Identification of barriers to industrial symbiosis

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Table of content

Summary

Industrial symbiosis (IS) is a practical expression of the circular economy in which under-utilised resources, materials, energy, water, by-products, or expertise, generated by one company or sector are put to productive use by another, generating mutual economic, environmental and social benefits. The European steel industry, as one of the largest generators of solid, gaseous and liquid by-products among the energy-intensive industries, has been an early and active participant in symbiotic exchanges/ transactions, both by supplying its by-products (slags, dusts, sludges, off-gases) to other value chains and by absorbing residues from other sectors (biomass, plastics, off-gases from ammonia/urea production) into its own processes. This deliverable focuses specifically on the Symbio-Steel project analysis of non-technical barriers that constrain the wider deployment of IS in the steel sector: the social, regulatory, economic, organisational and informational obstacles that persist even where a technically sound symbiotic solution exists.

1.Introduction

The Symbio-Steel project aims to accelerate the adoption of IS solutions within the European steel sector by promoting cross-sectoral collaboration, resource efficiency, and circular economy strategies. Building on the objectives of the European Green Deal[1], the project focuses on identifying opportunities to transform steel industry by-products, residues, and energy streams into valuable resources for other industrial sectors. Through the monitoring and dissemination of outcomes from previous national and European projects, Symbio-Steel supports the development of sustainable industrial networks capable of reducing waste generation, lowering CO_2 emissions, and decreasing dependence on virgin raw materials.

The deliverable addresses one of the key challenges limiting the broader implementation of IS in the steel industry: the existence of non-technical barriers. While technological solutions for IS are increasingly available, factors such as regulatory complexity, economic uncertainty, organizational structures, stakeholder engagement, and social acceptance continue to hinder their large-scale deployment. This deliverable therefore aims to identify and analyse these barriers through a comprehensive review of scientific literature, industrial case studies, and best practices, including both successful and unsuccessful examples of symbiotic cooperation in the steel sector. Based on the findings, the study will derive recommendations and policy guidelines intended to facilitate IS implementation, strengthen intersectoral cooperation, and support the transition toward a more resilient and climate-neutral European steel industry.

[1] European Commission, Communication No. 640, 2019. The European Green Deal; (COM No. 640, 2019), Commission of European Communities, Brussels, Belgium, 2019

2. Industrial Symbiosis in the Steel Industry: Overview

2.1 Two directions of by-product utilisation

IS in the steel sector can be usefully organised around two complementary flows. The first is the external utilisation of by-products generated by the steel industry, whereby residues from ironmaking and steelmaking become inputs to other value chains. The second is the internal utilisation, within iron and steel production, of by-products and residues generated by other industries. Both directions are actively pursued across Europe, and both are subject similar non-technical barriers, even though the specifics might differ.

2.1.1 External use of steel by-products

Ironmaking and steelmaking slags (e.g. blast furnace (BF), basic oxygen furnace (BOF), electric arc furnace (EAF) and ladle furnace (LF) slags) are the principal solid by-products of iron and crude steel production, amounting to roughly 10–20% of crude steel mass[2]. The slags production account for about 77% of by-products in the steel industry[3]. BF slag generated in Europe in 2023 was used, mainly as a cement and concrete addition or in road construction, while about 80% of steel slags (BOF, EAF, LF) were valorised in road construction, further metallurgical recovery, fertiliser, hydraulic engineering and cement/concrete addition. Portland blast-furnace cement, made by inter-grinding or blending Portland clinker with granulated BF slag, is one of the most mature and widespread examples of external by-product use.

While slag research is focused on the physical/environmental properties of the material, other barriers hinder its valorisation. As an example, EU trade in slag-based products remains limited: bulk transport costs means that slag valorisation is generally confined to a radius of some 150–200 km around the steel plant, and cross-border trade in ferrous slags across the

[2] Colla, V., Branca, T.A., Petrucciani, A., Sergi, C., Mirabile, D., Cirilli, F., Morillon, A., Algermissen, D., Wang, C., Nylund, E., Yu, H., Jarnerud Örell, T., Rieger, J., Kieush, L., Snaet, D. (2026). Recent achievements of Industrial Symbiosis in the steel sector based on the Symbio-Steel project: a review. Matériaux & Techniques, 114(1), 103

[3] Euroslag Association 2021 (www.euroslag.com)

EU has been estimated at under 1% of the roughly 48 million tonnes produced annually[4]. This is as much a market and regulatory phenomenon as a logistical one and is discussed further in Section 3.

Another successful symbiosis stream is zinc-bearing EAF dusts where approximately 250,000 tons per year of zinc are recovered in Europe through the pyrometallurgical Waelz process[2]. Steelworks off-gases (BF gas, coke oven gas, BOF gas) rich in carbon monoxide and hydrogen are mainly used internally to substitute natural gas or to generate electrical energy. However, they represent also an emerging external symbiosis pathway, being investigated and, in some cases, industrially deployed as a carbon feedstock for the chemical industry, replacing fossil-based feedstocks[5].

2.1.2 Internal use of by-products from other industries

The steel sector absorbs residues generated elsewhere as partial substitutes for fossil carbon and virgin raw materials. Carbon-bearing materials such as biomass-derived char (biochar), selected waste plastics and rubber residues can partially replace coal, coke or natural gas in several iron and steelmaking routes, contributing to CO_2 emission reduction when the substituted material is of fossil origin[2]. In cokemaking, biomass or its pyrolysis products can typically be blended with coal at around 2–10% of the coal charge before coke strength and reactivity are compromised; in iron-ore sintering, biomass-derived char can replace part of the coke breeze, with laboratory and pilot scale replacement ratios of up to 60% reported, although this remains largely at the experimental rather than industrial stage. In the BF, waste plastics can be injected through the tuyeres together with pulverised coal, with industrial applications demonstrating injection rates of about 60–80 kg per tonne of hot metal; in EAF steelmaking, plastics, biochar, waste rubber and fine carbon residues from other industries can substitute part of the carbon charge, with polyethylene substitution rates of around 30% reported under favourable feed-preparation conditions[2].

Another symbiosis pathway are steelworks off-gases used as feedstock for the production of ammonia and urea in production of fertilizers, an approach explored in depth within the Horizon 2020 INITIATE project[6], which reported net CO_2 emission reductions of the order of 1,365–1,546 kg CO_2-equivalent per ton of steel compared with a reference case, alongside higher CO_2 avoidance rates and lower CO_2 capture costs[2].

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[4] Handley P. and Vasuyau V. (2020). Legal and environmental bottlenecks and opportunities for slag based products valorisation. 6th International Slag Valorisation Symposium, Mechelen, Belgium.
[5] Metabolic (2023). Industrial symbiosis between the steel and chemicals industries. Metabolic project report
[6] Innovative industrial transformation of the steel and chemical industries of Europe (INITIATE): https://www.initiate-project.eu/

2.2 Why non-technical barriers matter

Even where such exchanges are technically demonstrated at pilot or industrial scale, uptake is frequently constrained by factors unrelated to process feasibility. A recurring finding across the literature and HEU/RFCS research projects is that IS implementation is affected not only by technological, economic and infrastructural obstacles, but equally by regulatory, organisational, social and cultural ones, and that many companies simply lack awareness of IS as a viable strategic option. The remainder of this report focuses on these non-technical dimensions.

3. Non-Technical Barriers: Literature Review Findings

Analysis of the literature and HEU/RFCS projects for technological, economic, regulatory or policy, informational, organisational, social and geographical barriers to IS have been done as part of the Symbio-Steel project. The non-technical categories most relevant to the steel sector are regulatory and legal barriers; economic and market barriers; organisational and managerial barriers; informational barriers; and social and cultural barriers. These categories are not mutually exclusive and interact strongly in practice, as illustrated in Section 4.

3.1 Regulatory and legal barriers

The single most frequently cited non-technical barrier specific to by-product utilisation is the legal status of secondary materials under EU and national waste legislation. Under the Waste Framework Directive (Directive 2008/98/EC)[7], a residual material may be classified either as waste, as a by-product (Article 5), or, following a recovery operation, as having achieved end-of-waste status (Article 6) if it satisfies four cumulative conditions: it is commonly used for a specific purpose, a market or demand exists for it, its use is lawful, and its use will not lead to overall adverse effects on the environment or human health (European Commission Waste Framework Directive guidance; Knowledge for Policy glossary). EU level end-of-waste criteria have so far been established only for a limited set of streams (iron, steel and aluminium scrap (Regulation (EU) No 333/2011), glass cullet, and copper scrap) leaving most steel by-products, including several slag types, dependent on national or single case end-of-waste decisions that vary in stringency and timeframe across Member States.

This patchwork creates real barriers in practice. Whether a given slag is treated as a by-product or as waste depends on the specific metallurgical route and its subsequent handling: for instance, granulated BF slag intended for cement production can generally be considered a by-product falling outside the waste definition, whereas desulphurisation slag, being rich in sulphur and unsuitable for recycling within the metallurgical circuit, is typically disposed of as waste[7]. Legal uncertainty of this kind raises transaction costs, discourages investment in valorisation infrastructure, and can trigger waste shipment or landfill obligations that make an

[7] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

otherwise viable symbiotic exchange commercially unattractive. Distinct legal question concerns the interaction between end-of-waste status and the REACH Regulation. Once a residue-based material is no longer classified as waste, it may fall under REACH registration and evaluation requirements applicable to ordinary chemical substances, adding cost and complexity to the development of novel symbiosis products[8/9].

Regulatory fragmentation across Member States compounds the problem for a sector that is, by nature, transboundary. A synthetic case study of steel, pulp and paper process-industry residues used to assess the development potential of symbiosis products against EU legal requirements found that institutional barriers, rather than technical ones, were the principal constraint on scaling up such products, and recommended the cooperative, joint design of incentives, policies and regulations across the institutions involved[8,9]. Conflicting or unclear regulations, complex approval processes and bureaucratic hurdles have been repeatedly identified as barriers that slow IS implementation and cross-sectoral collaboration[2,10].

3.2 Economic and market barriers

Economic barriers centre on the absence of a mature market for secondary materials and on the distribution of costs and risks between potential symbiosis partners. Low demand for recycled materials, limited market size, and the systematically low valuation of exchange materials relative to virgin substitutes have been identified as significant barriers to achieving circular economy through IS[2]. Overcoming them is said to require policy-driven market reforms, green public procurement, and harmonised international regulations capable of supporting a more competitive secondary-materials economy.

At plant level, internal barriers are often rooted in operational strategy with the risk of variation in by-product generation, insufficient effort devoted to finding new uses for surplus material, and excess or shortfall in by-product availability relative to demand, together with high processing or logistics costs and associated risks, were identified as key obstacles in a study of a Brazilian manufacturing network centred on cement and steelmaking industries[11].

[8] Husgafvel, R., Nordlund, H., Heino, J., Mäkelä, M., Watkins, G., Dahl, O., Paavola, I.-L. (2016). Use of symbiosis products from integrated pulp and paper and carbon steel mills: legal status and environmental burdens. Journal of Industrial Ecology, 20(6), 1187–1198

[9] Pajunen, N., Watkins, G., Husgafvel, R., Dahl, O., Heiskanen, K. (2013). Overcoming institutional barriers in the development of novel industrial residue based symbiosis products – case study at the national level in Finland. Minerals Engineering, 46–47, 144–156.

[10] Rahman, M.F., Islam, K., Islam, K.N. (2016). Industrial symbiosis: a review on uncovering approaches, opportunities, barriers and policies. Journal of Civil Engineering and Environmental Sciences, 2, 011–019.

[11] Sellitto, M.A., Kazuhiro Murakami, F., Butturi, M.A. et al. (2021). Barriers, drivers, and relationships in industrial symbiosis of a network of Brazilian manufacturing companies. Sustainable Production and Consumption, 26, 443–454

Insufficient access to capital compounds this picture: limited financial resources, and in particular a lack of funds for the initial investment required to adapt facilities or acquire specialised knowledge, disproportionately affect small and medium-sized enterprises (SMEs), which frequently lack the balance-sheet capacity to absorb the payback periods typical of IS investments. Illustrating the scale of the challenge, an assessment of the potential for using industrial waste heat in local district-heating networks found first order economic advantages of up to 23% cost reduction, but also identified payback periods exceeding the roughly five year threshold considered normal by industry, together with heat pricing and grid connection costs, as real barriers to project implementation, underscoring the continuing need for policy intervention to make such projects feasible[12].

The bulky, low value nature of many steel by-products (e.g. slags) means that transport costs quickly erode any economic advantage beyond a limited radius, which helps explain why cross-border trade in ferrous slag within the EU remains marginal despite significant production volumes. Fluctuating demand for by-products, whether driven by construction sector cycles or by commodity prices for competing virgin materials, further reduces the attractiveness of long-term symbiotic investment.

3.3 Organisational and managerial barriers

Organisational barriers relate to the internal culture, governance and inter firm relationships that determine whether a technically and economically viable symbiosis is actually pursued. Identified barriers include competition among industries, a lack of environmental concern or management support, resistance to change, weak collaboration, insufficient institutional support, lack of trust, and unequal power, status, time or spatial resources among potential partners as recurring organisational obstacles, alongside limited awareness of the IS concept itself and low employee engagement[2]. Lack of organisational trust, resistance to change and weak communication networks reduce the ability of firms to form and sustain IS partnerships, while a lack of institutional support constrains the regulatory reforms that would otherwise facilitate adoption.

Business confidentiality is a particularly persistent organisational barrier in the steel sector, where firms may be reluctant to disclose detailed information on production volumes, by-product composition or process schedules for competitive or strategic reasons. This confidentiality can generate an information asymmetry between potential partners (what has been described in the German language literature as an ‘Industrial Symbiosis Gap’), whereby

[12] Bottecchia, L., Kranzl, L., Zambelli, P. (2024). Driving industrial symbiosis: evaluating policy intervention effects on waste heat utilization in local district heating networks. Energy and Buildings, 324, 114865

the absence of shared, trustworthy data on waste and by-product flows prevents otherwise complementary companies from identifying each other as partners[13].

The role of the facilitator, a neutral third party managing the complexity of matching partners, brokering trust and mediating between industry, local government and public institutions, has repeatedly emerged as decisive for overcoming organisational barriers[14,15]. Facilitators can create awareness, screen firms, map local resources, and cultivate the collaborative culture on which symbiosis emergence depends. They can fill in the missing knowledge where facilitation capacity is absent, discontinuous, or under resourced, promising synergies frequently fail to progress beyond an initial feasibility discussion.

3.4 Informational and knowledge barriers

Closely related to, but distinct from, organisational trust barriers are informational barriers concerning the availability, quality and accessibility of data on by-products and waste flows. These include the lack of information about by-products and waste streams generated by other companies, insufficient technical and training information, weak operational information management, poor information-sharing mechanisms, and unclear job roles and responsibilities for managing symbiotic exchanges[2]. Poor information sharing reduces the pool of potential symbiotic opportunities for companies that would otherwise operate in isolation, and the lack of accessible information prevents firms from adopting technological solutions that could otherwise facilitate implementation.

The scarcity or poor quality of data on waste streams, generated across multiple, often geographically dispersed, sites is a specific technical informational barrier that raises the cost of collecting and processing the information needed to identify a match. Business associations, local governments and public institutions can play an important role in building the bonds of trust needed to overcome this barrier and in publicising success stories that lower the perceived risk of engaging in IS for the first time. The development of shared, sector specific databases and of digital matching platforms is widely proposed as a partial remedy, though the lack of dedicated IS training programmes for company staff remains a barrier to their effective use.

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[13] Rodin V and Moser S. (2021). The perfect match? 100 reasons why energy cooperation is not realized in industrial parks. Energy Research & Social Science, Volume 74, 2021, doi.org/10.1016/j.erss.2021.101964.
[14] Schluter, L., Mortensen, L., Drustrup, R. et al. (2022). Uncovering the role of the industrial symbiosis facilitator in literature and practice in Nordic countries: an action-skill framework. Journal of Cleaner Production, 379, 134652.
[15] Katana, K., Glaa, B., Mirata, M. (2024). Facilitator roles for knowledge sharing in industrial symbiosis networks during emergence. Business Strategy and the Environment, 33(8), 8540–8558.

3.5 Social and cultural barriers

Social barriers concern the awareness, acceptance and engagement of communities, workers and downstream users of symbiosis products. Local and social acceptance are important preconditions for the involvement of local businesses and communities in IS practices, and effective communication is needed to build trust and credibility between industrial operators, local communities and society more broadly. In the case of steel by-products used in construction or agriculture, public perception of 'waste-derived' materials can act as a residual barrier to specification and uptake by architects, contractors and public procurers, even where technical standards and environmental safety have been demonstrated, reinforcing the importance of clear labelling, standardisation and communication of end-of-waste status.

At the level of the wider industrial ecosystem, the emergence and persistence of successful symbiotic networks has been shown to depend on a form of collective identity and shared responsibility among the actors involved, extending beyond individual bilateral contracts and requiring an accepted local narrative of mutual benefit, as documented in the Kalundborg experience (see Section 4.1). Where such a shared culture does not develop (for instance where symbiosis is perceived by one partner mainly as a means of waste disposal for another, rather than as a genuinely mutual value proposition) relationships tend to remain fragile and vulnerable to disruption when market conditions change.

3.6 Interconnection of barriers

These barrier categories interact rather than operate independently. Regulatory uncertainty about the legal status of a by-product increases the perceived economic risk of investment, which in turn reduces management's willingness to commit organisational resources or to share sensitive operational data with a potential partner, and can ultimately affect the social legitimacy of the resulting product in the eyes of end-users and communities). The case studies reviewed in Section 4 show that a facilitator able to address several of these dimensions simultaneously (legal, economic, organisational and informational) is consistently associated with the more durable and successful symbiotic networks.

Table 1. Synthesis of non-technical barrier categories relevant to industrial symbiosis in the steel sector

Barrier category	Typical manifestation in the steel sector
Regulatory Legal	Ambiguous waste vs. by-product / end-of-waste status; fragmented national criteria; REACH interaction
Economic Market	Low, volatile prices for secondary materials; high logistics costs relative to bulk material value; long payback periods; limited SME financing
Organisational Managerial	Competition between potential partners; resistance to change; lack of trust; business confidentiality
Informational Knowledge	Poor data on waste composition and volumes; lack of shared databases; limited IS-specific training
Social Cultural	Low awareness of IS; public perception of waste-derived products; absence of shared local narrative of mutual benefit

4. European Case Studies: Successful and Unsuccessful Experiences

This section examines a set of European case studies that illustrate how the non-technical barriers described in Section 3 have played out in practice, both in cross-sectoral symbiotic networks in which steel plays a central role, and in dedicated steel by-product valorisation initiatives.

4.1 Kalundborg (Denmark): the benchmark industrial ecosystem

The IS network at Kalundborg, Denmark, remains the most frequently cited example of industrial ecology in the academic literature, and offers valuable lessons even though it is not steel-centred. It originated in 1961 with a pipeline supplying surface water from Lake Tissø to a new oil refinery, in order to conserve scarce groundwater, and grew organically over subsequent decades into a network exchanging water, steam, gas, sulphur, fly ash and residual heat among a power station, oil refinery, biotechnology company, plasterboard manufacturer and the municipality itself (UNEP/GIZ case study)[16]. The network is coordinated by the Kalundborg Symbiosis association, established in 1972, which standardises practices and facilitates collaboration among participants.

Analyses of Kalundborg emphasise that its success rests less on any single technology than on a long process of trust building among a stable set of partners, supported by consistent local government involvement in infrastructure provision and regulatory facilitation. The absence of comparable industrial ecology leadership elsewhere is frequently cited as the main reason why the model has proved difficult to replicate quickly in other locations, underscoring that organisational and social factors, rather than technical replicability, are the binding constraint on scaling up symbiotic networks.

[16] Jacobsen, N.B. (2006). Industrial symbiosis in Kalundborg, Denmark: a quantitative assessment of economic and environmental aspects. Journal of Industrial Ecology, 10(1–2), 239–255

4.2 Dunkirk (France): steel-centred industrial ecology under geographic constraint

The Dunkirk industrial complex, built around an integrated steelworks together with co-located power, chemical and port operations, is a frequently studied European steel centred symbiosis case, often analysed comparatively alongside Kalundborg to test theories of industrial ecology governance and the 'efficiency/resilience dilemma' inherent in tightly coupled industrial networks. Studies of Dunkirk highlight how the governance of the network, and the role of global recycling markets in by-product valorisation, shape the sustainability of the exchanges over time, illustrating that even a geographically concentrated and technically mature industrial cluster remains sensitive to the same organisational and market barriers identified in Section 3[17,18,19,20].

4.3 Legal status of steel slag and residue-based symbiosis products: a persistent regulatory barrier

A detailed case study assessing the development potential of 'symbiosis products' based on primary residues from integrated steel and pulp-and-paper mills against EU legal requirements found that institutional and regulatory barriers, rather than technical feasibility, were the principal constraint on scaling up such products[8,9]. The study highlighted, in particular, the uncertainty as to whether the REACH Regulation would apply to a residue-based product once it ceased to be classified as waste under end-of-waste legislation, and recommended the joint, co-operative design of incentives, policies and regulations across the institutions and Member States involved as the way forward. This case exemplifies how a technically mature by-product (in this instance, materials such as slaker grits with demonstrated agricultural value as a liming agent) can remain under exploited for years because of unresolved questions of legal classification rather than of process performance.

EU end-of-waste criteria remain in place only for a small number of streams (e.g. iron or steel), leaving the classification of most steelmaking slags to national or single-case decisions. This has been identified as a factor limiting the cross-border market for slag products and contributing to their largely local, rather than European, utilisation pattern.

4.4 Steel–chemicals symbiosis: carbon monoxide feedstock exchange

A further illustrative case concerns the exchange of carbon rich steelworks off-gases with the chemical industry as an alternative feedstock to fossil fuels, explored in a European project

[17] HE2020 C2FUEL Carbon Captured Fuel and Energy Carriers for an Intensified Steel Off-Gases based Electricity Generation in a Smarter Industrial Ecosystem
[18] HE2020 CORALIS Industrial Symbiosis in Energy Intensive Industries
[19] HE2020 3D DMX Demonstration in Dunkirk
[20] Notarnicola, B., Tassielli, G., Renzulli, P. A., Castellani, V., & Sala, S. (2017). Industrial symbiosis in the EU: Analysis of the potential for waste heat recovery. *Energy Procedia*, *121*, 192–199

(CORESYM "CarbOn monoxide RE-use through industrial SYMbiosis between steel and chemical industries[21]") evaluating the techno-economic and environmental implications of the shift, alongside the systemic barriers to its implementation at a European level[5]. This case shows that even where the environmental and technical case for symbiosis is strong, diverting an otherwise combusted or flared waste gas into higher value chemical production, the economic viability of the exchange depends heavily on the relative and volatile prices of fossil feedstocks and of carbon allowances, on long term offtake contracts that reduce discontinuity risk for both partners, and on the availability of policy instruments (such as carbon pricing or contracts for difference) that can bridge the initial cost gap relative to conventional fossil-based production.

4.5 Cross-case lessons

Taken together, these case studies point to several recurring lessons. First, durable IS networks (Kalundborg, and to a lesser extent Dunkirk) rest on long-term relationships, geographic proximity and a stable governance or facilitation structure, rather than on any single bilateral contract. Second, publicly funded facilitation, as demonstrated by The United Kingdom National Industrial Symbiosis Programme (NISP)[22], can rapidly unlock very large volumes of symbiotic exchange, but such gains are contingent on the continuity of funding and institutional support, and are put at risk by short political cycles or the discontinuation of an originating financing mechanism. Third, even technically mature and environmentally beneficial by-products can remain underutilised for extended periods where their legal classification under waste and chemicals legislation is unresolved or inconsistent across Member States, as illustrated by the steel and pulp-and-paper residue case and by the continuing fragmentation of end-of-waste criteria for slag. Fourth, market-based symbiosis involving high value but price volatile exchanges, such as carbon monoxide feedstock supply to the chemical industry, remains exposed to economic barriers that require dedicated policy instruments to overcome.

[21] https://ispt.eu/media/Coresym-report-2017-CarbOn-monoxide-RE-use-through-industrial-SYMbiosis-between-steel-and-chemical-industries.pdf

[22] The United Kingdom National Industrial Symbiosis Programme (NISP) 2023 to 2010

5. Policy Recommendations

Building on the barrier analysis and the case-study evidence set out above, the following recommendations are derived.

5.1 Regulatory and legal recommendations

- Extend EU level end-of-waste criteria to a wider set of steel by-products, in particular steelmaking slags, prioritising streams with the largest volumes and the clearest existing market applications, to reduce reliance on inconsistent national and single case decisions.
- Clarify, through EU guidance or a dedicated legislative interface, the relationship between end-of-waste status and REACH obligations for residue based symbiosis products, so that achieving end-of-waste status does not inadvertently create a new, disproportionate regulatory burden.
- Support the ongoing work of the European Committee for Standardization on a roadmap for IS standardisation, including harmonised terminology and criteria that can be applied consistently by national authorities.
- Simplify and harmonise cross-border waste shipment procedures for classified by-products moving between Member States, to help overcome the geographic and logistical barriers that currently confine much by-product trade to a narrow radius around the originating plant.

5.2 Economic and market recommendations

- Use green public procurement criteria to create stable, predictable demand for secondary materials such as slag based construction products, thereby reducing market and price volatility barriers.
- Provide targeted co-funding and de-risking instruments to invest in by-product valorisation infrastructure, recognising that payback periods for many IS investments exceed conventional industry norms.
- Encourage long-term offtake agreements between steel producers and by-product users (e.g. cement producers, chemical companies) to reduce the discontinuity risk that discourages investment on both sides of a symbiotic exchange.

5.3 Organisational and informational recommendations

- Establish or sustain, with dedicated and durable (rather than short-term) funding, independent IS facilitators at regional or national level.
- Develop shared, quality-assured digital databases of by-product availability and demand, potentially supported by AI based matching tools, to reduce the informational asymmetry between potential symbiotic partners while respecting legitimate business confidentiality.
- Integrate IS and circular economy content into technical and managerial training programmes for the steel and related sectors, addressing the skills and awareness gaps identified as a barrier to recognising and pursuing symbiotic opportunities.

5.4 Social recommendations

- Support clear labelling, technical standardisation and public communication of the environmental performance of by-product-derived materials, to address residual social acceptance barriers among specifiers, procurers and communities.
- Encourage the co-development of local narratives of mutual benefit between steel plants, their symbiosis partners and host communities.

6. Conclusions

IS is already a well-established feature of the European steel industry's approach to resource efficiency, encompassing both the external valorisation of iron and steelmaking by-products in sectors such as cement, construction and metallurgy, and the internal use of residues from other industries, including biomass, plastics and process gases, as substitutes for virgin raw materials and fossil carbon. The analysis presented in this deliverable confirms that the principal constraints on further scaling this activity are, in lots of cases, non-technical: an unresolved or fragmented legal status for by-products under waste and chemicals legislation; volatile or geographically limited markets for secondary materials; organisational barriers rooted in mistrust, confidentiality and resistance to change; informational asymmetries between potential partners; and social and cultural barriers related to awareness and acceptance.

Regulatory uncertainty surrounding residue-based symbiosis products point consistently to the same conclusion: technical solutions for by-product utilisation in the steel sector are, in general, available or within reach, but their deployment depends on sustained institutional support, coherent and harmonised regulation, viable market conditions, and a facilitated process of trust building between partners. Addressing these non-technical barriers, through the policy recommendations set out in Section 5, is therefore a precondition for realising the full potential of IS in the decarbonisation and resource efficiency transition of the European steel industry.

List of Tables

Abbreviations and acronyms

BF:	Blast Furnace
BOF	Blast Oxygen Furnace
EAF:	Electric Arc Furnace
EU:	European Union
HEU	Horizon Europe funding program
IS:	Industrial symbiosis
LF	Ladle furnace
M:	Month
NISP	United Kingdom National Industrial Symbiosis Programme
PU:	Public
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RFCS:	Research fund for coal and steel
SME	Small Medium Enterprise
T:	Task
WP:	Work Package