

Classification of Industrial Symbiosis Synergies: Application in the Biofuels Industry

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ABSTRACT

In the research field of industrial symbiosis, literature regarding classification methods for resource synergies and interactions is lacking. A few researchers have however provided the groundwork for classification of industrial symbiosis interactions and terms, though these terms may become confused with one another. In order to obtain better resolution of the characteristics of exchanges and interactions, i.e. synergies, a classification method is produced and tested in this paper. The classification method maps the interactions between different industries as well as the flows of products and utilities through origin-destination classifications to provide further details for provided synergies. Synergies between a core industry and external industries are examined in this paper, with the core industry represented by the biofuels industry, and without geographical boundaries. The classification method can be employed in other research projects and it is hoped that it will provide the background for further studies into conditions necessary for synergy implementation and provide subsequent details for research into economic and environmental benefits provided by synergies between industries.

1 INTRODUCTION

In the theories of industrial ecology, technical systems are viewed as both *industrial* and *ecological* [1]. Industrial focus is set upon products and manufacturing processes for which technological advances can lead to environmental improvement and decreased impacts. Ecologically, the theories of industrial ecology set industrial practices in the context of surrounding ecosystems, much like natural ecosystems, in order to discover approaches to handle wastes and recycle product flows to reduce environmental impacts and improve efficiency [2]. The theories originated in 1989 when two General Motors executives brought forward the term of “industrial ecosystems” in which traditional models of industry should be expanded and integrated in order to optimize energy and material consumption and minimize wastes which have then led to the expanded theories of industrial ecology and industrial symbiosis [3, 4].

Industrial symbiosis (IS) is a branch of industrial ecology that focuses upon physical exchanges of materials, energy and by-products on the inter-firm level, where the company is not viewed as an “island” but is involved interactively with numerous companies. This interaction involves the physical exchange of materials and energy between companies to promote mutually beneficial exchanges, i.e. “win-win situations.” [1, 5] Moreover, IS is

aimed at engaging traditionally separate industries through a collective approach in order to create competitive advantages for each and every cooperating industry through resource exchanges, synergistic possibilities and other cooperative approaches related to their geographic proximity [6].

Much of the current literature available for IS describes industrial activities and reasons for their implementation, success and existence [5, 7]. Though this provides an overview of the IS activities worldwide, it does not necessarily uncover the details into the types and characteristics of the exchanges [5]. Research into the characteristics and details of exchanges, i.e. synergies, can thus lead to a greater understanding of the development process and provide further information of the reasons for and conditions required for industrial activities.

In this paper, a method for the classification of synergies between industries is developed and tested to provide more details of the characteristics of the synergies between industries. The focus of this paper is upon synergies between a *core industry*¹ and *external industries*². The core industry of this paper is the biofuels³ industry, i.e. biogas, bioethanol and biodiesel industries, to make use of by-products, energy and other exchanges to increase the environmental and economical performance of biofuel production industries. Examples are therefore provided for the biofuel industry, though the classification method also has viability in other core industries.

2 BACKGROUND: INITIATIVES TO DESCRIBE SYNERGIES AND INDUSTRIAL SYMBIOSIS

In the theories of industrial symbiosis, the term *synergy*⁴ is used to describe the sharing of materials and energy for added value between industrial activities. The actual classification and identification however has been difficult to realize as many of the terms shared between industrial symbiosis and industrial ecosystems about resource sharing, synergies and exchanges are often confused and have varied meanings between disciplines [8]. Moreover, various terms such as regional resource synergies, eco-industrial parks circular economies and eco-industrial developments are commonly used to describe similar industrial symbiosis theories [5, 9].

Several authors have attempted to introduce structured classifications for industrial symbiosis literature. These categorization methods describe the networks, types of exchanges and geographical contexts for the exchanges and provide a means for structured research presentation in their own respective areas. Further details into synergies however have not been extensively provided from previous research papers though research such as Lowe, Chertow and van Berkel have provided a structured method to classify industrial symbiosis activities and exchanges between industries [3, 6, 8]. These classifications are described in

¹ The core industry is regarded as the reference industry for the research.

² All other industries outside of the core/reference industry.

³ For the remainder of this paper, the term *biofuels* refers to biodiesel, bioethanol and biogas and does not include wood or other biomass.

⁴ Synergy is defined in this report as the relationship and cooperation between industrial activities by the shared consumption, disposal and reuse of products and utilities.

subsequent text, as well as in Table 1, to show the hierarchical structure they provide for industrial symbiosis and synergies classification relating to this paper.

Table 1: Initiatives to Classify Industrial Symbiosis Exchanges and Interactions [3, 6, 8, 10]

Detail of synergies and exchanges 	Researcher (s)	Industrial Symbiosis Classification Description	Limitations/ Comments
	Lowe [3]	Types of eco industrial parks and their motivation	Reasons and Initiatives for Industrial Symbiosis
	Chertow [6, 10]	Geographical distribution of exchanges	Descriptions of types of exchanges between companies regionally and “virtually”
	Van Berkel [8]	Nature of synergy exchanges	Distinctions produced for interactions and sharing of by-products, utilities and management

In relation to the overall development of industrial symbiosis, Lowe [3, 11] clarifies different types of exchanges by creating three categories of *eco-industrial projects* in order to describe the reasons for industrial symbiosis within defined geographical areas. These include eco industrial parks or estates, by-product exchanges and eco-industrial networks which exist due different initiatives. The initiatives include creation of eco-industrial parks in order to develop companies with high environmental, social and economic benefits, utilization of by-products and for regional sustainability.

Chertow [6, 10] departs deeper into the descriptions of these projects and provides more detail into the exchanges. Chertow classifies five different types of exchanges due to their interaction within industries regionally and within a broader region. The exchanges are organized based upon their interactions within firms, among co-located firms, localized firms and firms within the “virtual” broader region though further detail is not covered.

Adding to the concepts provided by the previous researchers and going yet deeper into the details of the exchanges, van Berkel [8] thereafter argues that distinctions should be made about the sharing of utilities, by-product exchanges as well as planning and management. *By-product synergies*, *utility synergies* and *supply synergies* are used in this work to provide detail into the type and of synergy and handling of material and energy.

From the available literature on synergies and industrial symbiosis, it is apparent that further detail into synergies are lacking. Understanding the complexities and reasons for synergies in natural and industrial systems can provide factors for success and in this context, synergies are important in industrial symbiosis research. Synergies and theories revolving around the term, as defined by Corning [12], are important and provide the functional basis for the evolution of complex systems in nature, society and industry. The remainder of this report will thus provide details into a classification method for further details on synergies for industrial symbiosis projects and research.

3 SCIENTIFIC APPROACH

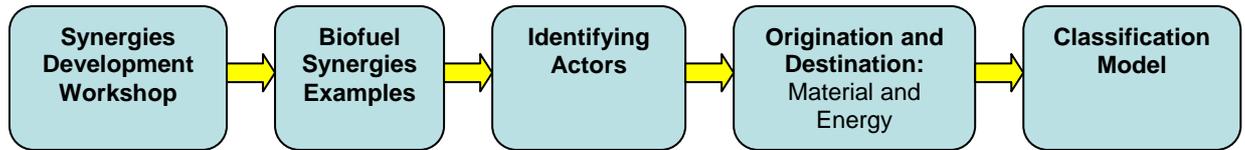


Figure 1: Developing the Classification Model from Biofuel Synergies Workshop

In order to identify details into synergies between industries and provide relevant information for further detail in industrial symbiosis studies, a workshop with regional biofuel industries and academic participants was conducted in the Östergötland county of Sweden. Synergies within as well as outside the biofuel industry were reviewed and documented by participants with roughly 70 synergies being produced from the session. These synergies incorporated material, services and energy exchanges between a broad range of biofuel and external industries [13].

Once these synergies were documented and a listing was produced, it was required to classify the synergies based on the actors involved in order to organize them for further understanding of the details involved. Synergies were thus classified as those between biofuel industries and external industries, and combinations thereof. Upon organization as such, further detail was drawn from these synergies by mapping their interactions in regards to their interaction and flows of materials and utilities by documenting the origin and destination of these flows.

While producing an organizational method for the listing of synergies, a classification tool was produced to document the synergy details previously mentioned. The production of this model was done iteratively in order to represent all details of interactions and synergies between the industries [13].

4 THE CLASSIFICATION MODEL

As mentioned previously, much of the classification currently provided by researchers for industrial symbiosis and resource synergies intends to classify exchanges in order to better define concepts in the broad field industrial symbiosis. This has thus led to more knowledge for industrial symbiosis activities, but has not produced a means by which to clarify characteristics and details of the synergies and exchanges between the companies. Hereafter, an approach to classify synergies further is expanded upon by the development and testing of a classification tool [13]. The tool will detail the industrial collaboration, energy and material flow classifications to provide further clarification and visualization.

4.1 Classification of Industry Collaboration

First and foremost, synergies can be organized with respect to their interaction within and outside of the studied production industries, i.e. biofuel industries. These collaborations can be conducted within the core business of the company, i.e. producing biofuels, or evolve between other processing within the biofuel actors businesses or other industries outside the biofuel industry. Upon classification, the respective synergies will subsequently have their courses routed, i.e. concerning where the synergies originate and are destined to conclude. Further details are provided in the following sections.

The interactions between industries produced include;

- Biofuel → Biofuel Synergies
- Biofuel → External Synergies
- External → Biofuel Synergies.

Biofuel to Biofuel Production Synergies

Flows of goods, materials and services between biofuel industries are classified as Biofuel to Biofuel Production Synergies (*Biofuel↔Biofuel Synergy*). Specifically, this classification defines synergies which deal directly with the use of services, utilities, by-products and products from one biofuel system being used in a subsequent biofuel system. In the case of the production synergies, by-products, products and services produced here are concentrated on those resources which are a directly involved in the core business of the biofuel production processes and to goods, materials and services between biofuel actors.

Examples of biofuel production synergies can include;

- Ethanol used in biodiesel transesterification reaction
- Biomass/Stillage from ethanol production used for biogas production.

Biofuel to External Synergies

Many goods, materials and services produced at biofuel industries are desirable in external industries. This is especially true where an organic material is processed and an organic material is produced as a by-product. External industries can use these materials, energy, etc. for their own inputs and thus avoid common sources from other industries, which could prove economically and environmentally more benign. These products and flows can thus be classified under the term (*Biofuel→ External Synergies.*)

Examples of such synergies can include;

- Stillage used for animal feed
- Biogas digestate used as bio-fertilizer.

External to Biofuel Synergies

External to Biofuel Synergies entail goods, materials and services from external industries which are applied as inputs to biofuel industries. Many materials from external industries are important inputs to biofuel production, and currently these industries must pay for the disposal of wastes. By making use of by-products and wastes and giving them a value, again environmental and economical efficiency become important drivers. Moreover, recently with the price of many biofuel raw materials increasing, external and alternative sources for inputs are becoming more common, especially in regards to biodiesel. In the case of biodiesel, as seed oils are increasing in price, large quantities of waste vegetable oils from industry are becoming a common feedstock.

Examples to this are as follows;

- Waste vegetable oil (WVO) from snack food industries used for biodiesel production
- Animal wastes used for anaerobic digestion (biogas production).

4.2 Energy, Services and Material Flows

Goods, energy and materials flow between biofuel producers and external industries. All of these material and energy flows include an origin and a destination from one industry to another and are used either in the production processes or as an input or service optimize the process.

Process/Product

Work produced by van Berkel [8], as previously described, have taken synergies developed from the direct employment of by-products and labeled these as “by-product synergies.” Interestingly, labeling as such can be argued as by-products can be classified as a by-product synergy, yet also be primary energy carriers and thus classified by other means. This case is true when referring to the use of one biofuel in a later biofuel process, as biofuels are energy carriers. Whichever the case, such reasoning will not be applied in this report. Biofuels produced at biofuel industries, in this context, are directly related to the core business of producing them will be referred to as biofuel *products*.

“*Process/Product*” in this paper will be applied to the origin or destination of a resource flow which is an input or output to a biofuel process, i.e. to the *core* biofuel *production steps* needed in the conversion of materials to biofuels and not to better the process.

Examples of the *process/product* classification are as follows;

- Raw oil for biodiesel production
- Cereal Grains for ethanol production
- CO₂ produced during fermentation.

Utilities

If by-products and synergies with these by-products do not involve the core concern of biofuel production at a particular biofuel actor, they shall be classified as a “utility.” The definition of utilities in this paper departs a step beyond that of van Berkel (2006) in describing the utility simply as the shared use of utility infrastructures, i.e. power, steam, air, etc. Hereafter utilities in this report shall be classified as those additional materials, goods and utilities which are not the primary concern of biofuel processing will also be included, i.e. those measures taken to make processes “optimal” in processing which may differ from other processes.

For example, the process of ethanol processing is conducted by direct fermentation of sugars and starch. Yeast ferments the sugars and creates alcohol and carbon dioxide. In large scale ethanol production the addition of some substrates, such as sulfur dioxide, to control pH levels in the process are done in order to optimize the reaction and fermentation process. However, other processes do not use this step, and in this case the added substrates will be classified as a utilities.

Examples of the *utility* classification are as follows;

- Methane produced during waste water treatment at ethanol plants
- Cleaning water from biodiesel process.

4.3 The Classification Model

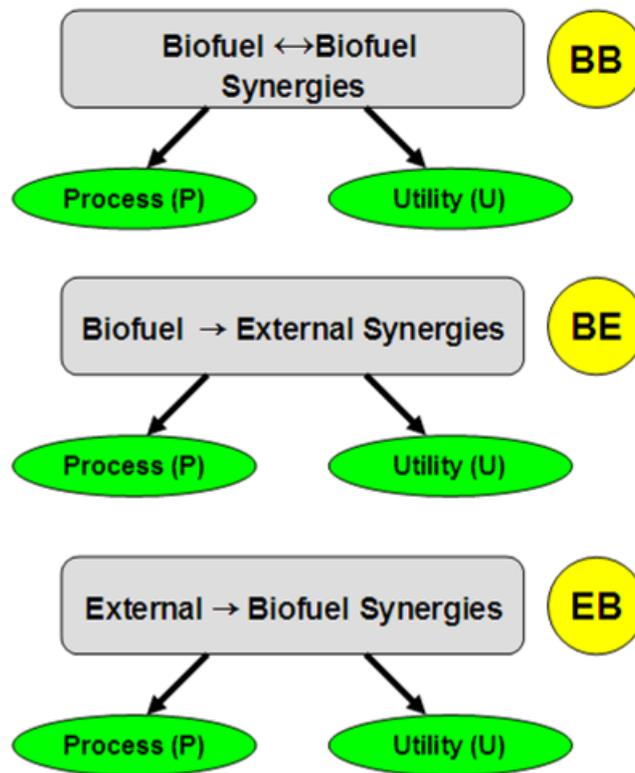


Figure 2: Classification Notation Model

Source: Author

Shown above, Figure 3 represents the aforementioned classification of industry collaboration and shows the outputs (which can also be subsequent inputs) for each. Furthermore, a letter notation is also shown to the side of the industry collaboration classification as well as a (P) or (U) below to portray the product/process, referred to here as simply the process as well as the utility flow respectively.

This letter notation, BB, BE and EB representing the interaction between biofuel and external industries respectively, will be attached to the relative industry collaboration, and combined with the resource input and output classifications in order to identify the type and flow of the synergy. The letter notations can be explained as follows;

- BB- An interaction between biofuel industries, i.e. a *Biofuel ↔ Biofuel Synergy*
- BE- An interaction between biofuel to external industries, i.e. a *Biofuel to External Synergy*
- EB- An interaction between external industries to biofuel industries, i.e. a *External to Biofuel Synergy*.

Subsequent letters attached to the type of interaction denote the product or utility flow. They are once again denoted with a P or U, for product or utility flow respectively. Notation can be explained as follows:

- PP- Originating as a *product/process* output from the first industry and destined as a *product/process* input in the subsequent industry

- PU- Originating as a *product/process* from the first industry and destined as a *utility* input in the subsequent industry
- UP- Originating as a *utility* from the first industry and destined as a *product/process* input in the subsequent industry
- UU- Originating as a *utility* from the first industry and destined as a *utility* input in the subsequent industry

Table 2 below represents several synergies classified with symbol notation. Subsequently, an example with a description of all symbol classification is given for a particular synergy to provide further details.

Table 2: Synergies Classified with the model [13]

Synergies	Classification	Comments/ Motivation
Glycerol from Biodiesel Production used in Biogas Production	BB-PP	<i>Glycerol, a major by-product of biodiesel production is used in many anaerobic digestion processes as a major source of carbon for methane production.</i>
Exhaust from Ethanol Producer used to dry Biogas digestate	BB-UU	<i>Exhaust from heating are considered a utility. Thereafter, drying of biogas digestate is done to optimize transportation options and also seen as a utility input.</i>
Ethanol Stillage used for Biogas Production	BB-PP	<i>In the case of green gas production, biogas is produced from biomass and thus stillage is a the main input/raw material</i>
Waste water from Biodiesel or Ethanol production used for Algae Production	BE-PU	<i>Waste water is considered a utility and used for external industry (Algae production)</i>
Glycerol from biodiesel production used for healthcare and cosmetics industry	BE-PP	<i>Glycerol is used as an important raw material in cosmetics</i>
Ethanol stillage used to produce energy pellets	BE-PU	<i>Ethanol stillage, a major by-product of ethanol production is used as energy pellets for subsequent industries. In this case the energy pellets are used for energy and thus classified as a utility.</i>
Animal fats from slaughtering used for Biodiesel Production	EB-PP	<i>Animal fats are by-products of the slaughtering industry and the major input for biodiesel product in the current case</i>
Algae harvested from Baltic Sea used for Biogas Production	EB-UP	<i>Natural algae harvesting is not the “main purpose” of the Baltic Sea, and thus considered a utility as it is a consequence of other factors which have optimized algae growth.</i>
Synthetic diesel production produces alcohol as a by-product, this can be used for biodiesel production	EB-PP	<i>Alcohol is produced during synthetic diesel production as a by-product and is necessary for transesterification during biodiesel production.</i>

Example: Snack Food Waste Vegetable Oil as Feedstock for Biodiesel Production (EB-PP)

Snack food companies must fry much of their products in vegetable oil, and thereafter this oil is recycled or even wasted. Waste vegetable oil from these snack food companies are usually of high quality due to strict standards on the oils and taste. This makes these oils, along with the sheer magnitude of supplies, a natural synergy between biodiesel producers and therefore snack food companies.

This synergy can be labeled as coming from an external industry and being applied to a biofuel company, i.e. an *External* → *Biofuel Synergy*, “**EB.**” Oil, an important input to snack foods, is a by-product directly related to the snack food production. The origin of this by-product is thus labeled as a product process, i.e. with a “**P.**” As a final destination, the oil is used in biodiesel production as an important input, and thus also labeled as a “**P.**” In summary the synergy can be classified as an “**EB-PP**” synergy.

5 CONCLUSIONS

In the field of industrial symbiosis, there are many terms used to describe similar activities and exchanges. Again, much of the literature available provides beneficial detail on industrial symbiosis, though the aim is to describe the benefits from producing industrial symbiosis; where few describe further detail into the actual synergies involved. Several authors have however provided increasing classification into the details and characteristics of synergies which has thus provided the groundwork for this research and classification model.

This paper has been aimed at providing a classification method to describe further detail into the flows of materials, products and energy between industries, i.e. synergies, and may thus be affixed to other research works. By researching a “core industry” with regards to “external industries” the classification tool provides a method to organize and classify synergies within and outside well defined industries e.g. the forest industry, eco-industrial parks and other industries. Moreover, by applying terms such as product and utility, details into the exchanges and their flows are mapped. Nonetheless, several of these definitions may not be exactly mutually exclusive. This is especially true in when energy can be classified as a product or utility. It is thus up to the researcher to denote the specifics and context of the research and apply the classification method accordingly.

The classification method also provides grounds for subsequent research into the nature of the synergies and details they provide. It is anticipated that the method will provide detail to discover trends and conditions for implementation for synergies, e.g. if core industries view product to product related synergies easiest to implement or whether biofuel to external industry synergies are seen as difficult. Information regarding organization aspects of synergies are not provided in the tool, though it may also benefit work as such. Moreover, details of the synergies may provide information for further research into economic and environmental benefits which Chertow and Lombardi view as important for industrial symbiosis research [14].

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