DRAFT ROADMAP FOR INDUSTRIAL SYMBIOSIS STANDARDISATION

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EXECUTIVE SUMMARY

Industrial symbiosis (IS) is increasingly recognised in European policy, research and innovation agendas as a practical means to advance circular economy objectives, improve resource efficiency and support climate-neutral industrial transformation. By enabling the reuse of underutilised resources across sectors, IS can reduce primary resource demand, limit waste disposal and strengthen regional industrial ecosystems. However, despite its growing policy relevance, the uptake of IS remains uneven across Europe, constrained by regulatory fragmentation, technical uncertainty and a lack of shared frameworks.

This document presents the first public version of the **European Standardisation Roadmap for Industrial Symbiosis**, developed under the RISERS project. Its purpose is to identify where standardisation can support industrial symbiosis, to highlight priority areas for action, and to provide a structured basis for further consultation, e.g., with Technical Committees (TCs), industry and public authorities. The roadmap does not propose mandates to TCs or immediate standardisation work items. Instead, it offers a coherent analytical framework to guide future standardisation, regulatory coordination and stakeholder engagement.

The roadmap is based on an extensive, expert-driven process carried out in 2025. This included the analysis of documented IS cases across Europe, qualitative assessments of legal, economic, spatial, technical and social conditions, and structured input from around 120 experts participating in ten thematic Working Groups (WGs) and two plenary sessions. The WGs addressed both cross-cutting foundations (IS concepts, end-of-waste, digitalisation and data) and sectoral priority areas (steel, batteries, packaging, waste heat, textiles, energy data and grids, biomass and waste wood). Their insights form the analytical backbone of this roadmap.

Across sectors, the roadmap confirms that industrial symbiosis is not a collection of isolated exchanges but a system-level transition. Its successful implementation depends on aligned regulatory frameworks, interoperable data and digital infrastructures, reliable quality-assurance practices, adequate skills and organisational capacity, suitable physical infrastructure, and predictable economic conditions. Fragmented implementation of end-of-waste criteria, inconsistent data semantics, limited testing and grading practices for secondary materials, skills shortages and unclear governance or contracting arrangements repeatedly emerge as barriers to scale-up.

Based on these findings, the roadmap formulates a set of high-level recommendations addressed to EU and national policymakers, standardisation bodies, industry, regional authorities and research organisations. These include improving regulatory coherence across Member States, developing shared cross-sector classification and metadata standards, supporting interoperable digital infrastructures (including alignment with Digital Product Passport developments), strengthening quality and safety practices for secondary materials, expanding targeted skills and capacity-building measures, clarifying governance and contracting frameworks, integrating IS into infrastructure planning, and improving economic and financial conditions for investment.

This first public draft marks the start of a broader consultation process. From January to summer 2026, the roadmap will be discussed with selected CEN and CENELEC TCs, National Standards Bodies (NSBs), National Committees (NCs) and the wider public. Feedback collected during this phase will be systematically analysed and used to refine and validate the recommendations. The final roadmap, to be published in December 2026, will serve as a strategic reference to support coordinated standardisation activities, inform policy development and enable more reliable and scalable IS practices across Europe.

HIGH-LEVEL RECOMMENDATIONS

Industrial symbiosis can only scale in Europe if certain horizontal conditions are strengthened across regulatory, digital, organisational and economic domains. While these recommendations highlight systemic challenges and opportunities, the following roadmap reveals a broader set of specific barriers that cut across all material and energy flows. These relate to inconsistent regulatory implementation, insufficient data interoperability, limited quality-assurance frameworks, gaps in skills and organisational capacities, incomplete infrastructure, and economic uncertainties that reduce investment confidence.

The following recommendations synthesise recurring insights from the roadmap. They outline strategic actions for policymakers, standardisation bodies, industry, regional authorities and research organisations.

1. **Improve coherence and interoperability in European regulatory implementation**

   Target actors: European Commission (DG ENV, DG GROW), Member State regulators, national waste authorities.

   The document repeatedly shows that divergent interpretations of **End-of-Waste**, inconsistent application of waste–product boundaries, and fragmented permitting rules slow down, or block IS pathways (steel slag, textiles, batteries, biomass). Regulators should improve mutual recognition, streamline interpretations, and provide clearer guidance to ensure materials can circulate across borders without administrative barriers.

2. **Develop shared, cross-sector classification and metadata standards**

   Target actors: CEN, CENELEC, ISO/IEC TCs; GS1; industry associations.

   Across Chapters 4 and 5, the absence of harmonised metadata, minimum datasets, and common semantics prevents matchmaking, digital integration, and safe reuse. Standardisation bodies should lead the development of **cross-sector resource descriptors** that augment existing systems (e.g., EWC) with functional, machine-readable attributes relevant for reuse, recycling and traceability.

3. **Support interoperable digital infrastructures and data-sharing frameworks**

   Target actors: CEN-CLC JTCs; energy-data operators; digital-platform developers; European Commission (Data Act & ESPR units).

   Digitalisation appears as a foundational theme: Digital Product Passports, digital twins, trusted data spaces, harmonised APIs, SoH/RUL datasets and monitoring architectures. Stakeholders should work toward **interoperable data models and secure exchange mechanisms**, aligned with ESPR, and emerging data-space initiatives. This is essential for battery reuse, energy-grid integration, packaging flows and biomass traceability.

4. **Strengthen quality, safety and testing practices to enable circular flows**

   Target actors: CEN-CLC TCs; testing laboratories; industry.

   The roadmap emphasises gaps in quality assurance for **second-life batteries, black-mass intermediates, packaging residues, biomass fractions**, and **textile feedstocks**. Actors should develop harmonised testing, grading, and safety protocols that increase market confidence, support risk management, and enable cross-border movement of secondary materials.

5. **Expand targeted skills, training and capacity-building programmes**

   Target actors: Industry, training providers, national agencies, standardisation bodies (for competence frameworks).

   Skills shortages appear systematically across all WGs: safe disassembly, diagnostics, digital capabilities, separation technologies, biomass pre-treatment, heat-recovery operations, and quality control. Capacity building should focus on **competence profiles and training programmes** that match sectoral needs, while SMEs require technical assistance to adopt new processes.

6. **Enhance governance models, liability clarity and contracting frameworks**

   Target actors: EU and national policymakers; legal experts; industry associations; standardisation bodies (for optional templates).

   Confidentiality, liability, responsibilities and lack of transparent contracting models limit participation in symbiosis. Actors should develop **voluntary templates or guidance** for data-sharing agreements, liability allocation, and long-term resource-exchange contracts, reducing transaction costs for companies.

7. **Invest in essential infrastructure and integrate symbiosis into spatial planning**

   Target actors: Local and regional authorities; energy-system operators; industrial park managers; investors.

   The roadmap highlights infrastructure gaps: district-heating networks, biomass storage, sorting facilities, disassembly centres, logistics platforms, and pipelines for heat or materials. Planners and operators should incorporate IS into **zoning decisions, investment plans and regional strategies**, ensuring that infrastructures are interoperable and co-located where needed.

8. **Improve economic conditions, risk-sharing mechanisms and financing models**

   Target actors: EU and national funding agencies; financial institutions; industry consortia.

   High CAPEX, uncertain feedstock volumes, volatile material prices and regulatory uncertainty stall promising projects. Actors should consider **risk-sharing instruments, stable off-take or heat-purchase agreements, targeted incentives, and support schemes** that create predictable economic conditions for IS investments.

9. **Ensure early and continuous engagement between industry and standardisation committees**

   Target actors: CEN, CENELEC, ISO, IEC TCs; industry stakeholders; R&I projects.

   The roadmap shows that standardisation is often reactive, while many gaps (especially digitalisation, batteries, packaging) evolve quickly. Structured engagement between practitioners and TCs should guarantee that standards continue reflecting industrial needs and that R&I results, e.g. from Horizon Europe, can be incorporated efficiently into standardisation processes.

10. **Treat industrial symbiosis as a system-level transition, not a set of isolated exchanges**

    Target actors: EU institutions, Member States, standardisation bodies, industry platforms, regional authorities.

    The roadmap consistently demonstrates that IS depends on **coordinated regulatory, infrastructural, digital and organisational conditions**. Actors should adopt integrated approaches that promote coherence across policy domains, planning instruments, funding mechanisms and standardisation activities.

1. INTRODUCTION TO INDUSTRIAL SYMBIOSIS

Industrial symbiosis (IS) is gaining increasing relevance as Europe advances its circular economy (CE), resource efficiency, and strategic autonomy objectives. Unlocking its full potential requires clearer, more harmonised practices for the transaction from materials, energy, and by-products to human resources between industrial actors. Standardisation can provide a critical foundation by improving reliability, interoperability, and regulatory clarity across sectors and Member States.

IS is recognised in EU policy, research, and innovation agendas as a key enabler to support CE and climate neutrality objectives. It can contribute to implementing the Circular Economy Action Plan (CEAP) and national strategies by reducing raw material demand, diverting waste from disposal, and creating industrial diversification in regional economies.

This first public version presents the emerging **European Standardisation Roadmap for Industrial Symbiosis**. It outlines initial priorities, identifies areas where standards and policies could support industrial exchanges, and proposes directions for further work. The document is intended for a broad audience of standardisation experts in Technical Committees, industrial stakeholders, researchers, and policymakers engaged in CE, supply chain management, and industrial transformation.

The roadmap builds on extensive stakeholder engagement conducted in 2025. This process included thematic discussions across ten Working Groups and two plenary meetings, bringing together experts from industry, public authorities, academia, and standardisation bodies. Their contributions form the analytical basis for the priorities and recommendations presented in this document.

This publication marks the start of a wider consultation process. From January to summer 2026, Technical Committees and the public will be invited to review the roadmap, assess the proposed priorities, and provide additional insight based on their technical, sectoral, and regulatory expertise. Feedback collected during this period will be systematically analysed and used to refine and validate the roadmap.

The final roadmap will be released in December 2026. Its objective is to provide a coherent strategic reference for European and national standardisation bodies, support coordinated action across industrial value chains and contribute to Europe's broader CE and competitiveness goals.

This first public draft therefore serves three purposes:

1. Presenting the structure and themes of the roadmap;
2. Sharing emerging standardisation needs identified by stakeholders; and
3. Launching an inclusive consultation to shape the final document.

By grounding the process in expert input and aligning it with Europe's long-term policy objectives, this roadmap aims to establish a shared foundation for advancing IS through standardisation.

A. CONCEPTUAL BACKGROUND: INDUSTRIAL SYMBIOSIS AND STANDARDISATION

Industrial symbiosis (IS) is increasingly recognised as a practical mechanism for operationalising circular economy (CE) objectives by enabling the exchange of materials, energy, water, and by-products across organisational boundaries. Conceptually, IS draws on systems thinking and industrial ecology, using ecological metaphors to describe mutually beneficial interactions among industrial actors. Early work in industrial ecology highlighted the need to understand industrial systems as interconnected networks of material and energy flows rather than isolated production units (Ayres, 1989).

The empirical development of the Kalundborg industrial network in Denmark provided an early and influential illustration of industrial symbiosis in practice. Rather than being centrally designed, the network evolved incrementally through cooperation between independently operating firms, demonstrating that symbiotic exchanges can emerge through pragmatic, business-driven decisions. This case helped establish industrial symbiosis as a distinct analytical concept and informed subsequent research and policy discussions (Ehrenfeld & Gertler, 1997).

The consolidation of industrial symbiosis as a recognised field occurred with the development of analytical frameworks that clarified its defining characteristics. Industrial symbiosis came to be understood as involving multiple actors and multiple resource exchanges, distinguishing it from bilateral recycling arrangements or conventional waste management practices. This clarification helped position IS as a systemic approach to resource efficiency with relevance across sectors and value chains (Chertow M. R., 2000).

During the 2000s, research increasingly focused on the conditions that enable industrial symbiosis, including institutional support, regulatory frameworks, trust among actors, and the role of intermediary organisations. Attention also shifted toward assessing economic and environmental benefits, reinforcing the relevance of IS not only for environmental objectives but also for industrial competitiveness and regional development (Chertow & Lombardi, 2005).

A further evolution occurred with the recognition that industrial symbiosis can be deliberately facilitated rather than relying solely on spontaneous emergence or geographic proximity. Process-oriented and network-based perspectives highlighted the importance of coordination, brokerage, shared learning, and governance structures in enabling symbiotic exchanges at regional and national scales. This shift broadened the applicability of industrial symbiosis beyond exceptional cases and demonstrated its potential for systematic replication.

The increasing institutionalisation of industrial symbiosis is reflected in the development of structured guidance and standardisation outputs, most notably the CEN Workshop Agreement CWA 17354:2018. This agreement translates insights from research and practice into an operational framework, providing guidance on stakeholder engagement, data sharing, legal considerations, and performance monitoring. By doing so, it positions industrial symbiosis as a repeatable and scalable practice aligned with European circular economy objectives.

More recently, industrial symbiosis has been increasingly framed as a concrete implementation mechanism within the broader circular economy agenda. While CE strategies often operate at a high level of abstraction, IS provides tangible pathways for closing resource loops across industrial systems. At the same time, ongoing debates around definitions, scope, and measurement underline the continued need for clarity, harmonisation, and shared reference frameworks (Boons, Chertow, Park, & Shi, 2017).

This roadmap builds on this evolution by focusing on how standardisation can support industrial symbiosis in practice. By addressing interfaces between sectors, reducing uncertainty in material and by-product exchanges, and supporting interoperability and regulatory coherence, standardisation can help translate the conceptual maturity of industrial symbiosis into scalable implementation across Europe.

2. METHODOLOGICAL APPROACH

This chapter elaborates on the methodology used to arrive at the status of outputs in the following sections of the roadmap. The roadmap is developed through a structured, expert-driven process that combines analytical work with broad stakeholder engagement. Its purpose is to identify where standardisation can support IS and to prioritise actions that are technically sound, feasible, and aligned with Europe's CE objectives. The overall process is based on the structure and methods used in the DIN Standardisation Roadmap on Circular Economy (DIN e.V.; DKE; VDI, 2023), while being tailored to the specificities of IS and the European stakeholder ecosystem.

The methodology integrates three elements:

1. Analytical foundations, drawing on existing standards, regulatory frameworks, and documented IS practices;
2. Stakeholder input, gathered through thematic Working Groups (WGs) and a broader plenary meeting;
3. Iterative refinement, including expert review and a forthcoming public consultation running from January to summer 2026.

This approach ensures that the roadmap reflects both technical realities and the practical needs of industries and public authorities.

A. ANALYTICAL FOUNDATION AND SELECTION OF PRIORITY SYNERGIES

RISERS built and analysed a longlist of existing IS cases — based on results of former EU projects such as EPOS (EPOS, 2019), SCALER (SCALER project, 2019) and MAESTRI (MAESTRI, 2017) and own research. This study uncovered real examples of how industries already exchange underutilised resources, sharing energy, materials, services and knowledge.

In this RISERS database, IS synergies are approached as a bilateral exchange between sink and source sectors. These exchanges cover a broad range of products that include materials (waste or byproducts), energy streams (heat or electric power) or services (shared logistics, infrastructure or knowledge) (MES).

Using the methodology described by Mendez-Alva et al. (Mendez-Alva, Cervo, Krese, & Van Eetvelde, 2021), the database allowed to map existing, and potential IS exchanges and MES streams across the European industrial landscape, unveiling a high occurrence of IS exchanges that use chemicals, minerals and food as source sectors, while cement, minerals and again chemicals are most common as sink sectors.

Applying the LESTS methodology (Maqbool, Piccolo, Zwaenepoel, & Van Eetvelde G., 2017) identifies drivers and barriers for successful exchanges in five domains: Legal, Economic, Spatial, Technical and Social. This screening tool helped to understand the dynamics behind the synergies. Opportunities were extracted from the study as well as well new trends for the implementation of synergies in existing and new industrial clusters.

During a qualitative LESTS assessment, the goal was to collect 50 MES streams. The 40 highest-ranking MES streams were tagged as high potential cases. For the remaining 10 cases, emerging synergies were added based on the defined priority sectors to include also new industrial activities such as in renewable energy or cluster services and new EU policies such as the Circular Economy Action Plan or the Critical Raw Materials Act. These 50 high potential synergies became the subject of a much more thorough analysis to select a final list of priority synergies (see figure 1).

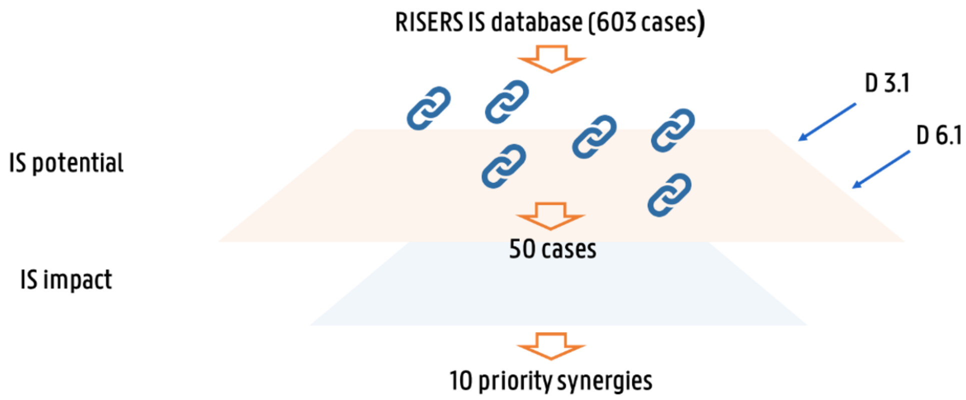

Figure 1. *Overview of the methodology for the synergy screening*

To select key synergies as use cases for the IS roadmap development, the full list of 50 MES streams is assessed for its people, planet, profit (3P triangle) impact using the broad set of indicators from the 3P framework and building from the work done in previous EU H2020 projects, such as MAESTRI, SCALER and EPOS. Added with data sourced from public databases and literature, fact sheets are compiled for each IS case giving a generic insight on the economic, environmental, and social benefits per synergy. Analysis of the fact sheets allowed to prioritise 10 high-impact synergies in the key sectors (see Table 1). As defined in the scope of the RISERS project, intra-sectoral exchanges are excluded. The final list of priority IS sectors covers up to seven process industries, added with 1-2 industries from the energy and/or bio-based sector and 1 emerging sector. Based on these criteria, the exchanges in **Table 1** were selected as priority IS synergies.

Table 1. *List of 10 selected priority IS synergies*

MES		Source sector	Sink sector	Synergy	3P impact very high on
BOF/EAF slag	M	Steel	Cement, Various	Recover BOF slag and provide Si, Al, Fe, Ca and Al for clinker raw materials Explore the possibilities to valorise slags from EAF steel production	planet
Waste heat	E	Various	Urban	Recover heat from process industry and use for urban heating	people
Plastic packaging	M	Various	Cement, Various	Use plastic waste from process industry as raw material in cement industry	planet
Waste steel	M	Urban, Various	Steel	Recover waste steel for recycling (secondary steel manufacturing)	planet
Energy data	S	Various	Energy	Optimise electricity sourcing and provide flexibility via demand-response	planet
Biomass	ME	Urban, Various	Refineries	Produce alternate fuels using Fischer-Tropsch process	planet
Waste wood	ME	Pulp and paper	Energy	Recover waste wood from pulp & paper sector to fuel combustion plants	planet

MES		Source sector	Sink sector	Synergy	3P impact very high on
Refractory materials	M	Steel	Glass, construction	Recover fly ash and extract mineral products for brick and roof tiles manufacturing	people
Textiles	M	Textiles	Various	Produce secondary raw materials from unwearable textile waste.	planet
EV batteries	ME	Transport	Energy/ Minerals	Recover lithium, nickel, cobalt and other critical raw materials, 2nd life for energy storage	planet

These priority synergies were restructured into seven verticals topic areas (see Figure 2): 'Steel, Slag & Refractories', 'Batteries', 'Packaging', 'Waste heat', 'Textiles', 'Energy data & Grids', 'Biomass & Waste Wood'. In addition, horizontal working groups, such as 'Industrial Symbiosis in general', 'End-of-Waste' and 'Digitalisation and data' were added. They are not related to one or more specific sectors and capture 'cross-cutting issues' relevant to the IS implementation. These horizontal topics were addressed through dedicated roadmap working groups.

The priority synergies also served as a basis for further research. Representative industry cases were identified for each priority synergy, and a scanning of IS-related standards and relevant CEN-CENELEC and DIN Technical Committees was carried out to determine relevant TCs and normative deliverables. This was complemented by a literature review on key enablers and barriers to implementation, as well as targeted interviews with representatives from industry and EU sector associations. The overall aim was to gather insights in sector-specific drivers and challenges for IS implementation, including regulatory aspects related to waste as a secondary resource, gaps in waste treatment standards, and the mutualisation of services, etc.

To confirm the anticipated leverage that an IS standard could bring, semi-structured interviews were conducted to collect information on the interaction between stakeholders in existing IS cases and gain insight into the dynamics of a synergy in practice. The interviews focused on decision-making processes by project managers and personnel onsite, on stakeholder engagement at the industrial cluster level, the communication with neighbouring enterprises and/or urban communities and the link between the emergence of IS synergies and existing standardisation frameworks. The results provided valuable insight into stakeholders' perceptions of opportunities and constraints for engaging in industrial symbiosis.

Building on the outcomes of the semi-structured interviews, together with literature sources, a SWOT assessment matrix yielded barriers and enablers per key synergy in each of the 5 LESTS domains (RISERS, 2025). Based on this analysis, IS Standardisation recommendations were formulated as an input for the RISERS working groups. In addition, a clustering potential analysis for priority synergies was developed to support the geographical mapping of IS potential across Europe.

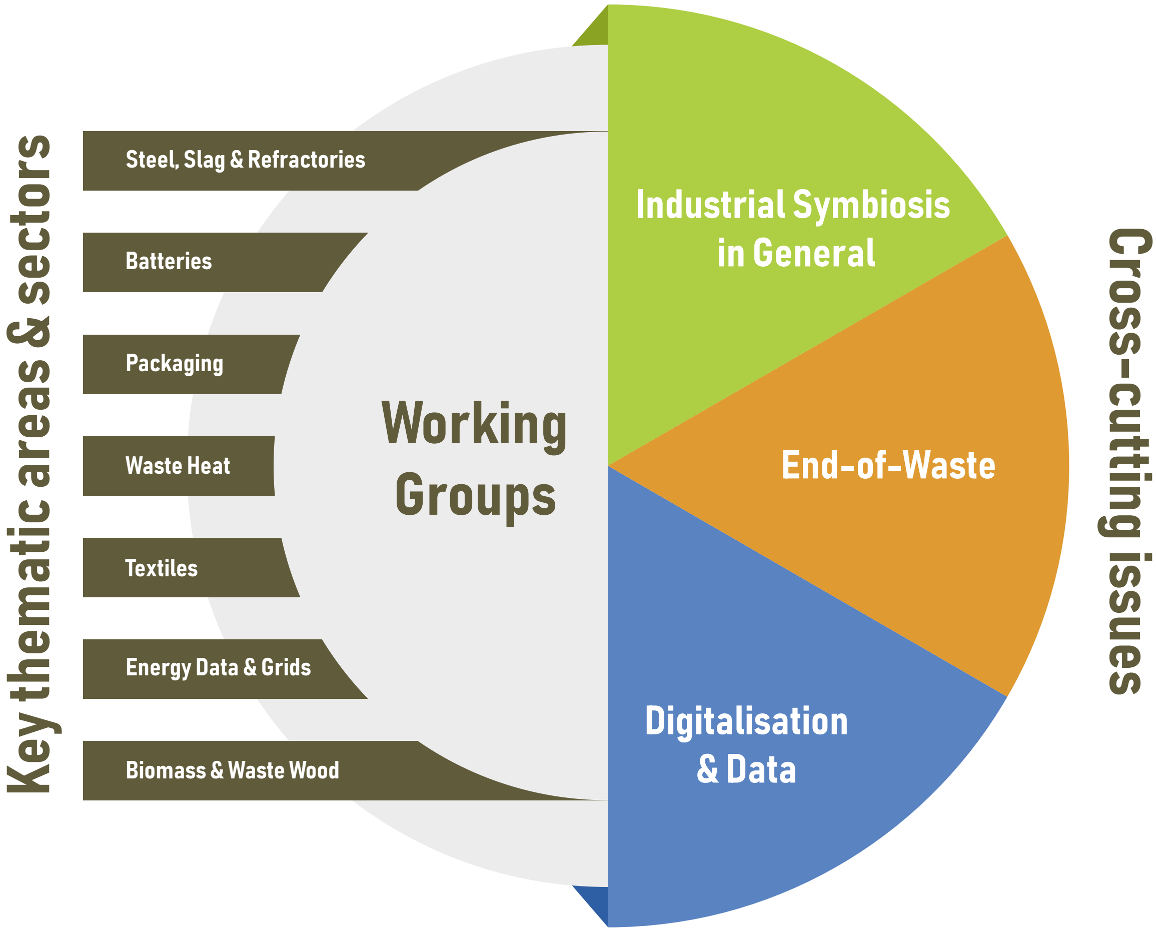

Figure 2. *Overview of RISERS working groups*

B. EXTERNAL STAKEHOLDER INPUT VIA WORKING GROUPS

The seven vertical topic areas provided the basis for topic-specific workstreams. In addition, three horizontal issues were identified as requiring dedicated attention across sectors: First, there is a constant need to advance the definition and terminology of industrial symbiosis. Second, a recurring field appears to be end-of-waste criteria across many sectors. Finally, digitalisation of platforms and respective data exchanges need to be discussed as horizontal enablers. As a result, ten thematic Working Groups were convened in 2025 to examine IS challenges and related standardisation needs. These WGs cover both horizontal topics (such as Industrial Symbiosis in General, End-of-Waste, Digitalisation & Data) and specific value chains (including steel, batteries, textiles, packaging, waste heat, energy data, and biomass).

The ten WGs were defined through a multi-step analytical process drawing on:

- Mapping of several hundred documented IS cases across Europe;
- Qualitative assessment based on legal, economic, spatial, technical, and social factors;
- Screening of environmental, economic, and societal impacts.

This process ensured that WG topics reflect areas of high practical relevance and strong potential for standardisation to support wider IS uptake.

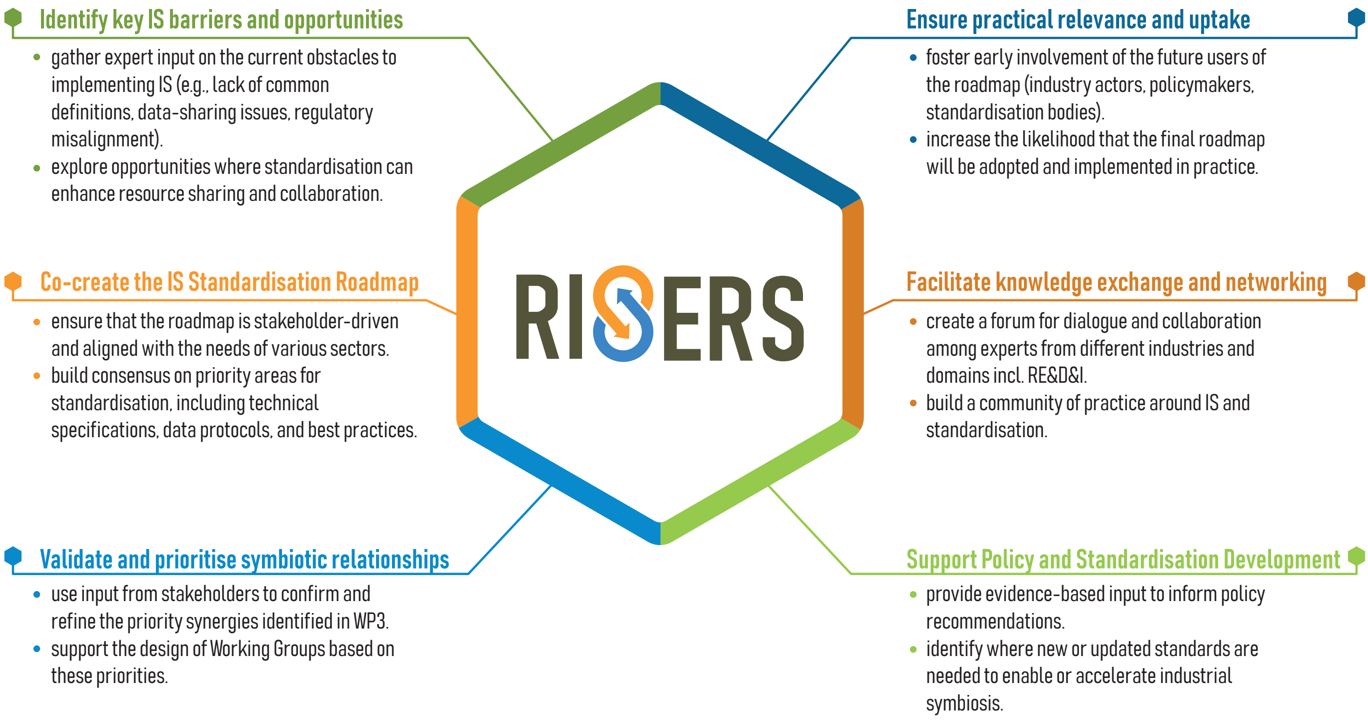

Figure 3. *Objectives of the Working Groups*

Each WG gathered experts from industry, standardisation bodies, research organisations, and public authorities. The first round of meetings concluded with an online plenary session on 5 June 2025, attended by approximately 120 participants. This session consolidated cross-cutting findings, validated preliminary priorities, and collected additional input through moderated discussions and polling. All results were subsequently presented at a hybrid plenary session in Brussels at the European Institute for Technology on 12 November 2025. The insights gathered through this process constitute the analytical basis of this first public version of the roadmap.

Table 2. *Overview on RISERS Working Groups*

Working Group	Focus
WG 01 Industrial Symbiosis in General	Definitions, system boundaries and cross-sector frameworks for industrial symbiosis
WG 02 End-of-Waste	End-of-waste criteria and regulatory conditions enabling reuse of secondary materials
WG 03 Digitalization & Data	Data interoperability, monitoring and digital infrastructures for industrial symbiosis
WG 04 Steel, Slag & Refractories	Reuse of steel by-products, with focus on quality, safety and cross-sector applications
WG 05 Batteries	Second-life applications of batteries, including testing, data and pathways to recovery
WG 06 Packaging	Circular use of packaging materials and standards supporting cross-sector flows
WG 07 Waste Heat	Recovery and use of waste heat across industrial and urban systems
WG 08 Textiles	Recycling and secondary raw materials from textile waste

Working Group	Focus
WG 09 Energy Data & Grids	Energy data exchange, grid interaction and flexibility for symbiotic systems
WG 10 Biomass	Valorisation of biomass and waste wood in industrial symbiosis

The roadmap was developed through an iterative process supported by continuous dialogue with experts across sectors and disciplines. WG Leaders moderated discussions and synthesised contributions, while the roadmap drafting team consolidated findings across all groups.

Therefore, the roadmap is being developed through seven interlinked steps:

1. **Landscape Mapping**

Review of existing standards, regulatory frameworks, and IS practices. This includes mapping relevant Technical Committees (TCs) at European and international levels.

2. **Stakeholder Input via Working Groups**

Collection of practical examples, challenges, and recommendations through WG discussions involving experts from industry, research, public authorities, and standardisation bodies.

3. **Initial Gap Identification**

Assessment of recurring barriers and needs based on mapping results, workshop inputs, and expert interviews.

4. **Drafting of Thematic Recommendations**

Development of initial proposals for standardisation, terminology, interoperability, data exchange, safety practices, and regulatory coherence.

5. **Validation and Consolidation**

Refinement of early findings during the June 2025 plenary session, thematic follow-up discussions, and a final plenary session in November 2025.

C. ITERATIVE REFINEMENT AND PUBLIC CONSULTATION

For the first half of 2026, this draft roadmap document will be put on the RISERS website, shared with the CEN and CENELEC Technical Boards (BT), as well as discussed with selected TCs to refine recommendations.

This phase includes the final two steps in the development of the roadmap:

6. **Public Consultation**

Release of the first public draft (this document), followed by targeted consultation with TCs, industry stakeholders, and the public. Feedback will be collected and integrated during 2026.

7. **Publication of Final Roadmap**

The final roadmap will consolidate validated recommendations and serve as a strategic reference for standardisation bodies, policymakers, and industrial actors.

Throughout 2026, feedback from the public and from TCs will be integrated systematically, ensuring that the final roadmap reflects a broad and authoritative set of perspectives.

This process is expected to conclude by Summer 2026. Afterwards follows a final editing phase to increase readability of the documents to ensure that messages are conveyed effectively. The final standardization roadmap will be published by December 2026.

3. HORIZONTAL FOUNDATIONS OF INDUSTRIAL SYMBIOSIS

The roadmap content addresses a set of cross-cutting topics that affect IS across all sectors. These topics, including definitions, regulatory conditions, data exchange, and digital infrastructure, form the foundational conditions under which symbiotic practices can emerge and scale. Coordinated progress in these horizontal domains as well as sector-specific efforts are needed to avoid fragmentation or limited applicability of approaches to IS. By introducing shared challenges and common standardisation needs early on, the roadmap supports coherent development across diverse material streams and industrial contexts.

A. HARMONISED TERMINOLOGY AND DEFINITION

The term 'industrial symbiosis' is dated to 1989, generally credited to Valdemar Christensen in Kalundborg, Denmark. Since that period, there have been many papers published and much debate as to what IS is and where it applies. In 2018, CWA 17354 Industrial Symbiosis: Core Elements and Implementation Approaches was published, which sought to bring clarity to the situation. The definition contained therein is:

> Industrial symbiosis is the use by one company or sector of underutilised resources broadly defined (including waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment and materials) from another, with the result of keeping resources in productive use for longer. Core elements of industrial symbiosis are the aspects that enable its identification. Elements considered core to industrial symbiosis are:
>
> - Returning underutilised resources (often called waste) to productive use;
> - Information about opportunities (e.g., data on other organisations' resources, or new technologies) is required to be able to advance a synergy;
> - Business conditions incentivising industrial symbiosis, which may be through market conditions or through policies and regulations (CEN, 2018).

The terminology associated with industrial symbiosis (IS) has been subject to long-standing debate, both with respect to the definition of IS itself and the language used to describe its mechanisms and outcomes. Inconsistent use of terms across policy, research, and practice has contributed to misunderstanding, legal uncertainty, and fragmented implementation.

To support clarity and consistency, this roadmap adopts a defined set of terms and language conventions. These apply throughout the document and are intended to ensure a shared understanding among standardisation experts, policymakers, industry stakeholders, and researchers.

TERMS USED IN THIS ROADMAP

Industrial Symbiosis

> *Industrial symbiosis is the use by one company or sector of underutilised resources broadly defined (including waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment and materials) from another, with the result of keeping resources in productive use for longer. Core elements of industrial symbiosis are the aspects that enable its identification.*

> This definition is taken from CWA 17354:2018 Industrial Symbiosis: Core Elements and Implementation Approaches.

Transaction

A mutually profitable link or flow between two (or more) organisations in which one organisation obtains novel sourcing of required inputs and another obtains value-added destinations for non-product outputs (or under-utilised resources).

The term "transaction" is preferred over "exchange" as it reflects business logic, value creation, and competitive advantage, and captures material and non-material flows, including knowledge, services, and expertise.

Under-utilised resource

A resource which is available but not fully used in its current state — for example by-products, residues, waste, excess capacity, expertise, logistics, or water/energy flows.

The use of this term shifts the focus from waste management to resource utilisation and reflects the broad scope of resources relevant for industrial symbiosis.

Network

A set of diverse organisations, typically separate, collaborating (through transactions) in a system-oriented way to foster eco-innovation and long-term culture change.

This perspective highlights that industrial symbiosis extends beyond isolated bilateral interactions.

Eco-innovation

Innovation that reduces environmental impacts, improves resource productivity, or creates new value streams through changes to processes, products, services, or business models.

In this roadmap, industrial symbiosis is framed as an enabler of eco-innovation rather than solely as an efficiency or waste-reduction measure.

Culture change (long-term)

The shift in organisational or industrial behaviour and mind-set over time, towards resource intelligence, collaboration, and system thinking.

This acknowledges that durable industrial symbiosis outcomes often depend on relational and organisational factors in addition to technical solutions.

Shared infrastructure, utilities, services, or knowledge

Instances where organisations collaborate to share assets, infrastructure, utilities (e.g., steam, water, waste-heat networks), services (e.g., logistics) that enable resource efficiency and IS transactions.

Such arrangements often strengthen network capacity and support the scaling of symbiotic solutions.

Resource processing

The processing of resources to a form where they can be used in a subsequent production process. The same resource could undergo a variety of different process methods, depending on the end use of the processed resource.

This term is used to distinguish productive transformation from waste management activities aimed primarily at disposal or neutralisation.

Synergy / synergies

The outcome of transactions in IS where the combined effect of organisations collaborating is greater than the sum of what they could achieve individually (in terms of resource efficiency, cost savings, innovation).

The term appears in IS literature and also in the CWA 17354 which refers to "Industrial symbiosis 'synergies' are transactions..."

Resource matching platform

ICT system that allows inputs of resources and the ability to find partner companies to create synergies. A range of functionalities associated with this main aim can be present, but are not essential to this main aim.

The term emphasises productive use rather than disposal or simple material swapping.

TERMS REQUIRING CAUTION OR NOT RECOMMENDED

Exchange

The term is widely used but can imply simple swapping of materials and may understate the business, innovation, and value-creation dimensions of industrial symbiosis. Where possible, "transaction" is preferred.

By-product (used in isolation)

While valid in regulatory contexts, exclusive reliance on this term can obscure the broader range of under-utilised resources relevant to industrial symbiosis. It should be complemented by broader terminology where appropriate.

Geographic proximity (as a defining condition)

Proximity can be relevant but is neither sufficient nor always necessary. Economic value, regulatory context, and logistical feasibility often determine viable distances for transactions.

Waste management (as the primary framing)

Framing industrial symbiosis mainly as waste management risks narrowing its scope and overlooking opportunities for innovation, value creation, and systemic change. Language should emphasise resource utilisation and productive cycles.

Waste exchange platform

This term does not adequately capture the functional scope of ICT tools used in industrial symbiosis and may reinforce a disposal-oriented perspective. "Resource matching platform" is used instead.

CHALLENGES, NEEDS AND RECOMMENDATIONS

IS depends on strong, confidence-based relationships among companies, knowledge agents, and government entities. Such networks enable open information exchange and stable collaboration. However, a lack of confidence, social inertia, lack of knowledge, both within and between companies, on resource use and availability, and insufficient awareness of industrial sustainability remain significant obstacles.

As noted in the introduction, IS is increasingly recognised in EU policy and R&I agendas as a tool to support circular economy and climate neutrality objectives, notably by reducing raw material demand, diverting waste from disposal, and supporting regional industrial diversification. Despite this recognition, IS remains unevenly implemented across sectors and regions. Key reasons for this relate both to understanding of IS and structural issues:

- **Lack of harmonised terminology and shared definitions:** Terms such as "industrial symbiosis," "by-product," "co-product," or "secondary raw material" are interpreted inconsistently in national policy frameworks, research initiatives, and private sector applications, leading to legal and market uncertainty and fragmented implementation.
- **Limited technical guidance:** Few standards[1] provide detailed instructions for identifying, implementing, and evaluating symbiotic relationships. Related standards in areas like life cycle assessment, material flow analysis, or environmental management do not directly address the specific dynamics of cross-industry or territorial cooperation. Standards bodies tend to struggle with the inherent cross sector nature of IS. Consequently, there is lack of practical expertise and know-how when it comes to putting IS in practice.
- **Context dependency:** IS practices are at times site- and sector-specific, which limits comparability and replication of solutions. Multi-national companies talk of being able to implement an IS solution in one location but being unable to replicate in another due to differing regulations such as EoW criteria.
- **Governance, leadership and management knowledge gaps:** Limited knowledge and awareness by public/private organisations' governing, leading and managing authorities/structures, such as Boards of Directors, Executive and Management Teams, with respect to environmental, economic, social, and strategic benefits of IS. This results in inadequate allocation of financial and information resources to IS initiatives.
- **Coordination and visibility gaps:** Potential synergies often go unnoticed due to the lack of systematic mapping tools and structured/standardised methodologies for matching and assessing exchanges.
- **Regulatory divergence:** Differences in interpretation of waste and by-product status, coupled with complex permitting procedures, create significant barriers.
- **Policy-related barriers** include restrictive regulations, complex bureaucratic processes, and uncertainty over future frameworks, particularly for waste and by-product classification.
- **Economic and market challenges** arise from unclear financial benefits, low disposal costs, limited financing, and market immaturity.
- **Unsteady availability of material.** Geographical distance can, at times, be a hindrance, if, say, a partner organisation cannot be found within the economic travel distance of a resource.
- **Technological gaps,** such as insufficient availability of reliable recovery technologies and integration problems, hinder implementation.
- **Inadequate infrastructure** can make exchanges unfeasible, while the absence of active intermediaries is limiting coordination.
- **Adaptation of existing standards** or creation of new ones for sustainable products derived from waste streams (e.g., low-carbon cement, bio-based polymers).

Evidence from the RISERS analysis of enablers and barriers confirms that successful IS depends on:

- A trust-based environment,

1 Examples are CEN/TR 16957:2016 – Industrial Symbiosis: Core Elements and Implementation Approaches; BS 8001:2017 Framework for Implementing the Principles of the Circular Economy

- Openness to sharing information,
- Operational cost savings,
- And can benefit from strong involvement of:
  - Anchor companies
  - Research and Development (R&D) institutions,
  - And government entities.

Facilitation has been shown to be a key driver for scale up of symbiotic operations. Conversely, social inertia, low disposal costs, market immaturity, inadequate infrastructure, and insufficient intermediaries can hinder implementation.

Opportunities for progress within a standard for IS include:

- Developing a **standardised IS definition**, common terminology, and shared metrics for all sectors. This would ensure understanding between all audiences and address many of the misunderstandings related to IS, examples being the use of terminology such as sharing/ exchange of resources, dependence on proximity
- Exploring diverse **governance/implementation models**, including facilitation along with ICT-based coordination mechanisms. Clarity could be brought to what is a governance model and what is a support or coordination mechanism. Areas where governance models connect could also be addressed, such as where a regional government funds a facilitated programme that is supported by ICT matching software.
- Establishing a **standards-based framework** related to material properties and quality, for transactions involving by-products, waste, and other resources. Thereby moving End-of-Waste criteria towards input standards related to the production process a resource would be used in, rather than how a resource is generated.
- Fostering collaboration with public/private organisations' governing, leading and managing bodies (Boards, Executive and Management Teams) **to mainstream IS as a mechanism to achieve sustainability and strategic outcomes**.
- Enabling large scale **digital matchmaking platforms** to increase visibility of available resources and potential partners, while addressing interoperability between platforms, thus removing barriers between platforms
- Providing targeted **financial incentives** and sectoral funding schemes to support initial investments and infrastructure needs.

By establishing a shared technical foundation through standardisation, IS can be more effectively integrated into regional planning, industrial development strategies (at regional, national and international levels), and sustainable procurement. This would facilitate the scaling of successful approaches in urban and industrial activity across sectors and Member States, contributing to both economic resilience and environmental sustainability.

Overcoming these challenges requires lots of action (recommendations for different entities are elaborated in chapter "recommendations"), enhancing networks (through support mechanisms such as facilitation), securing operational cost savings, promoting sectoral funding, and at times, benefiting from the involvement of anchor companies and R&D institutions to drive innovation and build capacity.

Recommendations for regulation

- Simplify by-product classification and harmonise end of waste criteria across jurisdictions. Possibly replacement of End of Waste (EoW) by standards
- Streamline permitting processes and reduce administrative burdens for IS exchanges.

- Promote governmental action plans, clustering initiatives, and awareness-raising to encourage adoption.
- Encourage policy frameworks that mobilise initiatives, facilitate partnerships, incentivise and embed IS in sustainable industrial strategies.
- Incorporate IS into the EU taxonomy for (sustainable) finance facilitation purposes

Recommendations for Standardisation

- Establish a standardised IS definition, common terminology, and shared metrics across sectors.
- Promote methodologies and tools for assessing the economic and environmental value of synergies, including logistics feasibility, such as those developed within H4C COP[2].
- Integrate IS considerations into existing standards such as LCA, material flow analysis, and environmental management.

Recommendations for Markets

- **Strengthen Relationships and Collaboration:** Foster networks, clusters, and associations among industries, environment professionals, researchers, innovators, waste managers, technology providers, logistics providers, knowledge agents, policy makers, and government entities to build trust and identify opportunities.
- **Financing and Incentives:** Implement sectoral funding programmes, economic incentives, and public/private financing mechanisms to address investment barriers and support infrastructure acquisition.
- **Geographical and Logistics Optimisation:** Prioritise proximity in planning; partner with logistics companies to optimise resource transport, waste collection/segregation/treatment; use tools to evaluate distance-related feasibility.
- **Data and digital infrastructure:** Leverage information technology tools including data platforms to systematically map out organisational processes and material flows in order to identify, and co-ordinate synergies as well as the transaction of resources.
- **Knowledge and Research Collaboration:** Engage R&D entities and academic institutions for practice-oriented studies, training, and dissemination to raise awareness of IS benefits. Highlight areas where standardisation is lacking or insufficient, particularly in cross-sector collaboration, digital tools, and sustainable product standards.
- **Overcoming Social Barriers:** Foster environments of trust and involve intermediaries/promoters to reduce resistance and broaden stakeholder participation.
- **Internal Organisational Structures:** Establish dedicated IS teams or functions within companies to identify and manage synergies strategically.

2 https://www.h4c-community.eu/knowledge-platform/ - last accessed 2025-12-18

Related Organisations and Technical Bodies

- **ISO/TC 324** – Sharing economy
- **CEN/TC 473** – Circular Economy
- **CEN/TC 183** – Waste management
- **CEN/TC 444** – Environmental management and circular economy
- **CEN/TC 465** – Sustainable Cities and Communities
- **CEN-CLC/COG H2** – Hydrogen
- **CEN-CLC/COG Construction** – Construction and the built environment
- **CEN-CLC/COG ACC** – Mitigation and Adaptation to Climate Change
- **CEN-CLC/COG ENV** – Environment
- ISO/TC 298 – Rare Earth
- ISO/TC 61 – Plastics
- ISO/TC 301 – Energy management and energy savings
- International Society for Industrial Ecology (ISIE)
- TCs dealing with LCA, environmental management systems, and resource efficiency (e.g. CEN/TC 165, CEN/TC 301, depending on sector links)
- R&D networks, universities, and innovation clusters active in IS-related projects

Related Deliverables in Policy and Standardisation

- **CWA 17354** – *Industrial Symbiosis: Core Elements and Implementation Approaches*
- **ISO/DIS 42500** – *Sharing economy — Terminology and principles*
- **ISO/AWI TS 42501** – *Sharing economy — General trustworthiness and safety requirements for digital platforms*
- **ISO/AWI TS 42502** – *Sharing economy — Guidelines for provider verification on digital platforms*
- **DIN EN ISO 14001** – *Environmental management systems – Requirements with guidance for use*
- **DIN EN ISO 14002-1** – *Guidelines for the use of ISO 14001 – Part 1: General*
- **DIN EN ISO 14002-2** – *Guidelines for the use of ISO 14001 – Part 2: Water*
- **ISO 14002-3** – *Guidelines for the use of ISO 14001 – Part 3: Climate*
- **ISO 14034** - *Environmental Management: Environmental technologies verification*
- **OECD report** – *Best Available Techniques (BAT) for Preventing and Controlling Industrial Pollution – Activity 5: Value chain approaches to determining BAT for industrial installations*
- **H2020 SCALER D4.5** – *Report on industrial symbiosis standardisation needs (identifying 286 national and international standards relevant to IS)*
- **Interreg SYMBI Activity 6 Report** – *Summary report on IS reporting & certification systems*

B. END-OF-WASTE

The concept of *End of Waste* (EoW) is central to enabling circular resource flows and unlocking the potential of secondary raw materials. Once a material is classified as waste, it becomes subject to specific legal obligations and restrictions that can hinder its reuse or further valorisation. Achieving EoW status – the transition from waste to non-waste – is therefore essential for reintegrating materials into industrial processes and supply chains.

European legislation, most notably Article 6 of the Waste Framework Directive (2008), provides a framework for defining EoW criteria. However, the implementation of these criteria varies significantly across Member States, sectors, and material streams. This fragmentation creates legal uncertainty and hinders the circulation of materials in IS.

One of the most pressing challenges is the lack of harmonised methodologies, leading to inconsistent interpretations. Materials considered suitable for reuse in one jurisdiction may still be treated as waste in another, complicating cross-border flows and market development. The process of attaining EoW status can be complex, costly, and time-consuming, particularly for emerging material streams without established EU-level criteria.

From a standardisation perspective, there is no widely agreed reference method for defining, demonstrating, and verifying EoW status. Technical criteria for quality, purity, safety, and traceability are rarely codified in a way that enables consistent implementation across sectors and regions. Standardisation could help reduce legal uncertainty, improve mutual recognition, and support market access for high-quality secondary materials.

CHALLENGES[3]

A limited development of EU-wide end-of-waste criteria and by-product status…… has led to the fragmentation of the Single Market for waste, secondary materials and by-products

The implementation of End of Waste (EoW) remains constrained by **fragmentation of criteria**, as national-level interpretations of EoW requirements vary significantly, resulting in inconsistent decision-making and regulatory uncertainty for economic operators, particularly those active across borders. **Complexity and cost** further hinder implementation, as the process for achieving EoW status is often lengthy, resource-intensive, and technically demanding, creating disproportionate barriers for smaller companies and innovative projects.

A lack of harmonised EU definition of by-products…. impedes the circularity of production processes

Lack of harmonised reference methods for assessing material quality, safety, and traceability undermines confidence in secondary raw materials and limits their integration into established value chains

3 Quotes from: The Single Market: our European home market in an uncertain world - Internal Market, Industry, Entrepreneurship and SMEs

National or regional end-of-waste criteria have been adopted by Member States in an uncoordinated manner and are not easily recognised between Member States

Limited mutual recognition of EoW decisions between Member States restricts cross-border trade and market development, as materials deemed to have ceased to be waste in one jurisdiction may not be accepted in another. These challenges are compounded by **regulatory gaps for new streams**, where emerging waste streams and novel recovery technologies lack clear criteria or standards, slowing innovation and uptake despite potential environmental and CE benefits.

RECOMMENDATIONS

Following a detailed discussion of the challenges associated with EoW within the working group, the following recommendations were developed. They focus on creating a more consistent and transparent framework through standardisation, while ensuring regulatory measures and incentives support market adoption and cross-border recognition. The importance was stressed that the recommendations must align with the conditions set out in Article 6 of the Waste Framework Directive, helping to ensure that materials are intended for specific uses, meet quality and safety requirements, and do not cause adverse environmental or health impacts. Together, these measures could reduce administrative complexity, enhance trust in secondary materials, and facilitate the development of a robust circular economy.

Standardisation

- **Develop high-level, horizontal EoW standards**

  Establish an overarching EoW standard applicable across sectors that defines common principles, baseline requirements, and assessment criteria. Such a standard would provide regulatory clarity while allowing flexibility for diverse material streams.
- **Enable material / sector /use-specific (vertical) standards**

  Complement horizontal standards with specific criteria that define acceptable material inputs, performance requirements, and end uses. This approach would ensure technical relevance while supporting innovation and market uptake.
- **Collect and analyse subnational EoW implementations** in a European-level repository. This should include technical criteria currently applied at regional, provincial, or local levels, with references to underlying national or subnational regulations where possible. The repository would support the identification of common practices and provide a foundation for harmonisation into unified European standards.
- **Map existing practices to current standards** to assess alignment and identify where locally developed EoW criteria can be substituted with existing or in-development standards once equivalence is demonstrated. This ensures technical consistency, supports regulatory compliance, and facilitates cross-border acceptance.
- **Standardise documentation and verification processes**

  Define common templates and procedures for documentation, conformity assessment, and verification to improve transparency, traceability, and trust between operators and regulators. Standardised documentation would also reduce administrative burden and facilitate audits and enforcement.
- **Assess the role of Industrial Symbiosis (IS) standards**

  Explore whether an IS-related standard could reduce or remove the need for separate EoW procedures in well-controlled, closed-loop systems.

Regulation

- **Align standards with regulatory processes**
  Strengthen coordination between EU-level and national regulatory processes so that standardised technical requirements can directly inform binding EoW criteria under legislation. This would improve coherence between voluntary standards and legal obligations.
- **Introduce economic incentives and disincentives**
  Support EoW implementation through incentives for reuse, recycling, and high-quality recovery, while introducing disincentives for landfill and incineration. Economic signals should reinforce regulatory objectives and support market development for secondary materials.
- **Support mutual recognition mechanisms**
  Develop mechanisms to support the mutual recognition of EoW decisions between Member States, potentially through harmonised assessment criteria, or EU-level validation processes. This would enhance trust, reduce duplication, and enable cross-border trade.

EoW, while undoubtedly useful, is slow, limited and fractured in its application. An alternative methodology, based on standards – both existing and to be developed – could offer a solution that would be quicker to implement, more flexible and more capable of adapting to new IS opportunities as they are identified.

Related EU Project: HARMONI

- **Title:** Harmonised assessment of regulatory bottlenecks and standardisation needs for the process industry
- **Standardisation Inputs:** Integrated new research into existing frameworks. Identified needs for data sharing standards and addressing IS complexity/ variability.
- **Policy Recommendations:** Harmonised European waste, water, and energy policies. Involved regional policy makers in regulation development.

Related EU Project: CORALIS

- **Title:** Creation Of new value chain Relations through novel Approaches facilitating Long-term Industrial Symbiosis
- **Standardisation Inputs:** Expanded energy efficiency standards (ISO 50001) for inter-plant exchanges. Proposed standards for Digital Product Passports.
- **Policy Recommendations:** Establish detailed criteria for By-product and End-of-Waste status. Promoted Renewable Energy Communities.

C. DIGITALISATION & DATA

Digitalisation is a key enabler of IS, offering the data infrastructure and tools needed to identify opportunities, arrange transactions, optimise resource flows and track the benefits. By making resource-related data available, accessible, and interoperable, digital solutions can facilitate supply–demand matchmaking, improve traceability, and support predictive, data-driven decision-making. Examples include digital marketplaces, AI-based matchmaking tools, integration of isolated monitoring systems via open Application Programming Interfaces (APIs), and the use of digital twins combined with life cycle and traceability data to model potential exchanges and assess their environmental and economic benefits.

In the European policy framework, initiatives such as the **European Data Strategy**, the **Digital Product Passport (DPP)** under the Ecodesign for Sustainable Products Regulation, and the **Common European Green Deal Data Space** illustrate the growing emphasis on interoperable and reliable sustainability-related data. These developments provide an opportunity to align IS practices with broader digital and CE initiatives, enabling scalable exchanges of materials, energy, and services when supported by common data structures, governance models, and technical standards.

Despite this potential, several barriers persist. Resource data is often fragmented, stored in incompatible formats, or inaccessible due to confidentiality concerns or unclear legal responsibilities. Even where data is available, differences in terminology, granularity, and measurement units impede integration. Existing Enterprise Resource Planning (ERP) systems (e.g., environmental reporting tools, product lifecycle databases) are rarely designed with symbiosis in mind, and SMEs may lack the resources to implement complex digitalisation solutions without targeted support or standardised approaches.

A further challenge is the absence of consensus on which datasets are most relevant for enabling symbiosis. Some initiatives prioritise material flow or waste characterisation data, while others emphasise location, infrastructure, compliance, or economic information. Without agreed minimum data requirements, many platforms fail to deliver reliable matches or actionable insights. Functional metadata — describing material properties, potential uses, and processing history — is often missing from classification systems. The sole reliance on European Waste Catalogue (EWC) codes can limit usability, leading to calls for combined systems that link these codes with functional attributes.

Trust and data governance remain critical issues. Concerns over intellectual property (IP), liability, and the misuse of commercially sensitive information limit willingness to share data. There is a need for clear rules, standardised confidentiality agreements, and trusted intermediaries to ensure secure, mutually beneficial exchanges.

Opportunities for standardisation and improvement identified across sources include:

- **Enhanced classification and metadata standards**, combining existing codes (e.g. EWC) with functional attributes, reuse potential, and processing history.
- **Integration of Digital Product Passports** for lifecycle and traceability data, adapted to different sectors beyond those already regulated.
- **Common frameworks for data sharing and confidentiality** to balance transparency with protection of sensitive information.
- **Harmonised APIs and interoperability protocols** to enable integration between diverse digital platforms and existing monitoring systems.

By aligning standardisation activities with emerging EU digital and CE frameworks, digitalisation for IS can become more discoverable, verifiable, and replicable, fostering greater uptake of circular practices across European industry.

CHALLENGES, NEEDS AND RECOMMENDATIONS

Digitalisation for IS is constrained by fragmented and incompatible data, limited interoperability between existing enterprise and reporting systems, and uncertainty around confidentiality, liability and IP when sharing commercially sensitive information. This leads to low discoverability of resources across organisations and weak comparability of data across sectors. There is no agreed minimum dataset for enabling matches; current classification systems (e.g. EWC) are often too coarse, and functional metadata about material properties, potential uses and processing history is missing. SMEs face capacity gaps to implement complex digital tools without targeted support. Clearer regulatory pathways (e.g. on byproduct use and EoW status) are needed to underpin data-driven exchanges and reduce perceived compliance risk. Collectively, these gaps limit trust, impede automated matchmaking, and slow the uptake of digital tools such as product passports, digital twins and shared platforms for material and energy flows.

STANDARDISATION

Enhanced Classification and Metadata Standards.

Classification of resources is required so that linked systems can have a common understanding of the nature of resources. Currently there is insufficient cross sector standardisation on the classification of products, materials and other resources. Where detailed standardisation is available, it is often industry/sector specific.

EWCs are widely used but have insufficient detail and they imply that the resource is a waste.

A possible approach is augmenting existing codes (e.g. EWC) with functional, machine-readable metadata describing specifications, reuse potential and processing history. Developing shared ontologies/templates could improve cross sector matching and reduce ambiguity in resource descriptions.

Digital Product Passports

There is clear value with DPPs to offer support for integrating lifecycle data and traceability into reuse pathways. On investigation, there is already considerable standardisation efforts in this area, specifically, it is a key part of the Ecodesign for Sustainable Products Regulation (ESPR). Therefore, there is currently no clear need for further standardisation beyond existing efforts (European Commission, 2024).

Interoperability of Data and Systems

Defining data models and API requirements to link enterprise systems and reporting tools was discussed. System interoperability is a vast area with many tools and technical standards already in place. In practice, additional standards on how systems integrate is not needed, but a common understanding of the meaning of transferred data is critical for success. The above suggested standard on **Enhanced classification and metadata standards** would greatly assist connections between systems, by giving a common understanding of the resource the transferred data refers to.

Consensus Frameworks for Confidentiality and Trust

Data confidentiality is a significant challenge in this area. This is combination of legislative and commercial concerns.

Potential fields for standardisation are developing guidance, model clauses and trust frameworks for confidentiality and controlled sharing, while trying to avoid rigid prescriptions that could hinder innovation. . Caution should also be raised against rigid data standards that might hinder IS innovation. Overall, there does not appear to be consensus on standardisation activities in this area due to its complexity and the variability across industries

Reusing Proven Industrial Symbiosis Pathways

The possibility of a standard approach to sharing IS pathways was discussed but the feasibility of standardizing knowledge sharing is unclear and could hinder IS innovation. This topic could be revisited in conjunction with DPPs or material classification approaches.

SELECTION OF RELATED POLICY DELIVERABLES AND EXISTING STANDARDS

Policy deliverables / initiatives:

- *European Data Strategy; Digital Product Passport under ESPR; Common European Green Deal Data Space.*
- *Ecodesign for Sustainable Products Regulation (ESPR) aims to enhance product sustainability by establishing ecodesign requirements, including Digital Product Passports.*

Standards / specifications:

- *ISO 23247 (Digital Twins); IEC 62832 (Digital Factory); ISO 14044 (LCA) and ISO 14001 (EMS); CWA 17354 (Industrial Symbiosis).*

Related organisations and technical bodies (examples)

- *ISO; IEC; CEN; CENELEC; GS1 (data standardisation). Potential relevance of web standards bodies for linked data/ontologies (e.g. W3C style approaches)*

4. SECTORAL PRIORITY AREAS

The second part of the roadmap focuses on sectoral priority areas where IS holds relevance. Each sector presents distinct material flows, regulatory contexts, and operational practices. Topics addressed include the reuse of steel slags and refractories, circular approaches in the battery and packaging sectors, recovery of waste heat, and the valorisation of textile waste, energy data, and bio-based materials such as biomass and waste wood. By analysing these areas, the roadmap identifies sector-specific standardisation needs that complement the cross-cutting issues addressed earlier. This approach supports the development of technical solutions while fostering alignment with sectoral policies, value chain dynamics, and market conditions.

A. STEEL, SLAG & REFRACTORIES

The steel, slag and refractories sector offer significant use in IS through the recovery and use of by-products generated in steel production. Slags from iron and steel production - such as those from blast furnaces (BF), basic oxygen furnaces (BOF), electric arc furnaces (EAF), Corex, HIsarna, direct reduced iron-electric arc furnace (DRI-EAF) and DRI-submerged arc furnace (DRI-SAF) routes - as well as spent refractories from high-temperature processes, can be used in construction materials, cement production, asphalt, agriculture and other industrial applications. Such valorisation contributes to reducing demand for virgin raw materials, lowering landfill use and improving resource efficiency.

Existing applications for slags have demonstrated technical feasibility in areas such as aggregates for asphalt and concrete, sand replacement in autoclaved aerated concrete, clinker production and use in fertilisers. Supplementary Cementitious Materials (SCM) applications represent an area with further high potential.

Despite this potential, slags from BOF and EAF as well as Corex, HIsarna, DRI-EAF and DRI-SAF processes show higher chemical and mineralogical variability than ground granulated BF slag, which creates uncertainty on performance and environmental fitness unless robust characterisation and treatment are applied.

Refractory materials, depending on composition (e.g. alumina-based, magnesia-based), can also be recovered from refractory, ceramic and other industries for reuse. However, market uptake varies and cross-sector deployment remains limited due to technical, regulatory and economic constraints.

Standardisation, legislation and regulation can play a central role in overcoming these barriers by supporting harmonised quality criteria, enabling cross-border use and creating confidence among end-users. For slag, relevant standards include EN 15167 for ground granulated blast furnace slag, EN 12620 for aggregates in concrete, EN 13043 for asphalt and EN 13242 for unbound materials. While many aggregate uses are technically well covered, gaps remain for new applications and for harmonising environmental performance requirements. Cross-border differences in waste versus by-product status, end-of-waste criteria and test methods currently limit market uptake and comparability of results.

This roadmap therefore focuses on harmonised approaches for assessment and standardisation, together with mutual recognition of test results, to enable wider deployment of secondary materials across industrial applications. By consolidating existing knowledge, identifying standardisation gaps and formulating recommendations, it defines pathways for integrating these materials into European markets more effectively, in line with CE objectives and relevant policy frameworks.

PRIORITY SYNERGIES

Steel production generates by-products with significant use in cross-sectoral IS. BOF and EAF slags, as well as other ferrous slags, can be used in cement production, asphalt, concrete, unbound aggregates and other construction applications, reducing the need for virgin raw materials and lowering CO_2 emissions. Spent Refractory Materials (SRM), once at end-of-life (EoL) of their use in steelmaking, can be recovered, processed and reused either in steelmaking or in other high-temperature industries, decreasing extraction of primary minerals. Steel scraps, such as turnings, swarf and demolition scrap, can be reintroduced into production cycles, improving resource efficiency and raw material security.

These synergies offer multiple benefits: reduction of landfill volumes, lower environmental impact of raw material extraction and greater resilience in supply chains. They also contribute to EU CE goals, enhance inter-industry collaboration and create potential economic opportunities from materials previously considered waste. Standardisation plays a crucial role in enabling these exchanges, by ensuring consistent quality, harmonised test methods and regulatory clarity for cross-border markets.

BOF & EAF AND OTHER FERROUS SLAG IN CEMENT INDUSTRY

This synergy focuses on the use of BOF, EAF and other ferrous slags from steel production as raw materials in clinker, as SCMs or as partial substitutes for cement in concrete. Owing to their calcium-, silicon- and iron-rich composition, these slags can replace virgin raw materials and contribute to significant CO_2 reductions in both steelmaking and cement manufacturing. Between 2000 and 2022, the use of granulated BF slag alone avoided 408 million tonnes of CO_2 emissions and substituted 1.1 billion tonnes of natural resources in the EU and UK, according to Euroslag (source: Stahleisen.de).

Standardization could help harmonize material specifications, testing methods/assessment methodologies, treatment processes and environmental safety thresholds across Europe. This would support broader market acceptance and regulatory clarity for using slags in construction.

To implement this synergy in practice, several steps must be taken to ensure the reliable and safe use of ferrous slags in cement and concrete production. A first priority is the establishment of uniform classification and processing practices across Europe to ensure consistent slag quality. This includes clear limits for chemical composition, harmonised approaches to environmental safety, and defined quality control procedures. Reliable assessment tools are needed to verify performance in cementitious applications and to ensure that variations in slag composition do not compromise product integrity.

Realisation of this synergy also requires suitable infrastructure and technologies. Processing facilities must be equipped for controlled cooling or quenching, removal of metallic iron, and fine grinding. These steps are essential for producing stable, usable slag fractions with predictable behaviour in cement and concrete. Complementary technologies, such as performance testing equipment and emerging digital traceability systems, will help ensure transparency and support harmonised assessment across the value chain.

Effective cooperation between steel producers, cement manufacturers and aggregate suppliers is another important enabler. Such collaboration supports the matching of material properties with technical requirements, facilitates coordinated investment in processing capacity, and helps establish long-term supply arrangements. Industrial clusters or regional partnership models can support more efficient logistics and reduce transport-related constraints.

The synergy offers clear benefits, including reduced clinker production and associated CO_2

emissions, as well as a substantial decrease in the use of virgin raw materials. However, several challenges still limit wider deployment. Slag composition may vary significantly between production routes and sites, occasionally leading to concerns over soluble or leachable metals. National differences in the legal status of BOF, EAF and other ferrous slags—whether classified as waste or by-product—continue to create uncertainty and can restrict market uptake. In addition, transport distances between steel and cement plants can affect economic viability, particularly in regions without established industrial clusters.

Related Technical Bodies:

- CEN/TC 51 Cement and building limes
- CEN/TC 104 Concrete and related products
- CEN/TC 121 Welding and allied processes
- CEN/TC 154 Aggregates
- CEN/TC 190 Foundry technology
- CEN/TC 202 Foundry machinery
- CEN/TC 203 Cast iron pipes, fittings and their joints
- CEN/TC 227 Road materials
- CEN/TC 265 Metallic tanks for the storage of liquids
- CEN/TC 267 Industrial piping and pipelines
- CEN/TC 350 Sustainability of construction works
- CEN/TC 396 Earthworks

Regulatory Recommendations

- Clarify the legal distinction between waste and by-product for BOF and EAF slags and harmonise EoW criteria to enable their recognition as secondary raw materials.
- Include EAF/BOF slags in harmonised standards under the Construction Products Regulation.
- Align legislative and regulatory requirements, including REACH, the Construction Products Regulation, the Circular Economy Act (CEA), and environmental reporting, and ensure mutual recognition of test results across countries.
- Ensure regulations are tailored to the intended applications of slag while maintaining EU-wide harmonisation.
- Define environmental conditions for waste recovery and the necessary environmental permit.
- Provide consistent EU-level guidance on CO_2 emissions allocation for by-products such as steel slag to ensure fair carbon accounting, avoid disputes between sectors and prevent greenwashing.
- Use public procurement criteria to incentivise low-carbon and by-product-containing materials.

Standardisation Recommendations

- Develop harmonised assessment methodologies for slag properties to ensure reliable characterisation and volumetric stability.
- Address compositional variation issues through appropriate standardisation measures.
- Develop standards for slag treatment and processing.

- Include ferrous slags from BOF, EAF, Corex, HIsarna, DRI-EAF and DRI-SAF processes in cement and concrete standards.
- Develop product standards for processed ferrous slags—such as chemically modified BOF slags, granulated EAF slags and other granulated ferrous slags—when used as SCMs in cement or concrete.
- Support broader use of ferrous slags through an initial focus on non-harmonised, performance-based approaches at national level, followed by a fully harmonised approach to enable cross-border consistency and wider market recognition.
- Align EU cement and national concrete standards to ensure consistent use of all qualified ferrous slags across Europe.

REFRACTORY USE IN HIGH-TEMPERATURE INDUSTRIES

This synergy addresses the reuse of spent refractory materials (SRM), which are essential components in high-temperature industrial processes such as steelmaking, glass production and cement manufacturing. Although refractories are designed for durability under extreme conditions, their EoL management remains challenging. Spent materials often exhibit significant variability in quality, limited traceability and a lack of "design for reuse". In many cases they are classified as waste, which further restricts their circulation back into industrial processes. Reintroducing refractory materials into production loops could substantially reduce the demand for virgin raw materials, lower environmental burdens and enhance resource efficiency across several energy-intensive industries.

Standardisation can play an important role in enabling this transition. Clear, harmonised approaches to material characterisation, quality benchmarks and EoW criteria would support trust in secondary materials and create greater certainty for industrial users. Traceability standards, for example through material passports or structured documentation of composition and performance, would help ensure that secondary refractory materials are suitable for specific applications and meet required safety conditions.

Implementing this synergy requires the development of structured collection and sorting systems at demolition sites, ensuring that spent refractories are separated, identified and preserved in a state suitable for recovery. Appropriate infrastructure is also necessary, including facilities for milling, classification and comprehensive testing. These installations allow spent materials to be processed into fractions with predictable characteristics and performance profiles.

The use of complementary technologies—such as material passports or digital traceability systems—can further strengthen the link between composition data and potential reuse pathways. Such tools make it possible to match secondary refractory materials with the technical requirements of steelmaking, cement production or other high-temperature processes.

Closer collaboration between refractory producers, industrial users in sectors such as steel, and specialised recycling companies is essential. Partnerships or industrial networks can facilitate coordinated collection, shared investment in processing capacity and streamlined material flows. These arrangements also support the exchange of technical data and common understanding of quality requirements.

The potential benefits are significant. Reuse conserves raw materials, reduces environmental impacts and can help reduce the overall carbon footprint of high-temperature industries. However, several challenges currently limit broader adoption. Regulatory frameworks remain unclear in many Member States, economic incentives are often insufficient to make recycling competitive with disposal, and the processing of spent refractories can require substantial energy. Addressing these issues is crucial for scaling circular practices in this field.

Related Technical Bodies:

- CEN/TC 51 Cement and building limes
- CEN/TC 104 Concrete and related products
- CEN/TC 187 Refractory products and materials
- CEN/TC 227 Road materials
- CEN/TC 350 Sustainability of construction works
- CEN/TC 396 Earthworks

Regulatory Recommendations

- Develop EU-level technical guidelines and harmonised end-of-waste criteria to define when spent refractories can be treated as secondary raw materials.
- Introduce incentives for reuse and penalties for landfilling where environmentally justified.
- Integrate reuse considerations into waste treatment regulations to support circular practices across high-temperature industries.

Standardisation Recommendations

- Create harmonised classification and testing methods for spent refractories.
- Set quality benchmarks for secondary raw materials in refractories to ensure consistent performance in downstream applications.
- Develop a dedicated standard for recycled refractories, including an EoW framework for secondary material use.

STEEL SCRAP VALORISATION (RECYCLING)

This synergy focuses on the recycling of steel scrap arising from industrial processes, including turnings, swarf and other production residues. Although steel is inherently recyclable and widely reused, several constraints still limit the full-scale circularity of steel scrap within and beyond the steel sector. Variations in scrap composition, the presence of contaminants, and incomplete information on material flows can complicate recycling and reduce the value of recovered materials. Addressing these barriers is essential for improving resource efficiency, lowering the environmental footprint of steelmaking and strengthening the EU's raw material security.

Standardisation can support these objectives by providing common definitions, classification systems and quality benchmarks for steel scrap. Harmonised traceability protocols and contamination control approaches would enable more predictable and higher quality recycling streams, improving market confidence and facilitating the integration of steel scrap into multiple value chains. These standards would also help align regulatory practices across Member States and encourage cross-sector collaboration.

To unlock the full value of steel scrap, several measures are required. Developing harmonised quality criteria is a central step, ensuring that scrap meets performance expectations for downstream uses. Improving contamination control—especially regarding coatings, oils, and alloyed elements—can reduce processing challenges and increase the suitability of scrap for higher-value applications. Establishing consistent sorting and screening procedures helps create more uniform material streams and facilitates efficient processing.

Realising this synergy also depends on appropriate infrastructure. Scaled-up collection, pre-treatment and transport systems are needed, particularly for smaller or decentralised scrap generators that currently face logistical challenges. Where possible, consolidating material flows can improve both environmental and economic viability.

Technological advancements play an important enabling role. Advanced sorting technologies and contamination detection systems can help differentiate scrap types, accurately identify impurities and improve the quality of recycled materials. These tools make it easier to direct scrap into suitable applications and reduce the need for extensive downstream correction.

Partnerships between scrap processors, industry associations and steelmakers are essential for identifying relevant actors, aligning quality expectations and coordinating investments in sorting and pre-treatment capacities. Such collaboration also supports better data exchange and more transparent mapping of scrap flows.

The benefits of an expanded steel scrap valorisation system are well established. Recycling reduces the demand for primary iron ore and significantly lowers energy consumption compared to primary steelmaking routes. At the same time, several challenges persist. Scrap composition varies widely between sources, contamination can reduce material value or require costly treatment and fluctuating scrap prices may affect the economic feasibility of recovery, especially for small-scale generators.

Related Technical Bodies:

- CEN/TC 135 Execution of steel structures and aluminium structures
- CEN/TC 183 Waste management
- CEN/TC 203 Cast iron pipes, fittings and their joints
- CEN/TC 459 ECISS - European Committee for Iron and Steel Standardization

Regulatory Recommendations

- Harmonise the application of existing EoW criteria and the Waste Shipment Regulation to ensure consistent legal recognition of scrap as a secondary raw material.

Standardisation Recommendations

- Define essential characteristics for different scrap types, including chemical composition, size and allowable contaminants.
- Set quality requirements to enable recycling across various applications and ensure that scrap meets specifications for intended downstream uses.
- Develop harmonised sorting, identification and contamination control protocols to ensure consistent steel scrap quality and facilitate safe, reliable reuse.

GENERAL NEEDS AND RECOMMENDATIONS

Across the IS opportunities examined, covering slags, spent refractories and steel scrap, several overarching challenges and needs emerge. A key issue is the **lack of harmonised European standards and legal clarity** regarding the classification of secondary raw materials (by-product vs. waste), which hinders cross-border use and market uptake. **Variability in material composition and quality**, combined with inconsistent testing and certification methods, complicates industrial reuse. **Data gaps and limited traceability** along value chains impede transparency and trust among stakeholders. Economically, **high transport and processing costs**, together with uneven regional infrastructure, limit feasibility in some areas.

Related organizations and technical bodies

- CEN/TC 51 – Cement and building limes
- CEN/TC 104 – Concrete and related products
- CEN/TC 154 – Aggregates
- CEN/TC 187 – Refractory products and materials
- CEN/TC 227 – Road materials
- CEN/TC 350 – Sustainability of construction works
- CEN/TC 396 – Earthworks
- CEN/TC 135 – Execution of steel structures and aluminium structures
- CEN/TC 183 – Waste management
- CEN/TC 459 – ECISS - European Committee for Iron and Steel Standardization
- National standardisation bodies and relevant industry associations

Related deliverables (policy and standardization)

- EN 15167 – Ground granulated blast furnace slag
- EN 12620 – Aggregates for concrete
- EN 13043 – Aggregates for asphalt
- EN 13242 – Aggregates for unbound and hydraulically bound materials
- Construction Products Regulation (CPR)
- REACH Regulation

Regulation:

- Clarify legal status by distinguishing clearly between waste and by-products, and harmonise EoW criteria across Member States to ensure consistent recognition of secondary raw materials.
- Align key legislative frameworks, including REACH, the Construction Products Regulation (CPR), the CEA and environmental permitting, to remove overlaps and facilitate mutual recognition of test results across borders.
- Include BOF/EAF slags and other ferrous by-products in harmonised standards under the CPR, while initially allowing non-harmonised, performance-based approaches to accelerate national uptake before transitioning to full EU harmonisation.
- Develop EU-level technical guidelines for spent refractories, defining quality, safety and environmental thresholds, and establishing incentives for reuse and penalties for landfilling where appropriate.
- Ensure consistency in CO_2 emissions allocation and reporting for by-products (e.g. steel slags) to provide fair carbon accounting and avoid double counting or greenwashing.
- Harmonise application of Waste Shipment and EoW rules for steel scrap, enabling its recognition and movement as a secondary raw material within the internal market.
- Leverage public procurement criteria and green infrastructure initiatives to incentivise the use of low-carbon, circular materials containing industrial by-products.

Standardisation:

- Develop harmonised assessment and testing methodologies for characterising material properties such as composition, volumetric stability and performance, to ensure reliability and comparability across Member States.

- Address compositional variability in standards for slags, refractories and scrap through performance-based approaches and clear specification ranges.
- Establish dedicated processing and treatment standards, particularly for ferrous slags (e.g. BOF, EAF, Corex, HIsarna, DRI-EAF, DRI-SAF) to ensure consistent quality of outputs for use in cement, concrete and aggregates.
- Develop product standards for processed ferrous slags (e.g. chemically modified or granulated variants) as recognised SCMs and align EU cement and national concrete standards to enable cross-border application.
- Create harmonised classification, testing and quality benchmarks for spent refractories to define safe and reliable reuse pathways, supported by a dedicated standard and EoW framework for recycled refractory materials.
- Define essential characteristics and quality requirements for steel scrap, including composition, size and allowable contaminants, and develop harmonised sorting, identification and contamination control protocols to ensure safe, consistent recycling across applications.

B. BATTERIES

The battery value chain holds a strategic position in Europe's transition to a climate-neutral economy. Batteries are essential for a wide range of applications, from electric mobility to stationary energy storage, and their use is expected to grow significantly in the coming decades. This growth brings both opportunities and challenges for implementing CE principles and IS in the sector.

IS in the battery domain involves creating links between manufacturers, users, recyclers, and other industries to optimise resource use, extend product life, and reduce environmental impacts. Examples include the reuse and repurposing of batteries in second-life applications, the recovery of valuable materials such as lithium, cobalt, nickel, and graphite, and the reuse of mechanical and electrical components[4]. Knowledge exchange and infrastructure sharing across value chain actors further support these objectives.

Recent policy developments, notably the **EU Battery Regulation** (European Commission, 2023), have introduced requirements for sustainable design, recycled contents, labelling, traceability, and the roll-out of digital battery passports. These measures are expected to improve transparency, enhance material efficiency, and strengthen the market for secondary materials. However, they also create new technical and organisational demands for stakeholders across the battery lifecycle.

Current barriers to IS in the battery sector include the absence of standardised procedures for assessing battery condition, state of health (SoH), and remaining useful life (RUL); the lack of interoperable data formats; and the variability in disassembly practices. Many battery designs do not allow for easy disassembly or component recovery, limiting opportunities for reuse and recycling. Data-sharing remains fragmented, and the implementation details of digital battery passports are still under development, creating uncertainty for stakeholders preparing for compliance.

Addressing these challenges through targeted standardisation can help unlock synergies in the

4 For the purposes of this paper, the terminology follows Regulation (EU) 2023/1542, Article 3: "reuse" refers to the use of a battery again for the same purpose for which it was originally designed, while "repurposing" refers to the use of a battery or its components in an application other than that for which it was originally designed

sector. Potential benefits include increased recovery of critical raw materials, improved safety and performance assurance for second-life products, and reduced dependency on primary resources. By aligning technical solutions with evolving regulatory requirements, IS in the battery value chain can contribute to Europe's strategic autonomy, environmental objectives, and economic resilience.

For many of the mentioned challenges, the European Commission has released respective standardization requests. Important examples are M/579 addressing topics related to the EU Battery Regulation, as well as M/604 which describes standard requirements for realizing a digital product passport.

Related Project: STAN4SWAP

- **Title:** Standardising swappable battery systems for L-category vehicles
- **Standardisation Inputs:** Focused on standards for interoperability and compatibility of swappable battery systems and stations.
- **Policy Recommendations:** Contributed to the EU Battery Regulation (2023/1542) and Alternative Fuels Infrastructure Regulation.

PRIORITY SYNERGIES

This document highlights four IS synergies that together enable higher resource efficiency, safety, and market uptake across the EU battery value chain. Second-life battery reuse/repurposing captures residual capacity from traction batteries for stationary storage by standardising grading (SoH/RUL), safe removal, and integration, reducing demand for primary materials while improving energy system flexibility. Components reuse targets the recovery of mechanical/electrical parts (e.g., connectors, wiring, fuses) via dismantling manuals and quality checks, lowering costs and waste while feeding repair and remanufacturing loops. Digital battery data underpins both synergies through interoperable datasets, incl. DPP attributes, that carry composition, test, and repair history across actors, enabling automated intake, safer operation, and transparent transactions. Material recovery via recycling focuses on harmonised collection, disassembly interfaces, and analytical methods (e.g., for black mass) to secure consistent secondary feedstocks of lithium, cobalt, nickel, and graphite for multiple receiving sectors.

Across all four, data by RISERS shows benefits including reduced landfill and emissions, higher yields of critical raw materials, safer logistics, lower CAPEX risk through clearer rules, and stronger cross-sector linkages (e.g., ceramics, fertilizers, and grid services). Early alignment of standards with the Batteries Regulation—especially for DPP, dismantling protocols, and black-mass classification—accelerates compliance and investment while supporting EU resilience objectives.

SECOND-LIFE BATTERY REPURPOSING

This synergy concerns the repurposing of traction batteries that have reached the end of their first life in electric vehicles. Once removed from vehicles by Original Equipment Manufacturers (OEMs), service networks or dismantlers, these batteries are assessed through grading, diagnostics and SoH or RUL testing to determine whether they remain suitable for stationary energy storage applications. By shifting energy storage from mobile to stationary uses, second-life applications can extend the useful life of battery systems, reduce demand for primary raw materials and lower the environmental footprint of both the mobility and energy sectors.

A wide range of actors participate in these value chains, including OEMs and Tier suppliers, dismantlers, logistics operators, repurposers and energy storage system integrators, as well as DSOs, TSOs, recyclers and market surveillance authorities. Safe handling and cross-border acceptance depend heavily on access to reliable information. Dismantling manuals, component-specific safety instructions and digital traceability mechanisms, such as attributes of the DPP, are essential for consistent testing, secure logistics and transparent condition assessment. A mature second-life market also relies on alignment between the standards governing EV batteries, energy storage systems and waste or transport regulations.

Implementing second-life battery repurposing requires standardised procedures for grading, SoH testing and certification so that actors can reliably determine whether a battery is suitable for repurposing or must move to recycling. Advanced testing laboratories and automated disassembly facilities provide the physical infrastructure required for safe extraction, condition assessment and preparation for repurposing. Additional infrastructure needs include secure storage areas, compliant transport solutions and interoperable digital platforms such as the Battery Passport, enabling data exchange between producers, dismantlers, repurposers and regulators.

Several enabling technologies support this process. Diagnostics tools and IoT-enabled access to Battery Management System (BMS) data are crucial for assessing condition and performance. Automated sorting and refurbishment systems can increase throughput and reduce manual handling risks. Partnerships can be formed through industry associations, collaboration between OEMs and recyclers or participation in European innovation platforms. These arrangements help align expectations, facilitate access to technical data and support the development of shared methods and training.

The benefits of second-life repurposing are substantial. Extending battery life enhances resource efficiency and reduces the environmental impact associated with producing new energy storage systems. It also supports grid flexibility and renewable integration. However, challenges remain. Many standards for assessing and certifying second-life batteries are still emerging, and the absence of harmonised testing frameworks leads to inconsistent results. Existing battery products were often not designed for repairability, complicating safe disassembly. In addition, legal uncertainties, such as unclear ownership rules and definitions of when a used battery is considered a product or waste, affect market confidence and hinder cross-border movement. Several standards relevant to second-life applications are already in preparation or undergoing revision, indicating strong momentum toward addressing these issues.

Technical Bodies (selection)

- CLC/TC 21X Secondary cells and batteries.
- CEN/TC 308/WG 18 Electric vehicles batteries
- IEC/TC 21 Secondary cells and batteries.
- IEC/TC 120 Electrical Energy Storage (EES) systems.

Related EU policies

EU Batteries Regulation 2023/1542, Waste Framework Directive, European List of Waste, Waste Shipment Regulation, Clean Vehicles Directive

Key standards & guidance for second-life preparation, testing, logistics

- EN 18061 — Road vehicles - Rechargeable batteries with internal energy storage - Steps, conditions and protocols for the safe repair and re-use and preparation for repurposing of modules and batteries designed for EV applications.
- DIN VDE V 0510-100:2023-04 — Safety of lithium-ion batteries from electrically propelled road vehicles for use in stationary applications.
- EN IEC 62660 — Secondary Li-ion cells for propulsion of electric road vehicles (performance/safety baseline for incoming used cells).
- ISO 12405 — Test specifications for Li-ion battery systems in EVs (useful for harmonising performance/diagnostics data captured before repurposing).
- EN 50625 (series) — WEEE collection, logistics, treatment (applies to EoL flows and interfaces between actors).
- IEC 62933 (series) — Electrical energy storage systems (relevant for stationary second-life integration and safety).
- ISO 14040 / ISO 14044 — Life-cycle assessment standards (framework to quantify benefits of reuse vs. recycling).
- SAE J2950 — Recommended practice for shipping/transport/handling of automotive Li-ion battery systems (safety for logistics between actors).
- ADR 2025 — Agreement concerning the International Carriage of Dangerous Goods by Road.
- Manual of Tests and Criteria – Part III, Sub-section 38.3: Lithium metal and lithium-ion batteries.

RECOMMENDATIONS

Standardisation — SoH/RUL and Grading

- In the short term, standardise test methods, data formats, and minimum parameter sets relevant for assessing the condition of used traction batteries, enabling transparent and comparable decision-making for reuse and repurposing without requiring disclosure of proprietary SoH or RUL algorithms.
- In the longer term, explore pathways for voluntary or class-based grading schemes that build on these standardised inputs, subject to industry acceptance and IP safeguards.
- Build on existing EV battery test standards (EN IEC 62660, ISO 12405) and ensure alignment with stationary energy storage integration requirements (IEC 62933).
- Embed minimum reporting requirements in dismantling and acceptance protocols and incorporate them into the DPP so that condition, test context and uncertainties follow the asset through the repurposing chain.

Standardisation — Dismantling Manuals & Safe Logistics

- Create a standardised structure for OEM dismantling manuals, covering scope, hazards, disconnection steps, tooling and diagnostic points to support safe extraction and component traceability.
- Reference EN 50625 for collection and logistics interfaces and align transport and handling guidance with SAE J2950, ADR 2025 and UN 38.3.
- Link dismantling manual sections to DPP identifiers so that safety updates and repair history remain accessible during repurposing, transport and storage.

Standardisation — Digital Battery Data for Repurposing

- Specify interoperable data fields and APIs for second-life use within the DPP, including composition, manufacturing batch, fault codes, SoH/RUL, cycle count, BMS access logs, repair history and test results.
- Address gaps in digitalisation and data—such as the lack of harmonised metrics or inconsistent manufacturing data standards—and enable automated intake, sorting and warranty management.
- Ensure consistency with requirements under the EU Batteries Regulation through comparative analysis.

Regulation — Business Models & Responsibilities

- Enable alternative ownership and service-based models (e.g., “usufruct” or lease-based arrangements) for second-life energy storage, clarifying liability and responsibilities across OEMs, repurposers and ESS operators.
- Provide guidance on when used EV batteries destined for testing or repurposing should be treated as products rather than waste, consistent with the Batteries Regulation and waste legislation, in order to facilitate cross-border movement and market uptake.

COMPONENT REUSE

Component reuse focuses on recovering functional elements from dismantled battery packs, such as connectors, wiring harnesses, fuses, busbars, housings and thermal management components, so they can be reintroduced into repair, remanufacturing or spare-part markets. Many of these components retain full or partial utility after battery end-of-first-life, and their reuse can significantly reduce the need for manufacturing new parts. This leads to material savings, reduced environmental impacts and lower energy consumption associated with producing replacement components.

The associated value chain includes OEMs and Tier suppliers, authorised repairers, WEEE and ELV treatment operators, specialised testing laboratories, remanufacturers and digital marketplaces. Reliable documentation and traceability, supported by DPP fields and standardised dismantling manuals, are crucial to ensure secure extraction, consistent testing and transparent redeployment of parts across different battery designs and chemistries. These elements help actors determine whether components meet performance and safety requirements and can be safely integrated into refurbished or remanufactured systems.

Implementing battery disassembly and component reuse requires standardised protocols for the safe removal of mechanical and electrical parts, including the handling of live circuits, connectors and thermal interfaces. The necessary infrastructure includes automated or semi-automated disassembly lines that can manage diverse pack architectures, as well as secure storage and testing facilities for verifying component integrity. Robotics, sensor-based sorting and diagnostic tools play an increasingly important role, allowing operators to assess usability, identify defects and minimise manual handling risks. Safety remains an overarching requirement across all process steps, given the residual energy, chemical risks and physical hazards associated with EV battery packs.

Partnerships to support component reuse can be formed through OEM–recycler collaborations, industrial consortia or innovation platforms, and may be formalised through memoranda of understanding or participation in joint standardisation initiatives. Such cooperation helps improve access to data, align expectations on component quality and develop shared procedures for dismantling and testing.

The benefits of component reuse include reduced material waste, cost savings for manufacturers and repairers, and extended component lifetimes. However, challenges persist. Manual disassembly is often unsafe, labour-intensive and inefficient, especially for designs not optimised for repair or reuse. Battery packs differ widely across models and chemistries, resulting in compatibility issues and limiting standardised approaches to component recovery.

Related Technical Bodies (selection)

- CLC/TC 21X Secondary cells and batteries
- CEN/TC 301 Road vehicles
- IEC/TC 120 Electrical Energy Storage (relevant for safe integration of reused components in systems)
- ISO/TC 297 - Waste collection and transportation management

Standards / deliverables (selection)

- DIN EN 18061:2024-04 – Rechargeable batteries with internal energy storage – Steps, conditions and protocols for the safe repair and reuse of modules and batteries designed for EV applications
- EN 50625 series – Collection, logistics and treatment of WEEE (covers dismantling practices and safe handling of components)
- EN IEC 62660 / ISO 12405 – Performance and test specifications for Li-ion cells and systems (reference values for component testing during reuse)
- CEN/TC 301/WG 18 upcoming deliverable: Road vehicles – Rechargeable batteries with internal energy storage – Guidance on Data explanation required in EU battery passport

RECOMMENDATIONS

Standardisation — Digital Product Passport (DPP) for Reuse

- Create standards for DPP data fields relevant to component reuse, enabling traceability and condition documentation for recovered parts.
- Ensure that component-level information can circulate transparently across markets, repair loops and remanufacturing pathways.

Regulation — Product vs. Waste Status

- Clarify legal definitions for battery and component status—such as usable, defective or critically defective—and specify when dismantled parts should be treated as products rather than waste.
- Provide legal certainty for cross-border movement and reuse in other sectors, consistent with waste legislation and product rules.

Regulation — Design for Dismantling and Manuals

- Require manufacturers to design batteries to facilitate safe and efficient disassembly and to provide detailed dismantling manuals.
- Manuals should contain component-level instructions and safety measures to support secure recovery of elements such as connectors, wiring and fuses, thereby increasing reuse and recycling potential.

DIGITAL BATTERY DATA

Digital data flows underpin every stage of a battery's lifecycle, linking OEMs, fleet operators, repurposers, recyclers, energy storage system (ESS) integrators, software providers and end users. MS logs, fault codes, test and repair histories, and composition information are essential for safe handling, performance assessment and lifecycle management. When these datasets are interoperable—supported by standardised formats and APIs—they enable consistent SoH and RUL assessments, safe logistics, automated intake processes and reliable warranty handling. They also provide the foundation for modelling and digital twins that support both second-life integration and recycling strategies.

In future energy applications, digital twins of batteries, storage systems and grid-connected assets will increasingly rely on harmonised identification schemes. The DPP provides this regulatory baseline: by linking a physical battery pack or module to a unique digital identity, manufacturers can connect their assets to digital energy twins in a secure and consistent way. This bridges information gaps between sectors, as energy operators and utilities typically do not have direct access to manufacturer data. Ongoing work under CEN-CLC JTC 24 and aligned with the Ecodesign for Sustainable Products Regulation will standardise the DPP system interface needed to enable cross-sector data exchange and ensure that digital twin environments can recognise and interact with battery assets across the EU single market.

Embedding minimum datasets within the DPP allows secure, role-based access for authorised actors across the value chain, while protecting commercially sensitive information and IP. System-level monitoring standards and emerging DPP frameworks are increasingly recognised as enablers of transparent transactions, more accurate condition assessment and improved circularity across the battery ecosystem.

Cross-sector data sharing will also increasingly be enabled by emerging trusted energy data spaces. In Germany, the Energy Data-X initiative—developed as a Catena-X-type model for the energy domain and aligned with Gaia-X principles—aims to create a federated, secure environment for exchanging operational and lifecycle data across the energy value chain. The initiative is designed to interoperate with the DPP and supports ongoing CEN-CLC/JTC 24 work on DPP system interfaces, strengthening long-term alignment between battery data, energy-system platforms and cross-sector applications.

Implementing standardised digital battery data requires harmonised formats for BMS access, SoH reporting, diagnostics and traceability, all of which must integrate seamlessly into the Battery Passport architecture. The necessary infrastructure includes secure cloud platforms, robust data-sharing protocols and real-time monitoring systems that can connect actors across borders and applications. Technologies such as IoT-enabled sensors, standardised APIs and cryptographic tools—potentially including blockchain-based solutions—can support tamper-proof traceability and ensure reliable data transfer. Partnerships may be established through OEM–recycler collaboration, software-provider networks or industry associations, formalised through agreements or participation in standards committees.

The benefits of interoperable digital battery data include improved lifecycle management, enhanced safety, better-informed reuse and recycling decisions and smoother coordination among stakeholders. At the same time, several challenges remain. Access to BMS data is often limited by proprietary systems, data structures differ widely across manufacturers and harmonised approaches for diagnostics and repair history are still emerging. Ensuring data security and maintaining confidentiality while enabling essential data flows is another ongoing concern.

Technical bodies (selection)

- CLC/TC 69X Electrical systems for electric road vehicles (data and communication interfaces)
- CLC/TC 21X Secondary cells and batteries (testing, safety, data aspects)
- IEC/TC 120 Electrical Energy Storage (system-level monitoring and interoperability)

Standards / deliverables (selection)

- DIN DKE SPEC 99100:2025-02 – Requirements for data attributes of the battery passport (key baseline for digital datasets)
- IEC 62933 series – Electrical energy storage systems (system requirements relevant for digital monitoring)
- ISO 14040/14044 – LCA standards (used for integrating environmental data fields into passports)

RECOMMENDATIONS

Standardisation — Interoperable Formats and Minimum Datasets

- Improve harmonised data structures and APIs for BMS access, SoH information, diagnostics and repair history.
- Embed minimum datasets within the DPP to support secure data exchange among OEMs, recyclers and repurposers.

Standardisation — Battery Passport Composition Data

- Ensure that DPP requirements include detailed composition information, such as critical materials and chemistries, as defined in the Battery Pass Technical Guidance (2024), enabling enhanced transparency and improved IS opportunities.

Regulation — Data Access Rights

- Clarify data access rights for reuse and recycling actors by defining which non-sensitive diagnostic and performance data can be shared while maintaining confidentiality, cybersecurity and commercial protections.
- Monitor and align with emerging trusted energy data spaces, such as the Energy Data-X initiative, where relevant, to ensure that battery-related datasets and DPP interfaces can integrate into federated, cross-sector energy data environments.

MATERIAL RECOVERY VIA RECYCLING

Material recovery from EoL batteries enables the extraction of valuable elements such as lithium, cobalt, nickel, manganese and graphite for reintroduction into battery supply chains or use in other industries. Cobalt recovered through refining, for example, can be used in pigments for ceramics, while manganese and lithium can be sourced not only from battery materials but also from industrial side streams or water treatment processes, reflecting a broader resource recovery ecosystem.

EoL batteries pass through several stages: collection, safe disassembly, depollution and pre-treatment processes such as discharge, dismantling and shredding. These steps generate intermediate streams—including black mass and metallic fractions—which are then refined through hydrometallurgical or pyrometallurgical processes. The recovered elements can reenter battery-grade material production or serve adjacent industrial applications. A wide range of stakeholders is involved in these flows, including OEMs, battery manufacturers, Producer Responsibility Organisations (PROs), logistics and depollution operators, recyclers, refiners, analytical laboratories, materials companies and regulatory bodies.

Harmonised classification and analytical methods for intermediates—particularly black mass—are critical for ensuring safety, consistency and commercial viability. Standardised interfaces with dismantling and logistics processes can improve transparency, promote trade across borders and support compliance with regulatory requirements. These elements are essential for scaling up IS between the battery, chemical, and raw materials sectors.

Implementing effective material recovery requires standardised procedures for collection, sorting and pre-treatment, as well as harmonised specifications for mechanical and chemical recycling routes. Infrastructure needs include specialised recycling plants capable of managing diverse feedstocks, safe storage and transport systems compliant with dangerous goods legislation and analytical laboratories for characterising recovered fractions. Key enabling technologies include hydrometallurgical and pyrometallurgical extraction systems, automated sorting lines and advanced material separation techniques that can accommodate a variety of chemistries and form factors.

Partnerships may be established through collaborations among OEMs, battery producers, recycling operators, mining companies and research institutions. These collaborations can be formalised through consortia, industry agreements or participation in standardisation committees. The benefits of advanced material recovery include improved resource efficiency, reduced environmental impacts and enhanced supply chain resilience. However, challenges remain. High capital costs, technological complexity, limited automation in battery disassembly, market uncertainty and price volatility all constrain investment. Near-term EoL battery volumes remain low, making feedstock availability unpredictable. Maintaining consistent material purity across diverse battery chemistries is difficult, and legal uncertainties surrounding ownership, responsibility and waste status continue to slow permitting and cross-border movements.

Related Technical Bodies (selection)

- CLC/TC 21X Secondary cells and batteries
- CEN/TC 301 Road vehicles
- IEC/TC 120 Electrical Energy Storage (relevant for safe integration of reused components in systems

Standards / deliverables (selection)

- EN 50625 series – Collection, logistics, and treatment of WEEE (interfaces with dismantling/recycling of packs and modules)
- ISO/TS 22451:2021 – Rare earth elements in industrial waste & end-of-life products: measurement methods
- ISO 22450 – Information requirements for rare earth recycling in industrial waste & EoL products
- EN IEC 62660 / ISO 12405 – Performance & safety tests, useful for assessing recovered fractions before downstream processing

RECOMMENDATIONS

Standardisation — Black Mass Classification

- Address fragmented approaches to black mass quality and classification by establishing a harmonised EU-level scheme.
- Use standardised analytical methods (e.g., ISO/TS 22451, ISO 22450) to enable reliable characterisation and facilitate cross-border trade.

Regulation — Design for Dismantling and Manuals

- As described in Synergy 02, require design approaches and manuals that facilitate safe and efficient dismantling to support high-quality material recovery.

Regulation — Clarify Product vs. Waste

- Clarify the legal definitions and responsibilities for EoL batteries and intermediate materials such as black mass.
- Provide consistent guidance to reduce delays in permitting, shipment and processing across Member States.

Regulation — Incentives for Recycling Investment

- Support early-stage investment in recycling capacity through measures such as tax benefits, grants or green financing, addressing high capital costs and uncertain feedstock volumes.

Regulation — Alternative Business Models (Usufruct)

- Develop "usufruct" or service-based ownership models in which OEMs or third parties retain ownership while granting usage rights.
- Such models can create incentives for design for recyclability and support controlled return flows for collection and recovery.

OTHER SYNERGIES

Beyond direct battery reuse and recycling, several cross-sector industrial symbioses emerge from battery-derived materials and repurposed assets. These synergies extend into sectors such as fertilizers, ceramics and pigments, electronics and digital technologies, and public energy systems using battery storage solutions (BSS/ESS). Material flows originate from recyclers, refiners and repurposers: black-mass refining produces lithium, cobalt, nickel and graphite fractions that feed into chemical, manufacturing and technology industries, while housings and auxiliary components can return to other production lines. Repurposed battery modules also flow into stationary storage applications, supporting energy buffering at industrial sites or grid-level services. Energy flows therefore complement material flows by enabling second-life systems to stabilise local energy use and support distribution and transmission networks.

Stakeholders involved in these cross-sector exchanges include recyclers and refiners, energy storage system integrators, DSOs and TSOs, downstream receiving industries, conformity assessment bodies and regulators. As these exchanges involve heterogeneous products and regulatory regimes, common quality and safety requirements (particularly for BSS) and stronger traceability frameworks are essential. Expanding traceability mechanisms such as DPP fields to material-level data can help reduce transaction risks and enable higher acceptance of battery-derived outputs across multiple sectors.

Implementing these synergies requires first mapping receiving sectors and their technical specifications, followed by defining quality and safety criteria for battery storage systems and establishing material-level traceability through the DPP. Harmonised interfaces for collection, logistics and testing are crucial to ensure that flows meet the expectations of receiving industries. The necessary infrastructure includes recycling and refining facilities, depollution and logistics hubs, energy storage integration testbeds and accredited analytical laboratories equipped to handle relevant testing methods (such as ISO/TS 22451 and ISO 22450).

Key technologies that support these cross-sector uses include hydrometallurgical and pyrometallurgical refining, advanced sorting systems, ESS control and monitoring platforms and secure data ecosystems that can authenticate the origin and characteristics of battery-derived materials. Partners can be identified through collaborations among OEMs, battery manufacturers and recyclers, as well as through sector organisations such as EUROBAT, BEPA/BATT4EU and RECHARGE, or networks engaged in broader circular industry transitions (e.g. Hubs4Circularity or CCRI initiatives).

The benefits of these synergies include diversifying outlets for recovered materials, such as supplying cobalt to the ceramics sector, lithium salts to fertilizer production or graphite to electronics, while also enabling grid services through repurposed energy storage systems. However, several challenges remain. Legal uncertainties related to product versus waste status hinder material flows across borders, and fragmented access to data can limit verification and quality assurance. Skills gaps in both dismantling and downstream processing can also slow adoption.

Standardisation — Quality and Safety for Battery Storage Systems (BSS)

- Develop common quality and safety requirements for repurposed or hybrid battery systems to ensure their suitability for stationary storage applications, building on ongoing work such as that led by CENELEC TC 21X WG 06.

Regulation — Receiving Sectors and By-Products

- Provide clear regulatory definitions governing the safe use of battery-derived by-products, such as cobalt for ceramics, lithium salts for fertilizers or graphite fractions for digital technologies, ensuring compliance with REACH and other sector-specific product standards.

Standardisation — Data and Traceability in Cross-Sector Uses

- Expand the DPP concept to include material-level data so that downstream sectors (e.g. fertilizers, ceramics, electronics) can access validated origin, composition and quality information for battery-derived inputs.

GENERAL NEEDS AND RECOMMENDATIONS

Across the battery value chain, several systemic challenges limit the broader deployment of IS practices. One of the most significant gaps is the absence of harmonised methods for determining SoH and RUL, which leads to inconsistent assessments of battery condition and prevents safe and scalable second-life applications. The data landscape remains fragmented: interoperable data formats and agreed minimum datasets are still lacking, complicating DPP implementation and limiting traceability across actors and borders. Harmonised DPP identifiers will also act as the anchor between physical battery assets and digital energy twins, reducing today's siloed data flows and improving cross-sector integration in energy-system applications.

Disassembly practices vary widely, and automation remains underdeveloped. The absence of standardised procedures reduces efficiency, increases handling risks and makes it difficult to scale repair, remanufacturing and material recovery operations. Similarly, classification and quality schemes for intermediates such as black mass are inconsistent across Member States, undermining market confidence and slowing the development of competitive recycling markets.

Cross-border movements face divergent interpretations of legislation, creating administrative delays and uncertainty over legal responsibilities. High capital costs and unclear future feedstock volumes hinder investment in recycling and disassembly infrastructure. Cooperation among actors is often limited by weak matchmaking mechanisms, restricted data access and uneven distribution of technical know-how. Skills shortages, particularly in safe dismantling, advanced diagnostics, automated processing and chemical recycling, remain a persistent constraint.

Additional barriers include inconsistent EoW classifications for dismantled modules, cells and intermediates, which slow permitting procedures and complicate logistics. Price volatility of secondary materials continues to affect business planning and investment decisions. Addressing these challenges requires coordinated regulatory alignment, targeted incentives, improved traceability and quality standards, and capacity-building across the battery ecosystem.

Relevant organizations and technical bodies

- CEN/TC 301 Road vehicles
- CLC/TC 21X Secondary cells and batteries
- CLC/TC 69X Electrical systems for electric road vehicles
- CEN/TC 249 Plastics
- CEN-CLC/COG eMobility

Relevant deliverables (policy and standardization)

- DIN EN 18061:2024-04 Road vehicles - Rechargeable batteries with internal energy storage - Steps, conditions and protocols for the safe repair and reuse of modules and batteries designed for EV applications
- DIN VDE V 0510-100:2023-04 Safety of lithium-ion batteries from electrically propelled road vehicles for use in stationary applications
- DIN DKE SPEC 99100:2025-02 Requirements for data attributes of the battery passport
- Standardisation requests, e.g. M/604

Regulation

- Clarify legal status and harmonise rules: Define end-of-life classifications for batteries and intermediates (including black mass), harmonise waste-shipment requirements and clarify when dismantled components are treated as products rather than waste to enable predictable cross-border logistics and insurance coverage.
- Align legislation: Ensure coherence between the Batteries Regulation, REACH, Ecodesign requirements and other relevant frameworks to reduce administrative burden and avoid duplicative processes.
- Create incentives: Introduce targeted financial measures—such as tax benefits, grants and green financing—to support investment in dismantling, repurposing and recycling infrastructure.
- Enable cooperation: Facilitate matchmaking platforms and IS networks to help actors identify suitable partners across the value chain.
- Encourage transparency and new business models: Establish data-sharing frameworks that balance confidentiality with innovation and support ownership models (e.g., "usufruct")

that encourage product return flows and design for recyclability.

Standardisation

- Second-life and reuse: Develop EU-level standards for grading, SoH/RUL assessment, safety certification and harmonised second-life criteria, and integrate these into DPP requirements (e.g., drawing on DIN DKE SPEC 99100).
- Disassembly and logistics: Create standardised protocols for automated and manual disassembly and for repair/remanufacturing workflows, building on existing collection and logistics standards such as EN 50625.
- Digital data and traceability: Define interoperable data formats and minimum datasets for the DPP, covering SoH, composition, repair history, diagnostics and analytical results.
- Material recovery: Establish harmonised classification and analytical standards for black mass and recovered materials, referencing ISO/TS 22451 and ISO 22450.
- Skills and competence: Develop competence requirements and training schemes for dismantling, testing, logistics and recycling personnel to address existing skill shortages and ensure safe handling throughout battery lifecycles.

C. PACKAGING

Packaging plays a dual role in European value chains: it protects and transports products, yet its short life cycle generates substantial waste and requires significant resource inputs. It spans two main categories, logistic packaging used in business-to-business transport and consumer packaging used by end-users. IS offers four pathways to improve resource efficiency in this sector: reuse of packaging across industries; the use of waste and by-products from other sectors as feedstock, including biodegradable materials derived from organic residues; packaging designed for closed- and open-loop recycling; and the shared use of infrastructure and common strategies across companies.

Legislative frameworks such as the Packaging and Packaging Waste Regulation (PPWR), the European Plastics Strategy and national Extended Producer Responsibility (EPR) schemes aim to improve design, increase recyclability and encourage cascade use to reduce the dependence on virgin materials. In 2022, around 41 % of plastic packaging was recycled in Europe, with large variations across Member States; the target is 55 % by 2030. However, economic conditions currently limit progress. Many symbiosis initiatives face delays due to global price pressure, limited financial incentives and high upfront investment needs for logistics, sorting, cleaning and digital coordination platforms. Packaging is often the least costly element of a product, so circular systems—whether reuse or recycling—can be more expensive than maintaining existing single-use formats. Shifting to reuse also requires redesign of products and packaging, changes in consumer expectations and additional labour, which many companies struggle to mobilise.

Technical and regulatory challenges further complicate implementation. Variations in national interpretation of food-contact and chemical regulations hinder cross-border use of recycled and reused materials. Multi-layer structures, composite materials and varying input quality from other industries reduce recyclability, while biodegradable solutions based on agricultural residues require consistent processing conditions. The lack of standardised packaging designs, removable labels and clear acceptance criteria limits exchangeability between sectors. Infrastructure for collection, sorting, redistribution and storage—particularly under contamination-free conditions—remains insufficient. Digital matchmaking tools exist but provide limited visibility of available materials, and many projects lack personnel with relevant technical skills.

Despite these constraints, IS in packaging offers environmental and operational benefits. Reuse systems can significantly reduce emissions when sufficient cycles are achieved; waste streams from agriculture, textiles, paper, plastics, glass and metals can be repurposed as feedstock for new materials; and shared logistics or infrastructure can increase efficiency. Unlocking this potential requires coordinated regulatory alignment, improved design and material standards, supportive infrastructures and models that create economic attractiveness for circular practices.

Selected Relevant Technical Bodies

- CEN/TC 172 – Pulp, paper and board
- CEN/TC 249 – Plastics
- CEN/TC 261 – Packaging
- CEN-CLC/COG – Circular plastics
- CEN/TC 249/WG 11 – Plastics recycling/design for recycling
- ISO/TC 61/SC 14 – Plastics – environmental aspect

Related Project: REMADYL

- **Title:** Removal of Legacy Substances from polyvinylchloride (PVC) via a continuous and sustainable extrusion process
- **Standardisation Inputs:** Proposed EU-wide definitions for recycling yield and recycled content. Developed standards for substituting hazardous substances.
- **Policy Recommendations:** Supported market uptake of recyclates through tax reductions. Established EU-wide standards for analysing waste for classified substances.

Related Project: CIRCPACK

- **Title:** Towards circular economy in the plastic packaging value chain
- **Standardisation Inputs:** Referenced standards for material characterization, compostability and CE metrics.

PRIORITY SYNERGIES

IS opportunities in the packaging sector can be grouped into four priority synergies. The first concerns reuse across industries, where packaging that remains functional can circulate between companies without further processing. The second relates to using waste and by-products from other sectors as feedstock, including options based on recycled materials or biodegradable inputs from organic residues. Both synergies reduce reliance on virgin resources but require suitable infrastructure, stable material quality and interoperable systems. The third synergy focuses on packaging designed for closed- and open-loop recycling, enabling by-products or post-industrial materials from one company to become inputs for another. The fourth addresses shared use of infrastructure and common strategies, such as coordinated logistics, joint facilities or collaborative planning. Together, these synergies illustrate how resource flows, material design and organisational cooperation can support more circular packaging systems. In line with cascading use principles, reuse and shared infrastructure should be prioritised wherever technically and economically feasible, with recycling and recovery providing complementary routes for remaining fractions.

REUSE OF PACKAGING ACROSS INDUSTRIES

Reusable packaging allows companies to transfer packaging that remains functional without additional processing, reducing material consumption and waste generation. While applications already exist, such as reusable bottles, crates, jars and pooled pallet systems, the current share of reusable packaging remains low in most sectors, particularly in consumer goods and retail. EU targets for 20% reusable takeaway beverage packaging and 10% reusable takeaway food packaging by 2030 highlight the potential for broader uptake. Successful implementation depends on reliable systems for collection, cleaning and redistribution, supported by digital platforms that coordinate returns. Higher upfront costs, logistical complexity and dependency on consumer return behaviour remain central challenges. When implemented effectively, reuse can reduce greenhouse gas emissions, limit reliance on fossil-based single-use materials and create added value for packaging manufacturers and logistics operators through shared transportation networks.

Relevant organisations

- Packaging manufacturers and logistics operators
- Retailers and pooling system providers
- Waste-management and cleaning facilities
- Associations involved in packaging standardisation and reuse systems

Relevant deliverables (policy and standardisation)

- National and EU-level reusable packaging definitions and criteria
- PPWR provisions on reuse targets
- Practical guidelines from sectoral associations on return, cleaning and redistribution systems

RECOMMENDATIONS (Regulation and Standardisation)

- **Establish uniform definitions and criteria:** Harmonise EU and national terminology for reusable packaging, including requirements for reuse cycles, return logistics and deposit systems, to ensure consistent application.
- **Standardise return and cleaning logistics:** Develop interoperable procedures for collection, cleaning and redistribution to simplify reverse logistics and reduce costs, particularly for SMEs and new market entrants.
- **Encourage pooling and shared infrastructure:** Support legal and operational frameworks enabling multiple manufacturers to use standardised reusable packaging within shared systems.
- **Enable modular standardisation:** Allow customisation within a common framework rather than one-size-fits-all solutions, accommodating different product types and retail formats.
- **Support digital integration:** Promote the use of digital tools, QR codes, asset-tracking systems, return platforms, to improve visibility of available packaging and facilitate customer interaction.
- **Simplify compliance for SMEs:** Provide simplified pathways, templates and guidance, along with financial support where needed, to lower implementation barriers.
- **Promote consumer-friendly systems:** Prioritise ease of use through unified formats and return procedures across retailers to increase consumer participation.

- **Incentivise regional circular systems:** Encourage local cleaning and redistribution hubs to minimise transport emissions and strengthen regional reuse networks.
- **Improve information and storage conditions:** Ensure visibility of available packaging for redistribution, combined with adequate storage infrastructure to avoid contamination.
- **Standardise packaging products:** Promote packaging formats that are compatible across sectors, with fewer design variations and removable or reusable labelling to enable efficient exchange between companies.
- **Define clear requirements and acceptance criteria:** Establish transparent specifications for packaging standardisation, including durability, cleaning performance and suitability for multiple product categories.

USE OF WASTE AND BY-PRODUCTS FROM OTHER INDUSTRIES AS FEEDSTOCK

This synergy focuses on using waste streams and by-products from other industries to produce packaging materials, including biodegradable packaging derived from organic residues. A wide range of inputs can serve as feedstock: recycled plastics, paper, cardboard, glass, metals, composites, textiles and agricultural fibres. Industrial waste streams from production excess, post-consumer disposal and logistics operations can be repurposed into new packaging formats, reducing the need for virgin materials. Examples include paper and glass repulped or remelted for new packaging, natural fibres such as bamboo, palm leaves, banana leaves and jute used for compostable formats, and cereal residues like wheat straw, rice husk, corn stalks and spent grain processed into biodegradable films and composites. While these approaches diversify material sources and support circularity, several challenges remain, notably the difficulty of recycling multi-layered materials and ensuring consistent quality and safety of recovered inputs.

Relevant organisations

- Producers of recycled materials (plastics, paper, glass, metals, composites)
- Agricultural and bio-based material processors
- Packaging manufacturers using recycled or bio-based feedstock
- Sectoral associations working on material recycling and compostable packaging

RECOMMENDATIONS (Regulation and Standardisation)

- **Support material uptake across sectors:** Facilitate the use of secondary materials originating from industrial waste streams by ensuring regulatory clarity on acceptable inputs and processing requirements.
- **Clarify rules for biodegradable packaging:** Provide consistent guidance on permissible bio-based feedstocks, compostability criteria and end-of-life pathways for materials derived from agricultural and organic residues.
- **Address multi-layer recycling challenges:** Develop standards and methodologies to manage or redesign multi-layered structures that currently hinder recyclability and limit the use of recovered materials.
- **Ensure feedstock quality and safety:** Introduce harmonised criteria for contamination control, traceability and performance thresholds applicable to recycled and bio-based inputs.
- **Develop sector-specific processing guidelines:** Provide practical guidance for producers using diverse waste streams whose composition and processing conditions vary significantly across industries.

PACKAGING FOR RECYCLING (CLOSED AND OPEN LOOP)

This synergy focuses on designing packaging so that it can be recycled in closed- or open-loop systems, enabling one company's plastic or paper waste (or post-industrial by-products) to serve as feedstock for new packaging or for applications in other industries. Current practices include repurposing post-industrial plastics into raw materials for new packaging designs and blending PET post-consumer recyclate with other polymers for use in automotive and electrical components. Some stakeholders suggest the use of biodegradable packaging to enable nutrient return to agriculture, though this option is generally rated lower due to processing constraints and limited alignment with existing recycling systems. When implemented effectively, closed- and open-loop recycling can reduce reliance on virgin resources and provide opportunities for industries to incorporate recycled content into both packaging and non-packaging products.

Relevant organisations

- Packaging manufacturers using recycled content
- Recyclers processing plastics, paper and composite materials
- Industries using recyclates in non-packaging applications (e.g. automotive, EEE)
- Associations working on design-for-recycling and material circularity

RELEVANT DELIVERABLES (POLICY AND STANDARDISATION)

- PPWR provisions on design for recycling and recycled content
- National guidelines on recyclability and sorting requirements
- Technical specifications for closed- and open-loop material use
- FprEN 18120-1:2025 - Packaging - Design for recycling of plastic packaging - Part 1: Definitions and principles for design-for-recycling of plastic packaging

RECOMMENDATIONS (Regulation and Standardisation)

- **Strengthen design-for-recycling criteria:** Promote clear requirements for packaging formats that enable efficient material recovery in both closed- and open-loop systems.
- **Facilitate cross-sector recyclate use:** Provide regulatory clarity that allows materials recovered from one industry to be used safely in another, including non-packaging applications.
- **Support the uptake of post-industrial and post-consumer materials:** Encourage systems that redirect plastics, paper or composite by-products into new packaging formats or alternative industrial uses.
- **Address biodegradable packaging considerations:** Offer guidance on when biodegradable solutions are appropriate, acknowledging that they are generally prioritised lower due to limited compatibility with current recycling infrastructure.
- **Improve recyclate quality and traceability:** Introduce harmonised requirements for contamination control, sorting performance and documentation to ensure reliable use of recovered materials.

SHARED USE OF RESOURCES (INFRASTRUCTURE AND STRATEGY)

This synergy focuses on shared use of physical infrastructure, logistics and strategic cooperation between companies to improve the efficiency of packaging production, reuse and recycling. Joint use of facilities—such as cleaning, sorting, storage or recycling plants—can reduce operational costs and increase the availability of high-quality secondary materials. Logistical cooperation, including shared transportation and storage capacity, can streamline supply chains and limit duplication of effort. Strategic collaboration also extends to exchanges of experience, knowledge and technologies that support more efficient packaging processes and resource use. In some cases, strong partnerships or ownership links between user companies and recyclers facilitate stable access to recycled materials and enable coordinated planning. When organised effectively, shared infrastructure supports regional circular systems and improves the overall performance of IS initiatives.

RELEVANT ORGANISATIONS AND TECHNICAL BODIES (SELECTED)

- Packaging manufacturers and recyclers
- Logistics and storage service providers
- Companies operating shared processing or cleaning facilities
- Associations coordinating circular infrastructure or cooperation models

RELEVANT DELIVERABLES (POLICY AND STANDARDISATION)

- PPWR and national guidelines on shared infrastructure use
- Technical documents on logistics efficiency and contamination prevention
- Sectoral strategies for coordinated resource use

RECOMMENDATIONS (Regulation and Standardisation)

- Promote shared logistics and processing facilities: Encourage cooperation on transport, storage, cleaning and recycling infrastructure to improve efficiency and reduce costs.
- Facilitate technology and knowledge exchange: Support collaboration mechanisms that allow companies to share insights on process optimisation, resource use and packaging design.
- Clarify operational criteria for shared infrastructure: Define requirements for contamination-free storage, handling practices and roles and responsibilities when facilities are jointly used.
- Enable regional circular systems: Support local clusters of companies that jointly use infrastructure or share strategies, improving material availability and shortening transport distances.
- Support long-term partnerships: Encourage cooperation models between user companies and recyclers that ensure stable access to recycled materials and enable coordinated investment.

GENERAL NEEDS AND RECOMMENDATIONS

Across all four synergies, implementation of IS in the packaging sector is constrained by regulatory fragmentation, technical limitations, economic barriers and insufficient infrastructure. Single-use packaging remains cost-competitive, while reuse and recycling systems require additional investments in collection, sorting, cleaning, storage and digital coordination. Packaging is typically the least costly component of a product, so circular solutions often appear more expensive than maintaining existing formats, particularly under current global price pressure and difficult financial conditions. Many projects are therefore paused, and companies report limited available personnel to manage new circular systems.

Regulatory complexity adds further constraints. EU legislation relevant to packaging—including PPWR, EC 1935/2004, EU 10/2011, chemical regulations and national EPR schemes—is interpreted differently across Member States, complicating cross-border reuse, recycling and material transfers. Clear rules for multilayer and composite packaging are lacking, making recycling difficult. Restrictions on material use limit the application of recycled feedstock, especially in food-contact contexts. The absence of harmonised acceptance criteria, consistent definitions for reusable packaging and clear guidance for biodegradable options increases uncertainty for operators. Financial incentives are weak, and current market conditions rarely reward the transfer of packaging for reuse or the uptake of recycled or bio-based feedstock.

Technically, multi-layered and composite materials remain difficult to recycle, and variable quality of secondary feedstock from other sectors affects processability. Biodegradable solutions depend on controlled processing conditions and are not always compatible with existing waste systems. Digital matchmaking platforms are underutilised, and companies lack visibility on available packaging, storage capacity or feedstock. Storage infrastructure that guarantees contamination-free conditions is often missing. Limited standardisation of packaging formats, including labelling, dimensions and design, reduces interoperability between sectors. Skills gaps in testing, design for recycling, logistics and material processing further slow adoption.

Despite these challenges, IS offers environmental and operational benefits: reduced emissions through reuse, diversified material sources, shared logistics and infrastructure efficiencies. Unlocking this potential requires coherent regulation, aligned incentives, harmonised standards, improved infrastructure, and strong cooperation across the packaging value chain.

Related deliverables

Quality, classification & traceability of recyclates

- DIN SPEC 91446:2021-12 (classification of recycled plastics by data quality levels)
- DIN SPEC 91481:2024-02 (recycled polyamides classification)
- ISO 15270:2008 (recovery and recycling of plastics waste)
- EN 15343 series (traceability and recycled content for plastics)
- FprEN 18120-1:2025 - Packaging - Design for recycling of plastic packaging - Part 1: Definitions and principles for design-for-recycling of plastic packaging

Reuse / bio-based / compostability

- EN 13429 (reuse)
- EN 13432:2000 (compostability)
- EN 16785-1:2015 (bio-based content)

RECOMMENDATIONS FOR REGULATION

- **Simplify and harmonise regulatory frameworks:** Align national implementation of PPWR, EC 1935/2004, EU 10/2011 and related provisions to ensure consistent rules for reusable, recycled and bio-based packaging across borders.
- **Provide uniform definitions and criteria:** Establish clear terminology for reusable packaging, reuse cycles, cleaning requirements, deposit systems, feedstock types and biodegradable options.
- **Clarify rules for material use and multilayer packaging:** Issue guidance on acceptable configurations, contamination limits and end-of-life pathways, addressing the challenges of composite and multi-layer materials.

- **Introduce a centralised compliance portal:** Offer a digital platform consolidating all applicable regulations, testing requirements, templates, checklists and decision trees for operators, with particular support for SMEs.
- **Enable regulatory sandboxes:** Allow controlled experimentation with new packaging formats, reuse systems and bio-based materials under temporarily relaxed conditions.
- **Improve economic conditions for circularity:**
    - Introduce taxes on non-recycled or non-transferable packaging.
    - Redistribute tax income to CE measures.
    - Offer tax deductions for compliant reusable packaging.
    - Consider financial mechanisms for projects that lack clear business incentives.
- **Mandate participation with enforcement where necessary:** Ensure engagement through compliance obligations and fines, avoiding reliance on subsidies alone.
- **Support regional circular systems:** Incentivise local cleaning, sorting and redistribution hubs to reduce transport emissions and strengthen availability of suitable packaging.
- **Facilitate cross-sector cooperation:** Promote coordinated planning between regulators, industry and retailers to align objectives and implementation approaches.
- **Enhance consumer-facing systems:** Ensure regulatory clarity for return procedures, deposit systems and user interaction to improve participation in reuse schemes.
- **Strengthen and harmonise EPR schemes:** Use EPR contributions and modulated fees to incentivise reusable formats, high-quality recycling and use of secondary materials across sectors.

RECOMMENDATIONS FOR STANDARDISATION

- **Standardise packaging formats and design features:** Promote interoperable designs—including dimensions, material compositions and removable/reusable labelling—to enable exchange between different sectors.
- **Define harmonised acceptance criteria:** Provide clear specifications for contamination thresholds, cleaning outcomes, durability, return conditions and cross-sector suitability of packaging.
- **Strengthen design-for-recycling standards:** Evaluate and refine prEN 18120 and related series to ensure practical applicability for both closed- and open-loop recycling pathways.
- **Address multi-layer and composite packaging:** Develop standards and methodologies for redesign, recyclability assessment or alternative configurations to improve material recovery.
- **Support quality requirements for recycled and bio-based feedstock:** Establish harmonised criteria for contamination control, material performance and traceability across diverse input streams.
- **Expand modular testing standards:** Build on approaches such as DIN SPEC 5010 to provide accessible methods for evaluating barrier performance and recyclate safety without requiring full-scale studies.
- **Develop sector-specific guidance:** Tailor guidance for food, consumer goods and hazardous materials packaging to support consistent application of safety and performance requirements.
- **Enhance digital integration:** Create standards for digital tracking, matchmaking tools, QR-based asset management, and online auctions for used packaging.
- **Improve traceability and labelling:** Strengthen systems to differentiate food-grade and non-

food-grade recyclates and ensure visibility of available packaging and feedstock.
- **Support competence development:** Establish training frameworks for testing, logistics, design for recycling, contamination management and processing of secondary materials.

D. WASTE HEAT

Waste heat is thermal energy released into the environment without being utilised. Waste heat arises across multiple sources in industrial processes, power generation, data centres, as noted in the following priority synergies. It can be repurposed for applications ranging from space heating and industrial processes to district heating and cooling. Therefore, it represents an opportunity for IS. Waste heat recovery supports decarbonisation efforts, strengthens local energy flexibility, and can improve the overall energy efficiency of energy-intensive industries. Assessments indicate that energy-intensive industrial sites in the EU discard between 415 PJ (95 °C) and 940 PJ (25 °C) of heat annually[5], equivalent to 4-9 % of total industrial energy demand in 2015. The estimate the total waste-heat recovery potential across all industries is at approximately 304 TWh/year, with most of this potential located in the 100–200 °C temperature range (Papapetrou, Kosmadakis, Cipollina, Commare, & Micale, 2018).

The EU Energy Efficiency Directive acknowledge the strategic function of waste heat recovery in meeting clean-energy and climate objectives. Nevertheless, practical deployment remains limited.

Realising the potential of waste heat within IS requires cooperation between industries, utilities, municipalities and technology providers. Common reference frameworks for such collaborations can decrease costs and enable technical replicability and show regulatory feasibility.

Technical usability is determined by factors such as temperature level, temporal availability, spatial proximity to potential users and compatibility with existing infrastructure.

Related Technical Bodies

- CEN/TC 107 District heating and cooling systems
- CEN/TC 113 Heat pumps and air conditioning units
- CEN/TC 130 Space heating and/or cooling appliances without integral thermal sources
- CEN/TC 156 Ventilation for buildings
- CEN/TC 182 Refrigerating systems, safety and environmental requirements
- CEN/TC 228 Heating systems and water based cooling systems in buildings
- CEN/TC 234 Gas infrastructure
- CEN/TC 299 Gas-fired sorption appliances, indirect fired sorption appliances, gas-fired endothermic engine heat pumps and domestic gas-fired washing and drying appliances.
- CEN/TC 371 Energy performance of buildings

GENERAL NEEDS AND RECOMMENDATIONS

Across all synergies, the utilisation of waste heat in IS is limited by technical, regulatory, economic, social and organisational constraints. Technically, interconnection between potential suppliers and users remains scarce, and no standardised classification methods exist for defining waste-heat streams by temperature, availability or quality. Low-temperature heat

5 See sEEnergies Open Data (2020): https://s-eenergies-open-data-euf.hub.arcgis.com/search?categories=%252Fcategories%252Fd5.1

recovery technologies and required infrastructure—pipelines, heat exchangers, industrial heat pumps and thermal storage—are insufficiently deployed. Monitoring systems, leak detection solutions and system-balancing tools are underdeveloped. Large-scale industrial heat pumps, essential for upgrading low-grade heat to usable temperatures, are not yet widespread.

Regulatory challenges include fragmented responsibilities for permitting and infrastructure planning, lengthy approval processes (especially for small-scale networks), and inconsistent treatment of waste heat across EU directives and national frameworks. In many regions, municipal heat mapping and planning are not mandatory. Waste-heat recovery often lacks robust policy frameworks, market signals for grid services and cross-sector governance structures. Legal uncertainty, confidentiality concerns and unclear pricing frameworks further impede cooperation.

Economically, the high capital cost of infrastructure contrasts with uncertain long-term returns, especially where fossil gas prices remain competitive. Targeted financial support schemes or favourable market conditions are frequently absent. Social and organisational barriers include low public awareness of waste-heat benefits, reluctance among companies to share operational or location data, perceived dependency risks between suppliers and users and the complexity of project development for local communities.

Standardisation gaps persist across energy-management systems, including flexibility requirements for heat pumps, cybersecurity and privacy protections for technical systems, and secure mechanisms for exchanging process-related data. Contracting structures remain highly heterogeneous, with no standardised pricing mechanisms or template agreements. Monitoring, auditing and reporting on the sustainability performance of heating and cooling networks—including renewable contributions and waste-heat recovery—lack harmonised methodologies.

Addressing these challenges requires coordinated policy instruments, supportive incentive systems, harmonised technical standards and clear governance frameworks across sectors.

One step towards efficient sharing of waste heat is the Identification, quantification and valorisation of waste-heat sources. Available data must be heterogeneous in format, metrics and granularity.

Harmonised approaches for classification and characterisation of heat intensive systems enable comparability and planning of waste-heat streams.

Needs include better visibility and data on waste-heat sources, harmonised methods for assessment and classification, supportive regulatory conditions and standardisation for technical, contractual and data-related aspects.

Legal and contractual uncertainties include questions of ownership, pricing structures, data exchange and risk allocation. This complicates exchanges, particularly across organisational or sectoral boundaries.

Related Organisations and Technical Bodies

- **CEN/TC 107** – District heating and cooling systems
- **CEN/TC 113** – Heat pumps and air conditioning units
- **CEN/TC 130** – Space heating and/or cooling appliances without integral thermal sources
- **CEN/TC 156** – Ventilation for buildings
- **CEN/TC 182** – Refrigerating systems, safety and environmental requirements
- **CEN/TC 228** – Heating systems and water-based cooling systems in buildings
- **CEN/TC 234** – Gas infrastructure
- **CEN/TC 299** – Gas-fired sorption appliances and related systems
- **CEN/TC 371** – Energy performance of buildings
- **IEA-IETS Task XV** – Industrial excess heat recovery working group
- Industrial site operators
- District heating companies and network operators
- Technology providers (heat exchangers, pumps, pipelines, control systems)
- Local authorities and municipal energy planners
- Regulators and financiers

Related Deliverables and Standards

- **Energy Efficiency Directive (Directive (EU) 2023/1791)**
- **Renewable Energy Directive (Directive (EU) 2023/2413)**
- **Energy Performance of Buildings Directive (Directive (EU) 2024/1275)**
- **European Green Deal** and national energy and climate plans
- **EN 15316 series** – System energy performance and efficiencies
- **EN 15377 series** – Embedded surface heating and cooling
- **EN 16905 series** – Electrically driven heat pumps
- **EN 16723 series** – Natural gas and biomethane for injection and transport
- Municipal energy and heat-mapping plans
- Permitting and grid-connection procedures for district heating
- Metering and interoperability requirements for heat-transfer systems

RECOMMENDATIONS

REGULATION - Data Management and Exchange

- Require systematic mapping and disclosure of waste-heat potential for large industrial sites and infrastructure operators.
- Integrate waste-heat data into municipal and regional heating and cooling plans.
- Develop business-model templates to increase transparency of heating markets and improve visibility of waste-heat availability.

REGULATION - Contractual and Governance Frameworks

- Establish model legal frameworks clarifying ownership, pricing, liability and rights for waste-heat transactions.
- Streamline permitting procedures and address fragmented authority structures.

- Create open-access district heating frameworks to avoid market dominance by legacy operators.
- Provide governance playbooks for low-temperature district heating and cooling networks.

REGULATION – Technical Integration and Performance Monitoring

- Introduce minimum efficiency and performance benchmarks for waste-heat recovery systems.
- Enable support schemes linked to verified CO_2 savings.

REGULATION – Incentives and Market Signals

- Provide tax incentives, premium tariffs and targeted funding for waste-heat integration projects.
- Mandate heat-recovery feasibility assessments for new industrial sites and large infrastructure.
- Counteract low fossil-fuel prices with fiscal measures that reflect the externalities of carbon-intensive heating systems.
- Implement fast-track permitting for energy-infrastructure projects.
- Integrate sustainable heating into urban-planning initiatives and localise energy-intensive industries strategically.
- Allocate public funding to breakthrough projects and align fiscal incentives to shift markets toward CO_2-neutral alternatives.
- Support workforce skills development for implementing heat-valorisation projects.

STANDARDISATION – Data Management and Exchange

- Develop standardised protocols for waste-heat classification, metering and data-exchange formats (temperature, flow, availability).
- Establish confidentiality-aware frameworks (NDAs, secure data-exchange channels, IP handling mechanisms).
- Create standardised auditing and reporting methods for sustainable heating, renewables shares and waste-heat utilisation.

STANDARDISATION – Contractual and Governance Frameworks

- Develop template contracts for waste-heat supply, including performance guarantees, technical specifications, pricing logic and sustainability reporting.
- Provide standardised liability clauses to reduce perceived dependency risks.
- Simplify project development through templated procedures and user-friendly documentation.

STANDARDISATION – Technical Integration and Performance Monitoring

- Define interoperability requirements for connecting potential suppliers and users.
- Develop technical specifications for safety, performance monitoring, leak detection, balancing and maintenance across waste-heat networks.
- Provide guidance for interconnection with district heating, industrial processes and heat-pump systems.

STANDARDISATION – Incentives and Market Signals

- Harmonise methodologies for calculating CO_2 savings from waste-heat utilisation to support eligibility for incentives and ensure comparability across regions.

PRIORITY SYNERGIES

Waste heat recovery creates multiple synergies across industrial, municipal and energy systems. Heat released from industrial processes, energy-generation facilities and data centres can be repurposed to supply district heating and cooling networks, neighbouring industries or public buildings, reducing reliance on primary energy sources and lowering greenhouse gas emissions. Stakeholders identified a wide range of sources—including waste incineration, food production facilities, cogeneration units, data centres, Organic Rankine Cycle systems, biogas plants, aquathermics and geothermal installations—with receiving sectors such as district heating networks, industrial clusters and public buildings. These exchanges can contribute to system resilience by diversifying supply and enabling local energy solutions.

Additional opportunities relate to integrating waste heat with other technologies such as solar thermal, nuclear heat, deep geothermal, thermal storage, phase-change materials, power-to-heat, CCS-related heat recovery, combined heating and cooling and hydrogen cogeneration. These combinations can support decarbonisation of heating and cooling, enhance energy efficiency and create regional economic value. Standardised approaches to classification, quality assessment and integration of waste-heat streams would improve comparability, support planning processes and increase replicability across regions.

INDUSTRIAL WASTE HEAT TO DISTRICT HEATING NETWORKS

This synergy focuses on capturing thermal energy from major industrial processes—such as manufacturing, waste incineration or food production—and supplying it to municipal district heating networks (DHNs). Heat is recovered through heat exchangers and transferred via insulated pipelines, with integration into existing DHN control and operational systems. Implementation requires cooperation between industrial site operators, district heating companies, local authorities and financiers, supported by proactive municipal energy planning and clear contractual arrangements. A central challenge is the temporal mismatch between industrial heat supply, which may be continuous or batch-based, and DHN demand, which varies seasonally and by peak-load periods. Addressing this mismatch typically requires adding thermal storage capacity. When effective, this synergy reduces carbon emissions from heating, improves overall energy efficiency and can provide stable long-term revenue for suppliers.

RECOMMENDATIONS

Regulation

- Introduce mandatory municipal heat mapping and planning to identify and prioritise waste-heat integration opportunities.
- Streamline permitting processes for district heating connections and industrial-DHN integration.
- Provide financial incentives or de-risking instruments to support heat-transfer infrastructure and long-term contractual arrangements.
- Include waste-heat reuse in sustainability assessments and reporting for data centres and other industries, in line with Art. 26(6) and (7).
- Ensure building regulations allow recovered waste heat distributed via district heating and cooling networks to contribute to improved primary energy performance.
- Enable the creation of thermal energy communities that can share energy produced from "renewable waste heat".

Standardisation

- Develop standard methods for classifying waste-heat streams (e.g. temperature levels, quality parameters).

- Establish harmonised metering protocols for accurate measurement of recovered and delivered heat.
- Define interoperability specifications for integrating industrial heat sources into DH networks, including control-system compatibility and connection requirements.

DATA CENTRE HEAT RECOVERY

This synergy focuses on capturing low- to medium-temperature heat generated by data-centre cooling systems and supplying it to district heating networks (DHNs) or nearby commercial and residential buildings. Data centres consumed 76.8 TWh of electricity in the EU in 2018 and represented 2.7 % of electricity demand; this share is expected to rise significantly by 2030, with projections ranging from a 28 % increase to potential two- or three-fold growth in some countries due to AI-driven expansion (European Commission, 2024). New requirements introduced by the EU Energy Efficiency Directive (EED) and corresponding national laws impose mandatory energy reporting, green-power use and performance metrics such as Power Usage Effectiveness (PUE) and Energy Reuse Factor (ERF). From July 2026 onward, new data centres must achieve PUE ≤ 1.2 and ERF ≥ 10 %, increasing to ≥ 20 % by July 2028. These rules create the first EU-wide legal framework for quantifiable waste-heat valorisation in the sector, setting a precedent for other energy-intensive industries (European Commission, 2025).

Implementation requires heat exchangers, pumps, insulated piping and integration into building-heating systems or DH networks. Large-scale heat pumps may be needed to upgrade low-temperature heat to usable levels, and modernisation of DHC networks may be required to accommodate these temperature ranges. Significant financing is typically necessary, supported through national and EU schemes. Cooperation between data-centre operators, DH operators, building owners and municipalities depends on clear governance frameworks and transparent pricing arrangements. Benefits include reduced carbon footprints for data centres and predictable low-carbon heat supply for local energy systems.

Relevant Organisations and Technical Bodies (selected)

- Data centre operators
- District heating and cooling network operators
- Technology providers (heat exchangers, heat pumps, piping, control systems)
- Building owners and facility managers
- Municipalities and local authorities

Relevant deliverables (policy and standardisation)

- EU Energy Efficiency Directive (EED) requirements on PUE and ERF
- National permitting frameworks for data-centre infrastructure
- Guidelines on integrating low-temperature heat into DH networks

RECOMMENDATIONS

Regulation

- Mandate feasibility assessments for waste-heat recovery in all new large-scale data centres.
- Link environmental permitting to ERF targets and require integration of waste-heat recovery options into municipal district heating and cooling planning.

- Ensure permitting frameworks support connection to DHC networks and the deployment of heat-pump systems needed to upgrade low-temperature heat.
- Use ERF-based reporting obligations to enhance transparency and support municipal planning processes.
- Standardisation
- Establish harmonised protocols for low-temperature waste-heat recovery, including interface requirements with DH systems and building-heating infrastructure.
- Define interoperability specifications for heat exchangers, heat pumps and control-system integration.
- Standardise quality metrics for building-level heat integration to ensure reliability and safety.
- Harmonise ERF calculation and reporting methods to ensure comparability and compliance across Member States.

WASTE HEAT TO INDUSTRIAL CLUSTER INTEGRATION

This synergy focuses on transferring recovered heat from one industrial process or facility to another within an industrial cluster, thereby reducing the need for fossil-based process heat and improving overall energy efficiency. Process-to-process heat integration also accommodates emerging needs for industrial cooling, enabling combined heating, cooling and storage solutions. Implementation relies on systematic energy-management tools (particularly Pinch Analysis) to map heat and cooling demands across the cluster. Pinch Analysis identifies optimal matches between hot and cold streams, ensuring internal efficiency is maximised before considering external valorisation. In practice, deployment often follows a stepwise roadmap, beginning with simple bilateral exchanges and progressing toward more complex, site-wide integration.

Material and Energy Flows

Recovered heat from one industrial process is supplied to another facility within the same cluster, displacing fossil-based heat sources. Exchanges may also occur between different processes within a single production site. New opportunities emerge from the increasing presence of data centres, battery parks and bio-based industrial processes. Integration of industrial cooling needs into combined systems can further enhance efficiency. A key principle underpinning this synergy is the Trias Energetica: waste-heat recovery must be secondary to avoiding or reducing energy consumption. Heat valorisation should therefore not lock industries into inefficient processes.

While internal heat recovery within a single site is primarily an energy-efficiency measure rather than industrial symbiosis, it is a necessary first step in applying the Trias Energetica. IS materialises when heat is exchanged across organisational boundaries within an industrial cluster.

Involved Stakeholders

Industrial site operators, cluster managers, energy service companies (ESCOs), technology providers and regulators.

Implementation requires geographic proximity, compatible temperature levels, shared infrastructure, contractual frameworks for energy exchange and, in many cases, large-scale heat pumps to upgrade heat to usable temperatures. Benefits include reduced energy costs, increased competitiveness and emissions reductions.

RECOMMENDATIONS

Regulation

- Encourage or mandate energy-intensive industrial sites to participate in independent Pinch Analysis studies to systematically map internal and external heat and cooling demands.
- Enable shared-infrastructure ownership models and clarify liability and pricing structures for cross-company heat exchanges.
- Streamline permitting for shared infrastructure to reduce fragmented responsibilities, transaction costs and lengthy procedures.

Standardisation

- **Standardise Non-Disclosure and IP frameworks:** Develop template NDAs and protocols for managing IP related to shared process-data exchanges, enabling neutral third-party data handling (e.g. via ESCOs or cluster managers).
- **Define metrological protocols for heat exchange:** Establish standards for metering, data-quality control, temperature measurement and verification of exchanged heat quantities.
- Create guidelines for interconnection, safety requirements and performance monitoring of process-to-process heat integration systems.
- Harmonise standards for waste-heat mapping, secure but transparent data exchange between sectors and incentive structures for cluster-level cooperation.

WASTE HEAT RECOVERY WITH INDUSTRIAL HEAT PUMPS

This synergy focuses on the use of industrial heat pumps (HPs) to capture low-temperature waste heat and upgrade it to higher, usable temperature levels for industrial heating or cooling. Industrial HPs are a key technology for the electrification and decarbonisation of heat supply, enabling low-grade heat from various processes to be reintegrated into production or supplied externally. Implementation requires a systematic approach beginning with energy audits and feasibility studies to identify recoverable waste-heat streams and assess the economic viability of heat-pump deployment. The technology is advancing rapidly, with demonstrators achieving upgraded temperatures of up to 160 °C in closed-loop industrial drying systems.

Material and Energy Flows

Industrial heat pumps recover low-temperature waste heat from industrial cooling and heating processes and upgrade it to higher temperatures for reuse. This may be applied within a facility, across an industrial cluster or in combination with district heating networks.

Involved Stakeholders

Industrial site operators, cluster managers, energy-service companies, engineering firms, technology providers, utilities and regulators.

Implementation requires high-temperature industrial heat pumps, heat exchangers, and compatible control systems. Benefits include energy-cost savings and emissions reductions. Challenges include high upfront investment, integration complexity and intermittent availability of waste-heat sources.

RECOMMENDATIONS

Regulation

- Enable shared infrastructure ownership models and clarify liability and pricing structures for cross-company heat-pump-based heat supply.
- Improve electricity–gas price ratios to strengthen the economic case for electrification and

operation of industrial heat pumps.

- Establish streamlined, predictable procedures for timely grid connection of electrified industrial processes, including high-capacity heat-pump installations.
- Support feasibility assessments through regulatory frameworks that recognise waste-heat recovery as part of industrial decarbonisation planning.

Standardisation

- Develop guidelines for interconnection, safety requirements and performance monitoring for both process-to-process heat exchanges and external supply into district heating networks.
- Specify requirements for performance monitoring, maintenance and safety of industrial heat-pump systems.
- Standardise waste-heat auditing and characterisation methods (temperature levels, heat flows, availability profiles, Coefficient of Performance (COP), Seasonal Performance Factor (SPF), etc.).
- Provide harmonised documentation frameworks to support transparent comparison of heat-pump performance across sectors and applications.

CONVERSION OF WASTE HEAT TO ELECTRICITY

This synergy focuses on converting waste heat into electricity, enabling facilities to recover low- to medium-temperature thermal energy and generate usable power. Implementation begins with a waste-heat audit to quantify temperature levels and heat flows, followed by feasibility studies assessing the technical and economic viability of available conversion technologies. System design and integration must be tailored to the facility, after which installation, commissioning and ongoing maintenance are required. For most low- and medium-temperature waste heat, the Organic Rankine Cycle (ORC) is the most commonly used technology, employing low-boiling-point fluids to drive a turbine. Thermoelectric generators (TEGs) provide an alternative for smaller-scale applications. Required infrastructure includes heat exchangers, the ORC or TEG power block, and equipment for grid interconnection. Cooperation typically involves industrial operators, ESCOs and technology providers, with ESCOs often offering financing through joint ventures or performance-based contracts. Benefits include improved energy efficiency and partial substitution of grid electricity, while challenges arise from high capital costs and the low energy density of many waste-heat sources, which necessitates large heat exchangers.

Material and Energy Flows

Low-temperature waste heat is captured and converted into electricity using technologies such as the Organic Rankine Cycle (ORC), Kalina Cycle, or thermoelectric generators (TEGs).

Involved Stakeholders

Industrial site operators, cluster managers, energy-service companies, engineering companies, technology providers and regulators.

RECOMMENDATIONS

Regulation

- Introduce mandatory waste-heat disclosure for large energy users to increase visibility of electricity-generation potential.
- Establish feed-in tariffs, tax credits or other financial incentives specifically for electricity produced from waste heat, improving economic feasibility for ORC and TEG systems.
- Streamline permitting processes for installing waste-heat-to-electricity systems, including

grid-connection procedures for small and medium-scale generators.

Standardisation

- Develop universally accepted protocols for waste-heat auditing and characterisation (temperature, flow, availability), ensuring reliable input for technology selection.
- Establish interoperability standards for key conversion technologies such as ORC and TEG systems, including heat-exchanger interfaces and control systems.
- Define consistent performance metrics (e.g., electrical efficiency, net power output, system losses) to support technology comparison, procurement and financing.

E. TEXTILES

The textile sector is undergoing significant transformation driven by environmental, economic and regulatory pressures. As one of the most resource-intensive industries, it generates substantial waste across the value chain, from production scraps to post-consumer garments. IS offers multiple opportunities to reduce this impact by supporting reuse, recycling and valorisation of textile materials in sectors such as construction, automotive, insulation and packaging. EU-level initiatives, including the EU Strategy for Sustainable and Circular Textiles and forthcoming measures under the ESPR, provide an overarching framework for circularity, but practical implementation depends on harmonised technical guidance, traceability systems, material-recovery infrastructure and effective cross-sector collaboration.

However, the complexity of textile products presents substantial challenges. Fibre blends, coatings, dyes and accessories complicate sorting and recycling, while the absence of standardised material identification and traceability systems limits the efficient separation of waste streams and the matching of materials with suitable recycling or reuse pathways. Fibre-to-fibre recycling capacity remains limited, resulting in most end-of-life textiles being downcycled or incinerated. Definitions and performance indicators for circular textiles — including recycled content, recyclability and durability — are not applied consistently, creating uncertainty and limiting uptake of secondary textile materials in downstream industries.

Cross-sectoral opportunities are not systematically exploited. Textile residues are seldom recognised as potential inputs for other value chains, even though remnant fabrics and production waste could be used in decorative construction materials, insulation products or packaging solutions, and cotton fibres and packaging bobbins could be redirected to alternative manufacturing processes. Such exchanges require increased awareness, reliable quality-assurance mechanisms and incentives for stakeholders to participate. Additional barriers include the complexity of separating composite waste streams (e.g. textiles with printed paper patterns), high separation and logistics costs and insufficient regulatory clarity. Addressing these challenges through targeted standardisation, including classification schemes, quality criteria and testing protocols for secondary textile materials, can improve market confidence and support wider IS within and beyond the textile sector.

PRIORITY SYNERGIES

Industrial symbiosis in the textile sector centres on closing material loops by redirecting production residues and post-consumer textiles into higher-value applications across other industries. These exchanges reduce landfill and incineration rates, conserve raw materials and create opportunities for secondary textile-based products in construction, automotive, insulation, packaging and technical applications. Environmental benefits include lower greenhouse-gas emissions and reduced energy demand, while economically, companies can realise cost savings on raw materials and develop new circular product lines that strengthen competitiveness.

Identified synergies include separating composite textile waste for reuse in decorative construction materials and composites; repurposing remnant fabrics and cotton fibres for packaging components, bobbins and industrial uses; reintroducing industrial and smart textiles into automotive, sports or technical sectors; collecting and sorting post-consumer textiles for fibre-to-fibre recycling; and transforming coarse fibres and textile by-products into geotextiles, insulation or reinforcement materials for paper and cardboard. These exchanges depend on investments in separation and recycling technologies, harmonised quality standards and regulatory incentives. Standardisation can facilitate uptake by providing agreed testing protocols, classification schemes and traceability requirements that ensure material reliability and safety in new applications.

FABRIC WASTE WITH PRINTED PAPER PATTERNS TO DECORATIVE CONSTRUCTION MATERIALS

This synergy involves redirecting fabric waste containing printed paper patterns from garment production into decorative construction materials. The process requires collecting production residues, separating textile and paper components and processing the recovered fibres into products such as decorative panels, composite boards or insulation materials. Effective uptake depends on availability of separation technologies, on-site sorting at production facilities and reliable material testing for mechanical and durability performance. Cooperation between textile and construction stakeholders can be facilitated through industry platforms and targeted matchmaking initiatives.

Material and Energy Flows

Fabric waste containing printed paper patterns is collected, separated to remove paper and processed into decorative construction products, composite panels or insulation boards.

Involved Stakeholders

Garment producers, textile industry associations, waste-management companies, construction-material manufacturers and testing laboratories.

Related Organisations and Technical Bodies (selected)

- **CEN/TC 248** – Textiles and textile products, particularly WG 39 on CE
- **CEN/TC 351** – Construction products – Assessment of release of dangerous substances
- **CEN/TC 127** – Fire safety in buildings

Related Policy and Standardisation Deliverables

- EU Strategy for Sustainable and Circular Textiles; Ecodesign for Sustainable Products Regulation (ESPR);
- EN ISO 13934-1:2013 / EN ISO 13934-2:2014 (tensile strength/elongation);
- EN ISO 13937-1/-2/-3/-4 (tear properties);
- EN ISO 12947-1/-2/-3/-4 (abrasion resistance – Martindale);
- EN 1624:1999 / EN 1625:1999 (burning behaviour of industrial/technical textiles);
- EN ISO 6940:2004 / EN ISO 6941:2003 (ease of ignition / flame spread)
- **prCEN ISO/TR 11827 rev** – Identification of fibres
- **(WI=00248761)** – Categorisation of and requirements on non-virgin input materials
- **(WI=00248804)** – Circular economy for textile products – Collecting, handling, sorting and storing specifications for used textile products and textile waste
- **prEN ISO 6940** – Ease of ignition of vertically oriented specimens; **prEN ISO 6941** – Flame spread properties
- **FprCEN/TS 18272-1** – Circular economy for textile products – General principles and guidance

RECOMMENDATIONS

Regulation

- Mandate the separation of paper and textile waste at production sites.
- Support producers through incentives for pre-sorting textile residues at source.

Standardisation

- Develop performance-testing standards for textile-based construction materials (e.g. strength, abrasion, weathering).
- Establish classification and labelling schemes for secondary textile materials used in construction applications.

REMNANT FABRICS AND COTTON FIBRES TO PACKAGING, BOBBINS, INDUSTRIAL APPLICATIONS

This synergy focuses on redirecting remnant fabrics, offcuts and cotton fibres from yarn production into packaging materials, bobbins and other industrial applications. These secondary materials can replace virgin inputs in packaging and industrial processes when clean, consistently collected and properly specified. Implementation relies on dedicated collection systems for clean production residues, adaptation of packaging and industrial manufacturing processes and the development of quality specifications to ensure reliable material substitution.

Material and Energy Flows

Remnant fabrics, offcuts and cotton fibres are collected from textile mills and redirected into packaging materials, textile bobbins or liners for industrial applications.

Involved Stakeholders

Textile mills, packaging manufacturers, logistics providers and industrial equipment suppliers.

Related Organisations and Technical Bodies

- CEN/TC 248 – Textiles and textile products
- CEN/TC 172 – Pulp, paper and board
- CEN/TC 261 – Packaging

Related Policy and Standardisation Deliverables

- EU Packaging and Packaging Waste Regulation (PPWR); Ecodesign for Sustainable Products Regulation (ESPR).
- **CEN ISO/TR 11827:2016** (fibre identification); **EN ISO 1833 series** (blend quantification); EN ISO 13934-1/-2 (tensile); EN ISO 13937-1/-2/-3/-4 (tear).
- **prCEN ISO/TR 11827 rev** – Identification of fibres
- **(WI=00248761)** – Circular economy for textile products – Categorisation of and requirements on non-virgin input materials
- **(WI=00248804)** – Circular economy for textile products – Collecting, handling, sorting and storing specifications for used textile products and textile waste
- **FprCEN/TS 18272-1** – Circular economy for textile products – General principles and guidance
- **(WI=00248763)** – Circular economy for textile products – Design for circularity

RECOMMENDATIONS

Regulation

- Encourage the reuse of clean textile residues in non-textile manufacturing through targeted amendments to waste legislation.
- Integrate such secondary-material flows into extended producer responsibility schemes.

Standardisation

- Develop specifications for fibre cleanliness, strength and dimensional stability for packaging and industrial applications.
- Provide guidelines for the safe handling of textile residues and their integration into packaging production lines.

INDUSTRIAL AND SMART TEXTILES TO AUTOMOTIVE, SPORTS, AND TECHNICAL SECTORS

This synergy focuses on repurposing end-of-life industrial textiles, including coated fabrics, functional textiles and smart textiles, for secondary applications in automotive interiors, sports equipment and technical liners. Implementation requires removal of incompatible components such as embedded sensors or metal parts, followed by performance testing to ensure materials meet the safety, durability and functionality requirements of the receiving sectors. Collaboration between textile recyclers, technology developers and sector-specific manufacturers is essential to adapt these materials to new regulatory and technical contexts.

Material and Energy Flows

End-of-life industrial textiles and smart textiles are collected, disassembled where necessary and adapted for use in automotive components, sports equipment or technical applications.

Involved Stakeholders

Automotive manufacturers, sports-equipment producers, textile recyclers and technology developers.

Related Organisations and Technical Bodies

- CEN/TC 248 – Textiles and textile products
- CEN/TC 301 – Road vehicles
- CEN/TC 162 – Protective clothing

Related Policy and Standardisation Deliverables

- Ecodesign for Sustainable Products Regulation (ESPR); sector-specific safety and performance standards.
- **CEN ISO/TR 23383:2020** (smart textiles – definitions/categorisation); **CEN/TR 17945:2023** (textiles with integrated electronics/ICT – definitions/categorisation); **EN 16812:2016** (electrically conductive textiles – linear electrical resistance); **EN ISO 24584:2022** (sheet resistance of conductive textiles); **EN ISO 17971:2025** (screen-touch properties of fabrics).
- **(WI=00248765)** – *Textiles and textile products – Smart textiles and electronic textiles – Method for testing the impact of smart textile elements in clothing on the user cognitive load*
- **(WI=00248801)** – *Smart textiles and electronic textiles — Textile products with active lighting — Determination of the luminance*
- **EN 16422:2025/AC:2026** – *Classification of thermoregulatory properties;* **prEN ISO 11092** – *Measurement of thermal and water-vapour resistance*
- **FprCEN/TS 18272-1** – *Circular economy for textile products – General principles and guidance*
- **(WI=00248761)** – *Categorisation of and requirements on non-virgin input materials*

Recommendations - Regulation

- Introduce guidance for the safe reuse of functional and technical textiles in regulated sectors.
- Support innovation in smart-textile disassembly through targeted R&I funding.

Recommendations - Standardisation

- Develop testing protocols for durability, safety and performance of secondary functional textiles in automotive, sports and technical applications.
- Establish traceability requirements for reused smart textiles to ensure compliance with sector-specific regulations.

POST-CONSUMER TEXTILE COLLECTION AND SORTING TO FIBRE-TO-FIBRE RECYCLING

his synergy focuses on collecting post-consumer textiles and sorting them by fibre type and quality to enable mechanical or chemical recycling into new textile fibres. Successful implementation requires harmonised collection systems at municipal level, deployment of advanced sorting technologies such as near-infrared (NIR) scanning and stable market demand for recycled fibres. Cooperation between municipalities, sorting facilities, recyclers, fibre producers and fashion brands is essential to establish reliable supply chains for high-quality secondary fibres.

Material and Energy Flows

Post-consumer textiles are collected, sorted by fibre composition and condition and processed through mechanical or chemical recycling into new fibres for textile production.

Involved Stakeholders

Municipal collection services, textile sorting facilities, recyclers, fibre producers and fashion brands.

Related Organisations and Technical Bodies

- CEN/TC 248 – Textiles and textile products
- CEN/TC 351 – Construction products – Assessment of release of dangerous substances
- CEN/TC 172 – Pulp, paper and board

Related Policy and Standardisation Deliverables

- Waste Framework Directive; EU Strategy for Sustainable and Circular Textiles.
- **CEN ISO/TR 11827:2016** (fibre identification); **EN ISO 2076:2021 / EN ISO 6938:2014** (fibre naming/definitions); **EN ISO 1833-1:2020 + EN ISO 1833 series** (quantitative blend analysis); **EN ISO 20705:2020** (quantitative microscopical analysis); **EN ISO 3758:2023** (care labelling symbols)
- **(WI=00248804)** – *Circular economy for textile products — Part 4: Collecting, handling, sorting and storing specifications for used textile products and textile waste*
- **FprCEN/TS 18272-1** – *Circular economy for textile products — General principles and guidance*
- **prCEN ISO/TR 11827 rev** – *Identification of fibres*
- **(WI=00248761)** – *Categorisation of and requirements on non-virgin input materials*
- **prEN ISO 4484-4** – *Microplastics from textile sources — Quantitative analysis of material released during washing*
- **prEN ISO 1833-1** – *Quantitative chemical analysis — General principles of testing*

Recommendations - Regulation

- Mandate separate textile collection at municipal level by 2025 in line with EU waste legislation.
- Provide financial incentives for investment in automated sorting facilities, including NIR-based systems.

Recommendations - Standardisation

- Establish harmonised fibre-identification and labelling requirements to support efficient sorting.
- Develop quality criteria for recycled fibres to ensure their suitability for high-value textile applications.

COARSE FIBRES AND TEXTILE BY-PRODUCTS TO GEOTEXTILES, INSULATION PANELS, PAPER REINFORCEMENT

This synergy concerns the use of coarse textile fibres and manufacturing by-products as inputs for geotextiles in civil engineering, insulation materials or reinforcement layers in paper and cardboard. Implementing these exchanges requires adapting manufacturing processes to accommodate secondary textile materials, conducting tests to verify mechanical and environmental performance and establishing logistics for bulk material transfer between textile processors and downstream sectors.

Material and Energy Flows

Coarse textile fibres and by-products are processed into geotextiles, insulation panels or reinforcement components for paper and cardboard products.

Involved Stakeholders

Civil engineering companies, insulation manufacturers, paper mills and textile processors.

Related Organisations and Technical Bodies

- CEN/TC 248 – Textiles and textile products
- CEN/TC 249 – Plastics
- CEN/TC 207 – Furniture (relevant for fibre-based components)

Related Policy and Standardisation Deliverables

- Construction Products Regulation; EU Green Public Procurement criteria.
- **EN ISO 13934-1/-2** (tensile); **EN ISO 13937-1/-2/-3/-4** (tear); **EN ISO 12947 series** (abrasion); **EN ISO 5084:1996** (thickness)
- **prCEN ISO/TR 11827 rev** – *Identification of fibres*; **prEN ISO 2076** – *Man-made fibres — Generic names*
- **(WI=00248761)** – *Categorisation of and requirements on non-virgin input materials*
- **(WI=00248804)** – *Circular economy for textile products — Collecting, handling, sorting and storing specifications for used textile products and textile waste*
- **FprCEN/TS 18272-1** – *Circular economy for textile products — General principles and guidance*
- **prEN ISO 6940** – *Ease of ignition*; **prEN ISO 6941** – *Flame spread properties*

Recommendations - Regulation

- Include secondary textile fibres as approved input materials in relevant sectoral regulations.
- Support pilot projects demonstrating technical feasibility in geotextile and insulation applications.

Recommendations - Standardisation

- Define performance standards for textile-derived geotextiles and insulation materials.
- Establish testing methods for fibre reinforcement in paper products.

GENERAL NEEDS AND RECOMMENDATIONS

The textile sector faces significant technical, organisational and regulatory barriers that limit the uptake of industrial symbiosis. A key technical challenge is the heterogeneity of textile materials: fibre blends, coatings, dyes and accessories complicate recycling and prevent separation into uniform material streams. Composite waste — such as fabric with printed paper patterns — requires specialised separation technologies that are often unavailable or cost-prohibitive. Recycling infrastructure remains insufficient, particularly for fibre-to-fibre processes, resulting in most end-of-life textiles being downcycled or incinerated. The absence of harmonised quality standards and performance indicators for secondary textiles further undermines market confidence and makes it difficult for downstream sectors to integrate textile-based secondary raw materials.

Logistical and economic constraints include high transport and storage costs, limited local processing capacity and underdeveloped markets for secondary textile products. Organisational barriers arise from low cross-sector awareness: many industries do not yet recognise textile residues as viable inputs. Regulatory gaps include inconsistent requirements for collection and sorting across regions and the absence of mandatory measures to incentivise separation at source. While social acceptance challenges are generally limited, they may emerge in applications involving consumer-facing products. Addressing these issues requires coordinated regulatory measures, investment in advanced separation and recycling technologies and targeted standardisation efforts to provide clear and reliable frameworks for quality, safety and performance of secondary textiles across sectors.

Related Organisations and Technical Bodies

- CEN/TC 134 – Resilient, textile, laminate and modular mechanical locked floor coverings
- CEN/TC 172 – Pulp, paper and board
- CEN/TC 214 – Textile machinery and accessories
- CEN/TC 248 – Textiles and textile products
- CEN/TC 261 – Packaging
- CEN/TC 289 – Leather
- CEN/TC 301 – Road vehicles
- CEN/TC 351 – Construction products – Dangerous-substance assessment
- CEN/TC 357 – Stretched ceilings
- CEN/TC 443 – Feather and down
- CEN/TC 127 – Fire safety in buildings
- CEN/TC 162 – Protective clothing

Related Policy and Standardisation Deliverables

- EU Strategy for Sustainable and Circular Textiles
- Ecodesign for Sustainable Products Regulation (ESPR)
- Waste Framework Directive
- EU Packaging and Packaging Waste Regulation
- Construction Products Regulation
- EN ISO 3758 – Care labelling code using symbols
- EN ISO 2076 – Man-made fibres – Generic names
- EN ISO 1833 (series) – Quantitative chemical analysis of fibre blends
- EN ISO 12947 – Abrasion resistance of fabrics
- EN 16732 – Determination of certain flame retardants in textile materials
- Textiles — Circular economy for textile products — Part 4: Collecting, handling, sorting and storing specifications for used textile products and textile waste (WI= 00248804)
- EN ISO 4484-1:2023 and EN ISO 4484-3:2023 (microplastics release from textiles during washing);
- CEN/TS 16822:2015 (self-declared environmental claims – terms); EN ISO 5157:2023 (environmental aspects – vocabulary)
- Textiles — Circular economy for textile products — Part 1: General principles and guidance (FprCEN/TS 18272-1)
- Textiles — Circular economy for textile products — Categorisation of and requirements on non-virgin input materials (WI=00248761)
- Textiles — Circular economy for textile products — Design for circularity (WI=00248763)
- Textiles — Composition testing — Identification of fibres (prCEN ISO/TR 11827 rev)
- EN ISO 6940 / EN ISO 6941 — Textile fabrics — Burning behaviour (ease of ignition / flame spread)
- Smart textiles and electronic textiles — Method for testing the impact of smart textile elements on the user cognitive load (WI=00248765)

Recommendations - Regulation and Policy

- Introduce mandatory separation of textile waste streams at production and municipal levels, supported by extended producer responsibility schemes.
- Harmonise collection and sorting requirements across the EU to enable cross-border use of secondary textiles.
- Provide financial incentives for investments in advanced sorting, separation and fibre-to-fibre recycling infrastructure.
- Recognise secondary textiles as approved inputs in relevant sectoral regulations, including construction, packaging, automotive and insulation.

Recommendations - Standardisation

- Develop testing protocols and quality criteria for secondary textile materials in cross-sector applications, including mechanical strength, abrasion resistance and fire safety.
- Create classification and labelling systems for recycled and reusable textiles to support traceability and ensure compatibility with intended uses.
- Establish harmonised fibre-identification and sorting standards to enable consistent

feedstock preparation for recycling processes.
- Specify performance standards for textile-derived products such as geotextiles, insulation panels and composite materials.

F. BIOMASS

Biomass encompasses a wide range of organic material streams with significant potential for recovery, reuse, and valorisation across multiple industrial sectors. Sources vary in origin, composition, and contamination levels, and include primary biomass such as dedicated crops, as well as secondary biomass streams such as lignocellulosic residues, waste wood (including bark), agricultural by-products, food industry residues, wastewater-derived biomass, and organic fractions of municipal solid waste. Typical supplying sectors include agriculture, forestry, the food industry, and wood-based manufacturing.

The diversity of these materials opens opportunities for cross-sector applications, provided that technical suitability and safety requirements are met. Biomass can serve as a feedstock for bio-based chemicals, construction materials, soil improvers, and bioenergy systems. Potential receiving sectors include construction, chemical and bio-based manufacturing, energy providers, and fertiliser production. Such exchanges enhance resource efficiency, substitute fossil-based inputs, and support progress toward climate neutrality.

European policy frameworks — including the Renewable Energy Directive, the EU Bioeconomy Strategy, and national circular economy plans — promote the cascading use of biomass, whereby high-value material applications are prioritised before energy recovery. This helps maximise environmental and economic benefits and prolongs carbon retention, particularly when biomass is incorporated into long-lived products or applied as soil amendments.

Realising this potential requires clearer classification systems, harmonised quality and safety standards, and strengthened coordination between biomass-generating and biomass-using sectors. Improved visibility of available resources, their characteristics, and application-specific requirements is essential for enabling reliable exchanges and fostering IS across the bio-based economy.

Related Project: REHAP
- **Title:** Systemic approach to Reduce Energy demand and CO_2 emissions of processes that transform agroforestry waste into High Added value Products
- **Standardisation Inputs:** Developed standards for bio-based products, including bio-based content declaration, sustainability criteria, and LCA application.

PRIORITY SYNERGIES

RENEWABLE ENERGY GENERATION FROM BIOMASS

Biomass such as waste wood can be transformed into renewable energy carriers including synthesis gas, biogas, bio-oil, biomethane, and hydrogen. Relevant technologies include pyrolysis, gasification, and Fischer–Tropsch synthesis. The synergy links biomass-generating sectors with energy providers and supports renewable energy objectives while complementing carbon capture and utilisation efforts.

Material and Energy Flows

Biomass streams, including waste wood, are converted into synthesis gas, biogas, bio-oil, biomethane, or hydrogen using pyrolysis, gasification, or Fischer–Tropsch processes.

Involved Stakeholders

Biomass generators (forestry, wood processing industries, municipal waste services) and energy providers.

Recommendations – Regulation

- Align end-of-waste criteria for biomass across Member States.

Recommendations – Standardisation

- Update the EN 16723 series for biomethane.
- Develop technical guidelines for waste wood classification, processing, and environmental safety.

CONSUMING BIOPRODUCTS

Vegetal by-products and animal manure can be used as organic fertilisers, as growing media for insects and algae, or as feedstock for biogas production. This pathway enables nutrient recycling and reduces dependence on synthetic fertilisers. Key actors include agricultural producers, waste management companies, fertiliser manufacturers, and bioenergy operators.

Material and Energy Flows

Vegetable by-products and animal manure are transformed into organic fertilisers, growing media for insect production, algae cultivation substrates, or biogas feedstock.

Involved Stakeholders

Agriculture, waste management companies, fertiliser producers, and bioenergy operators.

Recommendations – Regulation

Harmonise quality control requirements for fertiliser and biofuel production from residues across Member States.

Recommendations – Standardisation

- Support standards for biomass classification and safety.
- Develop performance criteria for fertiliser and biofuel production from vegetal and animal residues.

BIOPRODUCTS FOR UTILISATION IN INDUSTRIAL AND CONSTRUCTION APPLICATIONS

Fatty acids recovered from wastewater can be used in the production of polymers, biodiesel (via transesterification), pigments, and fermentation-based active compounds. Lignocellulose from woody waste carbonisation can be incorporated into construction materials, catalysts, or electrode applications. These pathways create opportunities for cross-sectoral synergies between wastewater treatment facilities, chemical producers, bio-based material manufacturers, forestry, construction, and industrial manufacturing.

Material and Energy Flows

- · Fatty acids extracted from wastewater are used as feedstock for polymers, biodiesel, pigments, or fermentation-derived compounds.

  Lignocellulosic fractions from woody waste carbonisation are used as inputs for construction materials, catalysts, or electrode applications.

Involved Stakeholders

Wastewater treatment facilities, chemical producers, bio-based material manufacturers, forestry and wood-processing actors, construction material producers, and industrial manufacturers.

Recommendations – Regulation

- Promote data sharing on feedstock availability and material specifications.
  Align safety and environmental criteria for industrial applications of fatty acids and lignocellulosic materials.
  Include end-of-waste provisions for woody biomass fractions to encourage reuse over incineration.

Recommendations – Standardisation

- Establish quality and performance standards for lignocellulosic materials in construction and electrode applications.
  Harmonise classification and quality criteria for lignocellulosic materials across the EU.
  Develop guidelines for best practices in collection, processing, and utilisation of these biomass streams.

BIOMASS-DERIVED CO_2 FOR INDUSTRIAL APPLICATIONS

CO_2 generated during biomass processing can be used as a feedstock for producing renewable fuels such as methanol, methane, sustainable aviation fuel (SAF), and dimethyl ether (DME). It can also be used in industrial applications including fire suppression, carbonated beverages, and food processing. This pathway contributes to circular carbon use by redirecting biogenic CO_2 into new value chains.

Material and Energy Flows

CO_2 captured from biomass processing is used in the production of renewable fuels (methanol, methane, SAF, DME) and for industrial applications such as fire suppression systems, carbonated beverages, and food processing.

Involved Stakeholders

- Biomass processing facilities, renewable fuel producers, industrial users (e.g., fire suppression, beverages, food processing).

Recommendations – Regulation

Promote data sharing on feedstock availability and specifications.

Recommendations – Standardisation

- Develop standards for CO_2 purity.
- Develop standards for bio-based chemical feedstocks.

GENERAL NEEDS AND RECOMMENDATIONS

The cascading use of biomass (prioritising high-value applications before energy recovery) is increasingly promoted in EU policy frameworks such as the Renewable Energy Directive, the EU Bioeconomy Strategy, and national CE plans. However, the principle remains difficult to implement in practice. Biomass waste treatment is still dominated by incineration and waste-to-energy, driven by economic considerations and divergent national regulations.

A central barrier is the absence of harmonised classification and quality standards for biomass. Biomass streams differ widely in origin, composition, and contamination levels, making it difficult for downstream users to assess suitability for material applications. Without clear definitions and technical specifications, cross-sectoral exchanges are constrained and opportunities for cascading use remain unrealised.

Regulatory divergence further limits uptake. The legal status of many biomass fractions, whether they are considered waste, by-products, or products, remains unclear. Differences in end-of-waste criteria and incineration restrictions between Member States restrict cross-border trade and hinder investment in shared processing or common valorisation infrastructure. These issues connect closely with challenges identified under end-of-waste discussions.

Economic and logistical factors also favour incineration as the cheapest and simplest disposal route, undermining higher-value uses. Data gaps on available resources, their properties, and specifications limit visibility of potential feedstocks and make matchmaking between suppliers and users difficult. Limited cross-sectoral collaboration, along with societal concerns about noise, odour, and environmental impacts, further constrain the adoption of biomass-based IS pathways.

Creating a functioning market for secondary biomass requires improving the visibility of available resources and ensuring that their characteristics are defined, comparable, and accessible. Clear classification, quality assurance, and coordinated exchange mechanisms are essential to enable cascading use and unlock cross-sectoral applications.

Recommendations – Standardisation

- Develop harmonised classification, certification, and quality standards for biomass and waste wood to support cross-border trade and high-value (cascade) use.
- Update biomethane and biogas standards (EN 16723 series) and create best-practice guidelines for collection, processing, and utilisation.
- Standardise data metrics and establish performance and safety criteria for biomass-derived products.

Recommendations – Regulation

- Align end-of-waste criteria across Member States and introduce mandatory biomass recycling to reduce landfill and incineration.
- Provide financial and tax incentives for CO_2 trade, biomass valorisation, and green hydrogen adoption.
- Simplify Guarantees of Origin to improve market uptake and integrate biomass strategies into broader climate and CE objectives.

Related Organisations and Technical Bodies

- CEN/TC 153 – Machinery for food and feed
- CEN/TC 223 – Soil improvers and growing media
- CEN/TC 260 – Fertilizers and liming materials
- CEN/TC 327 – Animal feeding stuffs – Sampling and analysis
- CEN/TC 335 – Solid Biofuels and Pyrogenic Biocarbon
- CEN/TC 383 – Sustainably produced biomass for energy applications
- CEN/TC 408 – Biomethane and renewable methane-rich gases
- CEN/TC 411 – Bio-based products
- CEN/TC 454 – Algae and algae products
- CEN/TC 455 – Plant biostimulants
- CEN/TC 460 – Food authenticity

Related Deliverables and Standards

- VDI 6310-1 – Classification and quality criteria of biorefineries
- DIN EN 17399 – Algae and algae products – Terms
- DIN EN 17477 – Identification of biomass of algae, cyanobacteria and related groups
- DIN EN 17480 – Methods for determining productivity of algae production sites
- DIN EN 17605 – Sampling and analysis methods for algae and algae products
- DIN CEN/TR 17559 – Algae and algae products – Food and feed applications
- DIN EN 17908 – Determination of total lipids in algae-based products
- DIN ISO 38200 – Supply chain of wood and wood-based products
- DIN EN 643 – European list of standard grades of recovered paper
- ISO/WD 13391 series – Wood and wood-based products – Carbon footprint methodologies
- Renewable Energy Directive; Bioeconomy Strategy; national CE plans

5. SYSTEM-LEVEL ENABLERS

Industrial symbiosis depends not only on sector-specific technologies and material exchanges but also on the broader systems that allow such cooperation to function and scale. Many of the conditions that enable effective symbiosis, for instance interoperable energy and data infrastructures, clear governance frameworks, skilled workforces, and supportive financial and regulatory environments, operate across multiple sectors of the economy.

This chapter highlights these transversal enablers. It identifies the structural elements that make it possible for industries to exchange resources, coordinate energy flows, share infrastructure, and build long-term collaborative arrangements. By strengthening these system-level foundations, Europe can improve the reliability, economic viability, and scalability of IS initiatives, supporting wider goals related to competitiveness, circularity, and the green transition.

A. ENERGY DATA & GRIDS

Energy systems are becoming increasingly decentralised, digitalised and integrated with industrial processes. In this environment, energy-related data play a critical role in enabling efficiency, demand flexibility and sector coupling. Industrial symbiosis in the energy domain, including shared renewable generation, distributed storage or waste-heat utilisation, depends on the ability to access and exchange energy data securely and efficiently across organisational and sectoral boundaries. Thus, energy data, for the most part, can be viewed as a supporting resource in the identification and progression of energy related industrial symbiosis. For example, there are instances where multiple actors pool their energy consumption and generation data, allowing them to respond to peaks and troughs of supply/demand across the network of actors, the energy data supporting the energy synergy.

Stakeholders such as distribution system operators (DSOs), aggregators, industrial consumers and energy communities are central to managing these flows, yet integration is hindered by persistent interoperability gaps. Industrial facilities often operate independent metering, monitoring and control infrastructures that are not aligned with systems used by neighbouring industries or energy-system operators. Variations in data formats, units, metadata, time resolution and communication protocols complicate coordination and limit opportunities for load balancing, shared storage and local energy exchange.

Limited visibility of local energy flows further constrains potential synergies, as detailed production and consumption data are frequently inaccessible or not collected at sufficient granularity. Governance challenges, including unclear data ownership, inconsistent access rights and differing liability rules across Member States, discourage industrial actors from sharing operational energy data even where mutual benefits are evident.

Emerging EU policy initiatives, such as reforms to the Electricity Market Design, the Data Act and the forthcoming Network Code on Demand Response, will introduce new requirements for data access, interoperability and governance. Standardisation can operationalise these frameworks by defining harmonised data-exchange models, interfaces and certification schemes that build trust and enable secure and transparent interaction between actors. Opportunities identified to date highlight the potential for secure energy-data exchange standards, interoperable communication protocols and shared digital infrastructure models to support grid modernisation, enable flexibility services and strengthen cross-sector coordination.

While these mechanisms do not involve physical by-product exchanges, they support IS as systematic enablers, recognising shared energy infrastructures, flexibility services and digital coordination as system-level symbiosis enabling efficient cross-sector resource use.

Relevant Organisations and Technical Bodies (selected)

- CEN/CLC/JTC 14 – Energy management and energy efficiency
- CEN/TC 294 – Communication systems for meters and remote reading
- CEN/TC 371 – Energy performance of buildings
- CEN-CLC-ETSI/COG SG – Smart Grids
- CLC/TC 205 – Home and building electronic systems
- CLC/TC 57 – Power systems management and associated information exchange
- CLC/TC 65X – Industrial-process measurement, control and automation
- CLC/TC 8X – System aspects of electrical energy supply
- CLC/TC 88 – Wind turbines

Related Project: SYMBIOPTIMA

- **Title:** Human-mimetic approach to the integrated monitoring, management and optimization of a symbiotic cluster of smart production units
- **Standardisation Inputs:** Proposed waste flow characterization and a European Waste Catalogue for secondary raw materials.
- **Policy Recommendations:** Leveraged the Eco-design Working Plan to drive standardisation for product durability and safety.

Related Project: SHAREBOX

- **Title:** Secure Management Platform for Shared Process Resources
- **Standardisation Inputs:** Developed the CEN Workshop Agreement (CWA) for IS to provide consensus on terminologies and core IS elements.
- **Policy Recommendations:** Used the CWA as a basis for widespread IS implementation. Aligned with the Waste Framework Directive to promote resource efficiency.

PRIORITY SYNERGIES

IS in energy systems can be supported through multiple forms of cooperation, including shared renewable-energy production and storage, flexible demand management and local energy-exchange schemes. These synergies can reduce costs, improve energy efficiency and support the integration of renewable resources while strengthening grid stability and resilience. Benefits include improved use of local energy flows, reduced emissions and increased energy security through diversified and decentralised energy sources. They can also lower system costs by reducing peak demand, avoiding grid congestion and postponing network reinforcements, while opening new opportunities for industrial stakeholders to participate in flexibility markets, energy-sharing schemes and demand-side management.

The synergies identified to date fall into five main areas: industrial flexibility services that support grid balancing; shared renewable-generation and storage infrastructures; integration of industrial IoT and automation systems into smart-grid environments; local energy exchange through community-based or peer-to-peer arrangements; and data-driven production planning that responds to dynamic price and grid signals. These opportunities depend on interoperable data exchange, coordinated governance between industries and DSOs and the availability of secure digital infrastructures. The following sections describe each synergy in detail, outlining material and energy flows, stakeholders involved and recommendations for regulation and standardisation.

ENERGY FLEXIBILITY SERVICES FOR INDUSTRIAL SYMBIOSIS

This synergy concerns the use of industrial energy flexibility — including load shifting, demand response and temporary adjustments in consumption or on-site generation — to support grid stability and enable more efficient integration of renewable energy. By modulating energy use in response to price signals, grid conditions or renewable availability, industrial actors can reduce system costs, avoid congestion and participate in emerging flexibility markets. Implementation depends on interoperable metering and control systems, real-time communication mechanisms and clear market rules for participation. Cooperation between DSOs, aggregators and industrial users is essential to establish trust, manage data sharing and develop viable business models.

Involved Stakeholders

- Industrial consumers, distribution system operators (DSOs), aggregators, energy-service companies (ESCOs), renewable-energy providers and technology developers.
- Related Organisations and Technical Bodies
- ISO/TC 205 – Building environment design (Facility smart grid information models)
- IEC/TC 3 – Information structures, documentation and graphical symbols
- IEC SyC Smart Energy – Systems Committee for Smart Energy (smart-grid architectures)

Related Standards and Deliverables (selected)

- ISO 17800:2017 – Facility smart grid information model
- IEC 61360 – Standard data element types and classification scheme
- IEC SRD 63200 – Extended SGAM smart energy grid reference architecture

Recommendations - Regulation

Clarify market-access rules for industrial flexibility providers and harmonise conditions for aggregator participation across Member States.

Recommendations – Standardisation

- Develop interoperability standards for demand-response communication to ensure compatibility across industrial, aggregator and DSO systems.
- Establish certification schemes for flexibility-ready devices to create trust and support market uptake.

SHARED RENEWABLE ENERGY AND STORAGE INFRASTRUCTURE

While energy data is a supporting resource for synergies, energy itself is a resource that can be used in industrial symbiosis transactions. In this example the synergy focuses on the shared use of renewable energy generation (such as photovoltaic or wind systems) and distributed storage technologies (including batteries and hydrogen-based systems) across industrial sites and local communities. Surplus energy from one facility can be stored and subsequently used by another, increasing overall system efficiency, improving local self-sufficiency and supporting the integration of variable renewable resources. Implementation requires technical compatibility between generation, storage and grid systems, as well as contractual frameworks that allow multiple parties to co-invest in and share energy assets. Cooperation between industries, DSOs and energy communities is essential to balance supply and demand and ensure equitable benefit-sharing.

Involved Stakeholders

Industrial producers, distribution system operators (DSOs), community energy groups, storage-system integrators and technology suppliers.

Related TCs:

- IEC/TC 21 – Secondary cells and batteries
- IEC/TC 69 – Electric road vehicles and electric industrial trucks (vehicle-based storage integration)

Related Standards and Deliverables (selected)

- IEC 61427-1 – Secondary cells and batteries for renewable energy storage – Off-grid applications
- IEC 61427-2 – Secondary cells and batteries for renewable energy storage – On-grid applications
- IEC 63382 – Protocol for management of distributed energy storage systems based on electric vehicles

Recommendations - Regulation

Enable direct-line arrangements and collective self-consumption models under national energy legislation, allowing industrial and community actors to jointly invest in and operate shared renewable and storage assets.

Recommendations - Standardisation

- Define interoperable interfaces for integrating storage systems into industrial and grid infrastructures.
- Standardise performance and safety certification schemes for shared energy assets to build trust among participants and facilitate wider deployment.

INDUSTRIAL IOT INTEGRATION FOR SMART GRIDS

This synergy focuses on integrating industrial Internet of Things (IoT) devices into local grid operations to enable real-time monitoring, control and optimisation of energy use and on-site generation. High-frequency data provided by IoT systems can support predictive maintenance, improve operational efficiency and facilitate dynamic interaction between industrial facilities and grid operators. Implementation requires harmonised communication interfaces, robust cybersecurity measures and reliable data exchange between industrial sites, DSOs and aggregators. Upgrading control systems, ensuring protocol compatibility and securing gateways for operational data exchange are essential steps. While the potential benefits include enhanced flexibility, reduced downtime and improved coordination with grid operators, challenges arise from cybersecurity risks, high integration costs and the complexity of managing heterogeneous IoT devices.

Involved Stakeholders

Industrial operators, distribution system operators (DSOs), ICT providers, equipment manufacturers and cybersecurity specialists.

Related TCs:

- ISO/IEC JTC 1 – Information technology (IoT architecture and interoperability)
- IEC/TC 65 – Industrial-process measurement, control and automation
- ETSI – IoT and machine-to-machine (M2M) interoperability standards

Related Standards and Deliverables (selected)

- ISO/IEC 30162:2022 – Compatibility requirements and network models for IoT systems
- IEC 62443 series – Industrial network and control system security
- ETSI IoT Standards – Interoperable and secure IoT frameworks

Recommendations - Regulation

Establish minimum cybersecurity and data-protection requirements for industrial–grid data links, ensuring secure exchange of operational information between actors.

Recommendations - Standardisation

Develop harmonised IoT communication protocols for energy-management applications, including requirements for interoperability, reliability and secure integration into industrial and grid systems.

LOCAL ENERGY EXCHANGE AND COMMUNITY GRIDS

This synergy concerns peer-to-peer and community-level use of co-generated electricity and heat among industrial actors, SMEs, municipalities and residential consumers within a defined local grid. Transactions/synergies may occur bilaterally or through organised community-energy schemes in which participants pool resources to optimise local generation, storage and demand. Implementation requires technical, organisational and regulatory alignment, including metering and settlement systems that can fairly allocate costs and benefits. Municipalities, DSOs and energy cooperatives often play a coordinating role in establishing governance structures and contractual frameworks. While benefits include enhanced local resilience, reduced transmission losses and collaborative approaches to renewable integration, challenges stem from fragmented national legal frameworks, limited interoperability of metering and settlement systems and the need for secure digital tools to manage local exchanges.

Involved Stakeholders

Local distribution system operators (DSOs), municipalities, energy cooperatives, industrial users, SMEs and residential participants.

Related TCs:

- IEC/TC 57 – Power systems management and associated information exchange
- IEC/TC 13 – Electrical energy measurement and control

Related Standards and Deliverables (selected)

- IEC 61850 – Communication networks and systems for power-utility automation
- IEC 62056 series – DLMS/COSEM standards for metering data exchange

Recommendations - Regulation

Support legal recognition of local energy communities and peer-to-peer energy trading, ensuring industrial and community participants have equal access to markets.

Recommendations - Standardisation

Develop standards for metering data formats, settlement procedures and interoperability between community-grid participants to enable transparent and equitable local energy exchange.

DATA-DRIVEN PRODUCTION PLANNING BASED ON PRICE SIGNALS

This synergy focuses on adjusting industrial production schedules in response to real-time or forecasted energy-price signals and renewable-energy availability. By shifting energy-intensive processes to periods of low prices or high renewable generation, industrial actors can reduce operational costs, lower emissions and contribute to grid stability. Implementation requires transparent access to market and grid data, alongside integration with industrial control systems and manufacturing execution systems (MES). Forecasting and optimisation tools enable automated decision-making, but challenges arise from interoperability gaps between energy-market platforms and industrial IT systems, reliance on accurate forecasts and potential conflicts between production constraints and energy market dynamics. Thus, in this example, we can see that energy data can be shared as a supporting resource across multiple actors who can then react to what that energy data informs them, with the energy production being from multiple actors.

Involved Stakeholders

Industrial producers, distribution system operators (DSOs), market operators and ICT providers.

Related TCs:

- ISO/TC 301 – Energy management and energy savings
- ISO/IEC JTC 1 – Information technology (smart-grid information models)

Related Standards and Deliverables (selected)

- ISO 50001 – Energy management systems
- ISO 17800 – Facility smart grid information model

Recommendations - Regulation

Ensure transparent, timely and non-discriminatory access to price, market and grid-status data for industrial users across Member States.

Recommendations - Standardisation

Define interfaces and data formats for integrating market signals into production-planning and MES systems, ensuring compatibility across industrial sectors and energy-market platforms.

GENERAL NEEDS AND RECOMMENDATIONS

Across all identified synergies, the deployment of IS in energy systems is limited by technical, organisational and governance-related barriers. Interoperability gaps are a persistent challenge: existing metering, monitoring and control systems often rely on incompatible data formats, units, time resolutions and communication protocols, restricting integration of industrial actors into grid operations and limiting coordination across sectors. Limited data visibility further constrains potential exchanges, as high-frequency and granular information on local energy flows, production and consumption is frequently unavailable or not collected. This hampers the identification of flexibility potentials, shared-storage opportunities and local energy-exchange models.

Uncertainty around data governance also affects uptake. Divergent rules on data ownership, access rights and liability across Member States discourage the sharing of operational data and reduce trust between industrial users, DSOs and aggregators. Regulatory fragmentation creates uneven conditions for participating in flexibility markets, shared renewable-energy schemes or community-level energy exchange. Security and trust issues — including concerns over cybersecurity, misuse of commercially sensitive information and the absence of certification schemes — limit willingness to adopt interoperable digital solutions. Overcoming these challenges requires harmonised regulation, secure and interoperable data-exchange standards and contractual frameworks that clarify responsibilities and safeguard sensitive information.

Related Policy and Standardisation Deliverables

- EU Electricity Market Design reform
- EU Data Act
- Network Code on Demand Response
- ISO 17800:2017 – Facility smart grid information model
- IEC 61360 – Standard data element types with associated classification scheme
- IEC SRD 63200 – Extended SGAM smart energy grid reference architecture
- IEC 61427-1 / 61427-2 – Batteries for renewable-energy storage (off-grid/on-grid applications)
- IEC 63382 – Management of distributed energy storage systems based on EVs
- ISO/IEC 30162:2022 – IIoT compatibility requirements and network models
- IEC 62443 series – Industrial control and automation cybersecurity
- ETSI IoT Standards – Interoperable and secure IoT frameworks
- IEC 61850 – Communication networks and systems for power-utility automation
- IEC 62056 series – DLMS/COSEM metering data exchange
- ISO 50001 – Energy management systems

Recommendations - Regulation

- Harmonise national rules governing aggregator participation, local-energy community models and direct-line or collective self-consumption arrangements.
- Ensure transparent and non-discriminatory access to grid, market and price data for industrial actors across Member States.
- Establish minimum cybersecurity and data-protection requirements for energy-related data exchange.

Recommendations - Standardisation

- Develop interoperability standards for metering, monitoring and control systems, including common data formats, units and communication protocols.
- Create certification schemes and trust frameworks for secure energy-data exchange to address confidentiality and security concerns.
- Standardise interfaces for integrating storage, demand response and distributed generation into industrial sites and local grids.
- Define common contractual templates and settlement procedures for local energy-exchange arrangements.
- Align energy-data exchange standards with broader EU initiatives such as the Data Act, the Digital Product Passport and sector-specific network codes.

B. DIGITAL PRODUCT PASSPORT

The Digital Product Passport (DPP) is emerging as a central instrument within the ESPR, intended to improve the availability, quality and interoperability of lifecycle data across European value chains. Within the context of industrial symbiosis, the DPP offers a structured mechanism for linking materials, components and products to machine-readable information on their composition, use history and sustainability attributes. Several chapters in this roadmap recognised the value of DPPs in improving traceability and enabling more informed decisions on reuse, repair, remanufacturing and recycling. This is already evident in the battery sector, where DPP attributes are developed to support condition assessment, safe handling and the development of digital twins that facilitate cross-sector integration and second-life applications. Similar opportunities exist in other domains where more granular and harmonised data could improve the circulation of resources between industries.

DPPs are the subject of significant regulatory and standardisation activity. The ESPR establishes the overarching requirements, while the European Commission's standardisation request M/604 sets out the development of the technical system architecture and data specifications. For sectors such as batteries, further elements are defined under the Batteries Regulation, including the digital battery passport and associated datasets. Because of this ongoing and anticipated work, there are no additional areas where standards specific to IS would be recommended. Instead, the primary task for the coming years from a symbiosis perspective will be to ensure coherence between emerging DPP structures and other enablers discussed in this roadmap.

The usefulness of DPPs for IS will depend on the practical interoperability of datasets across systems. Many of the digital tools considered in this roadmap, such as digital twins, matchmaking tools and resource-classification schemes, require consistent, machine-readable information that can be exchanged securely between actors. As DPP implementations progress, their integration into broader data ecosystems, including data spaces and sector-specific digital platforms, as supported by CEN-CENELEC JTC 24 'Digital Product Passport' as well as CEN-CENELEC JTC 25 'Data management, Dataspaces, Cloud and Edge', will shape the extent to which IS can benefit from improved transparency and traceability. In this sense, the DPP should be seen as a complementary building block within a larger digital infrastructure rather than a standalone solution.

Given the maturity of ongoing standardisation efforts, no immediate new standardisation activities are proposed at this stage. However, the roadmap recommends continued monitoring of developments under ESPR and related regulations, as well as early engagement with TCs responsible for DPP implementation. This will allow IS considerations to be reflected in future iterations of the passport. As sectoral DPPs mature, further opportunities may arise for aligning their datasets with IS applications, especially in areas where shared information could facilitate safe and efficient resource exchange across value chains.

C. KNOWLEDGE, SKILLS & CAPACITY

The implementation of industrial symbiosis across European value chains depends not only on technical standards and regulatory clarity but also on the availability of the appropriate skills, operational capacities and organisational capabilities within companies, public authorities and supporting institutions. Skills shortages present a structural barrier to scaling industrial symbiosis. These gaps extend across multiple domains: technical expertise in handling new separation, diagnostics and recovery technologies; operational know-how for safe dismantling, disassembly and testing; and digital capabilities required to manage data, use digital twins, interpret lifecycle information or work with emerging tools such as Digital Product Passports.

These challenges appear in sectors as diverse as batteries, packaging, waste heat, textiles and biomass. In the battery value chain, the lack of trained personnel in safe handling, State of Health testing, disassembly protocols and the management of live components was repeatedly raised as a constraint. In the waste-heat and energy-data domains, specialised knowledge is needed to operate monitoring systems, interpret metering data and engage with interoperability frameworks being developed at European level. Packaging and textiles exhibit similar gaps in relation to sorting, characterisation and quality-assessment methods, while biomass and waste-wood streams require expertise in contamination control, cascading use and material grading. Collectively, these shortages reduce the reliability, safety and scalability of potential symbiosis arrangements.

Beyond technical knowledge, capacity constraints include the limited ability of many companies, especially SMEs, to engage effectively with complex regulatory requirements and to adopt the digital tools or reporting systems that IS increasingly depends on. Several groups highlighted that unclear responsibilities, evolving legislation and fragmented information sources increase the perceived risk of participating in symbiosis arrangements. As a result, companies often lack the confidence, internal procedures or staff competencies needed to identify opportunities, evaluate compliance implications or implement new processes. This reinforces the need for targeted support measures that bolster organisational capacity, not just technical skills.

Given that these gaps are systemic rather than sector-specific, they require cross-cutting approaches that complement the technical and regulatory recommendations outlined elsewhere in the roadmap. The discussions point to the need for comprehensive training programmes covering disassembly, diagnostics, resource characterisation, heat-recovery technologies and digital competencies; certification schemes that validate skills relevant to industrial symbiosis; capacity-building initiatives for SMEs; and mechanisms that facilitate knowledge exchange between industries, research organisations and standardisation bodies. Alignment with broader EU initiatives, such as the ERA Policy Agenda and the European Skills Agenda, can provide a supportive environment for rolling out these measures and ensuring coherence across policy instruments.

In the context of standardisation, skills and capacity building play a dual role. On the one hand, they are necessary for the effective adoption and implementation of standards emerging from this roadmap. On the other, standardisation itself can help define training requirements, competence profiles and operational practices that enhance safety, reliability and interoperability across sectors. As IS scales, a stronger skills base will be essential for translating technical possibilities into practical, widely adopted solutions.

D. GOVERNANCE, CONTRACTING & INFORMATION SHARING FRAMEWORKS

Effective governance arrangements and clear contractual frameworks are essential for enabling industrial symbiosis to function reliably across sectors and jurisdictions. While technical and regulatory enablers form the structural foundation for symbiosis, many of the most persistent barriers arise from uncertainties around responsibilities, liability, confidentiality and information governance. These challenges affect both established symbiosis practices and emerging exchanges, and they are often amplified by the absence of standardised approaches to collaboration, data sharing and contractual design.

Across the sectors analysed in this roadmap, IS transactions typically require an unusual degree of interdependence between companies. Exchanges of waste, by-products, heat or materials frequently span different regulatory regimes, technical cultures and commercial environments. In this context, companies seek clarity on who bears responsibility for the quality and safety of transferred materials, how liability is managed in the event of failures, and which information must or may be disclosed to partners. The inconsistent application of waste legislation, especially fragmentation in the field of End-of-Waste, further complicates these issues, as actors must navigate overlapping product rules, waste requirements and contractual obligations when structuring exchanges.

Concerns over confidentiality and IP are common barriers. Companies are often reluctant to share operational data, compositional information or process details that may be commercially sensitive. While there is a potential role of standardised confidentiality clauses, trust frameworks or shared governance principles, there is no clear path toward formal standardisation in this area due to the variability of industrial contexts and the risk of creating rigid prescriptions that inhibit innovation. Governance solutions must balance flexibility with legal certainty, allowing actors to tailor arrangements while benefiting from common principles that reduce transaction costs.

Information-sharing challenges also extend to situations in which data availability is technically possible but organisationally constrained. For instance, the battery sector highlighted the need for access to diagnostic and testing information to enable second-life applications, yet companies raised concerns about data sensitivity and unclear responsibilities for managing shared information. Similarly, the textiles, packaging and biomass sectors described limited transparency in supply chains, which reduces confidence in the suitability of secondary materials and hampers cross-sector matching. These issues point to the need for more transparent and predictable governance frameworks that align with digital developments such as product passports, enhanced metadata standards and emerging data spaces.

IS frequently requires contractual arrangements that are unfamiliar to many companies. These include agreements for long-term supply of variable-quality materials, shared ownership or operation of infrastructure, and performance-based or service-based models for energy and resource exchanges. The absence of widely used templates means that actors often develop bespoke contracts, which increases legal and administrative effort and can result in inconsistent or insufficiently robust arrangements. Harmonised templates or guidance, where appropriate, could therefore support more widespread uptake by reducing uncertainty and facilitating transactions, particularly for SMEs.

Taken together, these findings highlight governance and contracting as system-level enablers that underpin all other elements of industrial symbiosis. While many issues fall outside the immediate scope of standardisation, the roadmap recognises that governance structures influence the practical feasibility of exchanges and the extent to which organisations can rely on shared data, common terminology and interoperable systems. As digitalisation and regulatory developments progress, opportunities may arise to formalise aspects of information governance, liability allocation or contractual design in ways that support safe, transparent and scalable symbiosis practices.

E. INFRASTRUCTURE & SPATIAL PLANNING FOR INDUSTRIAL SYMBIOSIS

Industrial symbiosis depends not only on regulatory clarity, data availability and organisational capacity but also on the physical and spatial conditions that make exchanges feasible. Several barriers were repeatedly identified that relate to the availability, interoperability and geographic distribution of infrastructure. These include limitations in transport networks for materials and intermediates, insufficiently coordinated district heating or cooling systems, constrained storage and pre-treatment facilities, and the absence of shared logistics platforms that allow multiple actors to utilise common resources efficiently. Such gaps restrict the practical viability of exchanges even when technical and regulatory conditions are favourable.

Spatial planning emerged as a particularly significant enabler. Many IS opportunities require close physical proximity, whether for the recovery of excess heat, the transport of biomass or waste wood, or the movement of materials such as slags, textiles, or packaging residues. Co-location within industrial parks or clusters reduces logistical costs, helps align environmental permitting, and facilitates the creation of shared services for sorting, treatment, or energy recovery. Yet in many regions, planning processes do not explicitly consider IS potential, resulting in fragmented industrial layouts or zoning rules that hinder the development of shared facilities. Similarly, local and regional planning authorities may lack the data or expertise needed to integrate symbiosis considerations into spatial strategies.

Several sectors illustrated these challenges clearly. In waste heat recovery, the absence of district heating infrastructure or suitable pipeline routes can prevent viable projects from being implemented even when waste heat sources and potential users are located relatively close to one another. For biomass and waste-wood applications, transport distances, storage requirements and contamination risks require dedicated facilities that are not always available or aligned with regional planning. Packaging and textile recycling rely heavily on sorting and pre-treatment infrastructure, which varies significantly across Europe and often lacks interoperability or sufficient capacity. These conditions shape the feasibility, scale and reliability of IS pathways.

Infrastructure challenges also interact closely with regulatory and economic uncertainties. Companies are often reluctant to invest in shared facilities if long-term access to feedstocks is uncertain or if divergent regulatory interpretations limit the movement of materials across borders. High upfront capital costs for treatment plants, pipelines or thermal networks further constrain adoption, particularly for SMEs. Investments are more feasible when supported by stable governance frameworks, long-term contracting models and coordinated planning among municipalities, industrial clusters and energy system operators.

From the perspective of standardisation, the discussions suggest that infrastructure and spatial planning are system-level enablers rather than topics for immediate technical standardisation. The main bottlenecks relate to coordination, visibility and alignment across actors rather than to gaps in existing technical specifications. However, standards can indirectly support infrastructure development by providing common approaches to quality assurance, monitoring, data integration and safety, elements that enable infrastructure to function across sectors and jurisdictions. As regions move towards more integrated planning for energy, waste and resource systems, further opportunities may emerge to formalise shared methodologies or guidelines that support IS at the territorial level.

Overall, strengthening infrastructure and spatial planning is essential to unlocking the full potential of industrial symbiosis. By addressing constraints in logistics, storage, heat networks and industrial zoning, and by fostering coordination between local authorities, system operators and industry, Europe can create the physical foundations necessary for the scalable and resilient exchange of materials and energy across value chains.

F. ECONOMIC & FINANCIAL ENABLERS

Industrial symbiosis relies on economic conditions that make resource exchanges viable, competitive and resilient over time. Promising symbiosis opportunities may fail to materialise not due to technical limitations, but because the financial incentives, risk profiles or market conditions do not support long-term investment. These constraints impact sectors differently but follow a common pattern: high upfront costs, uncertainty regarding feedstock availability, volatile commodity prices, and the absence of stable business models capable of distributing benefits and risks among actors.

One of the central challenges concerns the cost structure of symbiosis projects. Whether implementing advanced sorting infrastructure, establishing heat-recovery systems, or building pre-treatment facilities for biomass, companies face significant capital expenditure that may not be recoverable without predictable flows of materials or energy. This creates a perceived investment risk, particularly when exchanges involve secondary materials whose quality or classification status remains uncertain. Divergent regulatory interpretations, for example concerning End-of-Waste criteria, amplify this uncertainty by affecting market access and cross-border logistics. As a result, industries tend to favour existing waste management or energy solutions that may be less resource-efficient but offer greater regulatory and financial predictability.

Price volatility further complicates investment decisions, particularly in sectors such as packaging, textiles, or battery materials. Global price fluctuations for virgin materials can make secondary materials temporarily uncompetitive, reducing the economic rationale for establishing new processing or reuse pathways. Without mechanisms that reward environmental benefits or compensate for market instability, IS initiatives struggle to achieve the scale needed for economic resilience. SMEs feel these effects most acutely, as they often lack financial buffers or access to low-cost capital to experiment with new symbiosis arrangements.

There is a need for financial instruments and contracting models accounting for the characteristics of industrial symbiosis: Long-term off-take agreements, heat purchase agreements, power purchase arrangements, and shared-ownership models are important tools for distributing investment risk and stabilising revenue streams. In energy-related symbiosis, agreements that clarify responsibilities and value distribution between suppliers, users and system operators can help accelerate deployment. However, the absence of commonly used templates or guidance means that these arrangements are often negotiated on a case-by-case basis, increasing transaction costs and slowing adoption.

Public incentives and support schemes play a crucial role in shifting these dynamics. Targeted subsidies, tax incentives, premium tariffs or risk-sharing mechanisms could help bridge the initial viability gap for many symbiosis projects, especially in sectors where new infrastructure or technologies are required. Such instruments can also level the playing field for secondary materials by accounting for their environmental benefits and reducing dependence on fossil-fuel-based processes. Aligning these incentives with broader EU policy frameworks, such as CE goals, renewable energy targets and the Zero Pollution Action Plan, but also the Horizon Europe funding programme, can further strengthen investment confidence.

While economic and financial barriers do not directly translate into standardisation needs, they shape the environment in which standards are adopted and applied. Reliable economic signals encourage companies to invest in quality-assurance processes, data-sharing systems and interoperable infrastructures, all of which are essential for scaling industrial symbiosis. Conversely, weak or inconsistent economic conditions undermine the implementation of technical solutions, even when standards exist. The roadmap therefore recognises economic and financial enablers as integral to the systemic conditions required for symbiosis to thrive. Strengthening these mechanisms will support the uptake of the technical, regulatory and operational recommendations presented across this document and help ensure that industrial symbiosis becomes a competitive and sustainable element of Europe's industrial landscape.

6. OUTLOOK AND NEXT STEPS

The roadmap presented in this document marks the first consolidated articulation of the standardisation needs, regulatory considerations and system-level enablers required to support industrial symbiosis across European value chains. It reflects the insights generated through the RISERS project, involving about 120 experts, the cross-cutting analyses with Chapter 3, and the sector perspectives explored in Chapter 4. As a public document, it serves as a starting point for a broader consultation process with industry experts, standardisation bodies, policymakers and other stakeholders.

During 2026, the roadmap will be refined through structured feedback from CEN and CENELEC TCs, NSBs and NCs, industrial associations and public authorities. This process ensures that the recommendations are technically robust, aligned with regulatory developments and responsive to the practical needs of practitioners. The consultation will also help determine where standardisation actions are already under way, where additional initiatives are required, and where further coordination between sectors could deliver the greatest impact.

In parallel, the RISERS consortium continues to synthesise knowledge emerging from ongoing policy discussions, industrial initiatives and European research programmes. This iterative approach allows the roadmap to evolve alongside developments such as the implementation of the Ecodesign for Sustainable Products Regulation, the discussions around the upcoming CEA, and insights arising from digitalisation and energy systems integration.

The final version of the roadmap, to be published following the public consultation phase, will provide a clearer pathway for action. It will support CEN and CENELEC TCs in identifying priority areas for standardisation, guide policymakers in improving regulatory coherence and enable industry to engage in symbiotic practices with greater confidence. By strengthening the enabling conditions discussed in this document, the roadmap aims to contribute to a more resource-efficient, resilient and interconnected industrial ecosystem in Europe.

ANNEXES

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II. LIST OF ACRONYMS

Abbreviation	Explanation of abbreviation
3P	People- Planet- Profit
ADR	Agreement concerning the International Carriage of Dangerous Goods by Road
AI	Artificial Intelligence
AIT	Advanced Industrial Technologies
API	Application Programming Interface
B2B	Business-to-Business
BAFA	Federal Office for Economic Affairs and Export Control (Germany)
BATT2	EU Batteries Regulation (Regulation (EU) 2023/1542)
BEPA	Bureau of European Policy Advisers
BF	Blast Furnace
BMS	Battery Management System
BOF	Basic Oxygen Furnace
BSS	Battery Storage System
BT	Technical Board
CAPEX	Capital Expenditure
CCRI	Circular Cities and Regions Initiative
CCS	Carbon Capture and Storage
CE	Circular Economy
CEAP	Circular Economy Action Plan
CEN	European Committee for Standardization
CEN/CLC JTC	CEN-CENELEC Joint Technical Committee
CENELEC	European Committee for Electrotechnical Standardization
CLP	Classification, Labelling and Packaging Regulation
CO_2	Carbon Dioxide
CPR	Construction Products Regulation
CRM	Critical Raw Materials
CSRD	Corporate Sustainability Reporting Directive
CSRD	Corporate Sustainability Reporting Directive
DEC	Websites, patent filings, videos, etc
DIN e.V.	Deutsches Institut für Normung e.V.
DMP	Data Management Plan
DPP	Digital Product Passport
DRI	Direct Reduced Iron
DRI-EAF	Direct Reduced Iron – Electric Arc Furnace
DRI-SAF	Direct Reduced Iron – Submerged Arc Furnace
DSO	Distribution System Operator
EAF	Electric Arc Furnace
EC	European Commission
EED	Energy Efficiency Directive
EIT	European Institute of Innovation and Technology
EIT-RM	EIT Raw Materials GmbH
ELV	End-of-Life Vehicles
EN	European Standard
ENSPIRE	Enspire Science Ltd
ENV	Environment
EoW	End of Waste
EPC	European Product Classification
EPOS	European Plate Observing System
EPR	Extended Producer Responsibility
ERA	European Research Area
ERF	Energy Recovery Facility
ERP	Enterprise Resource Planning
ESPR	Ecodesign for Sustainable Products Regulation
EU	European Union
EUR	Euro
EV	Electric Vehicle
EWC	European Waste Catalogue
FhG	Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V.
GA	Grant Agreement
GHG	Greenhouse Gas
GIS	Geographic Information System
GJ	Gigajoule
GS1	Global Standards One (data standardisation organisation)
H_2	Hydrogen
ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IETU	Instytut Ekologii Terenów Uprzemysłowionych
IP	Intellectual Property
IPR	Intellectual Property Rights
IS	Industrial Symbiosis
ISL	International Synergies Ltd
ISO	International Organization for Standardization
ISQ	Instituto de Soldadura e Qualidade
JTC	Joint Technical Committee
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LESTS	Legal, Economic, Spatial, Technical, Social (analysis method)
LPG	Liquefied Petroleum Gas
MFA	Material Flow Analysis
MS	Member State

Abbreviation	Explanation of abbreviation
NACE	Statistical Classification of Economic Activities in the European Community
NC	National Committee (IEC member)
NGO	Non-Governmental Organisation
NIS	Network and Information Security
NSB	National Standards Body (ISO member)
OEM	Original Equipment Manufacturer
OPEX	Operating Expenditure
PCB	Printed Circuit Board
PCR	Product Category Rules
PE	Polyethylene
PEDR	Plan for the Exploitation and Dissemination of Results
PP	Polypropylene
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
PPWR	Packaging and Packaging Waste Regulation
PU	Public
PV	Photovoltaic
PV	Photovoltaics
R&D	Research and Development
R&D	Research and Development
R&I	Research and Innovation
RED	Renewable Energy Directive
RED III	Renewable Energy Directive (Directive (EU) 2023/2413)
RES	Renewable Energy Sources
RTO	Research and Technology Organisation
SAE	Society of Automotive Engineers
SC	Steering Committee
SDG	Sustainable Development Goal
SME	Small and Medium-Sized Enterprise
SoH	State of Health
TC	Technical Committee
TRL	Technology Readiness Level
TS	Technical Specification
UGent	Universiteit Gent
WEEE	Waste Electrical and Electronic Equipment
WG	Working Group
WMS	Waste Management System
WP	Work Package

III. DOCUMENT HISTORY

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