu, V. (eds) Food Waste Reduction and Valorisation. (2017). Springer, Cham. https://doi.org/10.1007/978-3-319-50088-1_9
- Materials Economics (2019). Industrial Transformation 2050 – Pathways to Net-Zero Emissions from EU Heavy Industry
- Sofia MariaIoannidou et a. ‘Future transitions for the Bioeconomy towards Sustainable Development and a Climate-Neutral Economy - Foresight Scenarios for the EU bioeconomy in 2050’. Bioresource Technology Volume 307, July 2020, 123093 Available at: https://www.sciencedirect.com/science/article/abs/pii/S096085242030362X
- SPIRE (2021). European Partnership Processes4Planet Roadmap. Available at: https://www.aspire2050.eu/p4planet/about-p4planet
- SPIRE (2021). European Partnership Processes4Planet Research and Innovation Agenda. Available at: https://www.aspire2050.eu/p4planet/about-p4planet
- SusChem (2021). SusChem Strategic Research and Innovation Agenda (SIRA). Available at: http://www.suschem.org/press-area/press-releases/suschem-publishes-new-strategic-innovation-and-research-agenda
- SusChem (2021). Sustainable Plastics Strategy. Available at: http://www.suschem-es.org/docum/pb/Plastics_Strategic_Research_Innovation_Agenda_FINAL.pdf
- https://ec.europa.eu/info/sites/default/files/swd-competitive-clean-european-steel_en.pdf
- https://www.eea.europa.eu/help/faq/what-is-particulate-matter-and
- https://ec.europa.eu/energy/sites/ener/files/documents/institute_for_european_studies_-_industrial_value_chain_-_a_bridge_towards_a_carbon_neutral_europe.pdf
- https://ec.europa.eu/environment/chemicals/international_conventions/index_en.htm#:~:text=Persistent%20organic%20pollutants%20(POPs)%20are,human%20health%20and%20the%20environment.
- APEAL (2022). the Association of European Producers of steel for packaging, https://www.apeal.org/statistics/
- CSP (2021). European Partnership for Clean Steel. Available at https://www.estep.eu/clean-steel-partnership/

- Eurofer (2020). European steel in figures
- European Commission (2020). Advanced technologies for industry, sectoral watch. Technological trends in the machinery industry. Available at: https://ati.ec.europa.eu/reports/Sectoral-Watch
- European Commission (2021). Working document: Towards Competitive and Clean European steel. Available at: https://ec.europa.eu/info/sites/default/files/swd-competitive-clean-european-steel_en.pdf
- ESTEP (2021). Clean Steel Partnership, Strategic Research and Innovation Agenda (SRIA). Available at: https://www.estep.eu/assets/Uploads/CSP-SRIA-Oct2021-clean.pdf
- European Parliament (2020). Energy-intensive industries, challenges and opportunities in energy transition. Policy department for Economic, Scientific and Quality of life policies. Directorate General for Internal policies. Available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2020/652717/IPOL_STU(2020)652717_EN.pdf
- Gerald Stubbe et al (2016). 'Zinc and Iron Recovery from Filter Dust by Melt Bath Injection into an Induction Furnace' (2016). Available at: https://www.velco.de/wp-content/uploads/2021/05/Erzmetall_Schmelzinjekt2016-1.pdf
- Harald Raupenstrauch (2021), 'RecoDust—An Efficient Way of Processing Steel Mill Dusts' (2019). Journal of Sustainable Metallurgy 5(11).
- Johannes Rieger (2021). 'Residue Valorization in the Iron and Steel Industries: Sustainable Solutions for a Cleaner and More Competitive Future Europe', Metals. Available at: https://www.mdpi.com/2075-4701/11/8/1202/htm
- Loose, Florian (2020). 'End-of-Life Carbon Fiber Reinforced Polymers in Steelmaking - Accessing a C-Rich Residue Stream as Alternative Reducing Agent', : Residue valorization in iron and steel industry - sustainable solutions for a cleaner and more competitive future Europe 2020-11-20 - 2020-11-20 Available at: https://www.teer.rwth-aachen.de/cms/TEER/Forschung/Publikationen/~lkua/Details/?file=809703&lidx=1
- Material Economics, (2020). Preserving value in EU industrial materials, a value perspective on the use of steel, plastics and aluminimum. Available at: https://materialeconomics.com/latest-updates/preserving-value-in-eu-industrial-materials
- SIM² KU Leuven/SOLVOMET & ArcelorMittal (2020). 'A novel ammoniacal leaching process to valorise Zn-rich Basic Oxygen Furnace sludges', Available at: https://eit-samex.eu/2020/11/09/a-novel-ammoniacal-leaching-process-to-valorise-zn-rich-basic-oxygen-furnace-sludges/
- World Steel Association (2015). Steel in the circular economy, a lifecycle perspective. Available at: https://worldsteel.org/publications/bookshop/circular-economy-life-cycle-steel/

ABBREVIATIONS AND ACRONYMS

3I:	Interregional Innovation Investments
AC:	Associated Country/Countries
AI:	Artificial intelligence
AMI:	Advanced Materials Initiative
AR:	Augmented reality
AT:	Austria
AUWP:	Annual Union Work Programme
B4P:	Built 4 People Partnership
BAT:	Best available techniques
BBI JU:	Bio-based Industries Joint Undertaking
BBRI:	Belgian Building Research Institute
BE:	Belgium
BG:	Bulgaria
BF:	Blast furnace
BIM:	Building Information Modelling
BOKU:	University of Natural Resources and Applied Sciences Vienna
BOF:	Basic oxygen furnace
BREF:	Best available techniques reference documents
CBE JU:	Circular Bio-based Europe Joint Undertaking
CCMT:	Climate change mitigation technology/technologies
CDW:	Construction and demolition waste
CE:	Circular economy
CEAP:	Circular Economy Action Plan
CE-TG:	Circular Economy Topic Group
CEI:	Circular economy industries

CEN:	European Committee for Standardisation
CENELEC:	European Committee for Electrotechnical Standardisation
CEN-TC:	European technical committee for plastics
CET:	Circular economy technology/technologies
CETI:	European Centre for Innovative Textiles
CFRP:	Carbon fibre reinforced polymer
CH:	Switzerland
CINEA:	European Climate, Infrastructure and Environment Executive Agency
CLP:	Classification, labelling and packaging of substances and mixtures regulation
CN:	People's Republic of China
CNIPA:	National Intellectual Property Administration of the People's Republic of China
CORDIS:	Community Research and Development Information Service
CPC:	Cooperative Patent Classification
CRM:	Critical raw material(s)
CSA:	Coordination and support action(s)
CSS:	Chemicals Strategy for Sustainability
CT:	Circular technology/technologies
CY:	Cyprus
CZ:	Czechia
DE:	Germany
DG:	Directorate-General
DG EAC:	Directorate-General for Education, Youth, Sport and Culture
DG ENER:	Directorate-General for Energy
DG ENV:	Directorate-General for Environment

DG GROW: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs

DG R&I: Directorate-General for Research and Innovation

DG REGIO: Directorate-General for Regional and Urban Policy

DK: Denmark

DPP: Digital Product Passport

EAF: Electric Arc Furnace

EBRD: European Bank for Reconstruction and Development

ECTP: European Construction Technology Platform

EE: Estonia

EEA: European Environment Agency

EFFRA: European Factories of the Future Research Association

EFSI: European Fund for Strategic Investments

EGD: European Green Deal

EARTO: European Association of Research and Technology Organisations

EIB: European Investment Bank

EIC: European Innovation Council

EIF: European Investment Fund

EII: Energy-intensive industries

EISMEA: European Innovation Council and Small and Medium-sized Enterprises Executive Agency

EIT: European Institute of Innovation and Technology

ELVD: End of Life Vehicle Directive

EPO: European Patent Office

ERA: European Research Area

ERDF: European Regional Development Fund

ERMA: European Raw Materials Alliance

ES:	Spain
ESG:	Environmental, social and governance
ESRF:	European Synchrotron Radiation Facility
ETP:	Textile European Technology Platform
ETS:	Emissions Trading System
ETSI:	European Telecommunications Standards Institute
EU:	European Union
EUR:	Euro
EUROSTAT:	European Statistics Office
FI:	Finland
FOAK:	First of a kind installation
FR:	France
GDP:	Gross Domestic Product
GHG:	Greenhouse gas
GR:	Greece
H2020:	Horizon 2020
H4C:	Hubs 4 Circularity
HADEA:	European Health and Digital Executive Agency
HE:	Horizon Europe
HPC JU:	High Performance Computing Joint Undertaking
HR:	Croatia
HU:	Hungary
ICB:	Industry classification benchmark
ICT:	Information and communication technology
IE:	Ireland
IEC:	International Electrotechnical Commission

IED: Industrial Emissions Directive

INCITE: Innovation Centre for Industrial Transformation and Emissions

INTERREG: Interregional collaboration

IoT: Internet of Things

IP: Intellectual property

ISO: International Standards Organisation

IT: Italy

IW: Industrial waste

JP: Japan

JPO: Japan Patent Office

JRC: Joint Research Centre

KIC: Knowledge and Innovation Community/Communities

KIPO: Korean Intellectual Property Office

KR: Republic of Korea

LCA: Lifecycle assessment

LEIT: Leadership in enabling and industrial technologies

LIBS: Laser-induced breakdown spectroscopy

LIFE: European Financial Instrument for Environment

LOD: Laser object detection

LT: Lithuania

LU: Luxembourg

LV: Latvia

MS: Member State(s)

MT: Malta

NACE: Statistical classification of economic activities

NGO: Non-governmental organisation(s)

NL: Netherlands

NO: Norway

NPBI: National promotional banks and institutions

OECD: Organisation for Economic Cooperation and Development

OITB: Open innovation test bed(s)

OVAM: Public Waste Agency of Flanders

P4P: Processes 4 Planet Partnership

PET: Polyethylene terephthalate

PL: Poland

PPWD: Packaging and Packaging Waste Directive

PRACE: Partnership for Advanced Computing in Europe

PT: Portugal

R&D: Research and development

R&D&I: Research, development and innovation

R&I: Research and innovation

REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals

RI: Research infrastructure(s)

RFCS: Research Fund for Coal and Steel

RNFBO: Renewable Fuels of Non-Biological Origin

RO: Romania

RoW: Rest of the world

RRF: Recovery and Resilience Facility

RRP: Recovery and Resilience Plan(s)

RTO: Research and technology organisation(s)

SA: South Africa

SABE: Strategic Advisory Body on Environment

SDG: Sustainable development goal(s)

SE: Sweden

SET Plan: Strategic energy technology plan

SI: Slovenia

SK: Slovakia

SME: Small and medium-sized enterprise(s)

SPIRE: Sustainable Process Industry through Resource and Energy Efficiency Partnership

SRIA: Strategic Research and Innovation Agenda

SRIP: Strategic Research and Innovation Plan

SSbD: Safe and Sustainable by Design

SWD: Staff Working Document

TI: Technology infrastructure(s)

TR: Türkiye

TRL: Technology Readiness Level(s)

TU: Technical university/universities

UK: United Kingdom of Great Britain and Northern Ireland

US: United States of America

USPTO: United States Patent and Trademark Office

VITO: Flemish Institute for Technological Research

VR: Virtual reality

VTT: Finnish Technical Research Centre

WEEE: Waste from electrical and electronic equipment

WFD: Waste Framework Directive

WPC: Wood Plastics Composites

ZPAP: Zero-Pollution Action Plan

ANNEXES

Annexes are available on a separate document on the EU Bookshop.

Annex 1: Methodology of technology assessment

Annex 2: Tables of circular industrial technologies

Annex 3: SME Survey

Annex 4: Overview of national investments and programmes of EU Member States and Norway

Annex 5: Workshops and consultations for the ERA Industrial Technology Roadmap for Circular Technologies and Business Models in Textile, Construction and Energy-intensive industries

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union.
You can contact this service:

- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
- at the following standard number: +32 22999696,
- via the following form: european-union.europa.eu/contact-eu/write-us_en.

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

EU open data

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

This second industrial technology roadmap, under the European Research Area, sets out 92 circular technologies in the textile, construction and energy-intensive industries, which address all stages of a material and product lifecycle. It indicates the means to develop and adopt these technologies, which can help reduce the impact of these industries on climate and the environment. It finds a leading position of EU companies in circular technologies, but also looks at the substantial research & innovation investment needs at EU and national levels and necessary framework conditions to put in place. It builds on contributions from industry, other R&I stakeholders, Member States, and relevant European partnerships.

Research and Innovation policy

Publications Office
of the European Union