MAESTRI

Total Resource and Energy Efficiency
Management System for Process Industries

Deliverable 4.1

Report on challenges and key success factors and gap analysis for industrial symbiosis

Date: 31/03/2017

WP4 Industrial Symbiosis

T4.1 Challenges and success factors for Industrial Symbiosis

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SPIRE Sustainable Process Industry through Resource and Energy Efficiency

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Executive Summary

The MAESTRI project aims to advance the sustainability of European manufacturing and process industries. This will be done by providing a management system in the form of a flexible and scalable platform and to guide and simplify the implementation of an innovative approach in organizations with the Total Efficiency Framework, which encompasses: Efficiency Framework, Management Systems and Industrial Symbiosis.

The overall aim of the efficiency framework is to encourage a culture of improvement within manufacturing and process industries by assisting the decision-making process, supporting the development of improvement strategies and helping to define the priorities for companies' environmental and economic performance.

The MAESTRI project aims to tackle improvements in the impact of manufacturing activities at both company level and system level in order to achieve significant results. A holistic approach will enable process monitoring and optimization, as well as focus on an integrated and cross-sectorial interaction that can have a greater impact within the process industry. MAESTRI project encompasses an Industrial Symbiosis (IS) approach, which, within the scope of sustainable manufacturing for process industries, fosters the sharing of resources (energy, water, residues and recycled materials) between different processes of a single company or between multiple companies.

This document presents a two-side approach in order to understand which challenges and success factors do arise when manufacturing companies attempt to engage with and implement an IS approach to improve resource efficiency in their operations. The first part is based on a literature review and analysis that introduces an overview of general challenges and success factors as well as their differences related to different ways of arranging IS implementations: self-organised, planned and facilitated processes. The second part brings the practitioners perspective. This was done through an exploratory study in which 14 companies, including MAESTRI industrial partners, participated as well as 2 institutions that were part of a national programme to facilitate IS. This document is "*living*" Report, i.e. will be updated within next months by interviews of German / Portuguese companies, partners of MAESTRI.

The results of this study will inform next tasks in WP4, namely the definition of a library of case studies and the design of a waste database as well as the development of a toolkit that can support companies to embark into the application of IS approach in their manufacturing operations. These results will additionally be considered as a source for the definition of new requirements within WP1 activities and as support for the integration of WP2, WP3 and WP4 into the Total Efficiency Framework.

MAESTRI
Sustainable Process Industry through Resource and Energy Efficiency
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680570

Table of contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680570

List of figures and tables

Abbreviations

B2B	Business to Business	IS	Industrial Symbiosis
B2C	Business to Customer	IT	Information Technology
CE	Circular Economy	KPI	Key Performance Indicator
CSR	Corporate Social Responsibility	MFA	Material Flow Analysis
EC	European Commission	NISP	National Industrial Symbiosis Programme
IE	Industrial Ecology	WP	Work Package

Definitions

Dyadic > It refers to relating to or based on two; twofold (Collins Concise English Dictionary).

Heuristic > It gives name to methods / techniques proceeding to a solution by trial and error or by rules that are only loosely defined (Oxford Dictionary of English).

Industrial Ecology (IE) > A systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to waste product, and to ultimate disposal (Graedel and Allenby, 1995).

Industrial Symbiosis (IS) > It encourages companies to adopt a collaborative approach in all aspects of their business so that resources can be recovered, reprocessed and reused elsewhere in the industrial network either by themselves or by other companies (WRAP, 2014).Value > It is the regard that something is held to deserve; the importance, worth or usefulness of something (Oxford dictionary).

Waste > It is any substance or object which the holder discards or intends or is required to discard (EU Waste Framework Directive, 2008).

Waste hierarchy > It regards to a priority order in waste prevention and management legislation and policy: (a) prevention; (b) preparing for re-use; (c) recycling; (d) other recovery, e.g. energy recovery; and (e) disposal (EU Waste Framework Directive, 2008).

Waste management > It regards to the collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker (EU Waste Framework Directive, 2008).

Sustainable Process Industry through Resource and Energy Efficiency
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680570

1 Introduction

Sustainability in manufacturing needs to be tackled at both company level and system level in order to achieve significant improvements. Non-labour resource productivity is one of the main areas to explore in order to identify opportunities to improve the social, environmental and economic performance of manufacturing companies. It is estimated that non-labour resource productivity could bring a 12% increase in the average annual profits for manufacturers, a 12% increase in national manufacturing employment and a 4.5% reduction of national greenhouse gas emissions in UK (LAVERY ET AL., 2013). An Industrial Symbiosis (IS) approach could support the search for improvement opportunities in non-labour resource opportunities at company and system level. Within a sustainable industrial system, manufacturers make better use of all inputs to their processes through exchanges of waste, by-products and energy with other companies/sectors (MANUFACTURING COMMISSION, 2015).

This introductory chapter will briefly introduce the IS concept and the different stages and arrangements for IS implementation processes. Furthermore, it will present the research process that has been carried out to complete Task 4.1 activities.

1.1 Background on Industrial Symbiosis

IS can be considered as a sub-discipline of Industrial Ecology (IE) that is concerned with resource optimization among collocated companies (JACOBSEN, 2006). IS as an idea was inspired by the example of Kalundborg, in Denmark where a complex network of material, water and energy exchanges between industrial actors and the local municipality emerged over a period of around 40 years. It was identified as an example of interest in the early stages of the Industrial Ecology movement, and became inspiration for the attempt to develop eco-industrial parks in the USA in the 1990's.

The starting point of Kalundborg symbiosis was the scarce availability of groundwater and the search for surface water. The latter became the central part of the exchanges occurring in the network, which comprises several large plants, including a waste water plant, an oil refinery, enzyme and insulin factories and a coal-fired power station. This network has also other linkages ranging from a fish farm to a bio ethanol plant (EHRENFELD AND GERTLER, 1997; CHERTOW, 2007; JACOBSEN, 2006).

The Kalundborg system emerged as a result of an uncovering process (CHERTOW, 2007) and its main strength lies in the interest of its business leaders on doing the 'right thing' for the environment while pursuing rational business benefits. Figure 1 illustrates the symbiotic exchanges in the Kalundborg system.

The literature approaches IS as a positive phenomenon, with benefits for example to the individual firms concerned and the communities, environments and economies of which they are a part. IS implementation can reduce resource use, pollutant emissions and waste discharges, increase revenue and generate new employment, and help to create a safer and cleaner natural and living environment (MIRATA, 2004; VAN BERKEL ET AL., 2009). Its main benefits are identified in the following areas (LOWE, 2001; MIRATAa, 2004):

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Sustainable Process Industry through Resource and Energy Efficiency
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- Economic benefits for the companies emerging from savings in the cost of inputs and the management of waste and opportunities of revenues generated by the higher values of by-products and waste streams;
- Environmental benefits due to the reduction in the overall resource needs of the industrial system, reuse and recycling of waste streams and control of pollution;
- Other business benefits derived from improvement in the relationships with other agents and the community, green marketing, social corporate responsibility and the creation of new business and market opportunities;
- Benefits for the community as a source of new employment, securing existing jobs, improving the local ecosystems or the creation of a cleaner and safer environment.

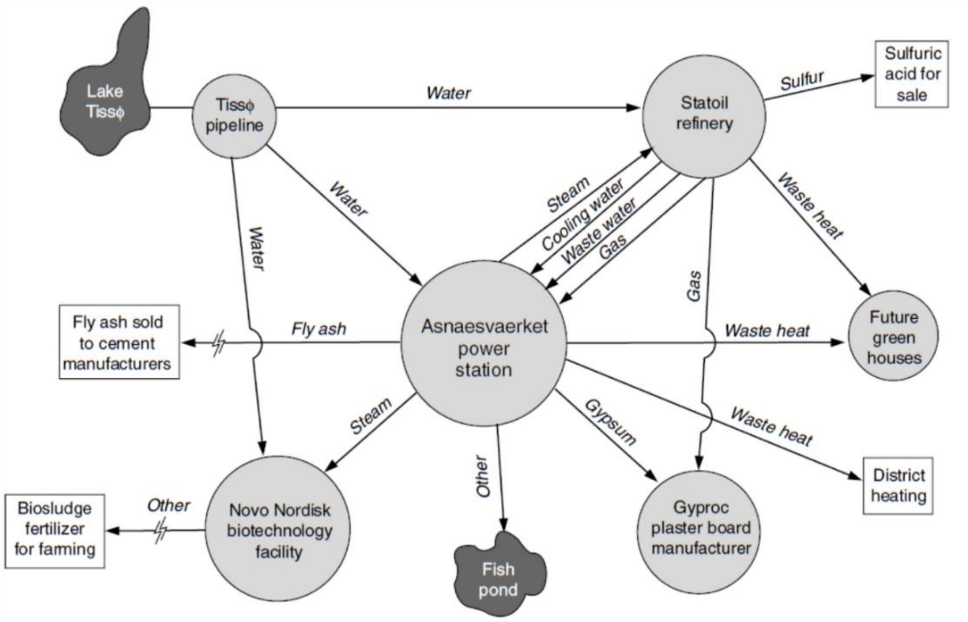

Figure 1 – Kalundborg symbiosis (Grann, 1997)

There are different types of IS related exchanges. They can occur as a one-off material waste exchanges between two parties or in more continuous flows exchanged within factory or organisation boundaries or between different companies with certain geographic proximity (CHERTOW, 2000). The entities participating in IS could be either companies or factories as IS opportunities arise at process level (LOMBARDI and LAYBOURN, 2012). Therefore, the IS concept can cover both, the cases in which IS opportunities are realised by a single company (intra-firm IS) and those realised in partnership with other companies (inter-firm IS). Inter-firm IS most prominent example is the Kalundborg case (explained above).

An example of intra-firm IS is the case of British Sugar that has added throughout the years new product lines by looking at opportunities for its by-products, low-grade heat and CO_2 gases (SHORT ET AL., 2014). Over a period of decades, this company focused on incremental process innovations which modified and extended its business model and, at the same time, delivered efficiency and productivity improvements to reduce costs and utilized internal waste streams to create new coproducts (SHORT ET AL., 2014). Next Figure 2 shows the current production and symbiotic lines in one of its factories.

MAESTRI
SPIRE Sustainable Process Industry through Resource and Energy Efficiency
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680570

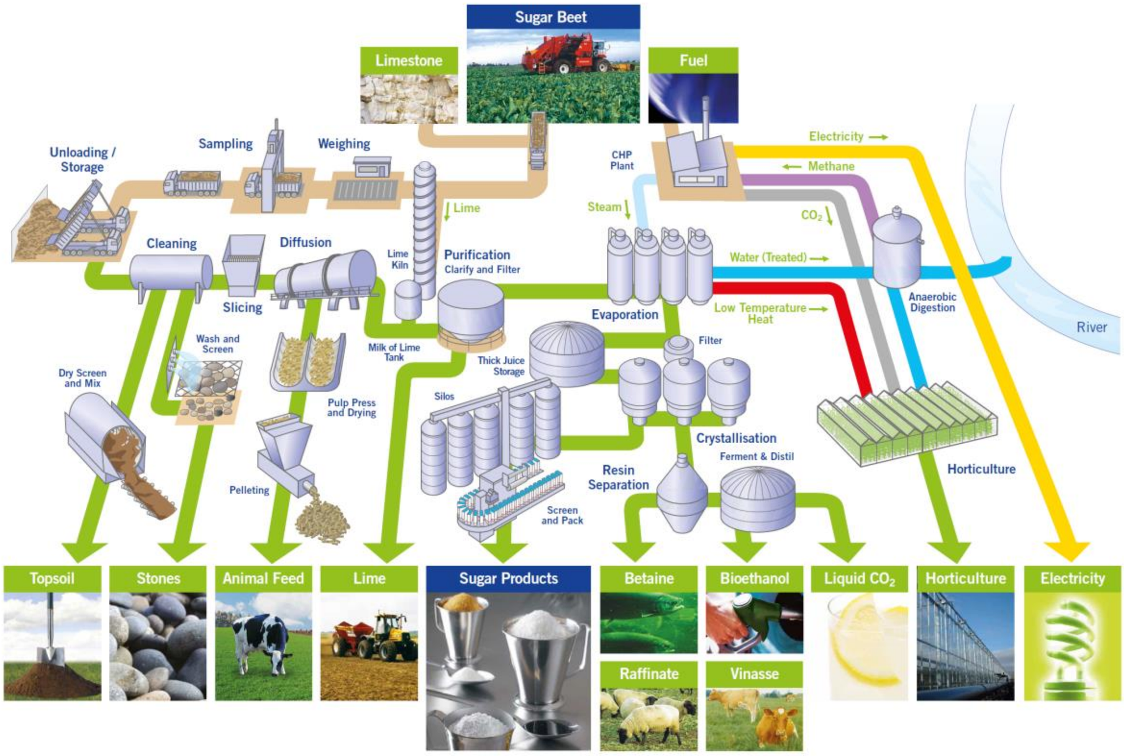

Figure 2 – British Sugar symbiotic lines (http://www.britishsugarlearningzone.com/how-our-factory-operates/)

The commonly shared image of IS contemplates symbiotic exchanges between companies belonging to different industries (inter-supply chain IS). However, by-products exchanges can be found as a common practice as part of supply chain activities or as initial stages for a larger implementation of IS (CHERTOW and EHRENFELD, 2012). Therefore, closed-loop cycles of materials amongst supply chain partners (intra-supply chain IS) are also seen as an application of IS principles (LEIGH and LI, 2015). These early linkages often originate through traditional trade events along companies' supply chains (CHERTOW and EHRENFELD, 2012).

Regarding intra-supply chain IS, LEIGH and LI (2015) reflect on the supply chain perspective of IS as a means to achieve competitive advantage and performance improvements for a firm and its supply chain. This is realized by higher levels of collaboration, knowledge creation and sharing along the supply chain partners and it would result on decreased costs, improved environmental performance, new sources for required inputs and commercialization of non-product outputs (YUAN and SHI, 2009; LOMBARDI and LAYBOURN, 2012; LEIGH and LI, 2015).

1.1.1 Definitions of Industrial Symbiosis

IS emerged as a construct drawn by observing the behaviour of industrial systems and interpreting the phenomenon observed. A number of definitions are offered by the literature however there is no immutable and definitive description of the concept.

In 2000, CHERTOW positioned IS as a part of the emerging field of Industrial Ecology which '*demands resolute attention to the flow of materials and energy through local, regional and global economies*'. In this context, IS was described as '*traditionally separate entities*

Sustainable Process Industry through Resource and Energy Efficiency
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680570

[engaged] in a collective approach to competitive advantage involving physical exchange of materials, energy, water'. This description emphasised collaboration and geographical proximity as key factors in the symbiotic exchanges.

CHERTOW later expanded on this view in 2007, introducing the 3-2 heuristic to aid the identification of symbiotic examples in practice. The 3-2 heuristic proposes a minimum of 3 organizations (none of which is primarily involved in recycling as an industry) exchanging 2 resources as a minimum condition for symbiosis and it clearly implies a network approach to IS, rather than a dyadic relationship between exchanging companies.

LOMBARDI and LAYBOURN (2012) offered a practitioner oriented view of IS drawing on the experiences of a UK based scheme, which was funded by the government from landfill tax to support waste exchanges between UK companies. Their definition frames IS as a tool for innovative green growth stating that '*IS engages diverse organizations in a network to foster eco-innovation and long-term culture change*' and explicitly diminishing the emphasis on proximity as a key determinant of IS.

TAO ET AL. (2015) gathered a set of proposed definitions for Industrial Symbiosis. Table 1 presents a selection of IS definitions, highlighting the key concepts included in each one. This table represents an extension of the work done by TAO ET AL. (2015).

The types of activities involved, when describing the IS concept, varies among definitions. Some of them focus only on resource exchanges while others give a most varied set of actions which includes resources sharing, recovery, reprocess and reuse. Some authors (MIRATA, 2004; SAKR ET AL., 2011 and BEHERA ET AL., 2012) focus on the identification of factors influencing IS development and its operational characteristics. These factors are related to multiple aspects, such as technical, political, economic and financial, informational, organisational and motivational (MIRATA, 2004). For example, BEHERA ET AL. (2012) suggests that the conversion of industrial areas into Eco-Industrial Parks can be realised if a mixture of economical, technological and organisational actions are undertaken. In particular, the author refers to technological (appropriate technologies have to be adopted or developed) and economic (the economic performance of participating businesses has to be enhanced by the IS implementation) feasibility as necessary conditions for IS to happen. The creation of connections and the sense of collaboration between companies is present in most of the IS definitions and list of influent factors, while the geographical proximity is explicitly mentioned in less than half of the definitions. The latter reflects the ongoing debate within the IS literature in what refers to proximity. Even though the IS concept was built on the possibilities driven by geographic proximity for the exchange of resources among different industries, certain types of waste may have trading opportunities at local, regional, national or global level (CHERTOW, 2000). For example, waste with high market value and relatively cheap transport cost such as metal, WEEE, plastics, paper and oil are mostly collected from and delivered to longer distances (CHEN ET AL., 2012). DESROCHERS (2004) and STERR and OTT (2004) argue that the adequate scale for IS is the region whilst others emphasize local collaboration and partnership (HEERES ET AL., 2004; GIBBS and DEUTZ, 2007). On the contrary, Lombardi and LAYBOURN (2012) suggest that geographic proximity is not necessary nor sufficient for realizing IS opportunities.

MAESTRI
SPIRE Sustainable Process Industry through Resource and Energy Efficiency
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Table 1 Selection of Industrial Symbiosis definitions (extended from TAO ET AL., 2015)

Author	Definitions of IS	Key concepts
Ehrenfeld and Gertler (1997)	*"IS is closely related to closed-loop material and energy use and involves the creation of linkages between firms to raise the efficiency, measured at the scale of the system as a whole, of material and energy flows through the entire cluster of processes."*	Closed-loop, creation of linkages, efficiency, material and energy flows, entire cluster of processes
Chertow (2000)	*"IS engages traditionally separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to IS are collaboration and the synergistic possibilities offered by geographic proximity."*	Collective approach, physical exchange, material, energy, water, by-products, collaboration, synergistic possibilities, geographic proximity
Jacobsen (2006)	*"A concept of collective resource optimization based on by-product exchanges and utility sharing among different co-located facilities."*	Collective resource optimization, by-product exchanges, utility sharing, co-located facilities
Van Berkel (2009)	*"IS is principally concerned with the recovery and reuse of wastes (materials, water, or energy) from one industry as alternative input in a neighbouring facility."*	Recovery and reuse, material, water, energy, alternative input, neighbouring facility
Sokka et al. (2011)	*"IS focus on the physical flows of materials and energy in local industrial systems. In an ideal IS, waste material and energy are shared or exchanged among the actors of the system, thereby reducing the consumption of virgin material and energy inputs, and likewise the generation of waste and emissions."*	Physical flows of materials and energy, industrial systems, share or exchange
Lombardi and Laybourn (2012)	*"IS engages diverse organizations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes."*	Network, eco-innovation, long-term culture change, value-added to non-product outputs
The Waste and Resources Action Programme, WRAP (2014)	*"IS encourages companies to adopt a collaborative approach in all aspects of their business so that resources can be recovered, reprocessed and reused elsewhere in the industrial network either by themselves or by other companies."*	A collaborative approach, all aspects of business, recover, reprocess, reuse, industrial network

MAESTRI
SPIRE Sustainable Process Industry through Resource and Energy Efficiency
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1.1.2 Industrial Symbiosis development process

The development of IS can be seen as a dynamic process leading to the creation of industrial ecosystems, within which new opportunities are expected to emerge over time (LIU ET AL., 2015). It is mainly an iterative process rather than a linear process, and mostly incremental rather than radical. An example of the incremental perspective in IS is given by the evolution of the IS network in Kalundborg. Its development is seen as an evolutionary process in which independent resource exchanges have been gradually established among the companies in the IS network. The factors influencing IS development and its operational characteristics are related to multiple aspects, such as technical, political, economic and financial, informational, organisational and motivational (MIRATA, 2004).

IS design, planning and implementation seems to be very frequently an ad hoc process built up for each specific context. Based on their research findings, GRANT ET AL. (2010) defined the development process for IS in five phases: (i) opportunity identification; (ii) opportunity assessment; (iii) barrier removal; (iv) commercialization and adaptive management; and (v) documentation, review and publication. The phases are briefly described herein.

Opportunity Identification regards the discovery of a new process to transform a by-product into a usable resource, the identification of links between inputs and outputs needed / produced in different organisations and the replication of successful exchanges done previously by similar organisations.

Opportunity Assessment concerns different methods based on tacit-based judgements or on explicit quantifiable information to evaluate different apsects of the IS opportunies identified. The understanding of barriers related to market, political, social, environmental, financial and technical feasibility relies more on tacit knowledge and it would be difficult to codify. Evaluations through quantitative methods or multi-criteria objective analysis methods can be more easily supported by ICT-based tools.

Barrier Removal relates to mechanisms to overcome the challenges related to IS exchanges implementation. Regulatory and public approval if the exchanges concern non-traditional resources may be necessary at this stage. Technology development of new processes to utilise the by-products or non-traditional resources could be also required and could include pilots and small scale demonstration

Commercialization refers to a full scale implementation of the IS processes, *and Adaptive Management* concerns the necessary implementation of feedback-based continuous improvement of the IS processes.

Documentation, Review and Publication concerns the communication stage of the process and it is seen as critical to establish a knowledge database on successful IS exchanges and processes.

In the specific case of region-wide attempts to implement IS, there are some steps pursued in facilitation programmes that can bring light into the activities needed in IS networks formation. General phases for facilitated IS are *conversation*, where regions' resources are studies and firms' engagement and interactions are enabled; *connection*, where linkages among firms are introduced and encourage through project definitions; and *co-creation*, where there is a focus on replicating high value exchanges and developing the necessary

MAESTRI
Sustainable Process Industry through Resource and Energy Efficiency
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680570

capacity around processing key regional resource streams (PAQUIN and HOWARD-GRENVILLE, 2012). Table 2 presents an extract from PAQUIN and HOWARD-GRENVILLE's work that describes the actions that facilitating actors take at each step and how the Is networks evolves.

Table 2. Actions and IS evolution (adapted from PAQUIN and HOWARD-GRENVILLE, 2012)

Steps	*Conversation*	*Connection*	*Co-creation*
Specific actions	- Taking strategic view of region's resources - Using pre-existing contacts to engage companies - Facilitating interaction spaces	- Strategically introducing relevant companies around low-hanging fruit - Deepening involvement with companies and projects	- Replicating high-value exchanges - Developing capacity around key regional resources
Network evolves through	Primarily serendipitous processes	Mixed of serendipitous and goal-directed processes	Increasingly goal-directed processes

1.2 Research process

Literature review and a set of 16 exploratory interviews were conducted for this work. The literature review carried out as part of the State-of-the-Art Review (within WP1) was taken as the starting point for the identification of challenges and success factors for Industrial Symbiosis. This initial results informed the development of a questionnaire to be employed in the exploratory interviews. Moreover, initial interviews with other researchers in the Industrial Symbiosis field has been also a source of valuable information to focus the industry interviews in terms of both case identification and selection and areas of enquiry within the questionnaire. The final questionnaire can be seen in Appendix A. Questions for the exploratory interviews.

A suite of practitioner interviews was carried out, encompassing several target interviewees: both companies from within the MAESTRI project and other companies that are not presently involved as well as facilitators and observers of IS implementation. These interviews provided insight into practitioner's current understanding and engagement with Industrial Symbiosis and elicit challenges to be addressed and success factors present in current IS exchanges.

Additionally, a more in-depth literature review was carried out to identify the current literature on IS implementation process and its challenges and success factors from the broader academic perspective. A cross case analysis was carried out to incorporate the findings from the exploratory interviews together with the results from the literature analysis.

The research process followed is shown in Figure 3.

Sustainable Process Industry through Resource and Energy Efficiency
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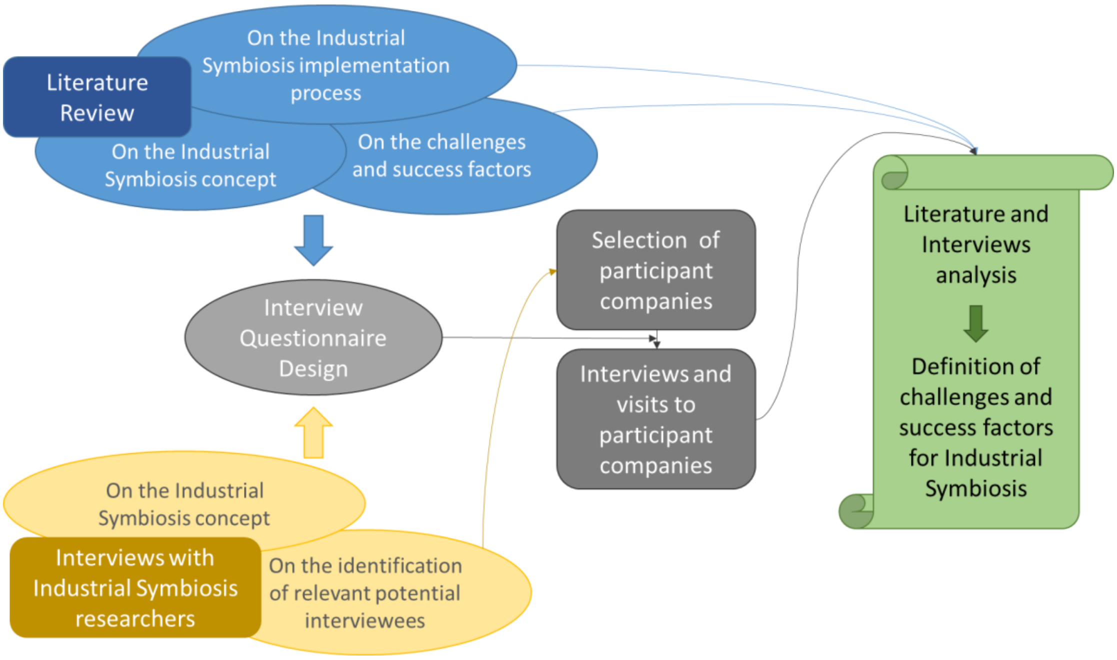

Figure 3. Overview of the research process

In addition to the industrial partners of MAESTRI project, a number of other companies in UK and Spain have been contacted to arrange interviews. The interviews were conducted during March, April and May 2016. The scope of the interviews were broad in terms of countries involved and characteristics of the companies (size, sector and stage in symbiotic exchanges implementation) in order to provide a wider perspective on challenges that may arise in MAESTRI industrial cases at later stages, and help enhance the wider applicability of the tools and concepts to be developed in WP4.

A summary of the interview objectives and protocol has been prepared as preliminary information to share with the target companies at the contact point. The final version of this document can be found in

MAESTRI
SPIRE Sustainable Process Industry through Resource and Energy Efficiency
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680570

Appendix B.

2 Challenges and success factors: literature review

This chapter will present the results of the literature review and analysis carried out. It will first introduce general challenges and success factors related to IS implementations, followed by more specific findings emerging from different ways of arranging IS activities.

2.1 Overall challenges and success factors

IS is materialised through exchanges of waste between a waste-producing facility and another facility where the waste can be used as an input to its production processes or in any other way. These exchanges can happen in different ways, according to CHERTOW (2000): exchange within a factory or an organisation; exchange among companies located in the same industrial area; exchange among companies not located in the same industrial area; exchange among companies across a broader region. Thus, as mentioned earlier, the IS concept covers both, the cases in which IS opportunities are realised by a single company itself alone and those realised in partnership with other companies.

The capability to engage in IS may strongly depend on company' size. Larger companies with multiple sites are more likely to engage on intra-firm IS between their different business divisions (ZHU ET AL., 2007). It can be argued that this does not exclusively refers to different companies. For example, large organisations producing a high variety of products in different production factories could see each of them as independent entities which sometimes have completely different production processes and accounting systems for resources, assets or final products. An example of this is the case of one of the UK's largest sugar producer explained in the Introduction. On the other side, SMEs would be more prompted to collaborate with others to realise IS opportunities. RUIZ PUENTE ET AL. (2015) investigated a large number of SMEs located in different industrial parks within the same region. Their study revealed that IS opportunities for SMEs come not only from the potential exchange of resources but also from the opportunities for mutualisation, i.e. for sharing or creating new waste management infrastructures, facilities and services between them. This type of solution would tackle the issue of 'whether there is sufficient flow of materials to make IS worthwhile' (CHERTOW, 2000), at least for the case of multiple co-located SMEs.

Cooperation is at the core of IS concept (CHERTOW and EHRENFELD, 2012; LOMBARDI and LAYBOURN, 2012). IS itself implies a sense of cooperation and networking either when the resource exchange is done at factory/organisation level or among different companies. This implies a change in company culture towards more collaborative approaches. A highly cooperative organizational culture within the industrial area would be expected to contribute to a successful IS implementation (SAKR ET AL., 2011). Trust and transparency are key elements to support inter-firm cooperation. Trust can facilitate the deployment of IS and the negotiation processes that needs to happen among the companies in the IS network. Indeed, trust could reduce the transaction costs for IS that can be defined as: (i) search costs, related to the identification of opportunities for exchanges; (ii) negotiation costs, related to the agreement on the terms of the exchanges; (iii) enforcement costs, related to putting in effect the contract (CHERTOW and EHRENFELD, 2012). Trust is favoured also by geographical proximity among firms, which enhances the transparency of actions and

Sustainable Process Industry through Resource and Energy Efficiency
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information sharing (ALBINO ET AL., 2016). Technical and information transparency fosters the spread of IS information, knowledge and experience previously held individually or bilaterally to more firms, creating a more cooperative culture and helping explore IS opportunities more collectively. In this manner, transparency can help diminishing or eliminating disparity of firms' capability to build IS (ZHU AND RUTH, 2014). Moreover, the basis of IS interfirm cooperation is the achievement of mutual benefits for companies involved (CHERTOW and EHRENFELD, 2012). Reciprocity, assured through mutually beneficial transactions, is required in order to assure long term commitment of companies engaging in the IS network (GIBBS, 2003; HIETE ET AL., 2012).

There are different challenges and enabling factors for IS at each stage within the IS development process. The lack of taxonomical classifications or common language for potentially exchangeable resources is a fundamental challenge within initial actions for opportunity identification (GRANT ET AL., 2010). Technological factors have been highlighted as potential enablers / barriers for IS applications. Concretely, BAAS (2008) underlines that the technical and regulatory capabilities are dominant at the initial stages of IS processes. In some cases, by-products cannot be used directly as inputs in other manufacturing processes and require to be treated by intermediaries or “middleman” (CHERTOW and EHRENFELD, 2012). The potential reuse may also depend on the maturity of the relevant technology for the waste treatment. However, the study performed by LYONS (2005) reflect that this had a relatively low importance in cases compared to the purity of inputs (which can directly affect trust between firms) and the possibility to ensure a steady supply of inputs (which makes the development of conventions easier), as well as the source for new information/opportunities or innovation..

GRANT at el. (2010) suggest that one way of providing a common practice for IS realisation is by bridging the gap between opportunity identification and commercialisation, thus, supporting the opportunities assessment and barrier removal stages in the development process. To narrow this gap, it is crucial to know which barriers companies will face when implementing business opportunities based on IS exchanges. Usual business barriers could affect IS projects such as risk, finance, capital mobility and availability of higher pay-back options elsewhere, as well as specific IS barriers related to the lack of large, continuous waste streams that could make the project attractive (CHERTOW, 2000).

Once opportunities are identified, it is necessary to create an environment of trust for the development of the IS project (RUIZ PUENTE ET AL., 2015). Otherwise, the willingness to collaborate and the communication between potential partners will be drastically reduced (GIBBs, 2003; CHERTOW, 2007). The creation of a network entity and a joint network vision during the planning process is seen as a key element for IS implementation and evolution (POSCH, 2012). There are still few studies on IS network evolution and resilience over time. Some factors, such as the closure of any involved companies, an adverse reaction of local community or the global / national trends in particular sectors, can create disruption in the network operation and cause radical changes or even its decline (MANNINO ET AL., 2015).

As part of the Documentation, Review and Publication stage of the IS development process, the communication of successful cases of IS applications seems to be critical. The establishment of a knowledge database on successful IS exchanges and processes could support the opportunity identification process (GRANT ET AL., 2010).

Sustainable Process Industry through Resource and Energy Efficiency
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2.2 Specific challenges and success factors in different types of arrangements

In IE, and by extension in IS, is a matter of discussion to which extent it requires external guidelines / management for its implementation (BOONS, 2008). Considering the degree of guidance, there are different types of arrangements for IS development that can be found in literature. The more serendipitous arrangement is based on companies' self-organisation while a planned IS will involve a third party that guides the process and encourages its development (CHERTOW, 2007). An intermediate arrangement between self-organised and planned IS has been proposed and named as facilitated IS (PAQUIN and HOWARD-GRENVILLE, 2009). Facilitation and coordination could be also seen as part of the evolution of self-organised IS after its initial stage in order to enhance the opportunities for collaboration (CHERTOW and EHRENFELD, 2012). An example of facilitated IS is provided by the establishment of symbiotic exchanges enabled by the national programmes that some countries are putting in place, such as the National Industrial Symbiosis Programme (NISP) in UK which is the world's largest coordinating entity for by-product use between regional clusters (CHERTOW, 2007; LOMBARDI and LAYBOURN, 2012).

The potential economic and environmental benefits of IS have motivated a variety of actors to attempt to deliberately bring about new cases of IS applications in industry. However, it has been observed that planning such a complex set of relationships is difficult, with few stable, successful examples observed, whilst apparently unplanned examples of IS continue to emerge and succeed (CHERTOW, 2007).

The following sections describe some particular challenges and success factors as well as differences in the implementation of each type of IS arrangement.

2.2.1 Self-organised Industrial Symbiosis

BOONS ET AL. (2011) assessed the current academic concepts and theoretical insights in terms of IS and considered self-organization a more feasible way for developing IS than facilitated IS, whilst acknowledging the role that coordinating bodies and governmental policies can have in influencing some of the enabling factors of IS.

CHERTOW (2007) differentiated the self-organized IS model from the planned EIP model and argued that the self-organized IS emerges from the decisions of private actors who are incentivised to exchange waste by revenue enhancement, cost reduction and business expansion. These business benefits are the attributes for on-going mutual self-interest.

Several authors have analysed the Kalundborg case, as the most prominent example of self-organised IS network. Some findings are reported herein.

The evolutionary nature that has enabled Kalundborg a success requires two factors – positive economic benefits and technical resolutions – to be in place simultaneously, which is hardly easy to realize in a forward-planning process for followers (EHRENFELD and GERTLER, 1997). The self-organisation process brings up symbiotic synergies that emerge from the invisible hand of the market rather than the hand of government so that it is usually not seen by people outside the IS network (CHERTOW, 2007). JACOBSEN (2006) explains that social relations within managers in Kalundborg network companies seem to be a reason why certain IS exchanges, which initially lack short-term economic benefits, were anyway put in place within the network. He assumes that these social connections are vital for the IS

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exchanges, especially at initial development stages which are characterised by higher uncertainty.

2.2.2 Facilitated Industrial Symbiosis

Facilitation and coordination could be also seen as part of the evolution of self-organised IS after its initial stage in order to enhance the opportunities for collaboration (CHERTOW and EHRENFELD, 2012). An example of facilitated IS is provided by the establishment of symbiotic exchanges enabled by the national programmes that some countries are putting in place, such as the NISP in UK which is the world's largest coordinating entity for by-product use between regional clusters (CHERTOW, 2007; LOMBARDI and LAYBOURN, 2012).

GIBBS (2003) reviews various types of IS cases and argues that commercial win-win reciprocity can assure mutually beneficial collaboration for all partners involved, which can be achieved in a bottom-up manner. But in a top-down context, facilitation can work well for helping firms get commercial win-win reciprocity. MIRATA (2004) assessed the National Industrial Symbiosis Programme (NISP) in the United Kingdom and contended that facilitation bodies and government policies can foster or impede IS development through directly or indirectly changing the enabling context of IS. HOWARD-GRENVILLE and PAQUIN (2006) looked into facilitated IS with network form and argued that a facilitator, like NISP, can play a key role in introducing firms to each other, helping firms to access government agencies, and assisting to build the network either focusing on the kernels of cooperation and attract related industries, or encouraging cross-industry exchanges.

2.2.3 Planned Industrial Symbiosis

As part of planned arrangements, IS has been considered as an approach for designing industrial states (SINGHAL and KAPUR, 2002) as well as Eco-Industrial Parks (EIPs) (GIBBS and DEUTZ, 2007). According to CHERTOW (2007), the IS concept has been applied to industrial development in the form of EIPs for three main reasons: to revitalise urban and rural sites, to promote job growth and retention and to encourage more sustainable development. She also acknowledges that some countries have embraced the IS concept for their industrial parks as a means to alleviate environmental degradation due to the presence of heavy industry and to improve water consumption, land use and greenhouse emissions. Planned IS model involves a conscious effort to identify firms and make them co-located to share resources, therefore, it frequently involves at least one governmental or quasi-governmental agency to promote IS with the local power, such as land use planning or long-term financing (CHERTOW, 2007). BEHERA ET AL. (2012) suggest that the transformation of industrial parks into EIPs could happen if all these factors are put in place:

- an economic principle to reduce cost and generate enlarged revenue in businesses;
- environmental policy that enables to increase resource flows and transactions for IS;
- new or existing technology available or to be developed to make the IS successful;
- the enhanced economic performance of participating businesses is closely related to making relationship to communities through business attraction and improved quality of life;
- the development will increase their environmental benefits across a community, such as improved community health and reduced GHG emissions.

Sustainable Process Industry through Resource and Energy Efficiency
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The above list of factors highlights the potential environmental benefits of IS and positive impact on the communities. They also point out to technological and economic feasibility as necessary conditions for IS to happen.

GIBBS (2003) investigated 63 Eco-Industrial sites across the U.S. and Europe. His research identified that there are quite few projects really initiated with the purpose of exchanging waste and cascading energy, thus, following an IS approach. Moreover, the main difficulties were found in relations to organisational aspects of networking and trust.

BRAND and DE BRUJIN (1999) and CHERTOW (2007) reviewed cases of planned industrial parks and argue that a suitable pollution control regulatory framework can effectively incentivise firms to explore potential synergies of by-products. But in return, over-controlled regulatory framework may restrict the possibilities of by-product reuse and recycle.

SAKR ET AL. (2011) suggested that success and limiting factors based on worldwide experiences can be categorized under (i) symbiotic business relationships, (ii) economic value added (iii) awareness and information sharing, (iv) policy & regulatory frameworks, (v) organizational and institutional setups, (vi) and technical factors. Table 3 presents a summary of their findings. Table 3 presents some of their findings for each category.

Table 3. Success and limiting factors for EIP development (from SAKR ET AL., 2011)

Category	Success factors	Limiting factors
Symbiotic business relationships	- Establishment of essential 'symbiotic' relationships between companies. - Collaboration and formation of business networks. - Active participation and empowerment of stakeholders. - Leaders functioning as communication platform between companies and providing company management and staff with important 'social' contacts. - Existing social networks may help to encourage environmental networking through forming mutual trust. - Trust in the competence of other companies. - Goodwill of other companies.	- To think that 'physical' energy, water, materials and by-product exchanges are the most important features of EIP development. - Lack of company interest. - Cooperation between companies cannot be mandated by the government. - Lack of stakeholders' involvement. - Absence of a champion. - Absence of trust in new dependency links.
Economic value added	- Involved parties gain an added economical value. - Willing to invest time, money and other resources in the development of an EIP.	- An exchange might be economically unsound or economically risky from a company perspective. - Lack of finance. - Costs of EIP planning are solely carried by the government.
Awareness and information sharing	- Establishment of low cost, high benefit utility sharing projects and "simple" exchanges. - Educate and inform companies of the potential benefits that can be achieved through the establishment of an EIP. - Effective structures for continuous technical assistance. - Transparent and efficient information exchange system.	- Unawareness of EIP principles and benefits. - Failure of companies to become engaged in the EIP. - The right people do not have the needed information at the right time.

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Policy & regulatory frameworks	- Policy intervention plays an enabling / catalysing role in helping to identify opportunities and creating appropriate conditions for inter-firm networking. - Stringent environmental laws that are effectively monitored and enforced by governmental agencies.	- Too much direct involvement from government promoting an unattractive agenda from the companies' perspective. - Existing regulations do not support EIP principles.
Organizational and institutional setups	- Bilateral exchanges fit within corporate organizational structure and overall management system of the park. - Highly cooperative organizational culture in the area. - Well established Corporate Social Responsibility (CSR) or similar systems (i.e EMS).	- The intended exchange may not fit in current corporate organizational structure. - Behavioral resistance toward cooperation. - Perceiving collaboration as risky for competitive relations. - Limited decision-making powers.
Technical factors	- Already some energy, waste and materials exchanges exist among various companies. - Utilising local technical-know-how.	- Absence of internationally accepted EIP standard

3 Challenges and success factors: practice review

This chapter provides an overview of the companies interviewed as part of the exploratory study and describes the main findings of the study. This chapter then complements the previous one and brings the perspective of practitioners to the analysis on challenges and success factors for IS implementations.

3.1 Overview of companies participating in the study

The exploratory study involved 10 companies and 2 institutions that participated in national-level IS facilitation programmes, as well as the industrial partners of MAESTRI project. A brief overview of the participants is given in next paragraphs. The participants' business activities are explained in very general terms to keep their anonymity.

Company 1 is a family-owned company working in the B2B sector of building materials. It is specialised in providing solutions for building spaces that require high hygiene and safety standards. This company has been ranked between the top 100 Best Companies to Work for several years. It has a strong focus on innovation and sustainability. It encourages its customers to recycle and reuse its products. This company has put in place a take-back programme through which its B2B customers and the customers of its customers can send back used products and scrap of their products created during the building process.

Company 2 is an SME working on the apparel manufacturing sector. Its main goal is solving environmental problems, by preventing materials from going to landfill, thus, using reclaimed materials to create clothing and household accessories. This company brings to their product design a mix of innovation and tradition, combining vanguard and classic designs with hand-made production. They donate 50% of their benefits to institutions and charities which are mainly related to the source of the reclaimed materials.

Company 3 works in the food manufacturing sector. It has a strong focus on product safety and traceability as well as product innovation. It is constantly looking for new products to

MAESTRI
Sustainable Process Industry through Resource and Energy Efficiency
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serve the emerging customer needs and to get the maximum value from all its raw materials. Its B2B customers are leading brands of international food and drink manufacturers. Its production plants are among the most efficient production systems in its sector. They own combined heat & power plants as well as bioethanol plants, which, for example, allows this company to be exporters of electricity to urban areas.

Company 4 is a family-owned company working in the service sector. This company is well-known for their community closeness, cooperative movement, recycling and the expansion of the sustainable culture by new technologies. It has gained several awards at European level in 2014 and 2015 to recognise their excellence and the sustainability in their operations. They are engaged in a cooperation with a local governmental institution watching over one of the largest European germoplasm banks for local varieties of plants and vegetables. The main goal of this company is to focus all their operations into creating pleasure, improving, creating value, sharing wealth and knowledge and ultimately, doing so in a sustained and sustainable manner.

Company 5 is a world-leading company working in the petrochemical industry. It has its origins in 1968 and it is inspired by tradition and proximity to its surroundings. It continuously searches to create higher value-added products and to improve the quality of its services and products while protecting people and the environment. This company is strongly committed to care about safety, quality and the environment. Thus, is assumes responsibility for all of its activities and tries to reduce the impact of their operations, going beyond the norms established by the legislation.

Company 6 has been working in the chemical sector for over 150 years, providing chemical products that serve as basis for other industries. This company aims to work towards a model of sustainable chemistry by addressing environmental and societal aspects while driving value creation and profitable growth. It performs life cycle assessment and calculates the environmental footprint for its products and their specific applications.

Company 7 is a world leading manufacturer of rubber and tyres goods, which supports customers to obtain higher efficiency and productivity. It has recently gained recognition at world-wide level for the outstanding quality of its products and services and its commitment to continuous improvement. The manufacturing plant that participated in the study is one of the key locations in Europe and recently got increased its manufacturing capacity.

Company 8 works in the textile manufacturing industry and it is successfully established in the international market. Its extensive product range includes everything from cotton classic fabrics to the latest innovations using technical fibres. It has a strong customer-oriented approach, focusing in quality and innovation. They work together with clothing manufacturers to adapt its products to their particular needs. They have strict quality control systems at every stage of production and experiments with the development of new fabrics. This company owns an industrial wastewater treatment plant and a cogeneration plant which are co-located to the manufacturing plant. Is has reduced the generation of waste, the atmospheric emissions and the energy and water consumption in all processes.

Company 9 is a world-leading producer of metal goods. Its activities goes along the whole value chain of metal. It owns some mining activities and also a plants to generate

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hydroelectric power. This company has a strong focus on caring about its employees and society well-being as well as environmental safety and quality responsibility. It aims at improving its products and production systems through the latest developments in technology and invests in finding those new technologies to stimulate growoth. Result of this research is a patented and globally recognised and used new technology.

Company 10 is an equipment manufacturer providing machinery as well as tailored solutions for the power generation sector. They have more than 35 years' experience in this sector and became world leader in equipment and equipment components for this sector. Additionally, they have presence in other sectors such as petro-chemical, railway and marine industry as well. The company has a broad experience in machinery construction, installation and service that allows them to offer personalized services to each client for each specific situation.

Company 11 is a leading manufacturer of plastic components and goods for a wide range of sectors, such as electronics, automotive, electrical and packaging. It also offers a wide range of high added-value services to deliver market-ready products. The company has a strong focus on pollution prevention, health and safety and performs very high quality standards. It is continuously investing in more efficient and technologically advanced production facilities to assure that its machinery is designed and built to maximise efficiency.

Company 12 is a family-owned business in the metal manufacturing industry with a history over 60 years. Its customers belong to very diverse sectors, ranging from automotive to transport and solar industry. Thus, it produces a high variety of diversified, metal-based products and services. The excellence of its operations is backed up by self-motivated people and an environment of learning and growth. This company develops solutions for its customers, increasing the value added to metal by using advanced technological innovations. It is currently undertaking an investment plan by increasing capacity and updating technologies.

Company 13 is a large manufacturer within the chemical industry, leading the EU market and supplying a wide range of customers, in the B2B and B2C markets. Its main goal is to deliver user-friendly products at the highest level of quality at an optimum price/performance ratio. Serving customers in over 20 countries, there is a broad variety in its customers' specifications which motivates a high degree of differentiation of its products. Thus, production plants are designed with emphasis on their flexibility capacity, in terms of number of batches and their volume, while assuring high quality standards in all of them.

Company 14 is a family-owned company that has been active in the international raw materials market for more than 160 years. Its chemical branch supplies a high variety of products such as binders, additives and pigments to customers from the coatings industry. It owns an application laboratory to develop customised products with individual characteristics, in response to its varied customer needs. The company has a strong focus on the ecological quality of its operations, e.g. reduction of volatile organic compounds and increase of the amount of renewable raw material used for production.

Company 15 has devised and managed IS facilitating programmes in around 30 countries. Its variety of projects related to IS applications range from feasibility reports and assessments

Sustainable Process Industry through Resource and Energy Efficiency
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at local, regional and national level to full implementation support to build IS networks and parks.

Company 16 partnered with Company 15 in one of its programmes to facilitate IS at national level. This company manages one of the world's largest online community for sustainable business practitioners. It has also a specialised channel for IS related activities and news. This online community is also a space to crowd-source ideas, solutions, and techniques for sustainability professionals.

3.2 Results

The manufacturing companies participating in the study had different levels of awareness and implementation of the IS concept. Half of the companies heard about the concept for the first time when they were contacted by MAESTRI researchers. Two of them heard about it before in forums or seminars related to the Circular Economy (CE) concept, however, they stated not to have a clear understanding on the IS concept yet. Three companies heard the concept for the first time a while ago, from researchers who investigated their cases and who gave this name to the interactions and exchanges the companies were already doing. Two companies had participated in a regional project looking at IS opportunities between the companies involved. The exchanges identified in that project did not get to the implementation phase.

Moreover, there seems to be a fine line between the concepts of IS and CE, as it was used interchangeably by the interviewees during some of the interviews. This shows a non-clear stand-alone conceptual space for the IS with respect to CE, at least from the perspective of the companies included in this study.

The study results show that even some companies that did not hear about the IS concept beforehand were actually doing symbiotic exchanges in their daily operations. Companies 3, 5 and 6 have been providing (selling) their by-products as inputs to other manufacturing companies / industries for more than 20 years in some cases. They all have a business mind-set of getting the most out of their raw materials by looking at business opportunities to optimise the overall production process. Companies 1, 8 and 9 have established some one-off material exchanges with other business units within the same organisation or with local/regional manufacturers of other sectors. Company 2's core business regards the reuse of disposed materials and scrap production from other factories, within its same sector in most cases. Company 4 is driven by the search of alternative sources for energy and water and the use of localised materials from local manufacturers. This company is partnering with a local council to create compost for local farmers and themselves, from its own waste materials.

Companies 3, 5, 13, 15 and 16 mentioned that the search for symbiotic opportunities, even when not named in this way, was a result of current legislation, such as landfill tax, or upcoming legislation, such as Environmental Protection Act or the Climate Change Act. Major risks or costs occurring in their business contexts have been mentioned as a common cause for the search of IS implementation by companies 15 and 16.

The following sections presents the results on challenges and success factors that companies are experiencing with regards to three generic stages of IS development. The

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three stages are: the identification of opportunities for IS exchanges, the design and planning of the exchanges and the actual implementation of the exchanges.

3.2.1 Industrial Symbiosis opportunities identification and definition

At this initial stage of development, the interviews results are presented here from 2 perspectives:

1) From the potential buyer perspective, i.e. how companies look for alternatives to their current input materials:

Companies that require highly specialised input materials have already their set of usual suppliers identified and they have ongoing agreements and contracts. It would be difficult to cut these relationships in order to introduce new suppliers of alternative input materials. Every time there is a new supplier for their input materials, it needs to go into a development period to test the new material and its behaviour within the manufacturing processes and in the final product. This development process can take from few months to more than a year in some cases. In some cases, large companies have centralised the raw materials purchasing processes and this leaves very little margin to modify input materials at plant or manufacturing process level and this may increase the time necessary for testing new materials for their processes.

Some companies get certifications that are connected to the input materials or the formulations they use to create their products. Changing one or more input materials in their formulations would create the burden of applying for new certifications based on the new formulations.

To create a resilient business model which is mainly / partly based on by-products or waste from other companies, the business should not be over reliant on these resources if there is not enough supply of them. Concerns over stability of prices and supply have been highlighted by facilitators as key challenges. Additionally, it seems to be important to keep a certain degree of control over the supply chain of the by-product that will be used as an alternative input material in order to ensure traceability and that the new input material complies with companies' values and standards.

Some companies have a proactive approach towards alternative input materials from other industries, with a continuous search for opportunities to make the most out of the material resources, while assuring materials availability and adequate arrival timings. One of these companies acknowledge that they have established commercial alliances in several occasions for alternative secondary input materials with durations similar to other input materials partnerships. The secondary input materials is then considered as a new input material that needs to be managed, this can be a barrier for some companies, if the new material does not bring additional benefits in terms of price or availability.

In some cases, a potential donor has been identified to provide new input materials to the companies' manufacturing processes. However, there is an investment needed from the donor side that prevents the exchange to be materialised or raw materials prices have significantly dropped and made the exchange not viable economically. Concerns over the prices of these new input materials and their associated transportation costs have been also mentioned by several companies.

Sustainable Process Industry through Resource and Energy Efficiency
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Companies that provide highly customised products to their customers are sometimes restricted to use the input materials indicated or even acquired by their customers. Raw materials are often agreed with customers, thus, in most cases there is not much margin to change them or influence customers' decisions towards more efficient material choices. This is a clear difficulty for them if they want to use input materials that come from other companies' manufacturing processes. Three of the companies interviewed are putting mechanisms in place to dialogue and assist their customers with regards to product design and selection of raw materials to use in products.

It appears that customers are also decisive when it comes to the percentage of recycled materials that they want in the final products. Therefore, the use of different types and quantities of alternative or recycled materials in manufacturers' processes depends on the customer requirements and mind-set.

Some manufacturing companies may introduce part of their scrap production into their own manufacturing processes. However, when processes are very sensitive, there is a limitation in the quantity of scrap that can be mixed with raw materials as in some cases it changes the characteristics of the input materials. Therefore, it could damage the machinery and / or modify certain characteristics of the final product. This happens also when by-products from other manufacturing processes are introduced in the mix of input raw materials for some companies interviewed, in some cases implying a reduction on the process efficiency

Establishing a collaboration with the potential donor of secondary materials at early stages, e.g. while performing material testing in formulation and production trials, seems to facilitate the solution search process and ensure win-win situations.

2) From the potential seller perspective, i.e. how companies look for solutions to their waste and by-products:

It is important to find a reuse solution that takes advantage of the nature of the material and in which the market need matches the size of the problem. The volume of the waste stream is an important factor to take into consideration. Some companies have mentioned their current concern regarding the need to look for multiple uses of their waste streams as current solutions based on one single buyer do not reuse the high volume generated.

Some companies are trying to find solutions for their waste and by-products. They follow different approaches. At business development level, top managers look for ideas to implement themselves by listening to new proposals from others and observing other companies' approaches and operations. Keeping in frequent contact / conversations with academic collaborators, technological centres and recycling partners are recognised as additional sources for ideas by some interviewees. Connections and interactions with sectorial associations has been highlighted as a source for ideas and collaboration opportunities. An important factor is to allow themselves certain space for taking risks to try new things and make mistakes to learn from. An open mind-set for innovation and flexibility to experiment with new ideas seem to be characteristics of companies that have successfully implemented industrial symbiosis. In this regard, one of the companies has a dedicated team for identifying and analysing new applications of

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SPIRE Sustainable Process Industry through Resource and Energy Efficiency
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their waste streams. This allows to have several feasibility projects running in parallel and increase chances to find good solutions.

At their own facilities, companies look for reuse or recycling solutions themselves. The symbiosis approach in some companies is embedded in their way of looking at their own production sites also. A production site becomes then a symbiotic space in terms of the processes that are on-site. The immediate trials address the reuse within their own facilities of their waste and by-products. When this is not possible, they may send it to authorised recyclers, as a way to avoid landfill. They need to pay to these authorised recyclers to take the waste from their facilities, therefore, companies keep on searching for other solutions themselves. This becomes a bit challenging for several reasons:

- They need to make an effort to analyse and characterise themselves their waste streams. Once this is done, it can be difficult for them to identify what to do next. Some companies have labs and development teams that analyse potential improvement ideas, others work with external labs or research / academic institutions.
- They need to figure out themselves which could be the potential uses of their waste materials. In some cases, it is challenging to find adequate resources to perform this activity. Some companies do it by using in-house laboratories, others by partnering with research / academic institutions, participating in facilitated events or even by running idea competitions in Universities to challenge students to find an alternative use to their waste materials. This support sometimes also includes to the search for potential partners through the third party network.
- Even when they find potential uses of their waste materials, it may happen that the waste materials cannot be traded if they are not included in a by-products catalogue. If not included in by-products lists, it can be only handled by authorised waste management companies and not be sold to other potential direct user. This can even have a regional character, i.e. regions within the same country having different permitted reuses for the same type of waste. This is preventing some companies from looking for potential uses of their waste materials that are classified as waste. This regulatory barrier was also mentioned by facilitators / observers of IS implementations.
- If the potential reuse can be done internally, e.g. within company's boundaries, there would be an assessment on its feasibility in terms of investment and technological needs and how to access the market for the new output, if it implies the development of a new product offering distinct from current ones.
- If the potential user is an external entity and it is enough interested, both companies can start the process to introduce the waste into the catalogue as a by-product so it can be subject to trade. This process is full of paperwork and can take from months to years.

The procedure to commercialise by-products is found often discouraging and it seems to be worth just for large quantities of waste/by-products.

Some companies are aware of the difficulties that others may have when recycling and reusing their scrap production due to the presence of certain substances that could damage the machinery during the treatment processes, e.g. some materials may need to

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be cut into pieces before being reused by other manufacturing processes. The awareness on reuse difficulties or on peculiarity of their waste streams can make companies very reluctant to join facilitated workshops or programmes to look for IS opportunities.

On the other side, companies could be encouraged to participate in IS facilitated workshops or programmes if they get some incentives or there is certainty that there is a solution and possible users available for their waste materials. This is an important challenge to promote a wider adoption of IS, as facilitation seems to have higher potential to achieve significant impact in terms of spread IS application in a shorter timeline.

Differences in terminology used in different sectors have been mentioned as a potential barriers to identify new exchange opportunities, while well-consolidated exchanges may have already built commonly known terms among sectors involved.

Packaging waste, if exists, is mainly sent to specialised recyclers. This seems to be a well extended practice in the companies interviewed.

Regional regulations on valorisation have been found useful to provide directions on possible reuse options of slag towards cement and construction industry. However, regulations for waste management change very often between countries, and even inside the same country, between regions.

Further support to contribute to the economic effort of developing new solutions and to the networking efforts to find the adequate users of waste streams have been mentioned as key to support more IS applications in industry.

3.2.2 Industrial Symbiosis exchanges design and planning

The interviews results on how relationships are established and how the actual exchanges are planned are presented herein.

Companies need to see the business opportunity in the IS exchange and there should be a business case supporting this and bringing value to their companies values and outcomes. This business case has been also mentioned as a key means to get resources and support from top management to invest in the IS implementation.

Waste material and especially waste energy like heat, which is delivered as a continuous stream may entail a special contractual problem: for the buyer it is essential, that he can dismount its equipment – a heater for example - to save costs when purchasing the waste energy. If the equipment needs to be hold ready as a backup system, it wouldn't have an economical advantage. On the other hand this is risky for the seller. If there is a delivery commitment, he would have to pay a contractual penalty if he could not provide the energy. This may be an obstacle for the seller to offer waste energy.

In a fast changing industry, where companies underlie a continuous adaption process to fulfill the market needs, it may not be advisable to close a long term contract for delivery of waste material or energy.

Indeed, companies' main concerns at this stage are the scarcity of suppliers and the transport costs to move waste materials, sometimes across different countries. This is a general business concern, which is also present in regard to IS exchanges. In some countries

MAESTRI
SPIRE Sustainable Process Industry through Resource and Energy Efficiency
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legislative restrictions hinder the transport of waste material even between different sites of one company. To enable IS, European or national law has to be adapted to enable and encourage symbiotic exchanges.

Distance, and its associated transport costs or lack of infrastructure, has been mentioned as a barrier for feasible IS exchanges to reach the implementation phase. One of the interviewees mentioned that they have established several successful collaborations, in some occasions providing the waste materials at no additional cost if the receiver agrees to cover the transport costs.

Some companies partner with recycling companies who help them to find a solution for their waste materials and connect them with their waste buyers. The partnership with recycling companies will allow the pre-treatment of the waste materials before it can be used by the potential buyers. This seems to be a beneficial solution for all parties involved, even though the burden of understanding the required volume may reside on the waste producing company as well as the search for potential buyers. The current practice of paying waste managers to dispose some materials was not satisfactory for some companies interviewed, thus, they have started to look for ways that can create more value out of these waste streams.

Some companies have found that collaboration with competitors or organisations from other industries using similar input materials is a way of achieving enough volume to make the IS opportunity viable and join forces to modify restricting regulations.

A success factor has been mentioned as to design the solution to maximize the value of the waste material or by-product. This implies, in some cases, leveraging on where the original material came from or what physical and chemical characteristics remain in the material at each stage of the production process. This knowledge is key to identify the possible reuses and how to design the exchanges to maintain that remaining value.

An internal barrier mentioned by some interviewees is the lack of awareness on the importance of segregation of different waste streams. One of the companies mentioned a scheme for segregation based on multiple collection points throughout the factory, combined with awareness raising activities including the presentation of positive business results enabled by the segregation of waste streams.

Company size has been highlighted not to be a barrier to engage and be active in IS. It was acknowledged that small companies may face challenges related to lack of resources to focus on new opportunities rather than concentrating in core business and daily operations. The engagement with IS seems to be more dependent on the business context rather than on the business size. Thus, from the facilitators perspective, there would be no additional issues for IS on company size differences, just the same as if they were trading for a non-waste product.

After an IS opportunity is identified, small companies may find it difficult to collaborate with large companies, even if they are the most adequate partners to pursue the IS opportunity. There seems to be a size mismatch problem that make partnerships difficult due to company size and working practices. It seems to be perceived both sides, the small company facing issues to assure the large companies that they are good partners and vice

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versa, the larger companies finding difficult to get small companies involved as they may be creating a strong dependency on the exchange. This is not an important issue for some large companies due to their reputation and prospective as a well-established business.

Even if an opportunity is identified, the legislation may take a long time to be developed in order to use the waste material as input. It is necessary to adapt standards to the rhythm of emergence / evolution of new substances and by-products and the discovery of their potential reuse. Some companies try to engage with regulators at early stages of legislation development, in order to convey their concerns and provide input on what could be listed as waste or by-product from their company's operations perspective. Many interviewees claim for legislation to be simplified and become more agile and flexible.

Moreover, some interviewees mentioned that uncertainties and changes in legislations / regulations, e.g. what to incentivise and for how long, make it difficult for companies to plan investments and evaluate accurately whether some symbiotic opportunities are worth to take forward or not.

During the planning process, keeping a learning approach to explore the different possibilities for implementation is essential as it can take a while to find an economically viable solution for the IS realisation. There is an important element of contextualisation that companies operating in different countries brought up. They identify a set of viable solutions to be applied to their by-product streams and select the most valuable according to the regional needs and incentives.

3.2.3 Industrial Symbiosis exchanges implementation and progress

The interviews results related to how the actual exchanges occur and continue over time are introduced in this section.

Most of the characteristics for successful IS implementation are similar to those needed to make successful any other business endeavour.

Transparency and information sharing with IS partners are important to ensure continuity of the material exchanges. One of the interviewed companies built a trust relationship through yearly agreements for 5 years; in this way, they built enough trust so now its agreements with by-product providers have a range of 10-15 years ahead. Credibility and reputation as a stable partner for symbiosis would attract more opportunities, and potentially, more successful symbiotic implementations.

In some cases, there is an identified IS opportunity and even the project reaches the level of design and planning. However, it does not reach the implementation phase due to high investment needed without long term guarantee of continuity or due to the business failure of one of the companies involved. Interviewees also mentioned that they may expect a payback period equal to other non-IS projects within the companies. However, if the symbiotic project would not pay back on that timeframe, they expect some government incentives to make it happen.

A barrier to reach the implementation phase or to keep the symbiotic exchange happening regards the prices of raw materials. In fact, several companies mentioned that they have viable and feasible projects to use secondary materials in their hands that were ideated

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when raw materials prices were higher. At the current state of lower raw materials prices, they were not implemented or they have been stopped as they became more costly.

On a more positive perspective, these proven secondary materials opportunities could be seen as back up plans when the raw materials prices get high again.

Similarly to supply chain clustering, government and legislators could incentivise co-location of companies in the same area whenever they have synergetic and supply related potentials (which is currently happening in many countries) and also whenever they have symbiotic potentials.

Moreover, once the IS approach is embedded in the way of doing business, companies look at what advantages the synergies between processes can bring to their current operations or to future operations. This happens specially in terms of sharing by-products and waste and in terms of reusing energy and other utilities. Companies at this stage of "awareness" are continuously looking for new synergies and opportunities to both getting inputs from other sources or using their outputs in more efficient and valuable ways.

Successful symbiotic exchanges maintained over time are not exempt from challenges. Some interviewees mentioned a great satisfaction with their achievements, even if they were not easy to implement. They mention hard work is behind the surface and difficulties emerged in the daily operations from many different sources: partners, regulators, capital investments and return of investments, delays and operational issues. The symbiotic exchanges are also subject to disruption due to changes in companies' business interests, there are long term collaborations that were ended due to business context changes of the parties involved.

4 Summary of findings and gap analysis

The study of IS has ranged from how IS can occur, the conditions and approaches which enhance the likelihood of success, to establishing the benefits of implementation in terms of economic and environmental performance. Research on IS implementation processes and stages, especially in regard to self-organised IS, is still limited.

IS can provide companies a means to improve their non-labour resource productivity. However, it is necessary to be cautious as IS may not be the only or optimal mechanism for all energy and resource efficiency problems. MIRATA and EMTAIRAH (2005) suggest that IS opportunities should be compared to other possible mechanisms for environmental improvement, in order to assess its viability and applicability. With potential improvement actions in the economic, environmental and social dimensions of business, the application of IS should be evaluated against other options for resource efficiency improvements. There is a need for further research on tools and methods that can support companies to identify and evaluate, at early stages of ideation, both the different possibilities for their waste streams and for enlarging their procurement activities by looking for symbiotic exchanges with other companies.

The appropriateness of the solutions will be strongly influenced by contextual factors. These factors can be related to social, informational, technological, economic and political

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aspects that will constitute a potentially enabling context for IS (COSTA ET AL., 2010). Regulations and the lack of standards, together with the long processes to declare a waste material as a by-product may be inhibiting IS development and efforts to make it really happen. Governments could implement regulatory measures to support IS implementation and create higher awareness among companies' top management. Regulations that penalize lower waste hierarchy management levels and coordination programmes to facilitate and assist companies during the IS opportunity identification stage are examples of possible supportive government interventions (COSTA ET AL., 2010).

Thus, there is not a one-size-fits-all when planning and implementing Industrial Symbiosis. Some specific characteristics will shape the scope and opportunities for Industrial Symbiosis in a specific context. These include but are not limited to; company size and production processes, geographical landscape and regional industrialization as well as country-specific trade regulations and policy. The high degree of characterization needed for the design of IS in different contexts means practitioners would benefit from support (e.g. tools and methods) developed specifically to address contextualization challenges for IS design and planning.

Last but not least, for IS to flourish in practice, all actors in a potential IS system need to derive value from the network. Understanding the benefits (both monetary and wider forms of value) provided to all actors in the system will help create the levels of trust that will keep the system running. Especially in facilitated IS, once the facilitator has left the system, built trust and well-understood benefits could support the survival of the IS system. It appears therefore that reciprocity is a key principal for practitioners wishing to design and implement IS, with the reciprocal benefits of network participation potentially underpinning long term success of IS implementations.

5 Concluding remarks

Integrating sustainability into manufacturing industry needs to be done at business as well as network level (VALKOKARI ET AL., 2014). IS could serve as an inspiration for initiatives that can support improvements at the whole system level. There is a dual purpose in IS implementation at individual firm level and system level. A broader view of industrial symbiosis (EHRENFELD AND GERTLER 1997) seeks to improve the system efficiency, yet for IS to flourish, the individual actors must be nourished with favourable economic outcomes.

The literature review showed that there is a higher number of studies of planned IS emergence and enabling and limiting factors than those of analysing self-organising IS. Several studies of the Kalundborg system focused on the social interactions that made it happen and studies on facilitated IS concentrated in the process followed for facilitation. However, most of the successful applications of IS started with a serendipitous approach, i.e. self-organising manner. The exploratory study with practitioners enabled to balance the study on challenges and success factors as companies offer their vision on their own engagement to IS and their actual opportunities for implementation. Thus, the results are more related to self-organised IS. This is really relevant for the MAESTRI project.

The lack of awareness and agreement amongst many of the participants as to what IS is (even amongst those engaged in IS) and how it relates to the CE suggests that the label

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may not be helpful in engaging companies. Furthermore – whilst the Circular Economy has gained significant profile, it is not clear that companies fully understand the activities necessary to deliver progress towards the vision. A consideration for the design and implementation of tools associated with industrial symbiosis is therefore that the instruments should focus on the activities (e.g. identify waste), the means (e.g. MFA, environmental assessment), the aims (in particular the benefits e.g. competitive advantage, environmental responsibility) from a business point of view rather than utilising the academic vernacular.

To this end a parallel may be drawn with the activities of WP2 & 3 which feature overlapping activities (e.g. value stream mapping) already well established, if not always well understood or implemented. Using these company friendly frames of reference may help in establishing traction within organisations, and encouraging integration of techniques where possible, could reduce confusion and increase uptake. However, care must be taken not to dilute the essential attributes of IS. A detailed cross comparison of activities and challenges implied by WP2 and 3 should be undertaken to explore implications for the integration of IS related concepts.

The focus of WP4 within MAESTRI project is to provide companies with methods and tools to develop self-organising IS to the extent that this is possible.

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Appendix A. Questions for the exploratory interviews

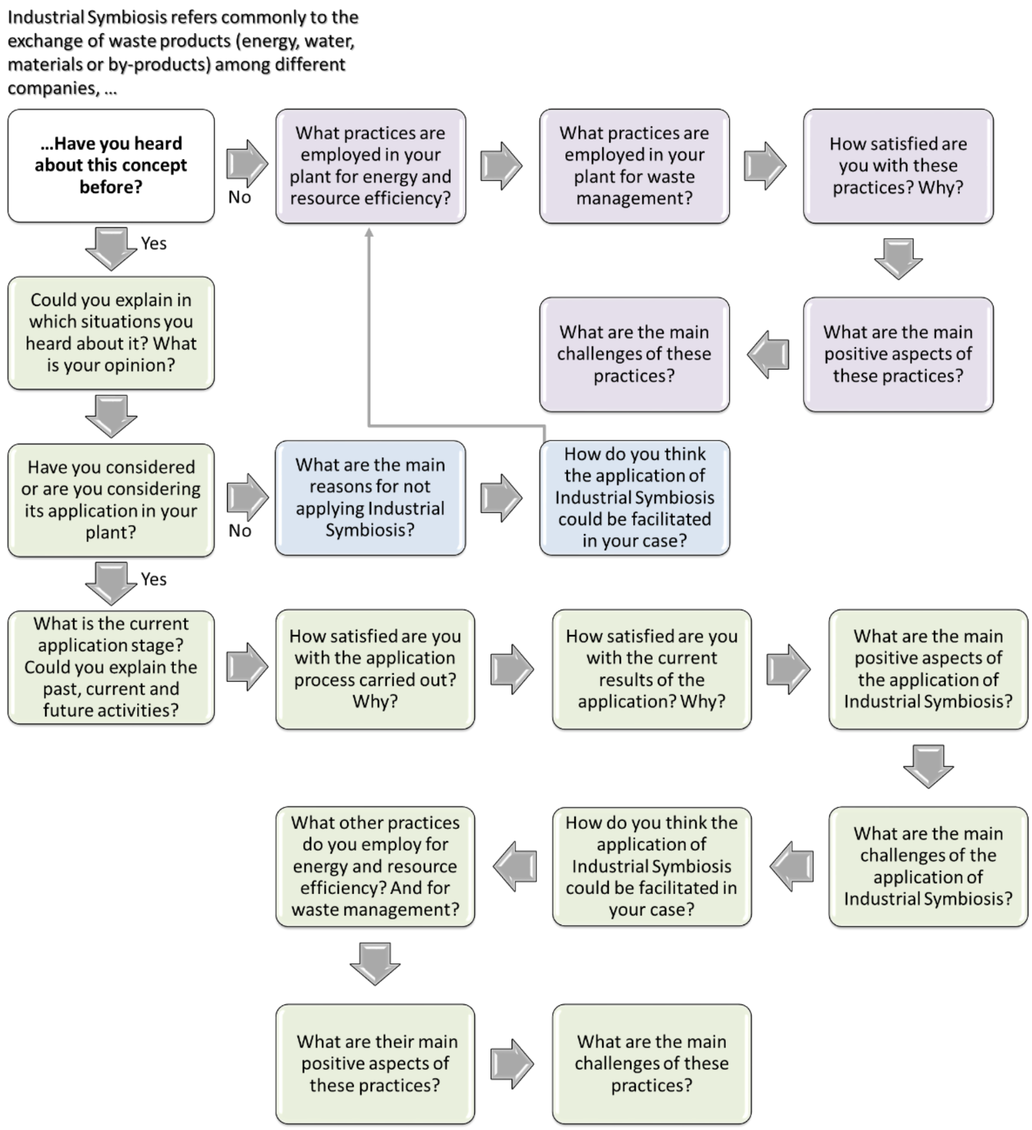
SOURCING OF MATERIALS, WATER AND ENERGY

Which are the main input/raw materials for your manufacturing processes? Which are the energy / water requirements for your manufacturing processes?

How is the sourcing / procurement process? Do you need to treat them before their use in your manufacturing facilities? Do you have strong specifications for your suppliers?

Have you ever considered using recycled materials or alternative sources, such as second-hand materials, unused energy or wastewater from other companies' operations? What are the main challenges related to materials, water and energy sourcing?

PRACTICES FOR ENERGY, RESOURCES AND WASTE MANAGEMENT



Would you like to make any further comment / remark?

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Appendix B. Document to contact potential participants

Page 1:

MAESTRI

Total Resource and Energy Efficiency
Management System for Process Industries

Interview Information

Industrial Symbiosis

Date: 08/02/2016

1. *Introduction*

This work is part of the activities of MAESTRI project (http://maestri-spire.eu/). The main objective of the project is to create both concepts and tools **to facilitate the adaption of energy and resource efficiency improvement strategies in process production systems** of any company (large, medium or small). University of Cambridge is leading the research on Industrial Symbiosis in this project.

Industrial Symbiosis refers to the collaboration among traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products.

As part of our initial activities for the MAESTRI project, **we are seeking companies in the manufacturing industry willing to participate in an exploratory study. We will be conducting interviews during the months of March, April and May 2016** in different locations.

The study is open to manufacturing companies located in Europe and working in any sector, particular attention will be paid to cases in the process industry but will also investigate other industries. Small, medium and large companies are equally welcome to participate in the study. The interviewee/s should have a managerial role in the company, either within the top management team or middle manager level.

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Page 2:

2. *Purpose of the interview and visit*

We are conducting these interviews to understand **manufacturing company challenges when engaging in energy and resource efficiency improvement strategies through an Industrial Symbiosis approach.** Prior knowledge or experience with Industrial Symbiosis is NOT required to participate. Understanding that different companies will be in a different position with respect to Industrial Symbiosis, this study seeks to interview companies with a range of experiences including cases of non-awareness on Industrial Symbiosis to cases of advanced implementation.

What can you get from your participation in this study?

- **Access to the report** that will be generated out of the exploratory study, which will present both challenges and success factors at different stages of engagement in Industrial Symbiosis approach for energy and resource efficiency.
- **Personalised report to position your company** against anonymous others.
- Possibility to follow up on project activities and results through Maestri Newsletter.
- Possibility to receive information on training events on Industrial Symbiosis activities within Maestri project.

3. *Interview protocol*

Semi-structured interview method (open questions). Expected duration: 1 h.

Location: Preferably at your manufacturing plant to be accompanied, where possible, by a visit to the facilities.

Follow up based on archival data (company's public reports and website).

<u>Confidentiality/ Anonymity statement</u>

The data collected through the interviews may be used to support the research objectives of MAESTRI project regarding the activities led by University of Cambridge on Industrial Symbiosis. This research may result in publications in project deliverables, journals or conference proceedings. Interview material will be presented mostly in an anonymous format, with company names and any case specifics that might identify the company removed. Verification and written approval will be obtained from the company prior the use of interview material in a non-anonymous context.

Contact person:

Dr Maria Holgado, Research Associate, University of Cambridge
Email: mh769@cam.ac.uk

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