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SYMBIOS: Digital Platform for Industrial Symbiosis & Circular Economy

WORK PACKAGE 2.6

Modelling the Mechanism and the Skills Gap of Industrial Symbiosis

LEATHER SECTOR

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Introduction

Industrial symbiosis (IS) is one of the most concrete operational strategies available for translating the abstract ambition of circular economy into measurable industrial practice. Rather than treating waste, by-products, energy residues and water as a cost to be disposed of, industrial symbiosis reframes them as resources with a market value for another actor, often in a different sector. This model has been developed within Work Package 2 (WP2: "Research on Industrial Symbiosis targeting Agrifood & Leather Sectors") of the Erasmus+ KA220-VET project SYMBIOS – Digital Platform for Industrial Symbiosis & Circular Economy (Project No. 2024-1-PT01-KA220-VET-000253813). It focuses specifically on the leather sector, one of the two strategic manufacturing sectors selected by the SYMBIOS partnership, chosen because leather is, structurally and historically, one of the oldest and most complete examples of industrial symbiosis in existence: an entire industry built upon the valorisation of a by-product of another.

Objectives of the Model

The purpose of this document is twofold, mirroring the two specific objectives of Work Package 2 set out in the project's Grant Agreement. First, it reconstructs the symbiotic mechanism that governs the leather sector: what industrial symbiosis means in this sector, which resources and flows are involved along the tanning process, which regulatory framework enables or constrains their exchange, which cross-sector connections are most promising, and which best practices already demonstrate that the model works in practice. Second, it maps the knowledge and skills that individuals and organisations need in order to operate professionally within this field, differentiated by target group (young graduates, employed workers, managers and decision-makers, and unemployed or disadvantaged groups), together with training tools and recommendations for VET providers and policy makers. Taken together, the two chapters provide the conceptual and pedagogical foundation on which the SYMBIOS Digital Platform, and specifically its open MOOC on industrial symbiosis (WP 3.1), is built.

Framing Industrial Symbiosis within the Circular Economy

Industrial symbiosis is not a synonym for circular economy, but one of its principal enabling mechanisms. Where the circular economy describes a systemic vision in which the value of products, materials and resources is maintained for as long as possible, industrial symbiosis describes the specific inter-organisational mechanism through which this is achieved when the actor able to create value from a resource is not the one that generated it. Chertow (2000) defined industrial symbiosis as the engagement of traditionally separate industries in a collective approach involving the physical exchange of materials, energy, water and by-products, generating mutual economic and environmental benefit. The leather sector offers what is arguably the clearest

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illustration of this logic available in European manufacturing: leather does not begin its life as a raw material extracted for its own sake, but as hides and skins, an unavoidable by-product of the meat and dairy industries classified as Category 3 animal by-product under Regulation (EC) No 1069/2009. As confirmed repeatedly during the SYMBIOS leather focus groups, the sector is therefore symbiotic by structure, not by choice: industrial symbiosis is not an optional add-on for tanneries, but the very condition of the industry's existence.

Relevance for the Leather Sector

The European leather industry represents a substantial share of global production while facing an acute internal circularity challenge: according to UNIDO figures cited repeatedly during the SYMBIOS focus groups, only 20–25% of the mass of a cattle hide is converted into leather, meaning that 75–80% requires alternative valorisation pathways at every stage of the tanning process, from the beamhouse to finishing. At the same time, the WP 2.3 needs-analysis survey confirms that the sector already possesses real foundations to build upon: two-thirds of the 30 surveyed companies (67%) report advanced, quantitative monitoring of their own waste and by-product flows, and 70% report some form of partnership for by-product valorisation, even if only a third of these are stable and long-term. This model is built to help convert that latent capacity into a systemic, scalable practice: it shows where the sector already generates value from what would otherwise be waste, where the regulatory framework supports or blocks such exchanges, and what knowledge and skills are needed to move from isolated best practice to everyday industrial behaviour.

Methodology and Sources

This model is grounded in the mixed-methods research carried out under Work Package 2 of the SYMBIOS project between late 2025 and mid-2026, complemented by the peer-reviewed and institutional literature on industrial symbiosis and leather manufacturing. The primary sources used are:

- **Focus groups (WP 2.2),** coordinated by COTANCE and SPIN360, involving twelve participants in total (six per session) drawn from tanneries, hide traders, academic institutions, sectoral associations and independent experts across the Netherlands, Spain, France, Germany, the United Kingdom, the United States and Australia, structured around three themes: state of the art, challenges, and possible solutions/future opportunities.
- **A cross-sector survey (WP 2.3)** administered to 30 leather-sector companies across 13 countries (with a strong concentration in Portugal and Italy, historically the two largest European tanning hubs), covering company profile, waste management and monitoring, industrial symbiosis partnerships, occupational health and safety (OSH) constraints, regulatory barriers, and skills and training needs.

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- **Semi-structured deep interviews with leather-sector stakeholders (WP 2.3)**, conducted with nine companies across Italy, Belgium and Portugal by SPIN360, UPT and COTANCE, exploring waste-stream characteristics, internal circular practices, external sustainability pressures, and self-assessed competence levels.
- **Desk research and sector-specific literature review (WP 2.5)**, covering the peer-reviewed literature on industrial symbiosis and leather manufacturing (Chertow, 2000; UNIDO, 2017; Kanagaraj et al., 2015; Sundar et al., 2011, among others) and the applicable European Union legislative framework.
- **A systematic review of existing Industrial Symbiosis learning offers (WP 2.6)**, covering structured education and training programmes for which industrial symbiosis is the primary educational objective, analysed through a purpose-built Industrial Symbiosis Learning Offer Analysis Framework (ISLOAF).

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Chapter 1 – Symbiotic Mechanism

1.1 Definition: Key Concepts and Principles

Industrial symbiosis (IS) is a collaborative approach in which traditionally separate industries engage in the exchange of materials, energy, water, services and information in order to improve resource efficiency and reduce environmental impacts. According to the classical definition proposed by Chertow (2000), industrial symbiosis involves the mutually beneficial exchange of resources among firms, generating environmental, economic and social benefits. The European Committee for Standardization (CEN, 2018) situates this exchange firmly within an industrial context, distinct from ordinary supply-chain trade.

The leather sector occupies a unique position within this definition, unlike most manufacturing industries, which generate by-products as a secondary consequence of producing a primary good, the leather industry's primary raw material, raw hides and skins, is itself the by-product of another industry, namely meat and dairy production. As one focus-group participant observed, leather is essentially a waste material until it is transformed and given value by the tanning industry. Industrial symbiosis is therefore not an optional strategy that the leather sector may or may not choose to adopt: it is the structural condition of the sector's existence. This has a direct practical consequence for how the sector must be understood: virtually every discussion of "the leather industry" is, from the outset, a discussion of a symbiotic relationship between at least two sectors, food/agri-food and leather and, at the by-product end of the tannery, potentially several more.

The fundamental principles of industrial symbiosis in the leather industry include:

- Structural, built-in symbiosis with the food chain: leather production begins with a Category 3 animal by-product (Regulation (EC) No 1069/2009), not with a virgin raw material, making the food–leather relationship the foundation of the entire sector rather than an add-on;
- Cascading use of hide components: because only 20–25% of the mass of a cattle hide is converted into leather (UNIDO estimate, repeatedly cited during the SYMBIOS focus groups), the remaining 75–80% must be valorised through cascading applications, food, pharmaceutical, cosmetic, agricultural or energy uses, before any residual fraction is disposed of;
- Stage-dependent recyclability: both the recyclability of tannery co-products and the potential for co-production diminish as the tanning process advances, delaying the recovery of a co-product systematically reduces its usability and value;
- Dual biological identity: leather is simultaneously a long-lived, highly durable, sustainable material superior to many alternatives, and a material that, at the end of its life, can

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re-enter natural or industrial recycling cycles. A duality that focus-group participants considered central to the sector's circular bioeconomy narrative;

- Cross-sector collaboration as a structural necessity, not merely an efficiency gain: the leather sector's raw material supply is entirely supply-driven by the meat and dairy value chain, meaning that cooperation across the two sectors is a precondition for adding value to hides, rather than a matter of choice for either industry;
- Creation of new business opportunities and revenue streams through the outbound valorisation of co-products in food, pharmaceutical, cosmetic, fertiliser, energy and construction-material markets.

This industrial symbiosis model aligns closely with the European Green Deal, the Circular Economy Action Plan, the EU Bioeconomy Strategy, and the United Nations Sustainable Development Goals, particularly SDG 12 (Responsible Consumption and Production). Notably, however, focus-group participants observed that successive editions of the EU Bioeconomy Strategy, including its 2025 update, do not yet explicitly recognise leather as part of the European bioeconomy, despite the sector meeting the Strategy's own definition of the sustainable use of renewable biological resources, a gap identified as a strategic priority for advocacy (see Section 1.3).

Outputs, Waste and By-products: A Fundamental Distinction

In the context of leather industrial symbiosis, the distinction between outputs, by-products and waste is not a secondary technicality but the foundation of the whole sector, since the tanning industry's principal output, (leather), is itself legally and materially a transformed by-product of another industry. Three categories need to be kept separate:

- The output is the primary product a company sets out to manufacture at each stage of the process: raw or salted hide leaving the beamhouse, wet-blue or wet-white leather leaving the tanning stage, crust leather leaving post-tanning, and finished leather leaving the finishing stage (see Table 1).
- A by-product is a secondary material generated alongside that output which has a certain, lawful further use without requiring further processing beyond normal industrial practice. For example, raw splits sold to the food and pharmaceutical industries for collagen and gelatine, or fleshings processed for biodiesel and pet food.
- Waste, by contrast, is a residual material for which the holder has not identified, or is legally prevented from pursuing, any further use, and which must therefore be disposed of.

This distinction is what determines, more than any single piece of chemistry, whether a given tannery stream can be valorised through industrial symbiosis or must be sent to disposal. As shown in Section 1.2, the same physical material, a shaving, a trimming, a piece of sludge, can be a

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valuable by-product or a costly waste depending entirely on whether a lawful, documented further use exists and whether an authorised recipient is available to receive it. The WP 2 research illustrates this directly: chrome-free (wet-white) shavings are, in composition, close to compostable soil improvers, yet without a recognised fertilising-product classification and enough authorised composting operators willing to accept them, they remain legally and commercially waste rather than by-product, even though the chemistry that would make them a by-product already exists. Understanding and correctly documenting this three-way distinction is therefore one of the foundational competences mapped in Chapter 2, and a precondition for any company seeking to move a material stream from the waste column to the by-product column of its own accounts.

1.2 Resources, Flows and Constraints

The Tanning Process: From Raw Hide to Finished Product

The tanning process transforms a raw hide or skin into finished leather through a sequence of stages (Beamhouse, Tanning, Post-tanning, and Finishing), each of which generates its own characteristic co-products and waste streams. A defining feature of the sector is that both the recyclability and the potential for co-production diminish as the process advances: delaying the utilisation of co-products systematically reduces their usability and market value. Materials recovered at the earliest stages retain rich, high-value application potential (food, pharmaceutical, cosmetic uses), whereas materials recovered only at the crust or finished-leather stage are largely limited to lower-value industrial uses such as construction materials or, in the least favourable cases, landfill.

Process stage	Animal by-product status	Typical co-products / waste streams	Illustrative valorisation pathway
Beamhouse (salted/raw skin)	Category 3 animal by-product, highest inherent value, most reuse restrictions	Trimmings, fleshings, hair, wool	Gelatine, collagen, glue, biodiesel, biogas, cosmetic ingredients; hair/wool for food supplements, fertilisers, insulation, textile fibre
Beamhouse (soaked/limed skin)	Category 3, transitioning	Lime fleshing ("carniccio"), lime splits, hair	Collagen and gelatine, fertilisers, biodiesel, keratin extraction
Tanning (chrome-tanned)	Waste / co-product, more limited options	Wet-blue (WB) shavings, wet-blue trimmings	Retardants, biostimulants (with careful formulation), chrome recovery; otherwise landfill or brick-making

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Process stage	Animal by-product status	Typical co-products / waste streams	Illustrative valorisation pathway
Tanning (chrome-free / vegetable / wet-white)	Waste / co-product, wider circular options	WW shavings, WW trimmings	Composting, soil improvers, bio-fertilisers, biodegradable flowerpots (pilot-tested)
Post-tanning / Crust	Genuine waste, narrower options	Crust shavings, crust trimmings, buffing dust	Solid fertilisers, protein hydrolysates, granules and bioplastics (with biopolymers)
Finishing / Finished leather	Genuine waste, most limited options	Finished-leather trimmings, offcuts, end-of-life leather	Roofing material, lightweight bricks, artificial suede, tactile wall coverings, recycled leather rolls, reuse as covers

Table 1. The tanning process from raw hide to finished leather: by-product status and valorisation pathways by stage.

Co-Products: Illustrative Input–Output Examples

The WP 2 research compiled a wide inventory of concrete co-production examples already documented within the sector, illustrating the diversity of valorisation pathways available at different points of the value chain:

Material input	Output / valorisation
Fresh by-products (WB/lime splits, WB hides, wet-salted hides, split crust, grain crust)	Gelatine and collagen
Calf split, raw hides, lime fleshing ("carniccio"), hair	Gelatine and collagen, glue, oil, fertilisers, biodiesel
Beef trimming, beef skin	Protein supplements for food
Raw hide trimmings, fleshings	Biogas, digestate
Tannery raw wool (France, Spain, Italy)	Carpet and felt
Sheep's wool	Wall panels
Hair	Hair-based creations; hydrolysed keratin
Animal proteins from Animal By-Products	Animal feed, pet food, fertilisers
Fleshing, hair, WB shaving, WB trimming	Protein hydrolysate

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Material input	Output / valorisation
WB scraps, finished-leather scraps (end-of-life, post-consumer and post-industrial)	Recycled leather rolls
Non-metal crust and dust; all types of crust and dust	Solid fertilisers
WB/crust shavings, trimmings, split; buffing dust; finished-leather trimmings	Granules and bioplastic (50% leather scraps / 50% biopolymers), recyclable
Leather residues from the footwear industry (60% content)	Tactile wall coverings
Finished leather and finished products	Recycled leather; intertwined "fabric", solid gadgets, interior products
Urban/industrial sludge; organic matter (animal/plant-based)	Compost
Municipal and industrial wastewaters	Recovered energy units (KEU); purified water

Table 2. Illustrative co-production examples across the leather value chain (compiled from WP 2.5 desk research).

This inventory confirms the general rule set out above: the earlier a material is recovered in the tanning process, the wider and more valuable its range of potential applications. Pre-tanning materials feed directly into food, pharmaceutical and cosmetic value chains, while post-tanning and finishing-stage residues are increasingly confined to lower-value, though still legitimate, industrial and construction applications.

Constraints on Valorisation: Perishability, Logistics and Recipient Capacity

Beyond the stage-dependent recyclability logic described above, three practical constraints determine whether a technically identified valorisation pathway can actually be realised.

- The first is perishability and transport economics: wet by-products (fleshings, splits, wet-blue and wet-white shavings, sludge) are heavy, bulky and prone to degradation, which means they are only economical to move over relatively short distances. A constraint that, as in the agrifood sector, makes geographic proximity and industrial clustering (Section 1.4) a practical necessity rather than a mere convenience.
- The second is recipient capacity: several WP 2.3 interviewees reported that usable, even compostable, material streams have no viable destination simply because too few operators are authorised to receive and process them, a market-thinness problem that no amount of technical improvement on the tannery side can solve alone.

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- The third is measurement and allocation: current Life Cycle Assessment practice does not consistently apply a fair allocation of environmental burden between the meat/dairy sector and the leather sector for the shared raw material (hides and skins), a methodological gap that, according to focus-group participants, systematically understates the environmental credentials of bio-based and chrome-free leather relative to alternative materials.

1.3 Policies and Regulatory Framework

The development of industrial symbiosis in the leather sector is supported by the broader EU policy framework promoting the circular economy, resource efficiency and the sustainable use of biological resources. While no single legislative instrument governs industrial symbiosis as such, several policies and legal acts contribute to creating an enabling or, in some respects, a constraining environment.

The European Union Level

Instrument	What it establishes	Relevance for industrial symbiosis
EU Circular Economy Action Plan (CEAP, 2020) & European Green Deal	Promotes sustainable production/consumption, resource efficiency, secondary raw materials, value-chain cooperation	Creates favourable framework conditions for industrial symbiosis across all manufacturing sectors, including leather
Waste Framework Directive (Directive 2008/98/EC)	Overarching EU legal framework for waste management; distinction between waste and by-products (Article 5) and End-of-Waste provisions (Article 6)	One of the most important aspects for IS: legal certainty on material classification is essential to facilitate exchanges. For leather, this is particularly relevant because hides originate as an unavoidable by-product of livestock production
Animal By-Products Regulation (Regulation (EC) No 1069/2009)	Animal health rules for animal by-products not intended for human consumption; hides/skins are, in most cases, Category 3 material	Provides the sanitary framework allowing safe collection, transport and processing of hides into leather, and conditions the downstream use of pre-tanning co-products (collagen, gelatine, pet food, fertilisers)
EU Bioeconomy Strategy	Supports sustainable use of renewable biological resources and circular bio-based value chains	Leather, produced from an unavoidable biological by-product of livestock production, fits the Strategy's objectives in substance, although successive editions

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Instrument	What it establishes	Relevance for industrial symbiosis
		(including the 2025 update) do not yet explicitly name leather as part of the European bioeconomy, an identified advocacy gap
EU Fertilising Products Regulation (EU) 2019/1009	Establishes requirements for fertilising product function categories and component materials	Currently excludes most leather-derived by-products from approved fertiliser routes, since leather was not considered when the Regulation was drafted and regulators frequently assume all leather is chrome-tanned, even when chrome-free
REACH Regulation	EU chemicals regulation on registration, evaluation, authorisation and restriction	Directly affects the classification and permissible use of tannery chemical residues and chromium-bearing streams, identified by survey respondents as a leading regulatory barrier
Corporate Sustainability Reporting Directive – CSRD (Directive (EU) 2022/2464)	Mandatory ESG and circular economy reporting for large companies and, increasingly, their suppliers	Drives the "compliance cascade" described in Chapter 2: tanneries are rarely in scope directly, but are increasingly required by large brand clients to report on waste management and circularity
Forthcoming Circular Economy Act	Announced initiative to strengthen the Single Market for circular products and secondary raw materials	Still under development; depending on final scope, may reduce regulatory barriers and further facilitate valorisation of industrial by-products
Forthcoming Biotech Act II	Expected to expand the EU policy framework for industrial biotechnology and biomanufacturing	May further enable bio-based valorisation pathways for leather-sector residues, in line with the EU Bioeconomy Strategy

Table 3. EU legal and policy instruments most relevant to industrial symbiosis in the leather sector (compiled from WP 2.6 legislative review and WP 2.3 survey findings).

Industrial symbiosis offers significant opportunities for the leather sector by improving resource efficiency, reducing waste generation, creating additional value from by-products and strengthening cooperation across value chains. At the same time, the WP 2.3 survey shows that

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regulation is perceived as the dominant structural constraint on this potential: environmental regulations (14 of 30 respondents) and chemical safety regulations, notably REACH (11 respondents), were the two most frequently cited regulatory areas affecting waste and by-product management, and administrative burden linked to permits and authorisations was the single most common type of regulatory barrier encountered (18 respondents), ahead of compliance costs and legal uncertainty (11 each).

National and Regional Level

At national and regional level, the enabling or constraining effect of EU legislation is filtered through how individual Member States transpose and enforce it, and through regional industrial infrastructure that can substitute for missing national instruments. Italy and Portugal, the two countries most represented in the WP 2.3 survey (9 and 13 respondents respectively), illustrate two different models. In Italy, the Tuscan tanning district benefits from a long-standing regional model of shared, consortium-based wastewater and sludge-treatment infrastructure (Section 1.5), which in practice substitutes for the absence of a dedicated national industrial symbiosis regulation by making compliance and valorisation economically viable at cluster level rather than for each tannery individually. Portugal, home to the largest single national contingent of surveyed companies, does not have a comparable formalised district infrastructure which may partly explain why Portuguese respondents were prominent among those reporting only informal or occasional by-product partnerships rather than stable, long-term ones.

Beyond formal legislation, the Leather Working Group (LWG) certification scheme operates as a quasi-regulatory instrument at company and supply-chain level across all survey countries: cited by several WP 2.3 respondents alongside ISO 14001, LWG embeds environmental and traceability requirements, including elements of chemical management and effluent treatment, that indirectly reward circular practice even in the absence of a binding national industrial symbiosis rule. In this sense, private certification is, for the leather sector specifically, filling part of the regulatory gap that national legislation has not yet addressed.

1.4 Cross-Sector Connections

In the leather sector, industrial symbiosis works best when the tannery is understood as one node within a value chain, rather than as a final, self-contained step. The sector exists by transforming a by-product of the food chain into a durable, bio-based material, and in doing so generates its own by-product streams that flow onward to other sectors. The food and agri-food chain therefore appears at both ends of the leather value chain: as the origin of the sector's raw material, and as one of the principal destinations for its own by-products.

Inbound Connections: What Flows Into the Tannery

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The defining inbound connection is with the meat and slaughter industry, which supplies the hides that would otherwise become waste. A growing second inbound flow brings agricultural and forestry by-products into the process as tanning inputs: the clearest demonstrated case is OlivenLeder (Germany), which converts olive-industry pruning residues, leaves and branches otherwise burned, into a bio-based tanning agent capable of replacing chromium salts, glutaraldehyde and synthetic auxiliaries, yielding leather with up to 97% bio-based content. This couples two by-product streams in a single process: a hide tanned with an agricultural residue. Conventional vegetable extracts (chestnut, quebracho, mimosa, tara) and bio-based fatliquors represent the same inbound logic at established scale, while emerging research on avocado pits and skins, grape pomace ("grape tannins"), olive leaf extracts and sea buckthorn tannins, technically validated in pilot projects in Spain and Italy, points to a widening set of agrifood-residue-based tanning agents.

Outbound Connections: Where Tannery Co-Products Go

By-product destinations depend on the stream and, critically, on its processing stage:

- **Pre-tanning by-products offer the strongest reuse opportunities:** raw splits, after a liming step, are sold to the food and pharmaceutical industries for collagen and gelatine. Fleshings and raw trimmings, processed without sulphur, are sold for biodiesel and pet food. Hair from the beamhouse is recovered for fertilisers or keratin. Recovered collagen is already used in pet food, nutraceuticals, and medical/pharmaceutical products such as capsules and coatings.
- **Post-tanning chrome-free streams (vegetable, wet-white)** are technically well suited to composting, soil improvers and bio-fertilisers owing to their low heavy-metal content. Vegetable-tanned residues are particularly effective: the combination of collagen-derived proteins and polyphenolic tannins supports gradual nitrogen release and root protection, a so-called "paradox" by which slow biodegradability produces efficient plant nutrition. Italian producers including SICIT, ILSA, Organazoto, Fertilizzanti Certaldo and Idea Verde already manufacture fertilisers and biostimulants from leather by-products at industrial scale, and Cuoio Depur valorises tannery sludge into fertiliser through the Fertilandia project.
- **Chromium-bearing streams** are excluded from the food and feed chain but not wholly from agriculture: chromium shavings are valorised into biostimulants and finished-leather trimmings are converted into biochar usable in agriculture where chromium's micronutrient role is managed through careful formulation. A pilot project successfully converted chromium-bearing shavings into biodegradable flowerpots. These streams are otherwise mainly directed toward chromium recovery, bonded-leather production, and energy recovery.

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The main barrier to expanding these outbound flows is regulatory rather than technological: even chrome-free post-tanning by-products, which could safely be used in organic agriculture, are generally not recognised under the EU Fertilising Products Regulation (2019/1009), because the Regulation was developed without considering leather by-products and because regulators often treat all leather as if it were chrome-tanned, without distinguishing chrome-free materials.

Modes of Collaboration and Interaction

Collaboration ranges from informal to highly structured. WP 2.3 survey evidence indicates that roughly 70% of leather companies operate some form of by-product partnership, but only a third of these (10 of 30) are stable and long-term, locating the central challenge in formalisation and outreach rather than in first contact between potential partners. Several recurring modes of collaboration were identified:

- **Direct supply before pre-tanning:** the highest-value raw splits, fleshings and fats are sold directly to the food, feed and oleochemical industries before chemical processing.
- **Exchange through specialised intermediaries:** renderers and valorisation companies connect tanneries with sectors such as agriculture and chemicals.
- **Industrial clusters:** companies share infrastructure such as wastewater treatment and sludge recovery facilities, as demonstrated in the Tuscan tanning district, where district-based consortium treatment plants operate a closed-loop water management system with regenerated water recirculated via shared vats.
- **Internal recycling:** some tanneries recover proteins from wet-white and crust leather residues and reuse them in the re-tanning process.
- **Digital matchmaking platforms:** initiatives such as SYMBIOS help companies from different sectors identify potential partners and create new industrial symbiosis opportunities, addressing the cross-sector knowledge gap explicitly identified by WP 2.3 interviewees, who noted that tanneries often do not know which industries could absorb their by-products, and vice versa.
- **Enhanced traceability along the supply chain,** increasingly demanded by brands and certification schemes and a precondition for many of the exchanges described above.

Two factors consistently determine whether these collaboration models can function in practice. First, there are not enough authorised companies able to receive and process leather by-products: for example, one interviewed tannery produces compostable, low-metal sludge but cannot fully valorise it because too few authorised operators exist to accept it. Second, successful exchange depends on good information: companies need clear, standardised technical data sheets describing each by-product and its characteristics.

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Cost–Benefit Considerations

For tanneries, industrial symbiosis brings several concrete benefits: it reduces waste disposal costs, creates new revenue from by-products, and helps companies meet the growing sustainability and traceability requirements of brands and certification schemes such as the Leather Working Group. These benefits are already visible in practice: one SME tannery interviewed under WP 2.3 reported savings of around €30,000 per month through process improvements and circular practices, while another reduced its environmental impact by 80% over six years while also improving leather quality. Better process design, such as recovering fats during fleshing or at the slaughterhouse itself, can further increase the value of by-products while reducing wastewater load.

However, important barriers remain. In many cases it is still cheaper to dispose of by-products than to recover and reuse them. Circular solutions become economically attractive only when companies can generate value from these materials instead of paying to dispose of them. Regulations create further challenges: companies must comply with rules on Animal By-Products, REACH, the EU Fertilising Products Regulation, and the distinction between waste and by-products, which is not always applied consistently across Europe. Current Life Cycle Assessment (LCA) methods may also not fully recognise the environmental benefits of bio-based and vegetable tanning systems, and transport costs limit many circular solutions, since wet by-products are heavy, perishable, and only economical to move over relatively short distances.

Overall, the strongest cross-sector link for the leather industry remains the food chain, which provides its raw materials. This is followed by the reuse of proteins and fats from the pre-tanning stage through well-established markets such as rendering, gelatine and biodiesel. Chrome-free by-products can also be used in agriculture, the technology already exists, but wider use is limited by current regulation. Chromium-containing by-products likewise have potential agricultural uses, provided clear rules and appropriate formulations are established. This is precisely where a tool such as SYMBIOS can make a real difference: helping companies find the right partners more easily, providing standardised information on by-products, strengthening cross-sector cooperation, and supporting better decision-making through LCA methods that fairly reflect the benefits of bio-based and circular solutions.

In Depth: Leather–Food Industrial Symbiosis

Viewed from the leather side, the relationship with the food and agri-food chain is not one connection among several but the structural backbone of the entire sector, and it runs in both directions. Upstream, tanneries are entirely dependent on the meat and dairy industry for their primary raw material: without the hides and skins generated by slaughterhouses as an unavoidable Category 3 animal by-product, there is no leather sector. This dependency means that the quality and usable yield of every hide entering a tannery (the Blößenrendement discussed in Chapter 2) is

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determined largely by decisions taken upstream, in slaughterhouse trimming, cleaning and hide-handling practice, over which the tanning industry itself has limited direct control. The SYMBIOS focus groups identified this upstream coordination, rather than any single technology inside the tannery, as the most critical leverage point for improving material efficiency across the whole leather value chain.

Downstream, the relationship reverses: the leather sector becomes a supplier back into the food and agricultural system. Pre-tanning proteins and fats recovered before chemical processing feed directly into established food-adjacent markets, gelatine and collagen for food and pharmaceutical use, rendered fats for animal feed and biodiesel, while chrome-free post-tanning residues, rich in the same collagen-derived proteins and polyphenolic tannins, are already used by Italian producers such as SICIT, ILSA and Organazoto to manufacture fertilisers and biostimulants for agriculture (Section 1.5). In this sense, the leather sector does not merely receive a by-product from agri-food and return a finished consumer good: at both ends of its own process, it is itself a supplier of agricultural and food-adjacent inputs, making leather–food industrial symbiosis a genuinely closed, two-way loop rather than a one-directional dependency. This is also precisely the mirror relationship described in the agrifood sector model developed in parallel under Work Package 2, and it is the natural first bridge for cross-sector matching between the SYMBIOS agrifood and leather learning communities (Section 2.3).

1.5 Best Practices and Benchmark

The examples below come from the project's own interviews, surveys and focus groups, complemented by public sources on the sector. They are not a strict benchmark with hard, independently audited numbers: most company examples are described by the companies themselves, and these tend to be sector leaders. The detailed cases are mostly European (Italy, Portugal and Germany) while the survey adds wider international coverage (Argentina, Brazil, the Netherlands, Turkey, the USA, Uruguay, Vietnam). Looking at the cases together, one pattern stands out clearly: the things that make symbiosis work in one place are the exact opposite of the things that block it elsewhere.

Model 1. Couro Azul (Portugal) – The All-in-One Chrome-Free Tannery

This large family tannery works completely chrome-free and reuses materials both inside the company and by selling them early. Raw splits are sold to the food and pharmaceutical industry for collagen and gelatine before tanning. Fats and fleshings are processed in-house and sold for biodiesel and pet food. Leftover crust and wet-white pieces are broken down and reused in the company's own re-tanning. Because it avoids chrome, its sludge has low metal content and could in principle be composted, but, as noted in Section 1.4, regulatory gaps rather than chemistry stand in the way.

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Model 2. OlivenLeder (Germany) – The Plant-Based Closed Loop

This company replaces conventional tanning chemicals with an agricultural by-product: it turns olive-tree prunings into a tanning agent that replaces chromium and glutaraldehyde, producing leather that is up to 97% plant-based and independently certified. Leftover plant material becomes heating pellets, and used leather scraps become fertiliser for organic farming. In short, one waste material tans another, and the end result returns to the soil.

Model 3. Italian Fertiliser Makers – SICIT, ILSA, Organazoto and Cuoio Depur

Leather-to-farming symbiosis only works if someone wants the by-products, and several Italian firms show that the demand is real: SICIT, ILSA and Organazoto make fertilisers and biostimulants from leather by-products at industrial scale. Fertilizzanti Certaldo makes fertiliser from vegetable-tanned scraps; and Cuoio Depur turns tannery sludge into fertiliser through the Fertilandia project. Together these companies represent the demand side of the chrome-free valorisation loop illustrated by Models 1 and 2.

Model 4. Argentina – Upstream Fat Recovery at the Slaughterhouse

Outside Europe, the clearest case identified is the recovery of fats at the slaughterhouse rather than at the tannery: because the fat is valuable, slaughterhouses collect it early, cutting the pollution load that would otherwise reach the tannery, a further illustration of the general principle, set out in Section 1.2, that earlier recovery is always a more valuable recovery.

SYMBIOS Focus Groups: Additional Case Studies from the Focus Groups

Beyond the four documented models above, the SYMBIOS leather focus groups surfaced several further cases directly reported by participants, illustrating how the general logic of earlier, closer, and better-coordinated recovery translates into local practice across different countries and market niches:

- **Germany — the ReeL project:** a government-funded initiative that developed a process to regenerate retanning agents from leather shavings, demonstrating the leather sector's long-standing innovation capacity in closing material loops within the tannery itself.
- **Brazil — geometrised hides:** an upstream pre-processing model in which hair is removed and the hide is cut so that only the relevant hide components are sent onward to tanneries, improving material efficiency before the tanning stage even begins.
- **Netherlands — the dairy–veal–leather chain (Vitelco):** a documented case in which calves are themselves a by-product of milk production, veal feed is largely made from by-products of human food processing, and hides/skins are one of many outputs handled by the slaughterhouse, illustrating a triple-nested symbiosis across dairy, meat and leather.

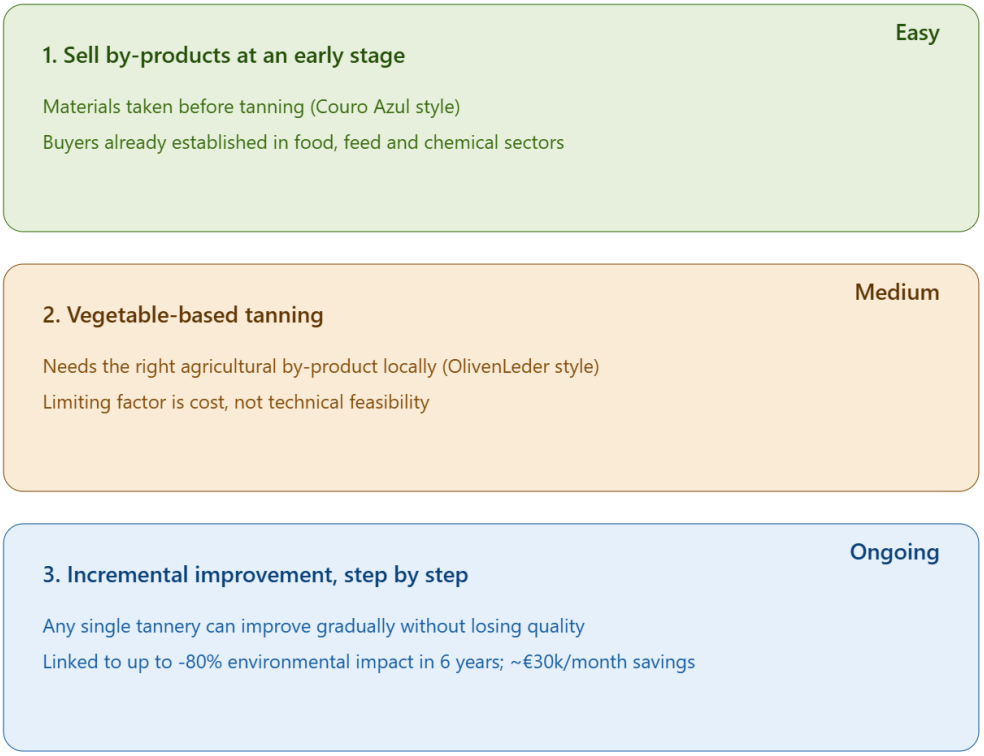
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- **Italy — the Tuscan tanning district:** companies share infrastructure such as consortium wastewater treatment and sludge recovery facilities, an industrial-cluster model directly relevant to smaller tanneries that cannot individually justify investment in advanced treatment technology.
- **United States/international — the alligator farming–tannery relationship:** an active, established collaboration between alligator farms and specialised alligator tanneries, which work closely with watch-bracelet and leather-goods manufacturers, illustrating symbiosis in an exotic-leather niche.
- **Spain/Italy — bio-based tanning agents from agrifood residues:** technically validated pilot-scale extraction of tannins from avocado pits and skins, grape pomace and olive leaf extracts, alongside sea buckthorn tannins, as chromium alternatives, aligned with the updated European Bioeconomy Strategy and potentially eligible for Horizon Europe funding.

Models That Can Be Copied

- **Selling by-products early (Couro Azul):** the easiest model to replicate. Almost any tannery can do it, because materials taken before tanning are simpler to reuse and already have established buyers in food, feed and chemicals.
- **Plant-based tanning (OlivenLeder):** works where the right agricultural by-product is locally available and buyers accept a somewhat higher price. The limiting factor is cost, not technical feasibility.
- **Incremental, small-step improvement:** any single tannery can improve gradually without compromising product quality. This approach was linked, in the cases documented, to an 80% drop in environmental impact over six years and, in one small tannery, savings of about €30,000 a month, alongside recipe optimisation and more efficient use of the leather surface area.

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What Works and What Gets in the Way

What makes symbiosis work:

- tanneries grouped close together (industrial clusters);
- shared investment, so no single company carries the cost alone;
- recovering materials early, before chemical processing makes them harder to reuse;
- never sacrificing leather quality, since buyers will not accept a lower-quality product;
- making changes incrementally rather than all at once;
- processing by-products in-house to capture their value directly; maintaining clear technical data sheets so that other industries can quickly judge a material's suitability;
- having approved companies ready to receive the material streams;
- possessing the skills and tools needed to identify and justify exchanges.

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What gets in the way is, almost point for point, the opposite of these conditions. The biggest problem is regulation: leather by-products are often treated as waste or not classified at all, and even clean, chrome-free scraps are shut out of approved fertiliser routes under the EU Fertilising Products Regulation 2019/1009, because leather was not considered when those rules were written and because regulators frequently assume all leather contains chrome. There are also too few approved companies authorised to receive the materials, so usable streams, such as Couro Azul's compostable sludge, have nowhere to go. Disposal remains cheaper than reuse in many cases, so tanners end up paying to get rid of by-products that have genuine value. Plant-based options are further held back by LCA methods that undervalue their environmental benefit. Inside companies, resistance to change, capital already tied up in chrome-based equipment, and a lack of the cross-field knowledge needed to spot opportunities all slow progress.

The lesson for SYMBIOS is straightforward: replicating a success mostly means recreating the right conditions, bringing isolated tanneries together, recovering materials earlier in the process, providing clear data and matchmaking so that buyers and sellers can find each other, and advocating for rules that recognise what the sector can already demonstrably do.

Digital Platforms Supporting Industrial Symbiosis

Unlike the agrifood sector, the leather sector research did not surface a dedicated national or sectoral digital matching platform comparable to Spain's Simbylay or Slovenia's CIRCI baza and VCG.AI. The clearest reference points instead come from outside the sector: the National Industrial Symbiosis Programme (NISP, United Kingdom), widely recognised as one of the most successful cross-sector facilitation initiatives, connecting thousands of companies and diverting millions of tonnes of waste from landfill (Laybourn & Lombardi, 2012); and, within leather specifically, the Leather Working Group's traceability and audit infrastructure (Section 1.3), which, while not a resource-matching tool, demonstrates that the sector is already capable of operating shared digital reporting systems at scale. This combination, a proven cross-sector model (NISP) and an existing sector-specific digital infrastructure (LWG) to build on, is precisely the gap the SYMBIOS Digital Platform's Community Section is designed to fill for the leather sector.

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Chapter 2 – Knowledge and Skills for Industrial Symbiosis

If Chapter 1 establishes that industrial symbiosis is structurally embedded in the leather sector, the WP 2.3 needs analysis shows just as clearly that unlocking its full potential is constrained less by technology than by a dual deficit of technical and regulatory competence, compounded by very low levels of structured training investment. This chapter maps that knowledge and skills gap, drawing directly on the WP 2.3 global survey of 30 leather-sector companies, the nine accompanying deep interviews, the two SYMBIOS leather focus groups, and the UPT systematic review of existing Industrial Symbiosis learning offers.

2.1 Required Knowledge and Skills

Across all data sources, the competences required to operationalise industrial symbiosis in the leather sector cluster into seven interconnected domains, each described below. Each domain is also mapped against the European Qualifications Framework (EQF), the ESCO classification of skills, competences, qualifications and occupations, and GreenComp, the European Sustainability Competence Framework (the full mapping is presented in Annex D). When asked to identify the main skills gaps limiting the implementation of circular or symbiotic practices, WP 2.3 survey respondents named technical skills (processes, materials, energy) most frequently (15 of 30 companies), closely followed by regulatory and compliance skills (14 companies), a striking co-dominance that the report's own discussion explicitly interprets as a dual technical-regulatory deficit: technical knowledge without regulatory literacy leads to well-intentioned but non-compliant circular initiatives, while regulatory knowledge without technical skills leaves companies unable to operationalise compliance into viable business processes. This dual deficit shapes the priorities described below, and is summarised at the end of this section ("Summary: Where the Gap Is Widest").

Waste and By-Product Management

EQF 4–5 · ESCO: Environmental Technician, Waste Management Manager · GreenComp: Acting for sustainability

The technical ability to characterise, classify, store, treat and document by-products so that they can legally and safely be exchanged, including practical knowledge of the distinction between waste and by-product status. The WP 2.3 survey shows this domain is already comparatively strong at the level of monitoring, two-thirds of companies (67%) report advanced, quantitative monitoring of waste and by-product flows, but weaker at the level of classification and downstream regulatory navigation, particularly for chromium-bearing streams.

Resource Efficiency and Process Optimisation

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EQF 5–6 · ESCO: Environmental Engineer, Environmental Expert · GreenComp: Embracing complexity in sustainability

The ability to recognise where in the tanning process a material can be recovered at higher value, understanding, in practice, the stage-dependent recyclability logic set out in Section 1.2, and to redesign processes (recipe optimisation, surface-area optimisation, earlier fat recovery) to increase both leather quality and by-product value simultaneously, as demonstrated by the SME tannery cases reporting €30,000/month savings and an 80% six-year reduction in environmental impact.

Commercial Negotiation and Business Case Development

EQF 6–7 · ESCO: Environmental Expert (advisory/consultancy function) · GreenComp: Acting for sustainability

The ability to translate a by-product into a viable commercial proposition: since disposal remains cheaper than valorisation for many streams, companies need the negotiation and pricing skills to make circular alternatives commercially attractive, including engagement with intermediaries such as renderers and specialised valorisation companies.

Networking and Partnership Building

EQF 5–7 · ESCO: cross-cutting, not tied to a single profession · GreenComp: Acting for sustainability

The relational competence to identify potential partners across sectors and to move from informal, occasional exchange (reported by 9 of 30 companies) to stable, long-term partnership (reported by only 10 of 30). This is one of the clearest gaps identified in the research: 70% of companies report some partnership, but formalisation, trust-building and the search for new partners beyond existing informal contacts remain limited.

Project Management

EQF 6–7 · ESCO: cross-cutting, relevant across all four named green professions · GreenComp: Acting for sustainability

The ability to structure, fund and steer a symbiotic initiative from idea to implementation, including engagement with the forthcoming Circular Economy Act and Biotech Act II funding opportunities, and coordination of multi-stakeholder district-based initiatives.

Problem-Solving and Systems Thinking

EQF 5–7 · ESCO: cross-cutting foundational competence · GreenComp: Embracing complexity in sustainability

The capacity to see the tannery as one node in a wider value chain rather than a self-contained process, understanding, for instance, how upstream coordination with slaughterhouses (on hide trimming, cleaning and classification) directly determines downstream valorisation options, a connection repeatedly emphasised across both SYMBIOS focus groups as the single most critical leverage point for improving circularity.

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Digital Skills (Platforms, Data Analysis and Traceability)

EQF 4–6 · ESCO: Environmental Technician; Environmental Protection Technologies · GreenComp: Acting for sustainability

The ability to use digital resource-matching platforms, to maintain standardised technical data sheets for by-products, and to respond to the growing traceability and supply-chain transparency demands of brands and certification schemes (ISO 14001, LWG, RSCI). Only 2 of the 30 surveyed companies report digitally supported monitoring systems, indicating that this remains an area of substantial untapped potential, directly addressed by the design of the SYMBIOS Community Section.

External Pressures Reshaping Required Competences

The WP 2.3 interviews identify a "compliance cascade" as an accelerating trend reshaping the competence needs of the sector: brands increasingly demand environmental and waste-management data from their tannery suppliers, conducting audits and requesting sustainability information; while tanneries are not directly subject to the Corporate Sustainability Reporting Directive (CSRD), their large clients increasingly oblige them to report on supply chains; and demand for recognised certifications (ISO 14001, LWG, RSCI) continues to grow. This trend means that competences in ESG data management, LCA and supply-chain traceability, historically peripheral to tannery operations, are rapidly becoming core requirements.

Summary: Where the Gap Is Widest

Competence/skill area	Frequency cited as a gap (WP 2.3 survey, n=30)	Strategic priority for training
Technical skills (processes, materials, energy)	15 companies	Highest priority
Regulatory and compliance skills	14 companies	Highest priority
Strategic and managerial skills	5 companies	Medium priority
Awareness or internal coordination skills	4 companies	Medium priority
Digital and monitoring skills	3 companies	Priority training area
Traceability skills	1 company	Niche, sector-specific priority
Time / resourcing constraint (not a skills gap)	1 company	Not addressable through training alone
No significant skills gap identified	7 companies	N/A — no training need reported

Table 4. Main skills gaps limiting circular/symbiotic practice implementation, leather sector (WP 2.3 survey, n=30, total responses=52).

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This picture is reinforced by the WP 2.3 deep interviews, which identified Life Cycle Assessment (LCA) expertise, cross-sector and industrial symbiosis knowledge, environmental and waste management competences, and collaboration/partnership-building skills as the key areas of deficiency across the sector. Interviewees explicitly highlighted the lack of cross-sector knowledge as a particular barrier: tanneries often do not know which industries could absorb their by-products as raw materials, and vice versa, precisely the information gap that a matching tool such as the SYMBIOS Digital Platform will be designed to close.

Investment in training on circular economy and industrial symbiosis remains very limited across the sector: only 4 of the 30 surveyed companies (13%) report regular, structured training, while 15 offer only occasional or ad hoc training and 11 provide no training at all. This is consistent with the general finding that the sector is currently addressing its skills deficit through informal, reactive means, leaving companies exposed as new regulatory requirements continue to evolve.

2.2 Skills by Target Group

Because the SYMBIOS Digital Platform is designed to serve lifelong learners at very different stages of their career, the knowledge and skills identified above must be translated into differentiated learning pathways for four target groups, consistent with the target-group definition adopted in the project's Grant Agreement. The EQF, ESCO and GreenComp mapping introduced in Section 2.1 and detailed in Annex D also broadly tracks this grouping: entry-level and employed-worker content clusters around EQF 4–5, while the strategic content aimed at managers clusters around EQF 6–7, providing an additional, externally recognised reference point for calibrating the difficulty and positioning of each learning pathway below.

2.2.1 Young Graduates: Entry-Level Competencies and Emerging Professional Profiles

Young graduates entering the leather sector, from chemistry, materials science, environmental engineering, or business backgrounds, need a solid conceptual foundation in both tanning technology and circular economy principles before they can meaningfully contribute to symbiotic initiatives. Entry-level competencies include:

- understanding of the tanning process and its stage-dependent co-product profile (Section 1.2);
- the practical distinction between animal by-product categories and waste/by-product classification under EU law;
- introductory Life Cycle Assessment, including an awareness of current allocation-methodology debates specific to leather (see below);
- digital skills in the use of sustainability data tools;

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- project management skills and economic and financial skills.

The research also points to emerging professional profiles for which formal qualification pathways are still scarce:

- the industrial symbiosis officer able to map a tannery's co-product streams and identify matching opportunities across sectors;
- the LCA and allocation specialist, needed because, as consistently raised in both SYMBIOS focus groups, current attributional LCA approaches often fail to apply a consistent, agreed allocation of environmental burden between the meat and leather sectors, undervaluing hides' status as a by-product;
- the valorisation technologist, bridging tanning chemistry and process engineering to design higher-value uses for pre- and post-tanning residues (collagen, gelatine, biostimulants).
- The near-disappearance of the traditional hide-puller (hide-desalter) profession, noted with concern during the focus groups as a loss of specialised expertise that directly affects raw-material quality entering the value chain, also represents an opportunity to redesign and reintroduce this competence within a modern, symbiosis-aware curriculum.

2.2.2 Employed Workers (C-VET and Lifelong Learning): Upskilling and Reskilling Needs

For workers already employed in tanneries and related operations, process technicians, quality managers, environmental officers, the WP 2.3 findings point unambiguously to the dual technical–regulatory deficit described in Section 2.1 as the priority for upskilling. Because only 13% of companies currently provide regular, structured training, the majority of the workforce is acquiring these competences informally or not at all, leaving companies exposed as regulation and market requirements evolve.

Priority upskilling needs include:

- correct classification and handling of chromium-bearing versus chrome-free streams, given that chromium classification was identified as the single largest technical-regulatory obstacle to scaling industrial symbiosis;
- practical application of REACH and Animal By-Products compliance to day-to-day operations; use of standardised technical data sheets for by-products;
- adaptation to new production models as chrome-free and bio-based tanning agents (vegetable extracts, olive-residue tannins, avocado- or grape-derived tannins) are introduced.

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Because these workers cannot easily leave their jobs for extended training, short, modular, work-based learning units combined with in-company mentoring, are the most realistic delivery format.

2.2.3 Managers and Decision-Makers: Strategic Competencies and Leadership for Sustainability

Managers and decision-makers (tannery owners, general managers, plant managers, sustainability directors, etc. and officials in business associations) require a more strategic mix of competences.

- The WP 2.3 research identifies regulatory advocacy as a distinctly managerial competence in this sector: because chromium classification, the exclusion of leather by-products from the Fertilising Products Regulation, and EU–national regulatory misalignment were identified as the dominant structural constraints on industrial symbiosis, addressing them requires managers and associations capable of engaging directly with EU and national regulators to improve classification frameworks and reduce administrative burden.
- Beyond regulatory engagement, managers need negotiation and partnership-building skills specific to industrial symbiosis: structuring supply agreements with slaughterhouses to improve upstream hide quality and Blößenrendement (clean usable hide yield), engaging with fertiliser and biostimulant producers (SICIT, ILSA, Organazoto and similar companies) as outbound partners, and building the internal business case for investment in chrome-free or bio-based process redesign.
- Leadership for sustainability also increasingly means managing the "compliance cascade" from major brand clients, converting what could be seen purely as a compliance burden into a market opportunity by developing robust circular practices and credible sustainability data capable of attracting and retaining premium clients.

2.2.4 Unemployed and Disadvantaged Groups: Reskilling Pathways and Labour Market Reintegration

The SYMBIOS target-group explicitly includes unemployed people and individuals with fewer opportunities, including workers over 50 at risk of skills obsolescence, and jobseekers whose previous skills have become less relevant to the sector's green transition. For this group, the priority is an accessible, non-formal entry point that does not assume prior technical background:

- basic literacy in circular economy and industrial symbiosis concepts,
- an understanding of the emerging green job market within tanning districts (hide sorting and grading, quality control of recovered materials, entry-level roles in by-product processing),
- confidence in using simple digital tools such as resource-matching platforms.

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The gradual disappearance of specialised upstream professions such as the traditional hide-puller, noted with concern during the SYMBIOS focus groups, represents a genuine labour-market opportunity: reskilling pathways that reintroduce and modernise this expertise, combining traditional hide-handling skill with an understanding of Blößenrendement and downstream valorisation requirements, could simultaneously address a documented skills gap and provide a concrete route back into employment. Because the SYMBIOS MOOC will be designed as an open, free-of-charge, asynchronous and self-paced tool with no entry requirements, it will be well suited to this group, and most effective when explicitly linked to local labour-market intermediaries (public employment services, chambers of commerce, sectoral associations) able to translate MOOC completion into a concrete next step.

2.3 Training Tools and Recommendations

Existing Training Programmes and Support Mechanisms

Unlike the agrifood sector, the leather sector does not have a single national ecosystem of dedicated circular economy platforms. What it does have, however, is a dense network of sector-specific research and technology centres, identified through the SYMBIOS leather focus groups, which already provide a technical support infrastructure that industrial symbiosis training can build upon.

- **SSIP – the Italian Leather Research Institute (Stazione Sperimentale per l'Industria delle Pelli, Italy):** a leading national leather research centre whose experts were directly engaged in the SYMBIOS focus groups, providing applied research capacity on tanning chemistry and process innovation that a sector-specific IS curriculum can draw upon.
- **CTIC – Leather Technology Centre (Portugal):** the Portuguese leather technology centre, engaged as a SYMBIOS focus-group participant, representing the applied research infrastructure of the country with the largest single contingent of companies in the WP 2.3 survey (13 of 30 respondents).
- **CTC Ars Tinctoria (Italy):** a further Italian leather research and testing centre contributing sector-specific technical expertise to the SYMBIOS research.
- **ITECH Lyon (France) and the University of Lleida (Spain):** academic institutions specialising in leather technology and innovation, engaged in the SYMBIOS focus groups, providing an existing higher-education base on which sector-specific Industrial Symbiosis modules could be built.
- **ResoCuir (France):** a French leather-sector cluster already actively engaged in industrial symbiosis practice, illustrating the same cluster-based support model documented for Italy's Tuscan tanning district (Section 1.5).

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- **The Leather Working Group (LWG) certification scheme:** beyond its function as a quasi-regulatory instrument (Section 1.3), LWG's audit protocol and associated guidance materials function in practice as an existing, widely adopted framework for environmental competence that any dedicated IS training offer should reference and build upon rather than duplicate.

These centres and clusters demonstrate a pattern consistent with the agrifood sector's own existing tools: technical research infrastructure and cluster-based cooperation already exist in several countries, but none of them currently offers a structured, competence-based Industrial Symbiosis learning pathway of the kind reviewed in the systematic review below, confirming that the SYMBIOS MOOC's leather section addresses a genuine gap rather than duplicating existing provision.

A Systematic Review of Existing Industrial Symbiosis Learning Offers

As in the agrifood sector, dedicated Industrial Symbiosis training offers remain relatively scarce worldwide. The SYMBIOS partner UPT conducted a structured review covering the period 2015–2026 to identify existing learning offers whose primary educational objective is specifically the development of Industrial Symbiosis competences, deliberately excluding courses that treat IS as only one topic within a broader circular economy or sustainability curriculum. Using a purpose-built Industrial Symbiosis Learning Offer Analysis Framework (ISLOAF), which analyses each offer across five dimensions (Learning Context, Curriculum Design, Pedagogical Approach, Assessment and Recognition, and Educational Insights), nine eligible learning offers were identified and documented.

Learning offer	Provider / context	Target group	Delivery / duration	Certification
Industrial Symbiosis Facilitator Training Program	INSIGHT Consortium (Erasmus+)	Multiple profiles	Blended, 150h	6 ECVET credits
Industrial Symbiosis Joint Curriculum / Live Course	INSET Consortium (Erasmus+)	Employed workers	Blended, 100h	Professional certificate
Industrial Symbiosis Manager Curriculum and MOOC	FReINDs Consortium (Erasmus+)	Employed workers	Online, 60h	Not reported
Smart Industrial Symbiosis	University of Stavanger (HE)	Young graduates	Hybrid, 5 ECTS	University credits

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Learning offer	Provider / context	Target group	Delivery / duration	Certification
Industrial Symbiosis (TKMJ38)	Linköping University (HE)	Young graduates	Campus, 6 ECTS	University credits
Industrial Symbiosis	TalTech (HE)	Young graduates	Campus, 3 ECTS	University credits
SUS0310 – Industrial Symbiosis	Steel University (industry academy)	Employed workers	Online, ~3h	Professional certificate
Symbiosis Training Program	Kalundborg Symbiosis / SACI	Employed workers	Blended, not reported	Certificate of participation
Industrial Symbiosis & Eco-Industrial Parks Development	Upskill Development	Employed workers	Online, 5 days	Professional certificate

Table 5. Evidence matrix of existing Industrial Symbiosis learning offers with IS as primary educational objective, 2015–2026 (UPT systematic review, WP 2.6).

Comparative Findings

The comparative ISLOAF analysis of these nine offers reveals a relatively small but diverse landscape, converging on several consistent educational characteristics. The reviewed offers fulfil four principal educational purposes:

- academic education,
- facilitator development,
- manager development,
- continuing professional development

and address three main learner groups:

- young graduates (typically through higher-education modules of 3–6 ECTS),
- employed workers (typically through Erasmus+-funded blended programmes or short industry-academy courses),
- professionals acting as facilitators or managers, reflecting a broader shift from purely discipline-oriented education towards competence development linked to explicit professional profiles such as "Industrial Symbiosis Facilitator" or "Industrial Symbiosis Manager".

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Curriculum design across the reviewed offers is predominantly modular, supported by explicitly defined learning outcomes, with common topics including IS principles, opportunity identification, stakeholder collaboration, implementation strategies, and analysis of real IS cases. A minority incorporate sector-specific examples (cement, ceramics, Eco-Industrial Parks). Pedagogically, case-based learning is the dominant methodology across all contexts, frequently complemented by project work, collaborative learning and discussion of authentic examples; higher-education courses balance conceptual understanding with project work, while professional training emphasises implementation and industrial practice. Assessment and certification vary by context, ECTS credits for university courses, ECVET credits and professional certificates for Erasmus+ and industry programmes, with Erasmus+ projects generally providing the richest public documentation of learning outcomes and materials.

Learning Methodologies

Consistent with both the comparative review and the target-group needs identified in Section 2.2, the SYMBIOS partnership recommends a blended methodological approach combining:

- **Work-based learning:** short, self-contained modules that employed workers can complete alongside their jobs, directly addressing real by-product streams and processes within their own tannery.
- **Competence-oriented, modular curriculum design:** built around clearly defined competences and identifiable professional profiles (Industrial Symbiosis Facilitator, Manager, Practitioner) rather than disciplinary knowledge alone, mirroring the dominant model identified across the nine reviewed learning offers.
- **Experiential and case-based learning:** use of the documented best practices in Section 1.5 (Couro Azul, OlivenLeder, the Tuscan district model, the Kalundborg/SACI Symbiosis Training Program) as concrete teaching material, allowing learners to see how abstract principles translate into operational reality.
- **Self-assessment and quizzes:** consistent with the asynchronous, self-paced design already used in comparable offers such as the FReINDs Manager MOOC and the Steel University SUS0310 course.
- **Peer networking and community-based learning:** which will be supported through the Community Section of the SYMBIOS Digital Platform, connecting learners with tanneries, business associations and researchers active in the field, and directly addressing the cross-sector knowledge gap identified in Section 2.1.

Recommendations for VET Providers

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The findings set out in this chapter translate into a compact set of design principles for VET providers responsible for designing and delivering industrial symbiosis training in the leather sector.

- **Adopt a competence-oriented approach:** design learning offers around clearly defined competences and identifiable professional profiles (Industrial Symbiosis Facilitator, Manager, Practitioner) rather than focusing exclusively on disciplinary or purely technical knowledge.
- **Prioritise the dual technical–regulatory deficit identified by the WP 2.3 survey:** any leather-sector IS curriculum must address chromium classification, waste-vs-by-product distinctions, REACH and Animal By-Products compliance side by side with practical process and valorisation knowledge, since neither alone is sufficient.
- **Favour modular curriculum design**: providing flexibility for different learner profiles and supporting lifelong learning, upskilling and reskilling, consistent with the dominant pattern identified across existing IS learning offers.
- **Combine conceptual understanding with authentic industrial practice**: through the systematic use of case studies, real industrial examples, project work and collaborative learning, enabling learners to apply knowledge in realistic implementation contexts.
- **Align assessment strategies explicitly with defined learning outcomes and intended competences**: using transparent assessment procedures and recognised certification to strengthen the credibility and transferability of Industrial Symbiosis education.
- **Remain flexible enough to address the differentiated target groups described in Section 2.2**: young graduates, employed workers, managers and disadvantaged/unemployed learners, rather than offering a single generic course.

Recommendations for Policy Makers

Policy makers shape the funding, recognition and regulatory conditions under which VET providers operate; the recommendations below are addressed to national and regional authorities, and to the European Commission and its agencies.

- **Prioritise regulatory clarity and harmonisation as the single highest-impact intervention:** targeted engagement with EU and national regulators to improve by-product classification frameworks (especially for chromium-bearing streams), reduce administrative burden, and align incentives with circular economy goals, since regulatory barriers were identified as the dominant structural constraint across all WP 2.3 data sources.

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- **Support the standardisation of by-product data:** encouraging the development and adoption of standardised technical data sheets for leather by-products to facilitate industrial symbiosis partnerships and matching.
- **Expand specialised educational provision:** the review identified a relatively limited number of structured learning offers dedicated specifically to Industrial Symbiosis worldwide, representing an important opportunity for policy-driven expansion, particularly at sector-specific (leather) level.
- **Encourage collaboration between higher education institutions, VET providers, industry and public authorities**: to ensure that learning offers reflect current industrial practice and evolving competence needs, including the emerging professional profiles identified in Section 2.2.1.
- **Support district-based and network models through funding instruments that de-risk shared infrastructure investment:** particularly benefiting SMEs that cannot individually justify the cost of advanced treatment or valorisation technology.
- **Recognise learning outcomes against European reference frameworks**: (EQF, ESCO, GreenComp), in line with the mapping presented in Annex D, so that certificates of attendance or completion issued through IS-specific courses, carry recognised value across borders.
- **Promote open educational resources, shared curricula and collaborative educational initiatives:** to facilitate the wider dissemination and adaptation of Industrial Symbiosis education across countries, sectors and educational systems.

Taken together, these thirteen principles describe a training offer that is modular rather than monolithic, practically oriented rather than purely disciplinary, and explicitly connected to a matching function rather than delivered in isolation, precisely the model the SYMBIOS Digital Platform's Learning and Community Sections are designed to embody.

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Conclusions

Summary of Key Findings

The combined findings from the WP 2 focus groups, the global survey of 30 leather-sector companies, and the nine accompanying deep interviews confirm that industrial symbiosis is structurally embedded in the leather sector: leather originates as a by-product of the meat and dairy industries, and the sector already relies on complex interconnections with agri-food, slaughterhouses, tanneries and downstream industries. The sector is not starting from zero, high rates of waste monitoring (67% advanced/quantitative), the prevalence of mostly informal industrial symbiosis partnerships (70% of companies), and documented examples of good practice in chrome-free operations, district-based water management, and cross-sector by-product valorisation demonstrate real existing capacity to build upon.

Despite this, the full potential of industrial symbiosis remains unrealised due to economic, regulatory, logistical and narrative barriers. A central finding is that upstream coordination, particularly between slaughterhouses and tanneries, represents the most critical leverage point for improving circularity and material efficiency: early-stage practices such as hide removal, trimming and classification directly determine leather quality, usable yields (Blößenrendement), and downstream valorisation options. Economic misalignment remains a major constraint, since market prices often fail to reward higher-quality hides or refined valorisation pathways, and because leather supply is entirely supply-driven by meat and dairy production, the sector's limited bargaining power reinforces the need for cross-value-chain cooperation rather than isolated optimisation.

Chromium classification stands out as the single largest technical-regulatory obstacle to scaling industrial symbiosis: the regulatory and technical constraints around chromium-containing by-products (particularly wet-blue shavings and sludge) restrict valorisation pathways that are, in several cases, already technically demonstrated. Regulatory misalignment between EU and national implementation, complex waste classification rules, and high administrative burden compound this constraint, creating a structural environment that currently rewards disposal over valorisation. Skills gaps are wide and only weakly addressed: the co-dominance of technical (15/30) and regulatory/compliance (14/30) skills gaps, combined with only 13% of companies investing in regular, structured training, leaves the sector poorly equipped for the transitions demanded by both market forces and future regulation.

At the same time, external pressures, brand requirements, ESG standards, and the indirect effects of the Corporate Sustainability Reporting Directive, are accelerating the transition imperative, creating an increasingly urgent business case for circular action, particularly for companies in the supply chains of major brands. Focus-group participants further underline the importance of a

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strategic narrative shift: leather is frequently perceived as an unsustainable or unethical material rather than as the long-lived, biogenic and circular material that the evidence in this model demonstrates it to be. Correcting this misperception, through transparent communication, aligned policy frameworks and credible environmental data (including fair LCA allocation rules between the meat and leather sectors), is identified as essential to unlock innovation, restore market value, and secure fair regulatory treatment.

Future Opportunities for the Sector

The barriers described above are real, but they are not, for the most part, technological. Almost every opportunity identified through the WP 2.3 research is a case of a solution that already exists somewhere in the sector, piloted in one company, one country, or one supply chain, waiting to be connected, funded, or simply made visible to the tanneries that could use it. The six opportunities below are therefore framed deliberately as near-term, actionable possibilities rather than long-range aspirations.

- Resolving chromium classification: developing clearer, EU-recognised classification frameworks for chromium-bearing by-products, building on already-piloted valorisation pathways such as biodegradable flowerpots from chrome-bearing shavings, represents the single highest-value regulatory opportunity identified in this research.
- Extending bio-based tanning agents: technically validated but not yet industrially scaled pathways, olive-residue tanning agents (OlivenLeder), avocado-, grape- and sea-buckthorn-derived tannins, offer a genuine opportunity to couple two by-product streams (agrifood residues and hides) within a single circular process, directly linking the SYMBIOS project's two target sectors.
- Reviving upstream expertise: the near-disappearance of the traditional hide-puller profession represents both a risk to raw-material quality and a concrete reskilling opportunity, particularly for the unemployed/disadvantaged target group described in Section 2.2.4.
- Scaling district-based models: the Tuscan consortium treatment-plant model demonstrates a replicable template for connecting isolated tanneries, particularly SMEs, into functional symbiosis networks through shared infrastructure investment.
- Digitalising matching and traceability: very low current uptake of digital monitoring (2 of 30 companies) and the persistent cross-sector information gap represent the clearest near-term opportunity for improvement, which will be directly addressed by the SYMBIOS Digital Platform's Community Section and standardised by-product data sheets.

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- Strengthening the leather–agrifood symbiosis corridor: as the SYMBIOS project's two target sectors, leather and agrifood already share one of the oldest symbiotic relationships in industry; explicit cross-sectoral training and matching between the two SYMBIOS sector communities, extending from hides through to bio-based tanning agents, is a natural next step for the platform.

What unites these six opportunities is that none of them depends on a technological breakthrough still to come: the enabling knowledge, the regulatory basis, and in most cases a working example, already exist somewhere within the evidence gathered for this model. The task ahead is one of connection, replication and scale, which is precisely the gap the operational recommendations below are designed to help close.

Operational Recommendations

This model is written to be used, not only read. The recommendations below are addressed directly to you, whoever you are as you reach this page, a tannery representative examining your own by-product streams for the first time, a student or jobseeker considering a career in the leather sector or the circular economy, a trainer or VET provider designing a course, an association or cluster officer, or a policy maker, rather than to the SYMBIOS partnership alone. Each one is a practical starting point, grounded in the evidence of this model, for turning an understanding of industrial symbiosis into action; the SYMBIOS Digital Platform will be designed to be the first concrete resource for taking any of the steps below.

- If you work in a tannery: begin with an internal audit of co-product recovery timing along the process stages set out in Section 1.2, since earlier recovery is consistently associated with higher valorisation value; prioritise turning informal, occasional exchanges (9 of 30 companies) into stable partnerships and long-term agreements.
- If you work in a slaughterhouse or elsewhere in the meat sector: invest in upstream hide-handling expertise and closer coordination with tanneries on trimming and classification practices; this research identifies that coordination as the single most critical leverage point for the entire downstream value chain.
- If you represent a business association, industrial cluster, or sectoral network: you are well placed to play the trusted-intermediary and advocacy role that this research shows is often missing, engaging EU and national regulators on chromium classification and the Fertilising Products Regulation and supporting the wider adoption of standardised by-product technical data sheets.
- If you train, teach, or design educational programmes: adopt the competence-oriented, modular approach described in Chapter 2, explicitly addressing the dual

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technical–regulatory skills deficit, differentiated by target group, and seek recognition against the EQF, ESCO and GreenComp reference frameworks so that what learners gain is portable and credible.

- If you shape policy or regulation: prioritise regulatory clarity on by-product versus waste classification for chromium-bearing streams; support district-based infrastructure investment for SMEs; and consider recognising leather explicitly within the EU Bioeconomy Strategy, closing an identified gap between the sector's substantive alignment with bioeconomy objectives and its current lack of formal recognition.
- If you are a student, recent graduate, or jobseeker curious about this field: you do not need a technical background to start. The SYMBIOS MOOC (Work Package 3.1) will be designed as a free, self-paced entry point with no prerequisites, use it to build the foundational knowledge and skills mapped in Section 2.2, and use the Community Section to connect with the tanneries and organisations named throughout this model.

None of these steps requires waiting for ideal conditions or a finished regulatory framework. The evidence gathered for this model shows, repeatedly, that the binding constraint on industrial symbiosis in the leather sector is more often a lack of authorised recipients, standardised data, or upstream coordination than a lack of technology or willingness, which means that reading this document and taking one of the steps above is, in a very concrete sense, already a contribution to closing that gap.

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References

Albino, V., Fraccascia, L., & Giannoccaro, I. (2015). Exploring the role of contracts to support the emergence of self-organized industrial symbiosis networks: An agent-based simulation study. Journal of Cleaner Production, 112, 4353–4366.

Buljan, J., & Kral, I. (2015). Introduction to treatment of tannery effluents. Vienna: United Nations Industrial Development Organization (UNIDO).

Chertow, M. R. (2000). Industrial symbiosis: Literature and taxonomy. Annual Review of Energy and the Environment, 25, 313–337.

Chertow, M. R. (2007). Uncovering industrial symbiosis. Journal of Industrial Ecology, 11(1), 11–30.

European Commission. (2019). The European Green Deal. COM(2019) 640 final.

European Commission. (2020). A new circular economy action plan: For a cleaner and more competitive Europe. COM(2020) 98 final. Brussels: European Commission.

European Commission. (2025). EU Bioeconomy Strategy (2025 update).

European Parliament and Council. (2008). Directive 2008/98/EC on waste (Waste Framework Directive). Official Journal of the European Union, L 312, 3–30.

European Parliament and Council. (2009). Regulation (EC) No 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption. Official Journal of the European Union, L 300.

European Parliament and Council. (2019). Regulation (EU) 2019/1009 laying down rules on the making available on the market of EU fertilising products. Official Journal of the European Union, L 170.

European Parliament and Council. (2006). Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). Official Journal of the European Union, L 396.

European Parliament and Council. (2022). Directive (EU) 2022/2464 as regards corporate sustainability reporting (CSRD). Official Journal of the European Union.

Gómez-Guillén, M. C., Giménez, B., López-Caballero, M. E., & Montero, M. P. (2011). Functional and bioactive properties of collagen and gelatin from alternative sources: A review. Food Hydrocolloids, 25(8), 1813–1827.

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.

This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License (CC BY-SA 4.0).

Kanagaraj, J., Senthilvelan, T., Panda, R. C., & Kavitha, S. (2015). Eco-friendly waste management strategies for greener environment towards sustainable development in leather industry: A comprehensive review. Journal of Cleaner Production, 89, 1–17.

Lasekan, A., Bakar, F. A., & Hashim, D. (2013). Potential of chicken by-products as sources of useful biological resources. Waste Management, 33(3), 552–565.

Laybourn, P., & Lombardi, D. R. (2012). Industrial symbiosis in action: The National Industrial Symbiosis Programme (NISP). London: International Synergies Ltd.

Lombardi, D. R., & Laybourn, P. (2012). Redefining industrial symbiosis. Journal of Industrial Ecology, 16(1), 28–37.

Neves, A., Godina, R., Azevedo, S. G., Pimentel, C., & Matias, J. C. O. (2020). The potential of industrial symbiosis: Case analysis and main drivers and barriers. Sustainability, 12(14), 5371.

Sundar, V. J., Muralidharan, C., & Mandal, A. B. (2011). Recovery and utilization of proteinous wastes of leather making: A review. Reviews in Environmental Science and Biotechnology, 10(2), 151–163.

United Nations Industrial Development Organization (UNIDO). (2017). The framework for sustainable leather manufacture. Vienna: UNIDO.

Van Capelleveen, G., Amrit, C., & Yazan, D. M. (2018). A literature survey of information systems facilitating the identification of industrial symbiosis. Journal of Cleaner Production, 178, 903–921.

Symbios Project internal sources (SYMBIOS WP2, 2025–2026)

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Annexes

Annex A – Glossary

Term	Definition
Industrial symbiosis (IS)	A collaborative approach in which traditionally separate industries exchange materials, energy, water, services and information to improve resource efficiency and reduce environmental impact (Chertow, 2000).
Category 3 animal by-product	Under Regulation (EC) No 1069/2009, animal material of low risk (including hides and skins from animals fit for human consumption at slaughter) permitted for a range of downstream uses subject to sanitary conditions.
Beamhouse	The initial stage of the tanning process, in which raw or salted hides are cleaned, soaked and unhaired, generating trimmings, fleshings, hair and wool as principal co-products.
Wet-blue (WB)	Hide that has undergone chrome tanning, giving it a characteristic pale blue colour; WB shavings and trimmings are among the highest-volume and most regulatorily constrained leather by-products.
Wet-white (WW)	Hide tanned using chrome-free agents (e.g., vegetable, aldehyde-free or metal-free systems); WW co-products have wider circular valorisation options owing to low heavy-metal content.
Crust	Leather that has been tanned and dried but not yet finished; crust-stage shavings and trimmings offer narrower valorisation options than pre-tanning materials.
Blößenrendement	A German tanning-industry term denoting the ratio of usable, clean hide surface area obtained after trimming, cleaning and unhairing — a long-established indicator of material efficiency and of the quality of slaughterhouse–tannery coordination.
By-product	A secondary material generated during a production process that has a certain and lawful further use without requiring significant additional processing (Waste Framework Directive, Art. 5).
Waste	A material that the holder discards, intends to discard, or is required to discard under regulatory frameworks.
Cascading use	The sequential use of a resource across successive applications, from highest to lowest value, before final disposal or energy recovery — of

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Term	Definition
	particular relevance to the 75–80% of hide mass not converted into leather.
Life Cycle Assessment (LCA) allocation	The methodological rule determining how much of the environmental burden of an upstream process (e.g., livestock farming) is attributed to a downstream by-product (e.g., a hide); a recurring point of contention for the leather sector, which argues for zero or minimal allocation given its by-product status.
Leather Working Group (LWG)	An industry certification scheme assessing the environmental performance of leather manufacturing, increasingly required by brands as a supply-chain condition.
REACH	The EU Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals, directly affecting the classification and permissible use of tannery chemical residues.
ESCO	The European Skills, Competences, Qualifications and Occupations classification, a multilingual classification used across the EU to describe skills, competences, qualifications and occupations.
GreenComp	The European Sustainability Competence Framework (European Commission, January 2022), describing the key competences needed to act in an environmentally sustainable way.

Annex B – Overview of Data Collection Instruments (Surveys, Interviews and Focus Groups)

B.1 Focus groups (WP 2.2)

Two online focus groups (Zoom), 1.5 hours each, held on 17 and 26 November 2025, coordinated by COTANCE and SPIN360, with six participants per session (twelve in total) drawn from: Vitelco (NL), University of Zaragoza (ES), LHCA (USA), ITECH (FR), the International Meat Secretariat, VDL (DE) — first session, 17 November; and Authenticae (UK), Universitat de Lleida (ES), an independent leather expert (UK), ResoCuir (FR), Beef & Lamb Australia, and CTCP — second session, 26 November. Sessions were structured around three themes: state of the art (current IS practices), challenges (regulatory framework), and possible solutions (future opportunities and replicability conditions), supported by real-time Mentimeter polling and a guiding presentation.

B.2 Survey structure (WP 2.3)

Administered to 30 leather-sector companies across 13 countries (Portugal 13, Italy 9, Germany 3, France 2, and one company each from Argentina, Brazil, Spain, the Netherlands, Turkey, the USA,

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Uruguay, Vietnam, and a worldwide-operating respondent). Structured in thematic sections aligned with the research objectives:

- Company profile and geographies (country, size, production process, market orientation, standards/certifications).
- Waste management and monitoring (monitoring sophistication, by-product types).
- Industrial symbiosis partnerships (partnership type and stability, internal IS practices, by-product destinations).
- Occupational Safety and Health (OSH) constraints on by-product reuse or exchange.
- Regulatory barriers (main regulatory areas affected, type of barrier encountered).
- Skills and training (skills gaps, training investment, self-assessed competence levels).

B.3 Interview protocol (WP 2.3)

Nine semi-structured deep interviews with leather-sector stakeholders, covering: waste streams and by-product characteristics; internal circular practices already in place; external pressures (brand requirements, CSRD, ESG criteria, certifications); and self-assessed competence levels, particularly in LCA, cross-sector/IS knowledge, environmental/waste management, and collaboration/partnership-building.

Annex C – Detailed Competence Framework by Target Group

Target group	Core knowledge	Core skills	Recommended entry point
Young graduates	Tanning process & by-product profile; animal by-product categories; introductory LCA/allocation issues	Basic co-product mapping; digital traceability literacy; report writing; Project Management and economic and financial skills.	SYMBIOS MOOC leather units; internships with tanneries/COTANCE members
Employed workers (C-VET)	Chromium vs chrome-free classification; REACH & Animal By-Products compliance; technical data sheets	Process adaptation (bio-based tanning agents); digital monitoring tools; basic negotiation with buyers/intermediaries	Short, modular work-based learning units; in-tannery mentoring

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Target group	Core knowledge	Core skills	Recommended entry point
Managers / decision-makers	Regulatory advocacy; circular business models; brand/ESG/CSRD requirements	Negotiation with slaughterhouses & fertiliser producers; strategic leadership; systems thinking	Strategic modules + Community Section networking; sectoral cluster engagement
Unemployed / disadvantaged groups	Basic circular economy literacy; hide-handling fundamentals	Digital platform navigation; entry-level hide sorting/grading and quality-control skills	Open-access, no-prerequisite MOOC units; links to public employment services

Annex D – Mapping of Competences to European Reference Frameworks (EQF, ESCO, GreenComp)

As required by the SYMBIOS Grant Agreement, the seven competence domains identified in Section 2.1 are mapped below against three European reference standards: the European Qualifications Framework (EQF), the ESCO classification of skills, competences, qualifications and occupations, with explicit reference to the green professions and green knowledge area named in the Grant Agreement (Waste Management Manager, Environmental Engineer, Environmental Expert, Environmental Technician, Environmental Protection Technologies), and GreenComp, the European Sustainability Competence Framework (European Commission, January 2022), whose four competence areas (Embodying sustainability values; Embracing complexity in sustainability; Envisioning sustainable futures; Acting for sustainability) provide the structuring logic for the right-hand column. This mapping is intended to give the SYMBIOS MOOC's learning outcomes, and any certificate of attendance or completion issued through the SYMBIOS Platform, a transparent and recognised anchor in existing European frameworks, rather than a self-referential competence list.

Competence domain (Section 2.1)	Indicative EQF level	Closest ESCO reference profession(s) / knowledge area	GreenComp competence area
Waste and By-Product Management	4–5	Environmental Technician; Waste Management Manager	Acting for sustainability

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Competence domain (Section 2.1)	Indicative EQF level	Closest ESCO reference profession(s) / knowledge area	GreenComp competence area
Resource Efficiency and Process Optimisation	5–6	Environmental Engineer; Environmental Expert	Embracing complexity in sustainability
Commercial Negotiation and Business Case Development	6–7	Environmental Expert (advisory/consultancy function)	Acting for sustainability
Networking and Partnership Building	5–7	Cross-cutting; not tied to a single ESCO profession	Acting for sustainability
Project Management	6–7	Cross-cutting; relevant across all four named green professions	Acting for sustainability
Problem-Solving and Systems Thinking	5–7	Cross-cutting foundational competence	Embracing complexity in sustainability
Digital Skills (Platforms, Data Analysis and Traceability)	4–6	Environmental Technician; Environmental Protection Technologies	Acting for sustainability

Table 6. Mapping of the WP 2.6 leather competence domains to EQF, ESCO and GreenComp, as required by the SYMBIOS Grant Agreement (WP 2.6 quality indicators).

Read alongside Table 4 (skills gap categories) and Annex C (competence framework by target group), this mapping shows that the domains where the technical-regulatory deficit is widest, resource efficiency/process optimisation and digital skills, cluster mainly around EQF levels 4–6 and around the "Embracing complexity in sustainability" and "Acting for sustainability" GreenComp areas, reinforcing the priority given to these domains in the recommendations in Section 2.3.

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