SymbioBeer

Industrial Symbiosis

Industry Guide

2021

Authorship & Acknowledgements

Authors: Giovanni Impoco (IMR), Oludunsin Arodudu (IMR), Geraldine Brennan (IMR)

Irish Manufacturing Research (IMR) would like to thank the following actors without which the SymbioBeer Good Practice Guide would not have been possible:

- *Panelto Foods*: Brian Guerin, Pierre Delannoy, Viraj Salvi
- *St Mel's Brewing Company*: Liam Hanlon
- *EPA*: Joe O'Reilly and Shane Colgan
- *SymbioBeer Stakeholder Workshop Participants (March 2021):* Representatives from Heineken, Diageo, Avoca Seafoods, Goodness Grain Bakery, Lough Ree Distillery, Biasol, Aryzta, Frylite, Adnams, Puratos, St. Mel's Brewery, Panelto Foods as well as local government and regional economic development agencies from Longford, Donegal, Derry and Strabane.
- *IMR Delivery Team*: Giovanni Impoco, Oludunsin Arodudu, Geraldine Brennan, David McCormack, Geraldine Ann Cusack and Adriana Saraceni.
- *Graphic Design*: Alina Yafasova, IMR

Executive Summary

Industrial symbiosis has been proven to be effective in delivering economic, environmental and social benefits, and in supporting global transition to a more circular economy. An industry-led consortium defined industrial symbiosis (IS) for the EU as: "*… the use by one company or sector of underutilised resources broadly defined (including waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment and materials) from another, with the result of keeping resources in productive use for longer*" (CEN, 2018, p. 7).

As in every transaction, economic returns and savings are very important. Within the context of Industrial Symbiosis (IS) transactions of by-products, the magnitude of economic returns and savings made is largely dependent on the availability and/or reliability of supply chains for transformation and valorisation of secondary raw materials, as well as the proximity of the transactions (i.e. locations and the distances within which the transaction takes place). The characteristics of the resource being transacted may however substantially influence the radius of industrial symbiosis activities.

These characteristics can include: 1) properties of the waste stream (i.e. its physical and chemical properties); 2) value of the waste stream (transformation and logistics costs could impact the final cost, making secondary raw materials more costly than raw materials, and hence not attractive; and 3) the geographical distribution of resource recovery facilities. In general terms, bulky low value waste such as construction and demolition (C&D) wastes and bio-waste tend to be restricted to local transactions, while low volume high value resources such as cobalt, may have an international scope.

Theoretically, two or more companies seem a perfect match for an industrial symbiosis cooperation. However, manifold heterogeneous barriers must be overcome on the way from conception/ideation to the successful implementation and operation of a viable synergistic transaction. Implementation of all types of industrial symbiosis cooperation requires navigation through various factors associated with the different stages or processes for implementation.

These factors can be drivers, barriers or enablers of industrial symbiosis adoption. They can be broadly related to the three pillars of sustainable development (environment, economic, social), "soft aptitudes" (information and collaboration) and/or "operational context" (technical support and regulations). They can also be specific to sectors or groups of sectors as demonstrated for brewery and bakery sectors, as well as other food and beverage sectors in Ireland by the SymbioBeer Demo. These different factors have high-level implications for implementation and need to be treated and applied contextually for facilitation of successful industrial symbiosis transactions among industry adopters.

This guide (i) describes the origin, definition and benefits of industrial symbiosis especially within the context of a circular economy; (ii) highlights the key resources for industrial symbiosis transactions in Europe and those currently under-exploited in Ireland; (iii) presents a framework for evaluation of industrial symbiosis opportunities (which prescribes a way of thinking about industrial symbiosis opportunities and basic principles for exploring them); (iv) unpacks lessons learnt from the SymbioBeer Demo as an example of an industrial symbiosis transaction (i.e. including identified barriers, enablers and higher value applications) and (iv) insights from literature and as engagement and interactions with representatives of the industry, local authorities/regional economic development agencies) for implementing and scaling industrial symbiosis transactions in the Food Sector in Ireland.

Acronyms & Glossary

ARMs	Alternative Raw Materials
C&DW	Construction and Demolition Waste
CARG	Compound Annual Growth Rate
CE	Circular Economy
CEN	European Committee for Standardisation
CWA	CEN Workshop Agreement
EC	European Commission
EMF	Ellen MacArthur Foundation
EPA	Environmental Protection Agency
EU	European Union
FISSAC	Fostering Industrial Symbiosis for a Sustainable Resource Intensive Industry across the Extended Construction Value Chain
IE	Industrial Ecology
IS	Industrial Symbiosis
NWPP	National Waste Prevention Plan
PET	Polyethylene Terephthalate
PP	Polypropylene
PVC	Polyvinyl chloride
RWMP	Regional Waste Management Plan
SCALER	SCALing European Resources with industrial symbiosis
SDG	Sustainable Development Goal
SME	Small and Medium Enterprise
SWOT	Strengths, Weaknesses, Opportunities and Threats
UK	United Kingdom
WEEE	Waste Electrical Electronic Equipment
WFD	Waste Framework Directive

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Introduction

Since the industrial revolution, global economies have developed in consonance with linear economy model, where "linear" refers to the cradle-to-grave flow of natural resources (also described as "take-make-waste").

In 2011, the European Union produced about 2.5 billion tonnes of waste, and lost about 500 million tonnes of waste that could have been valorised/reused (EC, 397 final, 2014). This implies that the European Union's economy loses a significant amount of potential secondary raw materials present in waste streams, as well as other opportunities and/or benefits deriveable from valorizing such waste.

Moving from a linear economic model to a circular economy entails much more than recycling materials contained in products at the end of their use-phase. It includes among other things, strategies that enable reuse, remanufacturing, and repair; strategies that stimulate new consumption patterns; and the potential and need to establish new business models. It also includes the stimulation of technological innovation, boosting employment from the development of environmental-friendly goods, and opening new benefits for consumers via provision of more sustainable products.

As a result of the development of many concepts and tools over the last years, awareness about the value of waste has gained momentum among local industries, politicians and citizens. Even when discarded, waste has associated costs related to pollution, resource depletion and scarcity of natural resources. As we transition towards a more circular global economy, the intrinsic value of waste can no longer be ignored, hence preserving natural resources via extraction of more value from wastes at any life cycle stage must be regarded as a priority.

1. European Circular Economy Opportunity

Several studies have estimated the size and the potential value of the circular economy to countries worldwide. The findings from some of major studies are as follows:

• World Economic Forum: Circular economy is estimated to provide economic opportunities worth over $1 trillion as well as significant social and environmental benefits (WEF, 2014).

• EU Commission: €600 billion in net savings for EU firms and up to two million jobs by 2030 (EC, 2014). Waste prevention, re-use and similar measures could save €630 billion net for EU businesses (or 8% of their annual turnover), create up to two million jobs while reducing annual total emissions of greenhouse gas by 2-4% by 2030 (EC, 397 final, 2014).

• Ellen MacArthur Foundation: €630 billion by 2025 in the EU (with focus on a subset of manufacturing industries) and €700 billion in material cost savings (with focus on global fast-moving consumer goods sectors) (EMF, Towards the Circular Economy: Economic and Business, 2013).

• UK Department for Environment, Food, and Rural Affairs: €63 billion per year in the UK (with focus on energy, waste, and water efficiency) (WRAP, 2014).

• The Netherlands Organization for Applied Scientific Research: €7.3 billion and 54,000 jobs for the Dutch economy (TNO, 2013).

•In Ireland, an estimated 100 million tonnes of materials are used annually within the economy (EPA, 2019) and a 5% material improvement across the economy could yield €2.32bn p.a. (Coakley et al., 2013).

Moreover, valorising waste, through circular economy strategies like industrial symbiosis, creates the opportunity for import substitution and reinforces the economic benefits of regional supply-chains to Irish companies.

2. What is Industrial Symbiosis?

2.1 Origins of industrial symbiosis

Industrial ecology operationalizes sustainability at three levels namely at facility/firm level, at inter-firm level, and at regional or global level. Industrial Symbiosis (IS) is a branch of industrial ecology (IE) that seeks to operationalize sustainability at inter-firm level by creating synergies which optimize the flow of material, energy and capital between the actors involved (Geyer, 2004).

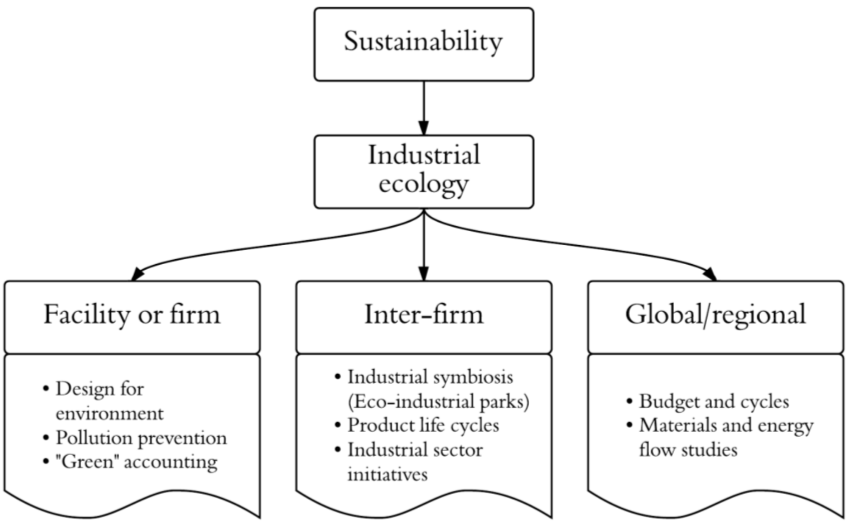

Figure 1 Industrial ecology operates on three levels ((Chertow, 2000)p. 315)

Although the paradigm is much older (Renner, 1947), the term industrial symbiosis was made more popular by the Danish Municipality of Kalundborg, now known as the "Kalundborg Industrial Symbiosis Network" . Kalundborg is the first widely recognized example of an industrial symbiosis involving an intricate network of material and energy exchanges. Even though the network has existed since the early 1970's, it was first recognized for its environmental efficiency in the late 1980's. By sharing ground water, surface water, steam and fuel, and by exchanging by-products which serve as input materials in other firms' processes, both high financial and environmental efficiency was achieved (Chertow, 2000).

2.2 Defining industrial symbiosis

There have been several definitions of industrial symbiosis but a workshop organized by an industry-led consortium in 2018 defined industrial symbiosis more holistically for the EU as: "… *the use by one company or sector of underutilised resources broadly defined (including waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment and materials) from another, with the result of keeping resources in productive use for longer*."
(CEN, 2018, p. 7)

2.3 Benefits of industrial symbiosis

Industrial symbiosis has been shown to deliver resource efficiency with an excellent value-for-money i.e. a return of less than €1 per tonne of CO_2-equivalent avoided (Laybourn, 2009)

Industrial symbiosis has been proven to be effective in delivering economic, environmental, and social benefits, and in supporting global transition towards a more circular economy. More specifically, the benefits of industrial symbiosis according to Laybourn, 2009 include the following:

Environmental: Decarbonisation, landfill diversion, water and virgin materials savings, energy reduction etc.

Economic: Increased sales & reduced costs, profits leading to tax revenues, increased competitiveness, demand-led innovation, new private investment opportunities etc.

Social: Job creation and safeguarding, cleaner environment, small and medium scale enterprise (SME) engagement etc.

3. Industrial symbiosis opportunities

In this section, we outline key resource flows available for industrial symbiosis transactions around Europe (Section 3.1). We also discuss high potential resource focused industrial symbiosis opportunities currently under-exploited in Ireland (Section 3.2).

3.1 Key resource flows for industrial symbiosis transactions in Europe

An overview of key resource flows that can be optimized by industrial symbiosis transactions within the EU are; plastics (3.1.1), WEEE (3.1.2), C&D Waste (3.1.3), Textiles (3.1.4), Wood (3.1.5) and which are discussed next in turn.

3.1.1 Plastics

In Europe, over 40 % of plastics are used in packaging, 20 % in construction and less than 10 % in the automotive industry (Eurostat, 2014). Others are used by the furniture, household appliances and agricultural products sectors. Although recovery and recycling rates of plastic are relatively high in Europe (mostly reused by sectors from which they originate), they could be much higher if not hindered by the diversity in plastic materials i.e. ranging from highly recyclable or reusable types (PET and PP) to others that are hardly recyclable (PVC).

If the approximately 6.8 million tonnes (40 %) of untreated, landfilled and incinerated plastic waste were to be recovered, then this could (at the Eurostat trade prices of around €250-350 per tonne) be worth up to €2.4 billion per year, representing a doubling of the existing market. However, in reality, only part of this would be economically recoverable for industrial symbiosis: in low valuable plastics, processing and logistics costs are too high comparing with a more convenient disposal (Domenech, 2018).

3.1.2 Waste from Electrical and Electronic Equipment (WEEE)

In 2013, WEEE streams in Europe amounted to 9.5 Mt, even though only 3.3 Mt (35%) were collected for treatment. This makes WEEE the least collected waste stream in the EU. An economic assessment of WEEE in the EU suggests there is a market potential of up to €2.1 billion (based on current levels), increasing to €3.7 billion in the future (Cucciella, 2015). WEEE is an important but complex waste stream to process, with potentially valuable quantities of critical raw materials recoverable. (Domenech, 2018).

3.1.3 Construction and Demolition (C&D) Waste

Construction and demolition wastes are very heterogeneous in type (including concrete, bricks, tiles, ceramics, roofing, insulation, wood, carpets, plastic pipes, organics, metals, gypsum, glass, hazardous waste, and many other miscellaneous items). C&D waste streams amount to 297 million tonnes according to Eurostat data from 2014), making it the largest waste stream in terms of volume in the EU (Domenech, 2018).The largest part by volume is mineral materials (mostly non-hazardous mineral materials) often disposed of at landfills. They are also the largest available waste stream for recovery and use in industrial symbiosis.

3.1.4 Textiles

Eurostat data of 2014 reports 2.3 million tonnes of textile waste in the EU. Although treatment, recycling and recovery rates are relatively high (>80%) there remains a balance of untreated and landfilled textile waste totalling around 0.8 million tonnes.

Based on an average price for used textiles of €250-350/tonne, an estimated market potential of up to €270 m can be estimated for the EU. This waste stream is probably the one with the widest array of applications, ranging from the plastic and rubber industries to construction and civil engineering works, to the automotive industry, as well as to the energy recovery and production industry (Domenech, 2018).

3.1.5 Wood

Wood is the largest biomass waste stream in terms of volume in the EU, amounting to above 50 million tonnes in 2014 (according to the Eurostat). 86% of wood waste is often treated, but around half (46%) of the treated wood waste is not recovered but disposed of at the landfill. The reason for this is partly the low prices of wood waste, with average prices ranging from around €60 up to €90/tonne. However, with high volumes available and if prices were at the high end of the range this could still be a significant market worth up to €2,700 million per year (if all non-recovered waste were to be used). Wood waste can find a second life in a host of applications including timber products, paper pulp for packaging, hygiene paper, animal bedding, building material, floor covering, pin boards and energy recovery (Domenech, 2018).

3.1.6 Used oils

In monetary terms, used cooking oil waste holds the biggest market potential from the biomass and biowaste category. It has been estimated to be worth up to €1.6 billion. According to Eurostat data (2017) collection and treatment of oil waste generated annually (about 4.2 million tonnes) is not very common (only 56 %), even though recovery rates for treated waste are high (86 %). There is therefore a good case to be made to improve collection and treatment of this waste, which can be transformed by the chemical industry or used for energy generation (Domenech, 2018).

3.2 High potential industrial symbiosis opportunities in Ireland

Despite having the potential for generation of multiple business opportunities, some high-value resource flows are still currently under-exploited in Ireland. The intrinsic value of such resource flows may however not be fully maximized without the facilitation of industrial symbiosis activities. Four key areas were identified in a 2020 assessment of Industrial Symbiosis opportunities in Ireland (Lombardi et al, 2020) namely; Cement (3.2.1); Sludge (3.2.2), Whey (3.2.3) and Solvents (3.2.4). In addition, Ireland is ripe for valorising biomass – see section 3.2.5 Circular Bioeconomy opportunities (Martinelli et al, 2020). These under-exploited high-value resource flows within the Irish economy are discussed next in turn.

3.2.1 Cement

Industrial symbiosis in the cement industry is based on application of alternative raw materials (ARMs) for fuel and raw materials substitution (as much as 85% of fossil fuel use). Opportunities exist in Ireland to engage more broadly in ARMs (for both fuel and raw material substitution) and to develop new technologies for expanding the accepted use of ARMs.

Substitute materials being used or investigated to replace fossil fuels and virgin raw materials include: pulverised fuel ash, cement kiln dust, broken moulds from ceramics industry, waste foundry sand and gypsum, mill scale (flakes of oxide coating), dried sludge and granulated blast furnace slag.

3.2.2 Sludge

Industrial symbiosis for sludge relies on established opportunities for extraction of valuable components from both municipal and industrial sludges which are not only high in protein and other nutrients but also have the potential for precious metal recovery. Opportunities exist to develop new technologies and apply existing ones in various sectors especially agriculture, building and construction, and pharmaceutical industry.

3.2.3 Whey

Ireland is home to various extraction techniques that valorise the components of whey. The opportunity for Ireland may be to adapt and extend the various technologies to extract whey for higher-value applications such that they are accessible to the micro, small and medium scale producers.

In 2018, 224 thousand tonnes of cheese were produced in Ireland (IFA, 2020). Per kg of cheese production, 7-9 litres of whey is produced. Total whey production is therefore estimated to be around 1.8 million t pa of which 70% goes to beneficial use. The remaining 30% (538 thousand tonnes) still present significant opportunity as the issue is not the processing know-how, but rather economically accessing this whey from smaller producers.

This 30% represents the whey produced seasonally and in small batches. New technologies are in development to extend the extraction of useful elements from whey. For example, a recent Horizon 2020 project (AgriChemWhey led by Glanbia Ireland) was awarded to research the conversion of whey permeate into lactic acid, with applications for biodegradable plastics, fertilisers and minerals for human nutrition (Irish Times, 2018).

3.2.4 Solvents

Eurostat reports the Irish waste treatment of 14,566 tonnes of solvents in 2014, down from previous years. About half (48% in 2014) go to incineration without energy recovery (class D10, 7023 tonnes), another 30% to incineration with energy recovery (R1, 4501 tonnes) while only 15% are recovered for recycling. Solvents currently going to disposal may be suitable for recovery and/or recycling: for instance, blended fuel from additional solvent capture in Ireland can act as substitute fuel with cement production processes. However, viable business models which comply with REACH / hazardous waste regulatory requirements are key to considerations of more efficient and economically viable recovery technologies based on industrial symbiosis . . One best practice to consider is the Turkish case of solvent recovery and reuse in printing (IFC, 2018).

3.2.5 Circular Bioeconomy Opportunities

Bioactives: The European bioactive ingredients market was worth €5.9bn in 2018 and is estimated to be growing at a compound annual growth rate (CAGR) of 6.77% to reach €7.9bn by 2023 (Martinelli et al, 2020).

Biobased chemicals: The EU market for biobased chemicals is expected to reach €50bn in 2030, representing a CAGR of 7% per annum (Martinelli et al, 2020).

Bioethanol: The Global Bioethanol Market was valued at €4.7mn in 2015 and is expected to reach €8mn by 2022, growing at a CAGR of 7.6% from 2016 to 2022 (Bio-Tic, 2015) (Martinelli et al, 2020).

4. Framework for evaluating industrial symbiosis Opportunities

For the evaluation of industrial symbiosis opportunities associated with potential resource flows and identification of the most feasible resource flow options for industrial symbiosis exploitation, a holistic framework that puts into perspective all factors relevant for such an evaluation should be adopted. See Figure 2 for an overview of the framework developed and tested in the SymbioBeer project.

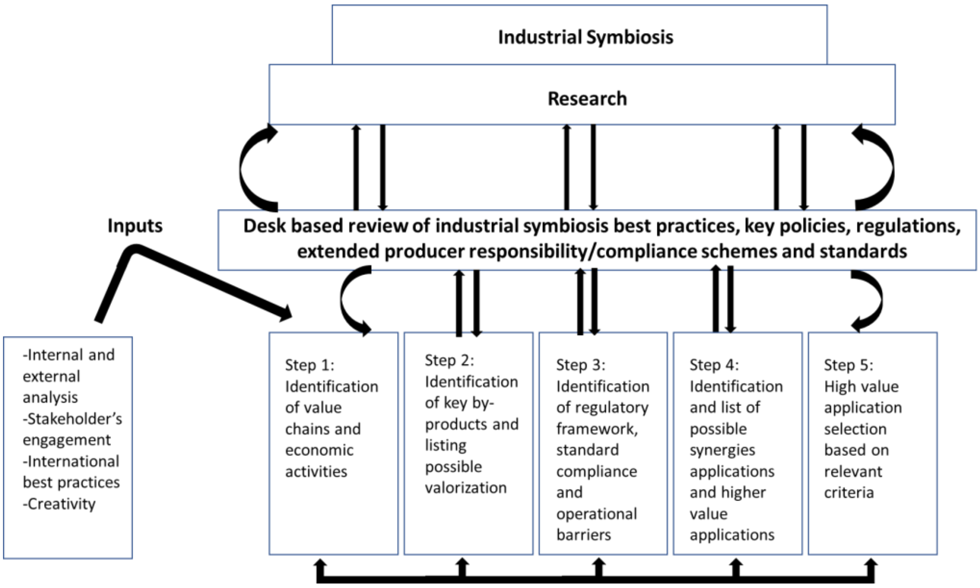

Figure 2 Industrial Symbiosis Framework (Source: SymbioBeer Final Report)

The SymbioBeer Project developed and applied a procedural (or stepwise) industrial symbiosis framework adapted from a desk-based review of industrial symbiosis best practices, key policies, regulations, extended producer responsibility/ compliance schemes and standards in Ireland and within the EU. The procedures/steps of the industrial symbiosis framework and source references are as described next.

• **Step 1**: Identify concrete value chains and economic activities for industrial symbiosis and gather data to underpin the related market potential (state-of-the-art on market potential and value chain from UNE166001:2006 standard and Garcia, 2018);

• **Step 2**: Identify key by-products and possible valorization pathway with the highest market opportunity and economic viability potential and conduct further analysis on barriers (state-of-the-art on economic exploitation, market potential, risk and critical point management from UNE166001:2006 standard, Jensen, 2016, Domenech, 2018 and Garcia, 2018).

This step includes analysis of company residues, an initial exploration of residue valorisation pathways for higher value applications (in terms of market value and availability), and a synthesis of operational barriers to potential industrial symbiosis valorisation. An understanding of possible areas of material input substitution through stakeholders' engagement and interaction, and a desk research on existing case studies, data, projects and technologies enabling industrial symbiosis internationally would also be relevant for drawing a list of higher value applications.

• **Step 3**: Identify the regulatory framework for analysing the barriers to industrial symbiosis, and for evaluating the functioning of the internal market and potential lost market opportunities related to these barriers (state-of-the art on legislation, market potential from UNE166001:2006 standard and Garcia, 2018). This step would help to understand the regulatory and standards compliance needed for the use of residues as material substitutes in another company.

• **Step 4**: Identify a list of anchor sectors, possible synergies and higher value applications (from existing case studies, data, projects and technologies enabling industrial symbiosis) for technical feasibility evaluation (state-of-the-art on market potential value chain and economic exploitations from UNE166001:2006 standard and Garcia, 2018, and ideas analysis from UNE 166002:2006). This step requires an analysis of existing higher value applications and best practices, as well as a sense checking process that takes into consideration the geographical, and value chain context of the different companies as well as the kinds of residues they produce.

• **Step 5**: Evaluate high value application selections based on relevant criteria (from innovation process from UNE 166002:2006, Jensen, 2016 and Domenech, 2018). For example, the criteria relevant for industrial synergies between two food sectors (bakery and brewery sectors) include proximity, technology readiness, assumption of risks, existing value chains/commercial agreements, regulatory and standards compliance, and economy and higher value applications (See SymbioBeer Final Report).

4.1 A way of thinking about industrial symbiosis

As already seen in Section 3, where were underlined key resource flows available for industrial symbiosis transactions in Europe and opportunities currently under-exploited in Ireland, industrial symbiosis opportunities are much more than the use of recycled products and transformation of secondary raw materials; they are also products, networks, private and public transaction services between industries, offering of new and common market solutions, and business and cooperation models for reducing production costs. (The SPIRE-SAIS alliance, 2021)

In order to explore more industrial symbiosis opportunities, the industrial symbiosis framework suggested and applied by the SymbioBeer project enabled the exploration of promising potential market exploitations that are not currently capitalised on or under-performing due to technical or operational barriers, or just because the possibilities offered are relatively unknown.

Moreover, Industrial symbiosis should not only ensure the secondary use of resources from the industrial process of one company/sector as input into the production chain of another company/sector, it should also ensure that secondary resource in whatever form is used for the highest value applications, hence amplifying resource efficiency.

4.2 Principles for exploring industrial symbiosis opportunities

In addition to the industrial symbiosis framework, basic principles need to be taken into consideration for determining higher value applications and for guiding the exploration radius of industrial symbiosis synergies as previously outlined by Jensen (2016) namely:

A. **Resources characteristics can substantially influence the radius of industrial symbiosis activities.** These include: 1) properties of waste stream (i.e. its physical and chemical properties); 2) value of the waste stream- this is because logistics could impact the final cost, making secondary raw materials more costly than raw materials, hence unattractive, and 3) geographical distribution of resource recovery facilities.

B. In general terms, **bulky low value waste**, such as construction and demolition (C&D) waste and bio-waste **tend to be restricted to local transactions**, **while low volume high value resources, such as cobalt, may have an international scope.**

Steam and waste heat valorization are necessarily restricted to the local level, as they cannot be transported over long distances. Fly ash, waste oil, common metals such as steel and aluminium are generally traded in local/regional markets while more valuable and scarce metals and minerals (i.e. rare earth minerals and critical metals) can travel considerable distances.

Key role in local networks is played by primary sectors such as pulp and paper, power production, forestry, metal, mining, and construction materials sectors. These sectors tend to play an important role, acting in many cases as anchor tenants of the network industries since they have the capacity of receiving and providing large input and output quantities respectively.

5. The SymbioBeer Demo

The SymbioBeer Demonstration Pilot demonstrated the feasibility of industrial synergies between two Irish food sectors namely the bakery and the brewery sectors. Section 5.1 gives a brief overview of participating sectors in the SymbioBeer Demo; Section 5.2 describes the objectives of the SymbioBeer Demo; while Section 5.3 discusses the barriers and enablers uncovered during the SymbioBeer Demo.

5.1 Irish Bakery & Brewing Sectors

Like those elsewhere, the beer industry in Ireland has high industrial symbiosis potential because it produces significant by-products usable for secondary purposes. It has a market size of €2 Billion, numerous business operators located all around the island (134), and provide jobs for up to about 3076 people, (Ibis World, 2019). In 2018, the Irish beer industry produced 9322000 hl of beer (Statista, 2019)

The bread and bakery industry in Ireland also has high industrial symbiosis potential for the same reason as the beer industry (i.e. production of significant by-products). It has a market size of €908 million, large number of business operators (903), providing jobs up to 6570 employees (Ibis World, 2019).

5.2 SymbioBeer – Demonstrating industrial symbiosis in Ireland's Food Sector

SymbioBeer (2020-2021) is a 2019 EPA Green Enterprise Funded project facilitated by Irish Manufacturing Research (IMR) which created an industrial symbiosis demonstration in the industrial area of Longford, between Panelto Foods (industrial bakery firm) and St Mel's Brewing Company (microbrewery). The SymbioBeer project's objectives was to demonstrate the potential of industrial symbiosis as a feasible strategy for improving the competitiveness and economic resilience of the industrial partners through new product development and product diversification.

The SymbioBeer Demo qualified and quantified the benefits of local sourcing of secondary residues for use as material substitutes for virgin raw materials /ingredients. Secondary use of a company/sectors' residues as industrial production inputs elsewhere will not only deliver economic benefits but also contribute to diverting waste into resource, and reducing greenhouse gas emissions and other environmental impacts associated with transportation, raw material extraction/cultivation.

5.3 Barriers & Enablers in the SymbioBeer Demo

Often, a barrier to implementation and scaling of industrial symbiosis can also be an enabler on the other end and vice-versa. During the SymbioBeer project, key barriers and enablers observed are summarised in Figure 3, Section 5.3.1 and Section 5.3.2. (See also the Demonstration Case Study and Final Project Report for more details).

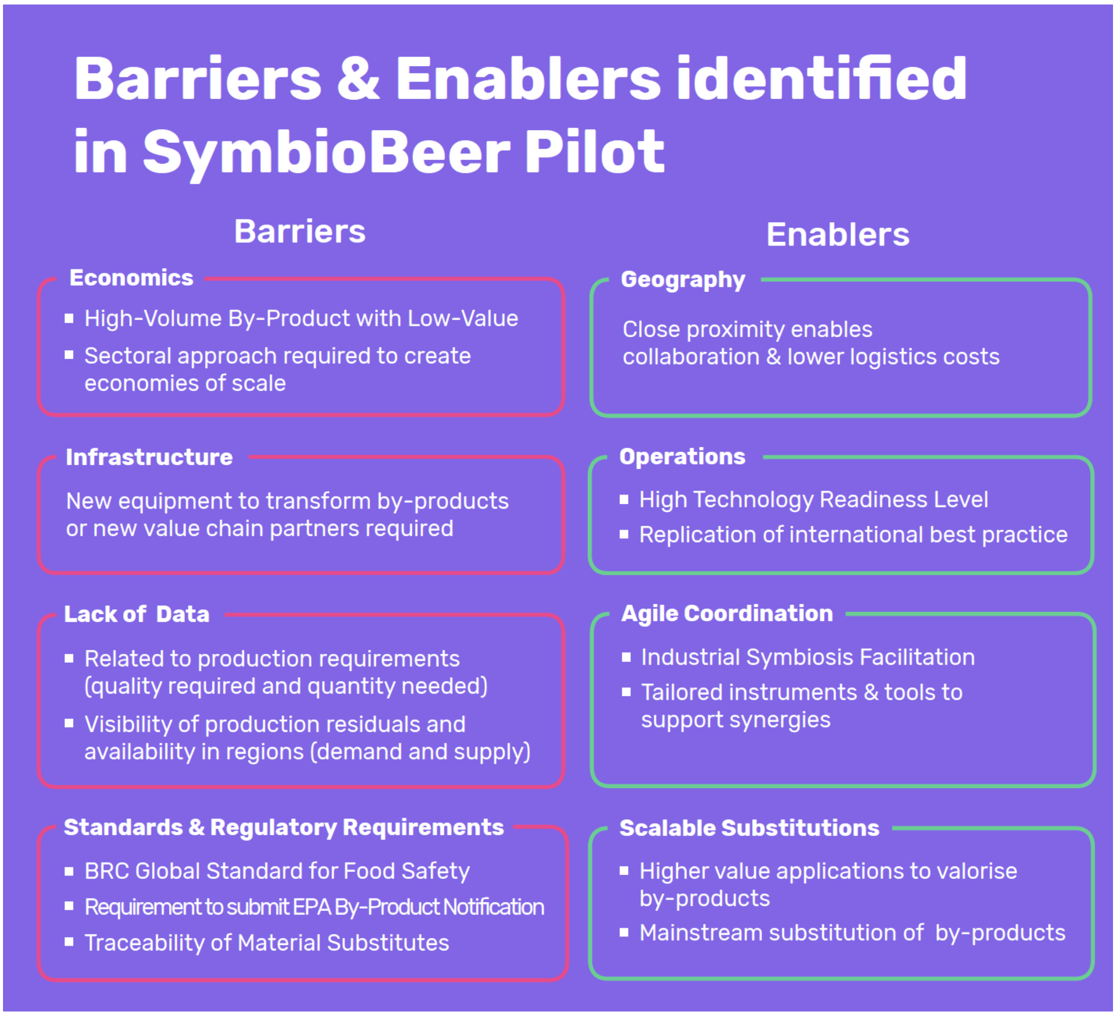

Figure 3 Barriers and enablers for SymbioBeer (Source: authors)

5.3.1 Barriers

New equipment/infrastructure requirements - a dryer and a milling equipment were required to transform the by-products into material substitutes suitable for production of an industrial-scale batch of beer (using surplus bread) and bread (using BSG as nutritional ingredient or flour). While the drying and crumbing of the surplus bread, and the drying and milling of the BSG was outsourced to Teagasc, scaling up their use for mass production would require St Mel's and or Panelto Foods to invest in the equipment or partner with a third party to transform their residues into material substitute.

Food Safety & Regulatory Requirements - For St Mel's Brewery to supply Panelto Foods with a BSG flour beyond the pilot, they would need a good quality notification to the Environmental Protection Agency (EPA) demonstrating compliance with by-product classification requirements (namely certainty of use, direct use without further processing requirements other than normal industrial practice; being an integral part of a production process; and lawful further use i.e. in compliance with the product, environmental and health protection requirements for specific uses, and on avoidance of adverse environmental or human health impacts). They might also need to certify this new product to at least BRC Global Standard for Food Safety (Grade A), to ensure conformity with set HACCP criteria and for the purpose of commercialization.

Economies of scale - 1-2-1 by-product transaction is insufficient to achieve economies of scale required for mass production. A cross-sectoral approach (a collaboration between multiple breweries and multiple industrial bakery) is necessary to achieve consistency in quality of material substitutes overtime (given variances in production residues) and necessary to make their mainstream application economically viable. Also, economies of scale may be relatively difficult because bakery and brewery production residues are high volume residues with relatively low value.

Lack of data on and visibility of production residues available in regions (for facilitation of demand and supply) is an additional barrier to scaling-up from limited edition pilots (utilising production residues) to mainstreaming material substitution in the brewing and bakery sectors.

5.3.2 Enablers

Proximity - Close proximity aids 1-2-1 by-product exchanges, facilitates collaboration and reduces logistics costs for the material substitute relative to virgin materials.

Replication of International Best Practices and High technology readiness level to transform by-products – Drawing on international best practice regarding valorisation of production residues in the bakery and brewing sectors (as done by the SymbioBeer Demo) will help identify multiple potential higher value applications. Also, technological readiness (i.e. availability of industrial dryers & milling machines) required to transform the residues into material substitutes is key for mainstreaming their use in these sectors.

Role for facilitator, tailored instruments and online tools – An existing cross-sectoral synergy outside traditional supply-chains is an enabler of industrial symbiosis activities. A national innovation partner (e.g. IMR) might be needed to facilitate this if not previously in existence. The identification of new product development opportunities and the facilitation of new collaborations (including technical support) using tailored instruments and online tools will also make the availability and demands for production residues more visible. All these are key to scaling-up implementation of industrial symbiosis.

Scalable substitution - Another enabler of industrial symbiosis between the bakery and brewery sectors is the availability of multiple valorisation pathways for higher value applications and the high potential for mainstream substitution.

5.4 Best practices: higher value applications

SymbioBeer Demo illustrated how industrial symbiosis can create new valorisation opportunities for new product development, diversion of waste from landfill and saving of virgin natural resources (i.e. virgin materials and ingredients) within the bakery and brewery sectors. This is highly replicable in other industries.

In Europe, multiple high value applications across different sectors have already been explored for residues coming from the bakery and brewing sectors. Irish companies can benefit from replicating some of such industrial symbiosis projects. Examples include:

1) High value polyphenols, which act as antioxidant in food and drink products, as well as in cosmetic and pharmaceutical applications can be extracted from brewery by-products (spent grains & distilleries' pot ale) (Consult, n.d.) ;

2) Brewers and distilleries by-products can be transformed into cost-effective, high-quality protein nutrients for aquaculture and animal feed industries (Horizon Proteins, n.d.)

3) Collected waste bread and bakery process residues can be transformed (with 98-100% conversion efficiency) into 98% advanced, waste-based ethanol, (a main component of major transport biofuel candidate and a main component of blended fuel mixtures). (FISS, n.d.)

6. Concluding Insights

This section describes insights for implementation and scaling up of industrial symbiosis.

Section 6.1 highlights general insights garnered from a review of previous publications by industrial symbiosis practitioners.

Section 6.2 discusses practical industry insights for implementation and scaling up of industrial symbiosis activities in Ireland (mostly based on experiences from the Irish food and beverage sectors). Practical industry insights for implementing and scaling industrial symbiosis activities in Ireland was drawn from engagements with stakeholders, via a stakeholder dissemination and interaction workshop facilitated by IMR (after the SymbioBeer Demo), involving representatives of local authorities and regional economic development agencies (from Longford, Donegal, Derry and Strabane), as well as industry representatives (from Heineken, Diageo, Avoca Seafoods, Goodness Grain

Bakery, Lough Ree Distillery, Biasol, Aryzta, Frylite, Adnams, Puratos, St.Mels and Panelto).

6.1 Insights from industrial symbiosis literature

Industrial symbiosis practitioners generally acknowledge that for industrial symbiosis transitions to take place, the following factors need to be in play: (a) factors related to the three pillars of sustainable development (environment, economic, social), (b) factors related to “soft aptitudes” (information and collaboration) and (c) factors related to “operational contexts” (technical support and regulations) (FISSAC, 2016).

Environment- The attractiveness and feasibility of industrial symbiosis in a global/climate change era is closely connected to the relative verifiability of its environmental benefits. This could be measured in terms of diversion of waste from landfill, savings of virgin natural resources (water, materials, or ingredients) and carbon emission reduction.

Social- All involved actors, public, private and other organizations must be willing to cooperate and commit themselves to the industrial symbiosis development process. Facilitating industrial symbiosis connections might be perceived as being very far from a firm’s core business objectives and thus not prioritized. In such cases the following will be required: (1) Organizational strategies, goals, and performance measures need to be re-evaluated, revised and aligned with industrial symbiosis to motivate managers to change their mindset and encourage their personnel to adopt same for meeting the company’s goals; (2) There must be cooperation and trust between key players in the spirit of information sharing; (3)Well-established communication channels between the industries and local community must be established (FISSAC, 2016), (Brand, 1999).

Economic- Lack of access to long-term financing and uncertainty about the profitability of the partnership might hinder the exploration of industrial symbiosis opportunities. High initial set up costs may be a big barrier to the creation of industrial symbiosis networks. This happens when costs of water, energy and disposal of by-products/waste are quite low. In such cases, using residues/ wastes are often less convenient than using cheaper raw materials because circular investments might be too high or have too high risks or impacts on the return on investment (CECP, 2007). It is therefore more convenient to dispose waste in such cases than utilising it for productive use.

Information- Lack of detailed qualitative and quantitative data on residue/waste streams and local industries’ material, water and energy requirements might lead to non-provision of strong basis for developing resource synergies. Other kinds of information such as material substitution needs, companies' residue transformation capacities, available technologies, production status are also often needed to foster industrial symbiosis transactions (Brand, 1999), (Mirata, 2004).

Collaboration- Willingness to collaborate among companies and sectors, availability of incentives and infrastructures for fostering cooperation between potential adopters, and proximity between waste/residue owners and potential secondary users are strong requirements for the facilitation of most industrial symbiosis transactions.

Technical support- To facilitate an industrial symbiosis transaction, one actor must have the capacity to transform the by-product that another actor has the need for i.e. the by-product/waste transformation capacity must match the material substitution needs for a successful industrial symbiosis partnership. Not only must the quality of the by-product match the need of the receiving actor, but the quantities must also be in the same magnitude for an exchange to be feasible. Other important technical support related factors include (i) the continuity of the flows and supply security (Jacobsen, 2004); (ii) the demand security i.e. material substitution market for residue/waste supply (FISSAC, 2016).

Regulations- Policies and regulations may serve both as drivers and barriers for industrial symbiosis and circular economy. While inconsistencies in environmental legislations and difficulties associated with obtaining approvals for by-product/waste reuse projects from the regulatory authorities can be a barrier; introducing higher taxes for waste disposal, banning landfilling of wastes, compulsory product, environmental and health safety regulatory procedures and legal requirements for recycling specific materials and so on, could be drivers of industrial symbiosis transactions (CECP, 2007), (Mirata, 2004), (SCALER, 2018).

6.2 Industry insights for scaling of industrial symbiosis implementation

From the stakeholder engagement and interactions (during the SymbioBeer project), we garnered that barriers to implementing and scaling industrial symbiosis in Ireland are of two major types: (a) **operational challenges** and (b) **licensing, standards and regulatory procedures/compliance requirements.**

A. Operational challenges

Operational challenges are either relate to; (1) *Supply of and demand for production residues for material substitution*; OR (2) *the infrastructures and supply chain relationships required to enable industrial symbiosis transactions*.

Operational challenges include (i) **data availability** and **willingness to share information** on residue availability and production/material substitution requirements, and (ii) **need for visibility of production residues and facilitation of use for higher value applications**.

While the operational challenges related to infrastructures and supply chain relationships required to facilitate industrial symbiosis transactions are characterized as (iii) **the need for sectoral approaches and new value chains**.

Even though there are no Irish regulations explicitly in conflict with industrial symbiosis transactions, there are still licensing, standards and regulatory procedures/compliance requirements that companies seeking to establish industrial synergies need to comply with.

This section explains how these barriers hinder the implementation and scaling of industrial symbiosis, while also offering individual and/or combinations of insights (in form of sectoral approaches, change of mindset, financial instruments, as well as assistance from policy makers and/or external actors) for navigation around or through them.

1. Operational Challenges related to supply of and demand for production residues for material substitution

i) Data availability and information sharing: Informing companies about industrial symbiosis possibilities is a key driver for its implementation. Determining actual industrial symbiosis possibilities are however closely linked to data availability and accessibility (i.e. information sharing) which is currently limited. Important data and information such as data on companies' size, structure and functions; and information on the quantity and quality of company's resource streams) are often rarely available. From an economic point of view, lack of access to relevant data makes the projection of potential economic return and subsequent implementation difficult. It also makes many waste/residues streams escape controlled paths, making the tracking of supply and demand, as well as the establishment of secondary raw material marketplaces almost impossible.

ii) Need for visibility of production residues and facilitation of use for higher value applications: For a successful industrial synergy where production residues can be used as material substitutes, they need to be available at a viable scale (quantity) and at suitable states/conditions (quality). However, in reality, there is often a mismatch between the quantity and quality of production residues generated by a company or a sector and the scale at which they are needed as material substitutes at the secondary raw material market. This is attributable to an inherent lack of visibility of the flow of supply of production residues from source companies or sectors on the one hand, and the demand for them as material substitute in destination or receiving companies or sectors on the other hand. Often, lack of visibility of production residues from the food and beverage sector leads to outright wastage and/or use of production residues for lower value applications (e.g., animal feed, anaerobic digestion, composting and landfill disposal).

From an operational and economic point of view, improving the visibility of the quantity and the quality of production residue available and ascertaining the scale at which they are needed for successful material substitution and industrial symbiosis will be crucial for lowering production cost and mitigating high taxation cost of imported ingredients by Irish food and beverage sector (due to post-Brexit implications)

The above operational challenges related to supply of and demand for production resides for material substitution (i.e. data availability and information sharing, as well as visibility for production residues and use for higher value applications) can be addressed through the assistance of and collaboration with policy making stakeholders and relevant institutions.

Companies' representatives and associations (i.e. chamber of commerce), as well as policy making stakeholders and/or regulatory bodies (e.g. EPA) can work together to:

i) develop and/or adopt shared approaches and methodologies for data collection and information sharing, (on production residues availability, potential higher value use and prospective secondary users) via public channels or platforms (e.g. online reporting tool or regularly updated online statistical database) as it is already done with waste statistics;

ii) recognise standards as one of the sources for data collection and as a tracking tool to ascertain availability and quality of production residues to be used as material substitutes;

iii) apply policy instruments and financial tools (e.g. taxation) as drivers for facilitating and diverting the use of production residues to higher value applications on the one hand (e.g. those prioritizing human nutrition), and discouraging lower value applications on the other hand (in accordance with the EPA Food Waste Hierarchy);

iv) initiate connections and facilitate partnerships between owners of production residues and potential secondary users through an industrial symbiosis facilitator or national innovation partner like IMR (based on available and shared data).

2. Operational challenges related to infrastructures and supply chain relationships required for facilitation of industrial symbiosis transactions

(iii) Need for sectoral approaches and new value chains-Creating sectoral approaches and new value chains are key steps for solving the infrastructural deficits and facilitating supply chain relationships for scaling industrial symbiosis transactions and lowering related product's unit costs. From a company prospective, there are many challenges to transitioning from pilot/market niche stage to mainstream adoption of industrial symbiosis. Investments in infrastructures and application of appropriate incentives for de-risking new value chains will help drive industrial symbiosis, especially in the food and beverage sectors where the value of residues are low and sourcing of raw ingredients from other virgin sources can even be cheaper.

Overcoming operational challenges related to infrastructures and supply chain relationships needed for industrial symbiosis facilitation can be addressed if companies' representative/associations (i.e. chamber of commerce) and policy making/regulatory bodies (i.e. EPA) can work together to:

(i) devise financial plans tailored towards reducing high set up costs, lowering high risks associated with new investments, and creating new players (e.g. start-ups, new partnerships etc.) for filling existing market gaps for implementation and scaling up of industrial symbiosis activities.

(ii) formulate financial instruments (e.g. taxation system) suitable for facilitating the use of residues for new higher value applications.

B. Licensing, standards, and regulatory procedures/compliance requirements

Compliance with relevant licensing, standards and regulatory procedures/compliance schemes are obligations that need to be fulfilled for industrial symbiosis transactions to occur. Guidelines for protection of human and animal food chains and safeguarding of human and animal health must be adhered to. Safe practices need to be implemented throughout the human and animal food production and use chains. This can be done by enforcing the integrity, legality and traceability requirements and protocols of production processes, and by ensuring alignment with regulations on the quality of final products.

Regulatory procedures binding the use of by-products and production residues within the human food production chains (food and beverage sectors) of Ireland include: (i) the HACCP certification criteria set by the Food Safety Authority of Ireland-in line with the Regulation 2004/852/EC of the European Commission, and (ii) the EPA by-product notification procedure-in line with Article 27 (on by-products and waste determination) and Article 28 (end-of-waste criteria) of the Waste Framework Directive i.e. S.I. No. 126 of 2011 of Ireland and Regulation 2008/98/EC of the European Commission.

(iii) For the Irish animal food production chains, licensing as a Feed Business Operator (FBO) and classification as "Suppliers of Feed Materials" by the Department of Agriculture, Food and the Marine (DAFM), verification of HACCP compliance via the FEMAS and EPA by-product notification (in accordance with Article 27 of Waste Framework Directive on by-products and waste determination- S.I. No. 126 of 2011) are important requirements to guarantee the safety and protection of animal health and production chains .

(iv) For retailers, the BRC Food Safety Standard is a well-recognized certification system that tests the compliance of traded food products on the retail market against set HACCP criteria. Compliance with licensing, standards and regulatory procedures/compliance schemes for food and beverage sectors are rigorous and time consuming and can therefore impact industrial symbiosis.

In an attempt to streamline the time invested by industry in licensing, standards and regulatory procedure compliance and facilitate industrial symbiosis company representatives from the food and beverage sectors, food standards bodies and regulatory bodies (i.e. EPA) could explore the role of:
(i) demystifying the inter-related licensing, standards and regulatory procedures/compliance schemes as one

of the tools needed for industrial symbiosis adoption in Ireland;
(ii) recognising licensing, standards and regulatory procedures/compliance schemes as one of the sources for data collection;
(iii) recognising and aligning licensing, standards and regulatory procedures/compliance schemes as one of the steps or processes in the fulfilment of their traceability requirements and protocols, and
(iv) working together on the collection of data on the quantity and/or quality of potentially available residues/material substitutes, in order to ease compliance with standards.

On a more general note, all the proposed insights for implementation and scaling up of industrial symbiosis are only workable if companies' managers are willing to re-evaluate and change their mindset to embrace industrial symbiosis and be open-minded to new collaborations despite the need to stay competitive.

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