The international ecosystem for accelerating the transition to Safe-and-Sustainable-by-design materials, products and processes.

Roadmaps per value chain with guidelines and inputs for EU Calls

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Abbreviations and Acronyms

Abbreviation	Definition
Cefic	The European Chemical Industry Council
CRM	Critical Raw Material
CSDDD	Corporate Sustainability Due Diligence Directive
CSRD	Corporate Sustainability Reporting Directive
D	Deliverable
DG RTD	Directorate-General for Research and Innovation
DPP	Digital Product Passport
EC	European Commission
ECS	Electronic Components and System
ELV	End of Life Vehicle
EOL	End of Life
EPR	Extended Producers Responsibility
ESPR	Ecodesign for Sustainable Product Regulation
EuCIA	European Composites Industry Association
GHG	Greenhouse Gas
IEA	International Energy Agency
ILS	International Labour Standards
IFRA	The International Fragrance Association
JRC	Joint Research Centre
LCA	Life Cycle Assessment
PFAS	Per- and Polyfluorinated Substances
PPWR	Packaging and Packaging Waste Regulation
PS	Polystyrene
PU	Polyurethane
PVDF	Polyvinylidene fluoride
R&D	Research and Development
R&I	Research and Innovation
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SME	Small and medium-sized enterprise

Abbreviation	Definition
SSbD	Safe and Sustainable by Design
SVHC	Substances of Very High Concern
VC	Value chain
WP	Work Package

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1 Executive summary

After working extensively in the first period of the project on each value chain (VC) and sub value chains challenges and gaps, this deliverable (D) associated to WP3 and its supportive roadmap is intending delivering a number of solutions proposals to the exposed challenges. As the number of challenges is very high, it has been chosen to focus on the biggest challenges and propose solutions for each value chain, or sub value chains, which are considered as priorities in terms of Research and Innovation needs. They don't all cover all aspects of the life cycle because they are a selection of priorities within a given value chain.

For the *packaging value chain*, the main challenges and solutions are:

- Incorporate recycled content in respect of safety criteria
    - Solution: Reduction of packaging waste volumes OR accelerate the development of recycling processes at industrial scale for plastic packaging
- Avoid successive substances substitutions
    - Solution: for regulation to consider group of chemicals instead of unique substances
- Enhance control of conformity to regulated substances and microplastics
    - Solution: obtain harmonized regulations: alignment of the different EU regulations and decisions of worldwide measures
- Interoperate Safe and Sustainable by Design (SSbD) data along the supply chain with respect of data confidentiality
    - Solution: To manage a precise SSbD evaluation along the entire life cycle, it is necessary to find a way to interoperate SSbD data along the Value Chain.
- Prioritize SSbD criteria to consider Research and Development (R&D) capacities of small and medium sized enterprises (SMEs) and industrials. The challenge is to maintain a multi-criterion, whole life-cycle assessment while applying part of the SSbD framework, to detect potential pollution transfer from one SSbD concern to another.
    - A solution to achieve a partial but valid SSbD assessment is to determine SSbD hotspots for the evaluated chemical, material, or product life cycle.

For the *textiles value chain*, the main challenges and solutions are:

- Natural or synthetic fibre production challenges such as environmental and human health hazards related to poor agricultural practices, use of toxic substances in fibre growing (insecticides in cotton cultivation) or fibre processing (antimony use in polyester fibre production, use of caustic soda and sulphuric acid in viscose production). Fibres made from cellulosic feedstocks may contribute to deforestation and desertification.
    - Solutions include the establishment of better agricultural practices especially in countries with more limited access to professional expertise and latest technologies.
    - The phase-out of harsh chemistry in fibre processing i.e., antimony-free polyester production or replacement of viscose process by cleaner cellulosic fibre processing options, or at least the management of hazardous chemicals in closed-loop systems with full recovery.
    - Intensive research work is underway to develop more biobased fibre materials that can over time help to reduce and eventually completely phase out textile fibres made from fossil feedstocks.

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- The use of a wide range of chemicals either to achieve specific functional properties in the final product (dyes, inks, finishes, coatings etc.) or to facilitate the processing (auxiliaries and other processing chemicals).
    - Solutions include general reduction of use of processing chemistry, the recovery of chemicals and energy from process water streams, the replacement of harsh conventional chemistry by more sustainable and where possible biobased chemistry (i.e. enzymatic processing), general waste prevention and reduction by use of advanced manufacturing technologies incl. online quality control.
- The manufacturing of textile-based final products in developing and emerging countries
    - Solutions for social sustainability improvements in global textile supply chains are international laws, legislative initiatives, agreements, or standards.
- Ensuring optimal selection, use, care, and maintenance by consumers
    - Several solutions are being explored and put forward by policy makers such as Ecodesign for Sustainable Product Regulation (ESPR) to ensure that textile products are designed and manufactured for durability, repairability or recyclability. A digital product passport (DPP) should guide consumers in better decision making when purchasing, maintaining, repairing, or disposing textile products.
    - Microplastic release can be mitigated through optimised processing and finishing of textile materials and through filtration in washing machines or water treatment facilities and correct disposal of the filtrates.
- Emissions and other environmental hazards from inappropriate disposal of textile waste
    - Textile waste management is a focus area of the revised European Waste Framework Directive, mandating separate post-consumer textile waste collection in all EU countries by 2025, the development of professional collection, sorting and recycling systems across Europe supported by Extended Producer Responsibility (EPR) schemes.
    - Significant research, technology development and pilot demonstration programmes are underway to develop textile waste sorting and recycling processes that are both lower impact than incineration and landfilling and economically viable in the face of relatively low-cost virgin materials. Mandatory recycled content quotas for various textile product categories are under consideration to incentivise commercialisation of recycled textile materials.

For the *construction value chain* (Concrete admixtures sub-value chain), the main challenges and solutions are:

- Developing alternatives to formaldehyde and melamine, that do not result in a loss of performance.
    - Solution: The solution would be to develop alternatives to melamine or formaldehyde based concrete admixtures, that offer comparable or even better performance in the end-use (concrete).
- Depletion of renewable raw materials could result in a loss in biodiversity particularly for one class of concrete admixtures that is based on the use of renewable or renewable raw materials, i.e. lignin.
    - Solution: There are basically two different options to address this challenge: (i) ensure that raw materials, such as lignin are responsibly sourced and do not lead to a loss in biodiversity, and (ii) develop alternative raw materials that are renewable.

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- A challenge is to further reduce emissions to air, water, soil during the production of concrete admixtures.
    - Solution: The chemical industry, including the construction chemicals industry, has been making, and needs to continue to make, improvement in their production processes to further reduce emissions to air, water or soil.
- The production of concrete requires a lot of energy, and the resulting greenhouse gas (GHG) emissions should be (further) reduced to meet the challenging goals of the European Green Deal.
    - Solution: Although concrete admixtures are added to cement in about 1-2 % wt., their use results in significant reduction of GHG emissions during the production of concrete. Continuous improvement in GHG emission reduction resulting from the use of concrete admixtures is a long-standing objective of the construction chemicals industry in Europe.
- The production of concrete requires significant amounts of water, which should be (further) reduced as part of the continuous improvement in the construction chemicals sector.
    - Although concrete admixtures are added to cement in about 1-2 % wt., their use results in significant reduction of the amount of water required for production of concrete. Continuous improvement in the reduction of water, resulting from the use of concrete admixtures is a long-standing objective of the construction chemicals industry in Europe.
- The reduction of the GHG emissions associated to transporting concrete and its raw materials. Concrete is a rather heavy material and therefore, requires significant amounts of energy in transport.
    - Solution: The key solution to reducing GHG emissions in transport is shortening the distances of transport by sourcing locally.
- The reduction of GHG emissions during the use of the building itself, which is significant, given the very long lifetime of a building.
    - Solution: The use of concrete admixtures results in more efficient use of concrete and therefore, results in the reduction of GHG emissions of a building over its lifetime.
- The reduction of GHG emissions during the demolition of deconstruction of a building.
    - Solution: Concrete waste is and can be reused, thus saving GHG emissions of buildings from virgin raw materials. Concrete admixtures are being developed to allow the use of recycled concrete.

For the *construction value chain* (polyurethane (PU)- and polystyrene (PS)-based insulation sub-value chain), the main challenges and solutions are:

- The use of PU-based insulation materials that they are manufactured from di-isocyanates, which are substances of very high concern (SVHCs).
    - Solution: Where deemed necessary, PU based insulation materials can be substituted by other insulation materials such as stone wool and glass wool. The latter already have a much higher market share in the EU.
- The use of PU-based insulation materials may result in emissions of SVHCs above EU regulatory limits.
    - Solution: The PU industry, from raw materials manufacturers to downstream users, have together developed a comprehensive training package for professional users of PUs. This package could be (further) promoted.
- The use phase of a building results in significant GHG emissions during its lifetime.

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- Solution: PU or PS based insulation could be used and/or further improved to save GHG emissions over the (very long) lifetime of a building.

➢ The reduction of waste resulting from PU- or PS-based insulation after its lifetime.
  - Solution: PU- and PS-based insulation waste contains a significant amount of energy that could be recovered from PU or PS-based waste.

For the *automotive value chain,* the main challenges and solutions are:

➢ Challenge: Minimizing the use of critical raw materials
  - Implementation of SSbD rules to minimize the use of CRM and other critical natural resources in automotive products.
  - Development of new advanced materials to replace critical raw minerals in critical automotive components (e.g. Ni, Co, Li, Cu, Mg, rare-earth) while optimizing for performance and affordability.

➢ Use of safe and sustainable materials
  - Renewable and low emissions materials with appropriate quality, quantity and performance for automotive industry applications (e.g. low CO_2 metals and alloys)
  - Further development of very low or negative CO_2 materials from generation 2, 3 and 4 feedstocks
  - Solutions for more sustainable automotive polymers (e.g. bio-based) while optimizing for performance and affordability.
  - Developing alternatives for hazardous polymers (e.g. PFAS [Per- and Polyfluorinated Substances]).

➢ Incorporating Ecodesign in the manufacturing process
  - Increased efficiency of manufacturing process to reduce and control material quantities
  - Technologies and sustainable materials to increase affordability and performance of critical systems as fuel cell and battery systems aiming to improve overall performance of electric vehicles.

➢ Sustainable Longevity and durability. Vehicles must be designed for longevity and durability, while enabling individual components and systems' features such as maintenance, repair, remanufacturing and updates.
  - Developing methodologies and simulation models to accurately predict ageing and degradation of critical functions and sub-system of vehicles (e.g. safety or powertrain components such as batteries. fuel cells)
  - Develop concept of digital twin based product passports for relevant components as per existing regulation or automotive industry needs
  - Data management systems for use-phase data including digital solutions to access essential information for repair and maintenance (e.g. product design information. Vehicle history. Availability of spare parts)
  - Solutions to maintain performance standards of critical functions (e.g. safety and powertrain components) for longer periods of time
  - Solutions for feature upgrades on older-generation vehicles (e.g. retrofitting of sensors and actuators or battery systems)
  - Development of solutions for preventive maintenance and repair strategies (e.g. through health monitoring sensors and contextual information including AI based).
  - Solutions to replace and/or upgrade end-customer specific features impacting customer experience (e.g. surfaces and displays).

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- Reversible personalization features to facilitate multiple lives and transfer of ownerships.

- Circularity and recyclability
  - Advanced material identification and separation at EoL (End-of-life) enabling the recycling of tailor-made materials
  - Automation of recycling processes
  - Use of downstream data (data generated prior EoL) for recycling process
  - Tools for prediction of recyclates volumes and respective material degradation/quality level
  - Strategies to maintain quality of recycled materials over multiple loops. Dedicated strategies for rare-earth and critical materials (e.g. magnets).
  - Methodologies to assess the quality of material at end-of-life for e.g. to assess the risk of certain substances preventing recycling or reuse
  - Material degradation assessment methodologies based on contextual information and quality insurance criteria linked with vehicle history
  - Strategies to identify and separate hazardous substances

For the *energy value chain* (batteries, solar and wind energy combined), the main challenges and solutions are:

- Minimizing the use of critical raw materials (CRM) (batteries)
  - Incorporating sustainability as a critical criterion for the development of advanced materials for batteries is imperative. However, the substitution of CRMs in batteries (Li replacement by Na, Ca, Mg, etc.) is still at the cost of performance.
  - The same applies for the substitution of polyvinylidene fluoride (PVDF) binders, possible source for PFAS: well performing solutions have not been found yet. The use of PFAS in battery manufacturing will come under particular scrutiny in the review of REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) secondary legislation to happen by 2024.
- Minimizing substance of concern such as PFAS (batteries)
  - Solutions comprise Research & Innovation (R&I) actions on the translation of the SSbD framework into practicable guidelines for the battery sector by defining common principles, tools and methodologies for evaluation of design for circularity. It should also include evaluation of battery design and materials from a reuse, recycle and repairability perspective.
  - Additionally incorporating evaluation of substances of concern as well as CRMs by substitution and/or alternative battery designs and finally the intensification of use of the available digital toolsets, such as virtual reality, machine learning and artificial intelligence.
- More sustainable battery production
  - New research needed for improving the environmental processing for battery production with
    - Research on reduction of specific energy consumption and emissions, minimize the use of chemicals and improving process safety, reduce cost and increase efficiency.
    - Validation of sustainable production processes in view of giga-scale application and to upgrade the degree of integration of sustainable manufacturing processes into the existing/ future lines.

- Battery recycling
    - Solutions comprise the improvement of the adaptability and flexibility of existing recycling processes and the development of new ones i.e. direct recycling.
- Efficient recycling of wind blades (wind energy)
    - Some solutions comprise the reuse of the wind blades, but many projects and initiatives are being developed to promote blade recycling through different technologies.
    - Wind Europe has teamed up with Cefic (the European Chemical Industry Council) and EuCIA (the European Composites Industry Association) to create a platform dedicated to seeking the best technologies, processes, waste flow management, value chain reintegration and logistics for recycling blades and composites.
    - Another solution in the future is on material level with the development of better recyclable thermoplastic composites instead of the thermoset materials.

For the *electronics value chain*, the main challenges and solutions are:

- Water use in the manufacturing of semiconductors
    - Solutions: the reuse of water inside the fab has been considered primarily as a cost-saving measure, as purification of the water is an expensive process. From the electronics Strategic Research and Innovation Agenda: the use of recycled and reclaimed water in the short term and achieving 100% recycled and reclaimed water in the long term (2033 and beyond).
- Energy consumption by electronic devices
    - Solutions: As market pressures to improve power efficiency are intrinsic in most applications of electronics, they are expected to continue to motivate design and material improvements that lead to better energy efficiency.
- High cost of repairing electronic devices
    - Solutions: Incentive programs that subsidize the cost of repairs have proven effective in helping the individuals to choose the repair option. Such programs are promoted by the Right to Repair Europe coalition and more national programs are envisioned as the result of the EU right-to-repair legislation.
- Materials efficiency at the end of life
    - Solutions: Right-to-repair regulations in the EU and around the world are helping to motivate the manufacturers to design electronics for improved repairability and simplified disassembly. These design changes are enabling the reuse of some devices after repairs/refurbishment or their disassembly at the end of life. Furthermore, automated, and robotic technologies are being developed and deployed for dismantling consumer electronics that are produced in large numbers (e.g., mobile phones), which helps to separate individual components that are rich in a particular material or materials (e.g., magnets or copper coils) for subsequent recycling.

Then, the commonalities between the different value chains are presented, listing the different Research and Innovation needs, as well as in some cases, investments needs, covering the different SSbD steps of the life cycle. These commonalities were discussed and agreed in a workshop gathering the value chains partners of the project on the 18/01/2024.

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SSbD raw materials

Critical raw materials

All VCs have critical raw materials as a common challenge (as a hazard issue for some of them and responsible sourcing challenges).

In all cases, solutions to minimize the use of critical raw materials can be achieved in research and development of advanced materials with similar or enhanced functionalities.

Renewable raw materials

In the area of renewable raw materials for biobased materials, which is applied in all value chains, all have in common the land-use and deforestation challenge and the most appropriate solution is looking for responsible sourcing.

SSbD Chemical/ Material Design and Production

Chemicals of concern/hazardous chemicals

The issue of chemicals of concern/hazardous chemicals as precursors or reactants, catalysts or solvents is shared also by all value chains, some more than others.

Substitution

There are cases like PFAS or phthalates for example that require substitution and new developments for alternatives (energy, automotive, fragrances, textiles mostly). It is recommended that those substitution developments can be tested in all possible sectors and applications.

This is considered as a huge challenge and more short and mid-term R&I efforts should be given to this particular topic.

Design for performance

It is considered of utmost importance to include performance or functionality (whether it is a material or an article) in the SSbD assessment. All value chains have this in common and safety and sustainability should be embedded in any search for better performance, for advanced properties or any substitution of chemicals.

SSbD Manufacturing, distribution, transport

Production processes

This is also concerning all value chains and the main points are the needs for electrification with renewable energy and low temperature processes through the development of recoverable catalysts for example.

Water efficiency

Again, this is a common point to all VCs, minimizing the water consumption, through recovery for example and also a clean energy pathway (greater energy efficiency and renewable energy implementation also play an important role in reducing the volumes of water).

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Design for reduced GHG emissions

The manufacturing of a material/product is the main source of GHG emissions and process towards lowest possible carbon footprints or even towards a climate neutral final product, including scope 3 emissions reductions is a key aspect of the SSbD assessment.

Finally, the following points, shared by all value chains to a larger or lesser extent, are considered to be key requirements and should be the subject to improvements or developments within an R&I work programme involving new or improved production:

- On site waste reduction/recovery
- Scale up investment requirements including demonstration plants
- Process control/Digitalization

➢ SSbD product/article

Microplastics

The challenge for eliminating microplastics is more important for plastics packaging and textiles but as plastics are used in the other value chains, this can be considered as a commonality. R&I needs are very high in this topic and solutions to be developed are linked with the application/value chain (end use).

Design for durability/extension of lifetime

This is considered as a key element for future product developments and all value chains are concerned.

Design for dismantling

All value chains where there are multicomponents are concerned with this (Automotive, construction, electronics mainly) but to a lower extent also packaging, energy and textiles).

Finally, the following points, shared by all value chains to a larger or lesser extent, are considered to be key requirements and should be the subject to improvements or developments within an R&I work programme (specific to a sector) involving new or improved products:

- Design for re-use
- Design for recyclability
- Design for repair
- Sustainable business models

➢ SSbD use/End-of-Life

Concerning the end of life of products and enabling their recycling the following priorities for developments are also shared by all value chains:

- Harmonized infrastructure for collection and sorting

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- Harmonized policies (for example waste legislation)
- Safe logistics
- Market place for secondary raw materials
- Installed recycling infrastructures: improvement of, or new recycling technologies and related investments
- Installed second life

In conclusion, this value chains roadmaps exercise is a first step in highlighting the priorities for each value chain in developing processes, products along the life cycle, which respond to the SSbD principles while looking for improved performance or new functionalities in the final product. It gives an indication of the Research and Innovation needs specific to each value chain and also shows the many commonalities which exist between them.

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2 Introduction

The need for innovative solutions within value chains (VC) has never been more pressing. This roadmap aims to address SSbD challenges in order to advance safety and sustainability across the six value chains (packaging, textiles, construction, automotive, electronics, and energy). By fostering collaboration, innovation, and a shared commitment to progress, this roadmap seeks to guide VC stakeholders towards a future where safety and sustainability are not just goals, but an integral part of every step of design and innovation processes.

This deliverable is part of task 4.5 in WP4: Value chain-specific research and innovation roadmaps, which aims to support the development of a holistic roadmap for the safe-and-sustainable-by-design (SSbD) approach and its criteria developed in WP3 with industry-specific information. The specific roadmaps will be compiled and reported and finally analysed in WP3. A workshop planned in M10 was replaced by 1 to 1 interviews with VCs and a workshop in M20 looking at commonalities between the VCs, in order to support them in developing the structure and content of the roadmap. Some value chains have published research and innovation (R&I) roadmaps and these were used as part of the analysis (mainly for textiles, batteries, electronics). Value-chain specific SSbD roadmaps were developed addressing specific prioritized R&I needs, looking at the most challenging safety and sustainability dimensions under specific innovation cases. These value chain-specific roadmaps considered upstream and downstream steps of the value chains including the Chemical Industry inputs, containing examples of actions required to be tackled through SSbD strategies under a specific sector. These actions are also used as inputs for possible EU calls and national funding programmes per value chain. This deliverable will be updated during the project duration with input from WP3 (M30).

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3 Objectives

Each roadmap per value chain will focus on different cases covering the life cycle of a family of products in a defined application (for example solar sub-value chain within the energy value chain).

The primary objective of each roadmap is to identify and prioritize the key safety and sustainability challenges developed under D4.1, D4.6 and D2.1 within each value chain. It is chosen to focus on the most critical areas where innovation is needed, and where the impact of such innovation is high.

The second objective of each roadmap is to build upon the insights gained from all the work done previously in the project on development of gaps and challenges, and therefore facilitate the development of innovative solutions: through technological advancements, process optimizations, or alternative materials. The SSbD framework was considered to ensure that safety and sustainability concerns are addressed, and still maintaining the value for industry and consumers.

As WP3 is developing a broadly supportive SSbD roadmap looking at all horizontal aspects, the objective here is to give concrete examples taken in each value chain which could lead directly to new Research and Innovation projects and calls for subsequent funding under the EU R&I work programme.

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4 Strategy/Methodology

Input for the value chain-specific roadmaps were obtained from:

- the challenges developed in WP2 (IRISS report D2.1) and one by one, give possible solution(s);
- each value chain shared important roadmaps from their specific value chains: Packaging [1-5]; Textiles [6-8]; Construction [9, 10]; Automotive [11-16]; Energy [17-20]; Electronics [21-24]; and
- several co-creation interviews were held between March and April 2023 where each value chain developed the input for their specific roadmap.

The input was then prioritized for possible concrete R&I call content. The associated technological solutions were then detailed by each value chain, as well as an indication of innovative steps required to increase the maturity of the technological solutions to address the challenges.

In each value chain paragraph, challenges and solutions have been prioritized from the interviews and these could be used for the development of projects in the EU R&I framework (possible future calls). Each value chain has chosen around 5 challenges/solutions within the life cycle considering the main priorities. Consequently, not all the SSbD steps are necessarily covered in this report. An update of this deliverable is planned for M30 (D4.11).

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5 Value chains challenges and solutions (preliminary specific roadmaps)

5.1 The Packaging value chain

5.1.1 SSbD Raw materials

Challenge: Incorporate recycled content in respect of safety criteria

For Packaging Value Chain, European regulation is currently changing. Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on packaging and packaging waste (PPWR)[25], should amend Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repeal Directive 94/62/EC. This will harmonize Safe and Sustainable regulation for packaging and packaging waste in EU countries. Two of the three PPWR proposal's options set up mandatory recycled content in plastic packaging based on contact-sensitivity, which is a new requirement compared to the Directive. First target for recycled content in plastic packaging are for 2030 with recycled content from 10% to 35% depending on technology (materials) and application (sensitive human exposure or not). In 2040, targets increase to levels from 50% to 65%. Plastic packaging wastes are easily contaminated by substances of concern during waste collection or sorting. Very few decontamination processes exist at industrial level to obtain plastic packaging waste suitable for sensitive applications like food packaging or cosmetic packaging. Nowadays most of plastic recycled materials are not suitable for such sensitive applications. On top of this, volumes of plastic recycled materials available on the market are still low compared to PPWR proposal's targets going up to 65% of recycled content in plastic packaging.

Possible solution:

Reduction of packaging waste volumes is a first way to achieve targets of incorporated recycled content. Less volumes equals less required recycled materials for packaging. PPWR includes requirements for this waste reduction, fostering changes of consumers practices, packaging design (smaller packaging, optimization of packaging volume) and giving support to new business models like reuse packaging.

A second solution is to accelerate the development of recycling processes at industrial scale for plastic packaging. Decontamination processes are key to enable larger volumes of plastic recycled materials. This concerns plastic packaging materials, but also inks and pigments used on all type of packaging (paper, glass, etc.).

Challenge: Avoid successive substances substitutions

The State of the science on plastic chemicals published by PlastChem project funded by Norwegian Research Council in 2024 [26] identifies over 4,200 chemicals of concern because they are hazardous to human health and the environment. This statement includes persistence, bioaccumulation and mobility hazard criteria. 980 chemicals of concern are regulated under existing multilateral environmental agreements and national and regional regulations address 1021 additional plastic chemicals. This means an active regulation of plastic chemicals of concern and still a huge coming work to pursue hazard assessment and regulation of plastic chemicals. Packaging Value Chain uses many of these chemicals, not only for plastic packaging, but also for

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other materials like paper, glass and wood through packaging labels, inks or protection against moisture or vermin. Industrials engage chemicals substitution once regulation confirms a restriction or a ban. As regulation is proceeding substance by substance this conducts to successive substitutions concerning regulated chemicals of concern used in packaging Value Chain. Phthalates substitutions are an example of experienced successive substitutions. Both industrials and regulators would prefer to avoid such successive changes which represent added substitution costs and demotivating progress on hazard reduction. The challenge is to switch from short-term perimeter of chemicals of concern restriction and ban to a long-term perimeter.

Possible solution:

A first level to achieve long-term perimeter of the chemicals of concern is for regulation to consider group of chemicals instead of unique substances. Regulation already started to implement it. REACH consider a restriction of PFAS as a group [27] and emitted a call for evidence on CMR 1A and 1B substances in children articles in August 2023 [28], in a similar spirit as for the Toys Safety Directive 2009/48/EC [29]. The State of the science on plastic chemicals published by PlastChem project also pledges for this group of substances approach [26]. At the industrial side, a mean to achieve long-term substitution is to anticipate chemicals of concern. This can be done by considering not only Substances of Very High Concern stated by REACH but also any CMR (carcinogenic, mutagenic or toxic for reproduction) substance. It represents higher substitution cost= R&D cost and investment but enables better payback thanks to less successive substitutions and design changes, and more innovative substitutions' solutions.

Challenge: Enhance control of conformity to regulated substances and microplastics

Packaging Value Chain is subject to several regulations concerning restricted or ban chemicals. Since 2023, intentional use of microplastics was added to the list of REACH restrictions: Commission Regulation (EU) 2023/2055 [30]. Disparities exist in the different regulations. An example of disparity is dibutyl phthalate for which REACH requires an authorization and food contact plastics regulation approves it. This brings to variable applications of the regulation in the packaging sector and difficulties to verify conformity. The deployment of recycled content makes control of regulated substances and microplastics even more complex. In addition, imported packaging represent a large part of the market share, largely due to imported products or packaging. Packaging waste is therefore of international origin, which increases the challenge to have them respecting EU regulations on substances and microplastics. Theoretically all products placed in the EU market should conform to EU regulation concerning substances of concern. In practice, very few packaging items are controlled in laboratories by authorities and industrials to determine absence of ban substances or microplastics. Studies examining composition of packaging items by analytical measures still detect ban substances, by example FCCmigex database [31]. This clearly indicates lack of controls concerning conformity of packaging to substances regulations.

Possible solution:

Best way to avoid variable practices concerning chemicals of concern and microplastics avoidance in packaging is to obtain harmonized regulations: alignment of the different EU regulations and decisions of worldwide measures. This is why chemicals of concern and microplastics topics have been included in the perspective of a Global Plastic Treaty. For sure increase of regulatory controls concerning ban substances or microplastics would support a better deployment and application on industrial side. Industrials can also act by favouring more

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local Value Chains: more local Value Chains increase the possibility of direct exchanges with the suppliers, controls on sites and harmonized practices in terms of substances or microplastics regulation.

5.1.2 SSbD Chemical/Material Design and Production

Challenge: Interoperate SSbD data along the supply chain with respect of data confidentiality

SSbD evaluation is considering the entire life cycle. Packaging Value Chain is complex and comprises many actors. To evaluate a chemical, material or product, it is necessary to collect upstream Value Chain data as the chemical, material or product's composition and its associated safety data and to know the application and obtain related data for downstream Value Chain steps such as use and end-of-life cycles. This creates challenges for both upstream and downstream actors of the Value Chain. For upstream actors, chemicals and materials are frequently designed for multiple applications. Access to data related to use and end-of-life cycles is complex. For downstream actors, access to upstream data such as complete chemical, material or product's composition and associated SSbD data is complex. Uncertainties remains for the SSbD evaluation due to this limited access to SSbD data, both for upstream and downstream actors. A frequent technique to handle these uncertainties is the use of generic data. Generic data usually bring to no significative difference between evaluated solution and considered baseline solution.

Possible solution:

To manage a precise SSbD evaluation along the entire life cycle, it is necessary to find a way to interoperate SSbD data along the Value Chain. Concerned technical and industrial or SSbD data are confidential in most cases and cannot be disclosed publicly. Having a trusted environment to share these data is key. The tools provided with the deployment of Digital Product Passport (DPP) can be a solution to interoperate data and have each actor accessing the needed data for SSbD evaluations occurring along the Value Chain.

Challenge: Prioritize SSbD criteria to consider R&D capacities of SMEs and industrials

The SSbD frameworks includes around 50 assessment criteria. Assessment is done on the entire life cycle which represents easily thousands of ingredients and processes to be evaluated. SSbD framework aims to obtain visible improvement of Safe and Sustainable performance compared to a baseline solution. Thus, we seek for improvement of score, not achievement of best possible score. R&D persons in charge of SSbD evaluation are mostly doing it at partial time of their mission in the packaging industry. This is true for both SMEs and large companies. All the above factors bring SSbD evaluation not assessing 100% of criteria. The challenge is to maintain a multi-criterion, whole life-cycle assessment while applying part of the SSbD framework, to detect potential pollution transfer from one SSbD concern to another.

Possible solution:

A solution to achieve a partial but valid SSbD assessment is to determine SSbD hotspots for the evaluated chemical, material or product life cycle. Hotspots can be valid for one or more applications, for the entire Value Chain or globally valid. Determination of hotspots is practiced for the packaging Case Studies included in IRISS project. It shows that hotspots can be application or technology dependent. For example, plastic and glass packaging have different hotspots, even

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if some common hotspots exist, like decarbonization of the industry. To get an impartial choice of hotspots, a multi-disciplinary acknowledgement, including academic scientists, toxicologists and citizen concerns would be a plus. With selected SSbD hotspots, priority can be given to them in SSbD assessment. This helps to collect precise SSbD data for them. It also focuses R&D team and accompanying scientist support on a limited perimeter. This a chance to accelerate development of guidance supports and tools for SSbD assessment.

5.2 The Textiles value chain

5.2.1 SSbD Raw materials

Challenge: Natural or synthetic fibre production

The textile sector uses both biobased and fossil-based raw materials. About 120 million tons of textile fibres are produced globally per year. About one third are bio-based, either natural fibres such as cotton, wool, flax, hemp, silk, jute, sisal, ramie etc. or biobased man-made fibres made primarily out of cellulosic feedstocks such as viscose, lyocell or modal fibres. Two thirds are fossil-based mostly produced out of a side-stream of the petrochemical industry, these include polyester, polyamides, polypropylenes or acrylic fibres.

Challenges related to natural or synthetic fibre production include environmental and human health hazards related to poor agricultural practices, use of toxic substances in fibre growing (insecticides in cotton cultivation) or fibre processing (antimony use in polyester fibre production, use of caustic soda and sulphuric acid in viscose production). Fibres made from cellulosic feedstocks may contribute to deforestation and desertification.

Possible solution:

Solutions include the establishment of better agricultural practices especially in countries with more limited access to professional expertise and latest technologies. The phase-out of harsh chemistry in fibre processing i.e. antimony-free polyester production or replacement of viscose process by cleaner cellulosic fibre processing options, or at least the management of hazardous chemicals in closed-loop systems with full recovery. Intensive research work is underway to develop more biobased fibre materials that can over time help to reduce and eventually completely phase out textile fibres made from fossil feedstocks.

5.2.2 SSbD Chemical/ Material Design and Production

Challenge: The use of a wide range of chemicals

The processing of textiles requires a wide range of chemicals either to achieve specific functional properties in the final product (dyes, inks, finishes, coatings etc.) or to facilitate the processing (auxiliaries and other processing chemicals). Many of these chemicals are applied in wet processes where a significant amount of the chemicals used end up in wastewater, which is not properly managed can lead to pollution of land and natural water basins.

Specific challenges are related to PFAS, fluorine or bromide-based finishing agents that provide highly functional material properties such as water-proofing, oil-repellence or flame retardance required in highly technical end products such as workwear and personal protective equipment.

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Also, the processing steps incl. spinning, weaving, knitting, dyeing, printing and finishing are responsible for up to 70% of the CO_2 footprint of a final textile product.

It is estimated that on average about 25-35% of fibre materials entering the textile manufacturing chain end up as industrial waste along the process and therefore never reach the use phase.

Possible solution:

Solutions include general reduction of use of processing chemistry, the recovery of chemicals and energy from process water streams, the replacement of harsh conventional chemistry by more sustainable and where possible biobased chemistry (i.e. enzymatic processing), general waste prevention and reduction by use of advanced manufacturing technologies incl. online quality control.

The introduction of new more sustainable (biobased or otherwise renewable) fibres into the textile processing chain is a long, tedious and costly process, because processing technologies need to be developed or adapted to the new materials, suitable processing chemistry must be made available and functional specifications of the final products need to be reached at a cost-performance ratio that makes them competitive with conventional solutions.

5.2.3 SSbD Manufacturing, distribution, transport

Challenge: The manufacturing of textile-based final products in developing and emerging countries

The manufacturing of textile-based final products, mainly clothing and home textiles takes place to a large extend in developing and emerging economies due to the high manual labour input into these processes. SSbD challenges here are more related to social aspects such as labour conditions such as fair pay, health and safety at work or worker rights such as the right to freedom of association.

In certain time critical segments of the market such as the so-called ‘fast fashion market’ products may be air shipped from manufacturing location to point of distribution or sale, which generates higher carbon footprint that during conventional land or sea transport.

Possible solution:

Solutions for social sustainability improvements in global textile supply chains are international laws, legislative initiatives, agreements or standards such as the Corporate Sustainability Due Diligence Directive (CSDDD)[32], the Corporate Sustainability Reporting Directive (CSRD)[33], the OECD Due Diligence Guidance for Responsible Business Conduct [34] or the ILO International Labour Standards (ILS) among others.

Excessive use of air freight can be avoided through better supply chain management systems, advanced technologies for better demand forecasting or local on-demand production using highly digitised, automated manufacturing processes.

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5.2.4 SSbD Use

Challenge: Ensuring optimal selection, use, care and maintenance by consumers

The main challenge during the use phase is to ensure optimal selection, use, care and maintenance (SUCAM) by consumers or professional purchasers or users of textile products with the goal of minimising the impact per use/wear through intensification or prolongation of the product lifetime. Rapid disposal due to poor quality, poor fit or rapid obsolescence is a particular problem for clothing and fashion products. Another challenge is the shedding of micro-fibrous particles (or microplastics in the case of synthetic fibres) during wash and wear of textile products.

Possible solution:

Several solutions are being explored and put forward by policy makers such as Ecodesign for Sustainable Product Regulation (ESPR)[35] to ensure that textile products are designed and manufactured for durability, repairability or recyclability. A digital product passport (DPP) should guide consumers in better decision making when purchasing, maintaining, repairing or disposing textile products.

Microplastic release can be mitigates through optimised processing and finishing of textile materials and through filtration in washing machines or water treatment facilities and correct disposal of the filtrates.

5.2.5 SSbD End of Life

Challenge: Emissions and other environmental hazards from inappropriate disposal of textile waste

The main challenge at the end of life of textile products are emissions and other environmental hazards through inappropriate disposal of textile waste. Effective recycling of post-consumer textile waste remains technologically challenging and mostly uneconomic due to the cost and effort related to separate collection, sorting, separation and recycling of textiles. Apart from a relatively limited downcycling of end-of-life textiles into cleaning wipes or non-wovens for insulation, packaging, surface protection or other rather low added value uses, most end-of-life textile waste today is incinerated or landfilled. Chemicals and slowly degrading material fractions can generate environmental hazards for many decades, especially in uncontrolled burning or poorly managed waste dumps, often in developing countries to which a significant share of European post-consumer textile waste gets exported.

Possible solution:

Textile waste management is a focus area of the revised European Waste Framework Directive [36], mandating separate post-consumer textile waste collection in all EU countries by 2025, the development of professional collection, sorting and recycling systems across Europe supported by Extended Producer Responsibility (EPR) schemes. Significant research, technology development and pilot demonstration programmes are underway to develop textile waste sorting and recycling processes that are both lower impact than incineration and landfilling and economically viable in the face of relatively low-cost virgin materials. Mandatory recycled

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content quotas for various textile product categories are under consideration to incentivise commercialisation of recycled textile materials.

Further References: [7, 37]

5.3 The Construction value chain

5.3.1 Concrete admixtures sub-value chain

5.3.1.1 SSbD Raw materials

The SSbD framework articulates clearly that chemicals and materials should not give rise to unacceptable risks. Some of the raw materials used in the concrete admixtures sub-value chain are classified as substances of very high concern as raw materials. Although their use is assessed not to give rise to unacceptable risk, there is pressure in the market to identify alternatives to such raw materials. Two types of raw materials are classified as substances of very high concern, i.e. formaldehyde and melamine and alternatives for these could be, and in fact have been, developed.

Challenge:

The challenge is to develop alternatives to formaldehyde and melamine, that do not result in a loss of performance.

Possible solution:

The solution would be to develop alternatives to melamine or formaldehyde based concrete admixtures, that offer comparable or even better performance in the end-use (concrete).

Challenge:

There is one class of concrete admixtures that is based on the use of renewable or renewable raw materials, i.e. lignin. Depletion of renewable raw materials could result in a loss in biodiversity.

Possible solution:

There are basically two different options to address this challenge: (i) ensure that raw materials, such as lignin are responsibly sourced and do not lead to a loss in biodiversity, and (ii) develop alternative raw materials that are renewable.

5.3.1.2 SSbD Chemical/ Material Design and Production

Challenge:

A challenge is to further reduce emissions to air, water, soil during the production of concrete admixtures.

Possible solution:

The chemical industry, including the construction chemicals industry, has been making, and needs to continue to make, improvement in their production processes to further reduce emissions to air, water or soil.

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Challenge:

The production of concrete requires a lot of energy and the resulting greenhouse gas (GHG) emissions should be (further) reduced to meet the challenging goals of the European Green Deal.

Possible solution:

Although concrete admixtures are added to cement in about 1-2 % wt., their use results in significant reduction of GHG emissions during the production of concrete. Continuous improvement in GHG emission reduction resulting from the use of concrete admixtures is a long-standing objective of the construction chemicals industry in Europe.

Challenge:

The production of concrete requires significant amounts of water, which should be (further) reduced as part of the continuous improvement in the construction chemicals sector.

Possible solution:

Although concrete admixtures are added to cement in about 1-2 % wt., their use results in significant reduction of the amount of water required for production of concrete. Continuous improvement in the reduction of water, resulting from the use of concrete admixtures is a long-standing objective of the construction chemicals industry in Europe.

5.3.1.3 SSbD Manufacturing, distribution, transport

Challenge:

One of the key challenges in the construction sector is reducing the GHG emissions associated to transporting concrete and its raw materials. Concrete is a rather heavy material and therefore, requires significant amounts of energy in transport.

Possible solution:

The key solution to reducing GHG emissions in transport is shortening the distances of transport by sourcing locally.

5.3.1.4 SSbD Use

Challenge:

Another challenge related to building is the resulting GHG emissions during the use of the building itself, which is significant, given the very long lifetime of a building.

Possible solution:

The use of concrete admixtures results in more efficient use of concrete and therefore, results in the reduction of GHG emissions of a building over its lifetime.

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5.3.1.5 SSbD End of Life

Challenge:

Following demolition of deconstruction of a building, GHG emissions could be reduced further.

Possible solution:

Concrete waste is and can be reused, thus saving GHG emissions of buildings from virgin raw materials. Concrete admixtures are being developed to allow the use of recycled concrete.

5.3.2 PU- and PS-based insulation sub-value chain

5.3.2.1 SSbD Raw materials

Challenge:

A key challenge in the use of Polyurethane (PU)-based insulation materials, is that they are manufactured from di-isocyanates, which are substances of very high concern (SVHCs).

Possible solution:

Where deemed necessary, PU based insulation materials can be substituted by other insulation materials such as stone wool and glass wool. The latter already have a much higher market share in the EU.

5.3.2.2 SSbD Chemical/ Material Design and Production

Challenge:

A key challenge in the use of Polyurethane (PU)-based insulation materials, is that their use may result in emissions of substances of very high concern (SVHCs) above EU regulatory limits.

Possible solution:

The PU industry, from raw materials manufacturers to downstream users, have together developed a comprehensive training package for professional users of PUs. This package could be (further) promoted.

5.3.2.3 SSbD Use

Challenge:

The use phase of a building results in significant GHG emissions during its lifetime.

Possible solution:

Polyurethane (PU) or Polystyrene (PS) based insulation could be used and/or further improved to save GHG emissions over the (very long) lifetime of a building.

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5.3.2.4 SSbD End of Life

Challenge:

A challenge is the waste resulting from PU- or PS-based insulation after its lifetime.

Possible Solution:

PU- and PS-based insulation waste contains a significant amount of energy that could be recovered from PU or PS-based waste.

5.4 The Automotive value chain

5.4.1 SSbD Raw Materials

Challenge: Minimizing the use of critical raw materials

The automotive sector is a large consumer of resources making it crucial that appropriate consideration is made on the sourcing and choice of materials. The use of sustainable, renewable, non-petrol-based materials should be favoured as opposed to materials that are linked to feedstocks from scarce materials, materials that are in competition with food sources and those which include hazardous substances.

When it comes to critical raw materials several are commonly used in the automotive sector (e.g. in batteries and fuel cells). While there is a clear push from the regulation and industry to invest and scale up recycling processes and capacity the demand for critical raw materials and other natural resources cannot be covered solely through recycling. Therefore the use of natural resources and particularly of critical raw materials must also be minimised by shifting to suitable alternatives.

Possible Solutions:

- Implementation of SSbD rules to minimise the use of CRM and other critical natural resources in automotive products.
- Development of new advanced materials to replace critical raw minerals in critical automotive components (e.g. Ni, Co, Li, Cu, Mg, rare-earth) while optimizing for performance and affordability.

5.4.2 SSbD Chemical/Material Design and Production

Challenge: Use of safe and sustainable materials

Material and chemicals used in the automotive sector must ensure a set of characteristics that comply with sustainability safety durability and customer appeal requirements. Therefore, an ecodesign approach to ensure multi-functionality, mobility and versatility of chemicals and materials is needed. The CO_2 footprint of the final product must also be considered right from the design and production phase.

Possible Solutions:

- Renewable and low emissions materials with appropriate quality, quantity and performance for automotive industry applications (e.g. low CO_2 metals and alloys).

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- Further development of very low or negative CO_2 materials from generation 2, 3 and 4 feedstocks.
- Solutions for more sustainable automotive polymers (e.g. bio-based) while optimizing for performance and affordability.
- Developing alternatives for hazardous polymers (e.g. PFAS).

5.4.3 SSbD Article Manufacturing

Challenge: Incorporating Ecodesign in the manufacturing process

One of the main challenges is to incorporate ecodesign in the manufacturing of increasingly smaller and more durable parts and components, with components often glued together or integrated into the main product structure. The design choices and production processes also have a strong impact on the end of life such as repairability and recyclability of materials.

Performance is also a crucial aspect of several automotive articles for which materials and design choices are relevant not only from an individual article perspective but from a system perspective.

Possible Solutions:

- Increased efficiency of manufacturing process to reduce and control material quantities.
- Technologies and sustainable materials to increase affordability and performance of critical systems as fuel cell and battery systems aiming to improve overall performance of electric vehicles.

5.4.4 SSbD Use

Challenge: Sustainable Longevity and durability

Vehicles must be designed for longevity and durability, while enabling individual components and systems' features such as maintenance, repair, remanufacturing and updates. This has a positive impact on the environment as materials are kept in use for longer, reducing the need for additional material consumption. At the same time, waste is minimised while the value of the vehicle is retained and possibly enhanced over a longer time span. With the increased electrification and the advent of software defined vehicles there will be added complexity. A better understanding of the lifecycle(s) of sub-systems like the electrified drivetrain (e-motor, battery, power electronics) will be crucial to keep vehicles in use as long as possible.

Maintaining vehicle attractiveness over time is important to keep the perceived quality level and the possible residual value for the end customer.

Possible Solutions:

- Developing methodologies and simulation models to accurately predict ageing and degradation of critical functions and sub-system of vehicles (e.g. safety or powertrain components such as batteries, fuel cells)
- Develop concept of digital twin based product passports for relevant components as per existing regulation or automotive industry needs

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- Data management systems for use-phase data including digital solutions to access essential information for repair and maintenance (e.g. product design information. Vehicle history. Availability of spare parts)
- Solutions to maintain performance standards of critical functions (e.g. safety and powertrain components) for longer periods of time
- Solutions for feature upgrades on older-generation vehicles (e.g. retrofitting of sensors and actuators or battery systems)
- Development of solutions for preventive maintenance and repair strategies (e.g. through health monitoring sensors and contextual information including AI based).
- Solutions to replace and/or upgrade end-customer specific features impacting customer experience (e.g. surfaces and displays).
- Reversible personalization features to facilitate multiple lives and transfer of ownerships.

5.4.5 SSbD End-of-life

Challenges: Circularity and recyclability

Closing the loop cycles on automotive parts and materials is also part of an SSbD approach. In order to strengthen Europe's resource sovereignty as well as to minimise the ecological footprint of ZEV a maximum of valuable materials must be recovered from End-of-Life Vehicles (ELV). Besides, upcoming ELV legislation foresees specific closed-loop recycling quotas. However, currently neither the quantity and quality nor costs of recyclates are meeting the demand of the automotive industry. Since quality is a key aspect of automotive design, more research will be needed on solutions to check the quality level of end-of-life components, acceptability criteria for recovered parts and overall, further improve the lifetime extension of components that can be re-used.

Separation and sorting technologies to facilitate access to materials and parts will be instrumental to the implementation of multiple recovery loops, especially for the value-added components, such as rare earths, as well as continuous improvement of mechanical and chemical recycling.

Possible solutions:

- Advanced material identification and separation at EoL enabling the recycling of tailor-made materials
- Automation of recycling processes
- Use of downstream data (data generated prior EoL) for recycling process
- Tools for prediction of recyclates volumes and respective material degradation/quality level
- Strategies to maintain quality of recycled materials over multiple loops. Dedicated strategies for rare-earth and critical materials (e.g. magnets).
- Methodologies to assess the quality of material at end-of-life for e.g. to assess the risk of certain substances preventing recycling or reuse
- Material degradation assessment methodologies based on contextual information and quality insurance criteria linked with vehicle history
- Strategies to identify and separate hazardous substances

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5.5 The Energy value chain, comprising sub-value chains Batteries, Solar and Wind Energy

The top five challenges and solutions in the sub-value chains of batteries, solar and wind are provided below.

5.5.1 Batteries sub-value chain

5.5.1.1 SSbD Raw Materials

Challenge: Minimizing the use of critical raw materials

A major challenge in Li Ion batteries for mobility and stationary batteries is to minimize the use of critical raw materials (CRMs) as Li, Ni, Co, natural graphite and others. The European Critical Raw Materials Act is the basis for building up the EU's capacities and strengthening the resilience of its critical raw material supply chains.

Possible Solutions:

The Critical Raw Materials Act aims to provide support for the extraction and processing of CRMs in Europe, which can be an opportunity for the battery raw material sector.
Solutions focus on securing access to raw materials from resource-rich countries outside the EU based on sustainable sourcing of raw materials (Co, Li, etc.), whilst at the same time new European sources of raw materials are in exploration. The focus is on the increase of strategic autonomy by boosting domestic production and reducing import dependence.

New battery components/systems are constantly in development and commercialisation with lower content of critical raw materials and this is based on the EU battery technology roadmaps lowering Co content (generation 3 with nickel manganese cobalt oxides (NMC) 811 cathode chemistry, even NMC 9 0.5 0.5). This generation 3 is further evolving to generation 4 (solid state) and to generation 5 based on post Li Ion systems.
The research gap here is to merge materials efficiency with SSbD criteria.
Incorporating sustainability as a critical criterion for the development of advanced materials for batteries is imperative. However, the substitution of CRMs in batteries (Li replacement by Na, Ca, Mg, etc.) is still at the cost of performance.
The same applies for the substitution of PVDF binders, possible source for PFAS: well performing solutions have not been found yet. The use of PFAS in battery manufacturing will come under particular scrutiny in the review of REACH secondary legislation to happen by 2024.
For the substitution of critical raw materials and PVDF/PFAS research, extensive ongoing work is done in the Batt4EU Partnership, see SRIA [38], in the ETIP Batteries Europe, see Roadmap [39] and in the SCA Battery 2030+Roadmap [40].

5.5.1.2 SSbD Design

Challenge: Minimizing substance of concern such as PFAS

The adoption of the Safe and Sustainable by Design framework is pushing battery cell producers to develop methodologies to apply the framework to the realities of battery manufacturing. This need is spurred on further by Article 6 of the Batteries Regulation and the proposed ban on PFAS.

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Possible Solutions:

Solutions comprise R&I actions on the translation of the Safe and Sustainable by Design framework into practicable guidelines for the battery sector by defining common principles, tools and methodologies for evaluation of design for circularity. It should also include evaluation of battery design and materials from a reuse, recycle and repairability perspective. Additionally incorporating evaluation of substances of concern as well as CRMs by substitution and/or alternative battery designs and finally the intensification of use of the available digital toolsets, such as virtual reality, machine learning and artificial intelligence.

Position Papers are being prepared on Digitalization, Sustainability, Social Science and Humanities, Hybridization, Safety and Education & Skills in the references cited above from Batt4EU [38], Batteries Europe [39] and Battery2030+ [40].

5.5.1.3 SSbD Manufacturing

Challenge: More sustainable battery production

Enhancing the sustainability of battery production has been a central goal in battery manufacturing projects. For instance, several projects are currently exploring innovative processing methods aimed at eliminating toxic solvents. This, in turn, reduces the environmental footprint of cell products and yields significant cost savings. These findings should be complemented by further research to implement these sustainable practices on a larger scale within European gigafactories' production lines. Another critical aspect involves applying these results to upcoming chemistries like solid-state batteries while simultaneously exploring opportunities to manufacture with lower energy consumption, renewable energy and reduced CO_2 emissions, particularly for emerging advanced materials.

Possible solution:

New research needed for improving the environmental processing for battery production with

1) Research on reduction of specific energy consumption and emissions, minimise the use of chemicals and improving process safety, reduce cost and increase efficiency.
2) Validation of sustainable production processes in view of giga-scale application and to upgrade the degree of integration of sustainable manufacturing processes into the existing/ future lines.

5.5.1.4 SSbD End-of-Life

Challenge: Battery recycling

The Battery regulation provides mandatory minimum levels of recycled content for industrial, SLI batteries and EV batteries. The initial Minimum Recycled Content levels for industrial and EV batteries are 16% for cobalt, 85% for lead, 6% for lithium and 6% for nickel. The regulation further introduces an electronic "battery passport", which allows for the digital storage of labelling and other required information on the battery's components and recycled content.
Even though batteries last longer than initially predicted, the number of End-of-Life batteries from e-mobility and stationary applications are increasing and will continue to increase in the following ten years. This means that both the number and capacity of recycling facilities need to increase. The new facilities need to be automated to reduce costs and reduce safety risks in all parts of the value chain. Due to the lack of standardisation, data about the form, composition, assembly modes, state of health, etc. are of utmost importance. The battery passport is seen as

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an enabler in this respect. Wider funding is needed, both for the collection, sorting and dismantling of batteries, and the recycling processes.

Possible solution:

Solutions comprise the improvement of the adaptability and flexibility of existing recycling processes and the development of new ones i.e. direct recycling.

It is the ambition of Battery 2030+ to transition to a new recycling model based on data collection and analysis, automated pack disassembly to the cell level, investigating reuse and repurposing whenever possible, automated cell disassembly to maximize the number of individualized components, and the development of selective powder-recovery technologies that recondition powders to battery-grade active materials that are reusable in batteries for automotive/stationary applications with significantly reduced logistical efforts.

5.5.2 Wind energy sub-value chain

5.5.2.1 SSbD End of Life

Challenges: Efficient recycling of wind blades

The useful life of a wind turbine is around 25 years, although it can usually be extended to 30 years if the investment in maintenance is adequate. Most of its components are recyclable, although the challenge lies in **recycling the wind blades efficiently**. The materials from which they are made are mostly composites, such as fibreglass, carbon fibre or various resins, so separating them for recycling is particularly difficult and expensive.

Possible Solution:

Some solutions comprise the reuse of the wind blades but many projects and initiatives are being developed to promote blade recycling through different technologies.

Wind Europe has teamed up with Cefic (the European Chemical Industry Council) and EuCIA to create a platform dedicated to seeking the best technologies, processes, waste flow management, value chain reintegration and logistics for recycling blades and composites.

Another solution in the future is on material level with the development of better recyclable thermoplastic composites instead of the thermoset materials.

5.6 The Electronics value chain

5.6.1 SSbD Article Manufacturing

Challenge: Water use in the manufacturing of semiconductors

Production of chips for electronics requires significant amounts of water, typically tens to hundreds of liters of water per chip. This amount of water is used to ensure the purity standards that are critical for the production process, so the use of water cannot be avoided, nor can it be dramatically reduced.

Possible solution:

The current arrangement between a fabrication facility (also known as a “fab”) and local authorities typically involves the fab taking a certain volume of water from local sources and

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then returning it to those sources. Because the water is highly purified before use and then treated and filtered before being returned, the quality of the returned water normally exceeds that of the intake. The design of this system evolved over decades, but, until recently, the reuse of water inside the fab has been considered primarily as a cost-saving measure, as purification of the water is an expensive process.

The most recent Strategic Research and Innovation Agenda (SRIA) published by the Electronic Components and Systems (ECS) in 2023 [22] has identified as one of the sustainability goals an increase in the use of recycled and reclaimed water in the short term and achieving 100% recycled and reclaimed water in the long term (2033 and beyond). Some of the relevant technological developments that will enable this transition have been identified in the SRIA, including filtration, reverse osmosis, precipitation, and membrane bioreactors.

5.6.2 SSbD Use

Challenge: Energy consumption by electronic devices

Energy consumption is inherent in using electronic devices, as they require an energy source to operate. Reducing and optimizing the energy consumption during the use phase is an objective that needs to be addressed by improving design, which includes the use of novel materials.

Possible solution:

In Electronics VC, market pressures are the primary driver for improving energy efficiency. For example, high-performance chips used in servers are designed considering that in data centers servers are densely packed and efficient cooling needs to be provided, often both at the level of the individual server racks and the datacenter as a whole. For computationally intensive applications, such as training of artificial intelligence (AI) models, the cost of electricity is a significant fraction of the operation costs. Accordingly, there is constant market pressure to improve the energy efficiency of the chips used in servers. In another example, the use of mobile phones is often limited by their battery capacity, making energy efficiency a critical consideration when a new generation of chips is designed.

These market pressures have proven to be very effective historically at ensuring the continuous improvement in energy efficiency of electronics. Currently, only approximately 20% of the lifetime carbon footprint of a mobile phone is associated with its operation [41]. In an example for high-performance server chips, the new-generation Blackwell chips from Nvidia illustrate the dramatic improvements in their energy efficiency, whereby the power required to train a 1.8-trillion-parameter AI model has been reduced to four megawatts from 15 required by the previous generation Hopper chips [42].

As market pressures to improve power efficiency are intrinsic in most applications of electronics, they are expected to continue to motivate design and material improvements that lead to better energy efficiency.

Challenge: High cost of repairing electronic devices

When individuals consider the option of repairing a device vs purchasing a new one, cost is an important factor. Repairing electronics requires specialized expertise, facilities, and components, all of which contribute to the cost of repairs.

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Possible solution:

Incentive programs that subsidize the cost of repairs have proven effective in helping the individuals to choose the repair option. Regional and national incentive programs that subsidize the cost of repairing electronics have been operating as early as 2017 and have been offered in Austria [43], France [44], Thuringia [45], Saxony [46], and several other locations around the EU [47]. These programs typically support the repairs carried out by the local SMEs, which represent an important part of the Electronics VC in the SSbD context. Such programs are promoted by the Right to Repair Europe coalition [48] and more national programs are envisioned as the result of the EU right-to-repair legislation [49].

5.6.3 SSbD End of Life

Challenge: Materials efficiency at the end of life

Each individual consumer electronic device contains many materials, including many critical ones, but for many of them only a gram or even less of each material per device. Accordingly, implementing materials efficiency measures at the end of life, whether via reuse or recycling, is challenging in terms of the underlying logistics and economics.

Possible solution:

Right-to-repair regulations in the EU and around the world are helping to motivate the manufacturers to design electronics for improved repairability and simplified disassembly. These design changes are enabling the reuse of some devices after repairs/refurbishment or their disassembly at the end of life [50]. Furthermore, automated and robotic technologies are being developed and deployed for dismantling consumer electronics that are produced in large numbers (e.g., mobile phones), which helps to separate individual components that are rich in a particular material or materials (e.g., magnets or copper coils) for subsequent recycling [51].

5.7 The Fragrances value chain

The associate partner IFRA informed that they are not in a position yet to propose solutions to the challenges. The reason is on the one hand, the different step stakeholders of the value chain have not been consulted yet; On the other hand, it is believed that the case study to be delivered by summer will enable the development of solutions to be proposed.

As IFRA is not bound to the DoA, it was agreed to allow further delay for this value chain.

5.8 Value chains commonalities:

As it has been presented in the previous deliverables of WP2 and 4 (D2.1, D4.1 and D4.8), we can see that the different value chains have many if not most of the SSbD challenges in common. Here we present a summary of those commonalities, which were discussed in a workshop between all the value chains partners in January 2024, and the corresponding R&I and investments needs agreed between them: SSbD raw materials:

Critical raw materials

All VCs have critical raw materials as a common challenge (as a hazard issue for some of them and responsible sourcing challenges). In all cases, solutions to minimize the use of critical raw

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materials can be achieved in research and development of advanced materials with similar or enhanced functionalities.

The electronics sector depends on other sectors for sourcing those raw materials (due to the difference in volume).

Another solution is enabling the recycling of those raw materials, and depending on each value chain, the chains and technologies for recovering the raw materials can be different (for example dismantling of a car and sorting of its components (metal /plastics/composites /foams) versus chemical recycling of mixed plastics packaging waste).

Renewable raw materials

In the area of renewable raw materials for the biobased materials, which is applied in all value chains, all have in common the land-use and deforestation challenge and the most appropriate solution is for responsible sourcing.

5.8.1 SSbD Chemical/ Material Design and Production

Chemicals of concern/hazardous chemicals

The issue of chemicals of concern/hazardous chemicals as precursors or reactants, catalysts or solvents is also shared by all value chains, some more than others. When a hazardous reactant is fully reacted (100%) it is stated by all that it is acceptable as long as safety measures are taken during production if there is exposure.

Substitution

There are cases like PFAS or phthalates for example that require substitution and new developments for alternatives (energy, automotive, fragrances, textiles mostly). It is recommended that those substitution developments can be tested in all possible sectors and applications.

This is considered as a huge challenge and <u>more short and mid-term R&I efforts should be given to this particular topic.</u>

Design for performance

It is considered of utmost importance to include performance or functionality (whether it is a material or an article) in the SSbD assessment. All value chains have this in common and safety and sustainability should be embedded in any search for better performance, for advanced properties or any substitution of chemicals, in which case the performance of the final product should always be a basic requirement for any safety and sustainability improvements and developments.

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5.8.2 SSbD Manufacturing, distribution, transport

Production processes

This is also concerning all value chains and the main points are the needs for electrification with renewable energy and low temperature processes through the development of recoverable catalysts for example.

Water efficiency

Again this is a common point to all VCs, minizimizing the water consumption, through recovery for example and also a clean energy pathway (greater energy efficiency and renewable energy implementation also play an important role in reducing the volumes of water).

Design for reduced GHG emissions

The manufacturing of a material/product is the main source of GHG emissions and process towards lowest possible carbon footprints or even towards a climate neutral final product, including scope 3 emissions reductions is a key aspect of the SSbD assessment.

Finally, the following points, shared by all value chains in a more or less extent, are considered to be key requirements and should be the subject to improvements or developments within an R&I work programme involving new or improved production:

- On site waste reduction/recovery
- Scale up investment requirements including demonstration plants
- Process control/Digitalization

5.8.3 SSbD product/article

Microplastics

The challenge for tackling microplastics is more important for plastics packaging and textiles but as plastics are used in the other value chains, this can be considered as a commonalities. R&I needs are very high in this topic and solutions to be developed are very much linked with the application/value chain (end use).

Design for durability/extension of life time

This is considered as a key element for future product developments and all value chains are concerned.

Design for dismantling

All value chains where there are multicomponents are concerned with this (Automotive, construction, electronics mainly) but to a lower extent also packaging, energy and textiles.

Finally, the following points, shared by all value chains to a larger or lesser extent, are considered to be key requirements and should be the subject to improvements or developments within an R&I work programme (specific to a sector) involving new or improved products:

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- Design for re-use
- Design for recyclability
- Design for repair
- Sustainable business models

5.8.4 SSbD use/End-of-Life

Concerning the end of life of products and enabling their recycling the following priorities for developments are also shared by all value chains:

- Harmonized infrastructure for collection and sorting
- Harmonized policies (for example waste legislation)
- Safe logistics
- Market place for secondary raw materials
- Installed recycling infrastructures: improvement of, or new recycling technologies and related investments
- Installed second life

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6 Conclusion

This first approach in developing SSbD Value chains roadmaps has allowed the team to work on proposing a first approach of solutions to the SSbD challenges that were extensively developed in D4.1, D4.8 and D2.1.

The value chains have many SSbD related challenges in common, like the sourcing of critical raw materials and their necessary recyclability, the energy intensive manufacturing processes, the use of hazardous substances and their treatment in the design process, the need for sharing data along value chains, and many more. They also showed in their analysis how the chosen application/sub-value chain and their resulting products are necessary for the society, and even essential in the short term when it comes to impact.

Four to five main SSbD challenges have been chosen to be translated to proposed solutions as presented in this deliverable. Some concrete cases will also be used in case studies to be developed in the second testing phase of the SSbD framework in collaboration with Joint Research Centre (JRC) and The Directorate-General for Research and Innovation (DG RTD) in May/June 2024. This work is proposed to be integrated to the Horizon Europe work programmes for accelerating the practical implementation of SSbD.

For the *packaging value chain*, the priority challenges and solutions Incorporate recycled content in respect of safety criteria

- Avoid successive substances substitutions
- Enhance control of conformity to regulated substances and microplastics
- Interoperate SSbD data along the supply chain with respect of data confidentiality
- Prioritize SSbD criteria to consider R&D capacities of SMEs and industrials.

For the *textiles value chain*, the priority challenges and solutions are:

- ➢ Natural or synthetic fibre production challenges such environmental and human health hazards related to poor agricultural practices, use of toxic substances:
- Solutions include the establishment of better agricultural practices
- The phase-out of harsh chemistry in fibre processing
- Intensive research work is underway to develop more biobased fibre materials
- ➢ The use of a wide range of chemicals either to achieve specific functional properties in the final product (dyes, inks, finishes, coatings etc.) or to facilitate the processing (auxiliaries and other processing chemicals).
    - ➢ Solutions for social sustainability improvements in global textile supply chains are international laws, legislative initiatives, agreements or standards.
- ➢ Ensuring optimal selection, use, care and maintenance by consumers
- ➢ Reduction of emissions and other environmental hazards from inappropriate disposal of textile waste

For the *construction value chain* (Concrete admixtures sub-value chain), the priority challenges and solutions are:

- ➢ Developing alternatives to formaldehyde and melamine, that do not result in a loss of performance.
- ➢ Depletion of renewable raw materials could result in a loss in biodiversity particularly for one class of concrete admixtures that is based on the use of renewable or renewable raw materials, i.e. lignin.

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- Further reduce emissions to air, water, soil during the production of concrete admixtures.
- The production of concrete requires a lot of energy and the resulting greenhouse gas (GHG) emissions should be (further) reduced to meet the challenging goals of the European Green Deal.
- The production of concrete requires significant amounts of water, which should be (further) reduced as part of the continuous improvement in the construction chemicals sector.
- The reduction of the GHG emissions associated to transporting concrete and its raw materials. Concrete is a rather heavy material and therefore, requires significant amounts of energy in transport.
- The reduction of GHG emissions during the use of the building itself, which is significant, given the very long lifetime of a building.
- The reduction of GHG emissions during the demolition of deconstruction of a building.

For the *construction value chain* (polyurethane (PU)- and polystyrene (PS)-based insulation sub-value chain), the main challenges and solutions are:

- Substitution of PU-based insulation materials, manufactured from di-isocyanates, which are substances of very high concern (SVHCs).
- Reduction of waste resulting from PU- or PS-based insulation after its lifetime.

For the *automotive value chain,* the priority challenges and solutions are:

- Minimizing the use of critical raw materials
- Use of safe and sustainable materials
- Incorporating Ecodesign in the manufacturing process
- Sustainable Longevity and durability. Vehicles must be designed for longevity and durability, while enabling individual components and systems' features such as maintenance, repair, remanufacturing and updates.
- Design for circularity and recyclability

For the *energy value chain* (batteries, solar and wind energy combined), the priority challenges and solutions are:

- Minimizing the use of critical raw materials (CRM) (batteries)
- Minimizing substance of concern such as PFAS (batteries)
- More sustainable battery production
- Battery recycling
- Efficient recycling of wind blades (wind energy)

For the *electronics value chain*, the main challenges and solutions are:

- Reduction of water use in the manufacturing of semiconductors
- Reduction of energy consumption by electronic devices
- Cost reduction of repairing electronic devices
- Materials efficiency at the end of life

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Then, the commonalities between the different value chains were also presented in this report, listing the different common Research and Innovation needs, as well as in some cases, investments needs, covering the different SSbD steps of the life cycle. These commonalities were discussed and agreed in a workshop gathering the value chains partners of the project on the 18/01/2024.

In conclusion, this value chains roadmaps exercise was a first step in highlighting the priorities for each value chain in developing processes, materials, products along the life cycle, which respond to the SSbD principles while looking for improved performance or new functionalities in the final product. It gives an indication of the Research and Innovation needs specific to each value chain and also shows the many commonalities which exist between them.

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