BIOFUEL SYNERGY DEVELOPMENT:
CLASSIFICATION AND IDENTIFICATION OF SYNERGIES USING INDUSTRIAL SYMBIOSIS

Michael Martin, , Jenny Ivner, Niclas Svensson and Mats Eklund
Linköping University
Environmental Technology and Management
Department of Management and Engineering

LiU Report Number:

LIU-IEI-R--09/0063--SE

BIOFUEL SYNERGY DEVELOPMENT:
CLASSIFICATION AND IDENTIFICATION OF SYNERGIES USING INDUSTRIAL SYMBIOSIS

LIU-IEI-R--09/0063--SE

Table of Contents

1 Abstract

Many critics argue that biofuel production worldwide account for huge losses in energy and materials. Moreover, a large portion of studies around biofuel production are concentrated on stand-alone plants, particularly ethanol production. However, by including by-products and making use of excess energy and material streams, industrial symbiosis methods can be applied to biofuel industries to improve both environmental and economical performance. The following report outlines an approach to apply industrial symbiosis to several biofuel industry actors through synergy development. Synergies were produced during a brainstorming session in order to bring forward innovative and technically feasible ideas toward partnership. From those synergies developed, the report outlines a method to classify synergies and cooperation between biofuel and external industries in order to ease implementation and understanding of possible symbiosis options for industry and academia.

2 Introduction to the Project

In the production of biofuels for transportation, i.e. biogas, biodiesel and bioethanol, a vast range of material and energy flows exists which are unique to each particular process. Every respective process has its share of demands and surpluses of by-products, material and energy which can be used further. The research project, “Synergies for improved environmental performance of first generation biofuels for transportation,” at Linköping University aims to find these synergies, demands and surplus material and energy flows. Thereafter these flows will be applied to the biofuel industry and external industries in a collaborative effort to increase energy efficiencies and reduce consumption of raw materials to increase the environmental performance.

The project is designed to be conducted in 3 separate phases. Phase 1 will identify, develop and analyze possible synergies and symbiosis options. Phase 2 aims producing environmental systems analyses of the biofuel production systems and rank processes based on energy balances in order to identify the best synergies and symbiosis options. Finally, Phase 3 will investigate the conditions required for implementation of new synergies and further innovations needed to improve environmental performance measures not applicable today.

2.1 Phase 1: Development and analysis of synergies and symbiosis options for biofuel production

Currently the research project is in Phase 1, i.e. developing synergies and documenting production processes. The aims of this Phase are as follows:

- Assemble information on current and proposed biofuel production processes and techniques
- Discover, develop and analyze synergies and symbiosis options for production of biodiesel, biogas and ethanol, examples of which might include:
    - Between the different biofuel production systems
    - Between the biofuel production systems and other entities
    - Mixture of waste products with feedstocks for production of biofuels

Upon a review of the production processes at biofuel industries, and discovery of large material and energy flows, synergies were required and developed with the aid of theories from industrial symbiosis literature. This report identifies the method and results from an exploration of synergies in both regionally and in the global context applied to biofuel industries.

3 Aim and Objectives

In line with Phase 1 of the research project, the said report shall aim at finding possible synergies in several biofuel industries and other external industries. Thereafter, a means to structure these synergies is necessary, as further research into other regions (and even globally) will be applied in the research project. This structured approach to synergies will thus help identify differences in approaches, opinions, etc. globally for biofuel synergies and symbiosis options. Lastly, a review of the details provided by the synergies session will be completed in order to show trends in the method provided for synergies participants and discover which types of synergies tend to be most relevant.

4 Background

4.1 Why Synergies? A Theoretical Background

A synergy, which from Greek is *syn-ergo* meaning working together, is phrase used to describe an effect where in which several parts work together to produce a final outcome greater than the sum of all the parts together. This approach also applies to current the area of biofuels, in which producing biofuels using by-products from each other produces greater benefits, both economically and environmentally. The following theories will shed further light on the approach toward better economic and environmental performance measures.

4.2 Industrial Ecology

Synergies research could not be possible without the underlying theories provided by industrial ecology literature. Industrial ecology theories deal primarily with the concepts of studying the waste and energy flows in industry, and discovering the resulting inefficiencies, mass balances, wastes and pollution created. It is in this way that industries can transform themselves from chiefly linear flows of resources and become more cyclical and efficient. Robert Ayres (1989) developed this concept, which was initially termed *industrial metabolism,* which has thereafter spawned a continued interest in industrial ecology research. Inspiration for many terms and the use of industrial ecology arise from ecological systems studies as the hallmark of efficiency. Natural ecological systems are not to be rivaled in terms of resource and energy employment and efficiency, and industrial systems continue to strive toward further integration and symbiosis.

Symbiosis is one way to create industrial ecology in industrial systems, similar to the manner in which natural systems interact and exist. Hereafter, *industrial symbiosis* is employed as a segment of industrial ecology to bind together several industries, not to create disorder, but on the contrary to enable cooperation and shared production for better economical and environmental performance. (Garner & Keoleian, 1995)

4.2.1 Industrial Symbiosis and Biofuels

Industrial symbiosis theories aim 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 cooperations related to their geographic proximity. (Chertow, 2000)

Van Berkel (2007) takes the theories from industrial symbiosis and reviews the theories of synergies research further in his paper entitled, “Regional Resource Synergies for Sustainable Development in Heavy Industrial Areas: An Overview of Issues and Opportunities,” in order to give a background for his research. In the said report, the concepts of by-product synergies, utility synergies and supply synergies are defined, according to Altham et al. (2004) and Bossilkov et al. (2005), as a means to define and categorize synergies between industries. However these definitions are not exactly mutually exclusive and many of the synergy classification when applied to actual synergies may be defined in one or more contexts. This is especially true in the case of supply synergies, which van Berkel (2007) does not include in his work.

The synergy classifications are defined, according to van Berkel (2007), as:

By-Product Synergies: “involve the use of previously disposed by-products from one facility by another facility to replace another business input. The by-product could be exchanged in solid, liquid or gaseous state, and could originate from process operations (e.g. processing residues and wastes from the manufacturing operations) or from non-process operations (e.g. maintenance, warehousing, administration, etc.). The driving fore for the resource exchange might be the recovery of specific materials, or the recovery of the nergy or water contained in the resource flow.”

Utility Synergies: “these involve the shared use of utility infrastructure, for example for production of energy carriers (e.g. power, steam, compressed air, etc.), production of process water (e.g. de-mineralized water) or for the joint treatment of waste and emissions (e.g. shared materials recovery facilities or wastewater treatment plants). The shared utility operation can realize economies of scale as it combines smaller by-product streams from several companies, or serves the smaller utility demands of several companies. Moreover, utility synergies generally bring in specialist operators (e.g. independent power producers or environmental service companies) to take charge of utility operations, enabling companies to concentrate on their key production processes.”

Supply Synergies: “these involve the co-location of a company with its key customer(s). As an example, an industrial gas company can custom design, build and operate an air separation plant next door to a major user of nitrogen, for example.”

Hitherto, these definitions and classification schemes in collaboration with the theories from industrial ecology and industrial symbiosis give rise to this very research project. More detail into synergy classification and a new approach to classifying and defining synergies will be presented in the preceding text.

4.3 Biofuel Production Process

The following sections provide a review of biofuel production techniques as well as synergy terminology. Moreover theories of synergy development and industrial symbiosis are also presented in order to provide relevant knowledge for the reader.

Biofuel production processes, whether biogas, bioethanol or biodiesel, are entirely different and unique. Through the processes of transesterification, fermentation or anaerobic digestion, biofuels are created from organic material and refined for use in vehicles or in other applications. The following sections illustrate the process of biofuel production for biodiesel, ethanol and biogas production with figures and a brief explanation in order to supplement the knowledge of the reader into the energy and material flows involved, which is essential for comprehension of the data and terms in the synergies provided.

4.3.1 Biogas Production

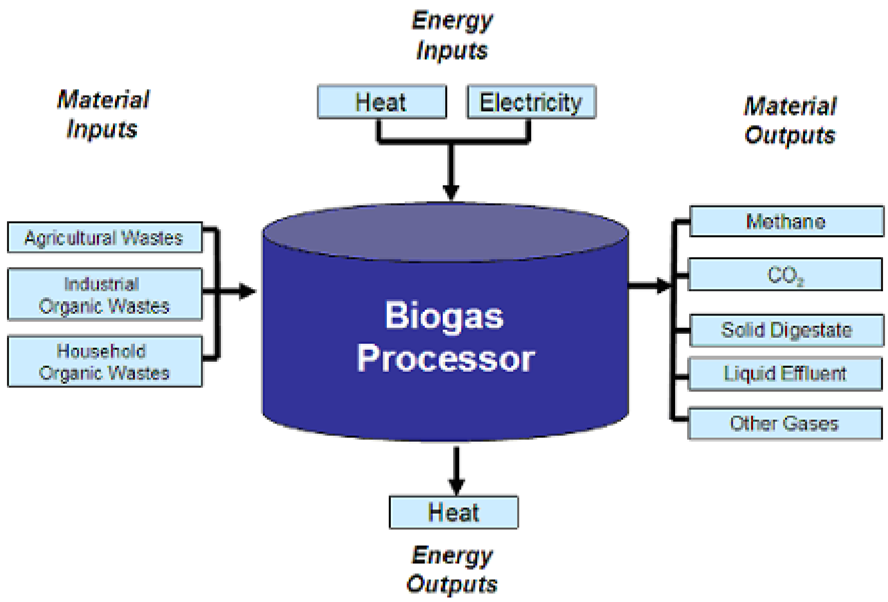

Figure 1: Biogas Production
Source: Author

Biogas is produced through the anaerobic digestion of organic material. Special bacteria are used in these processes which are naturally available to produce methane and carbon dioxide in an oxygen free environment, i.e. anaerobic. These bacteria are given near optimal conditions in the digestion chambers at biogas processing plants in order to efficiently and effectively extract the greatest amount of methane possible from given substrates. In order to control the process, heat is applied (in most cases) to reach these optimal conditions given the material inputs. Figure 1 represents a typical biogas system, although some variance can be apparent with other systems, including material inputs and outputs as well as energy inputs and outputs.

Inputs to the biogas system are varied throughout the range of digesters worldwide. In Sweden, common inputs to the system include, but are not limited to, the following:

- Agricultural Wastes
- Slaughterhouse Wastes

- Seized Smuggled Liquor
- Food Industry Wastes
- Kitchen Waste Products
- Glycerol
- Ethanol Stillage and Syrup

Further information regarding the biogas digestion process can be found in (Borjesson, 2007; Svensk Biogas, 2008).

4.3.2 Biodiesel Production

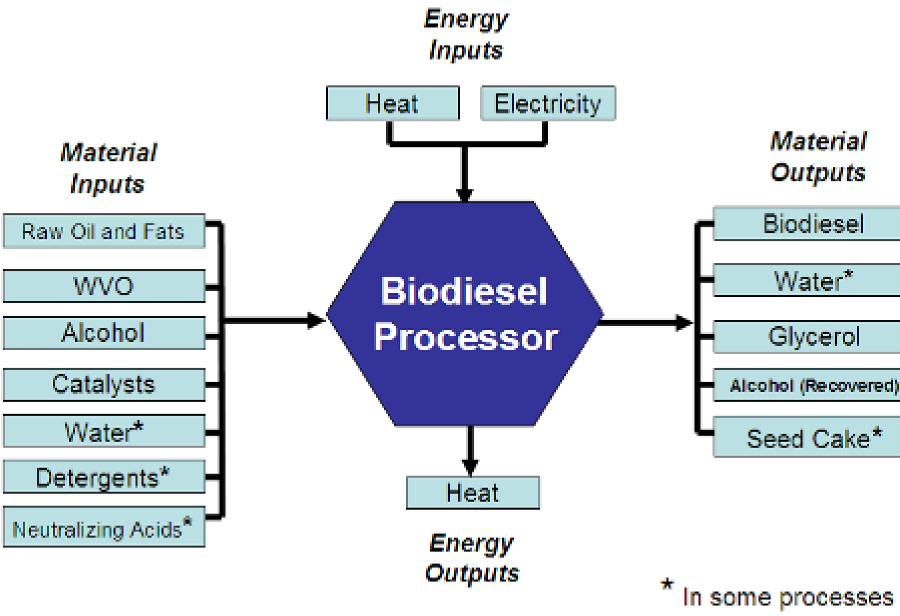

Figure 2: Biodiesel Production Diagram
Source: Author

The production of biodiesel is accomplished through the transesterification reaction. Transesterification involves separating fatty acids from their building block, glycerol, and subsequently replacing the glycerol with alcohol to produce a methyl ester. Like the biogas production process, additives are used to create optimal conditions, e.g. heat, catalysts and neutralizing acids. Figure 2 above shows a typical biodiesel process diagram with relevant inputs and outputs of material and energy. Interestingly, several inputs of oils are included as biodiesel can be produced from nearly any fat or oil, as well as recycled fats and oils, given that the fatty acid content is not too high. If the content of fatty acids is too high, the oil must be treated because using it in that state would produce an output of primarily soap, with a small fraction of biodiesel. Neutralizing acids are used to break the fatty acids apart and thus make it easier to bind the alcohol to them, with the help of catalysts, to produce biodiesel. Outputs from the process include biodiesel, glycerol, recovered alcohol, oil seed residues and in some cases, water. A typical depiction of a generic biofuel process is shown above to outline the basic inputs and outputs to the system.

Further information on biodiesel and its production methods can be found in (IEA, 2005; Mittelbach, 2006).

4.3.3 Bioethanol Production

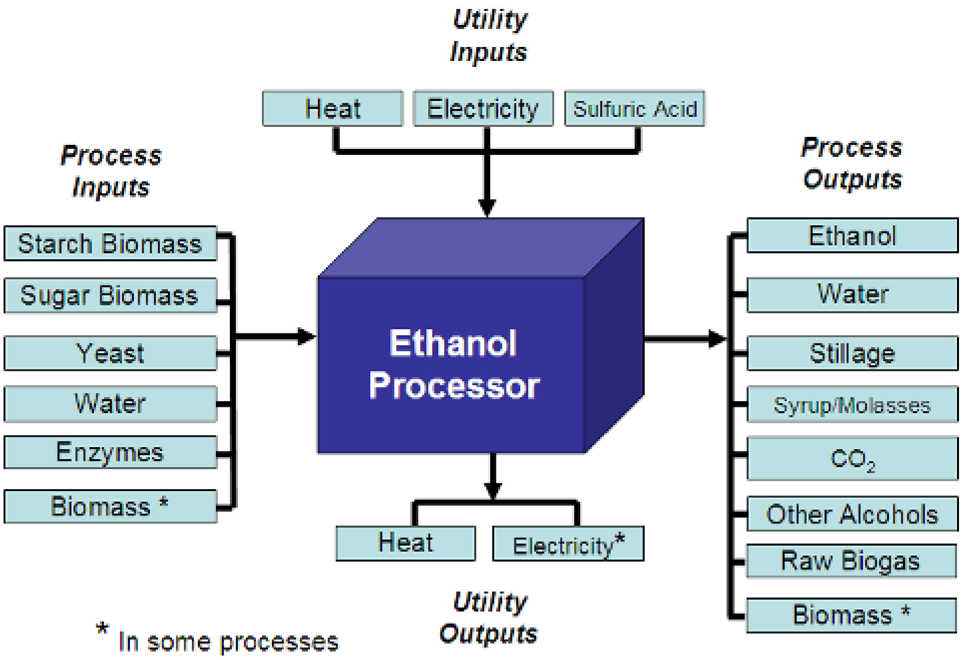

Figure 3: Ethanol Production Diagram
Source: Author

Unlike biodiesel and biogas production, ethanol production is quite common in many cultures in the form of alcohol production using a variety of raw materials. Fuel ethanol production is quite different in general however, but the fermentation of sugars and materials rich in starch is essentially the same.

Ethanol production is quite unique on a global perspective. European ethanol is produced using cereal and sugar beets, American ethanol with corn, beets and cereals and that produced in tropical regions with sugarcane and other sugar rich plants. Using yeast, water and enzymes the sugars and starch are broken down into simple sugars, which are then transformed into alcohol and carbon dioxide through fermentation. To optimize the process, heat, electricity and a number of other controlling substances are added. Outputs from the ethanol plant include, naturally ethanol, water, stillage, syrup, molasses, carbon dioxide, biomass and other alcohol. Figure 3 above displays a review of a typical ethanol production process. (IEA, 2005)

5 Methodology

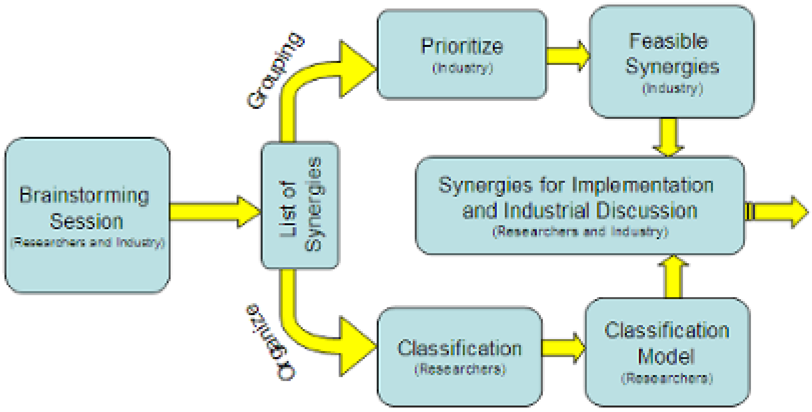

Figure 4: Methodology Diagram
Source: Author

5.1 Biofuel Synergies Workshop

An aim of Phase 1 in the biofuel synergies research is to identify and work with industries to produce relevant and realizable synergies. Therefore a reference group of industrial actors from relevant biofuel industries has been established as a forum to discuss, discover and implement synergies and innovative approaches to production. Actors from the biofuels reference group and researchers from academia collaborated in a brainstorming event to identify possibilities for synergies within the biofuel industry and with external industries.

It was important that a mix of individuals were present in order to build a lively discussion and a broad range of synergies. Participants were invited from a number of disciplines, and the following list of participants shows a range of expertise in everything from sales and research to process engineering and management of the industrial sites.

The following participants attended the event from academia and industrial partners:

Academia Participants:
Professor- Linköping University
Post-Doc- Linköping University
PhD Candidate- Linköping University
PhD Candidate- Linköping University

Industry Participants:
Local Manager- Ethanol Production Industry
Process Engineer- Ethanol Production Industry
Sales Support Manager- Biodiesel Production Machinery Supplier
Laboratory Manager- Biodiesel Production Machinery Supplier
Process Engineer- Biogas Production Industry/Utilities Supplier

Using post-it-notes, attendees were asked to brainstorm possible synergies with other biofuel actors, external actors and elaborate on surplus and demands of materials and energy within their own processes and beyond. The questions elaborated upon were as follows:

- Which other inputs are available for use in your own processes and where can they come from? This can be energy or material inputs.
- Which products could increase as a result of subsequent markets for your by-products? What markets are there for these? These can be energy or materials.

Once the brainstorming and notes were completed, the facilitator began assembling the suggested synergies from each participant. It was thereafter apparent that many of the synergies could be split based on subjects, and thus arranged on the whiteboard in subject areas. Discussions and explanations from individuals regarding their choice and reasoning from these notes were highly valuable and were audio recorded with the consent of the participants.

The meeting thus produced a wide array of possibilities for the future, as well as information on the feasibility by industrial actors for many of the synergies created. The list of synergies produced from the session can be found in later sections of this report.

Figure 5: Brainstorming Post-It Notes Grouped
Source: Author

Classification of synergies produced at a brainstorming event became apparent once discussions and review of the extent and content related to each respective synergy was needed. Thereafter, it was decided that the synergies would be classified in terms of their interaction with industries, i.e. between biofuel actors and external industries based on the theories of industrial symbiosis. Moreover, each synergy encompasses a respective origin and destination, and these should be identified during the classification. The following sections thus aim at identifying the classification in more detail.

5.2 Industry Collaboration Classification

Different classes of synergies exist from those produced at the brainstorming session. These can thereafter be classed with respect to their interaction within and outside of the biofuel production industries. Moreover, 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 as such, the respective synergies will subsequently have their courses routed, i.e. concerning where the synergies originate and are destined to conclude.

5.2.1 Biofuel Production Synergies

Flows of goods, materials and services between biofuel industries are classified as a, *Biofuel to Biofuel Production Synergies (Biofuel↔Biofuel Synergy)* . Specifically, this classification defines synergies which deal directly with the use of services, 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. Many processes exist inside biofuel production facilities that are employed to better the process or support subsequent processing, etc.

Examples of biofuel production synergies can be as such:

- Flue gas emissions from biogas production industry sent to ethanol production industry for combustion/Odor Control
- Biomass from ethanol production (other than stillage) used for biogas production

5.2.2 Biofuel to External Synergies

Many goods, materials and services produced at biofuel processing industries are desirable in other industries. This is especially true in biofuel production, 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 to External Synergies*.

A few examples of such synergies are as follows:

- Wet Stillage used for Animal Feed Direct (no drying)
- Biogas Digestate used as bio-fertilizer

5.2.3 External to Biofuel Synergies

The aforementioned classification is the direct opposite of the current classification, *External to Biofuel Synergies.* This classification entails goods, materials and services from external industries which are applied as inputs to the biofuel processing 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 becoming important drivers. Moreover, in recent times 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:

- Pelletizer at ethanol production industry employed with digestate from biogas production industry to make biomass pellets for fuel or feed
- Potato Chip/Snack Food WVO used for biodiesel production

5.3 Origin-Destination Classification

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. In order to obtain a better grasp of these flows and give more depth to the synergies, the use of mapping these flows is done by the introduction of the origin and destination of a product/process or utility, described in subsequent text.

These origins and destinations take the form of raw materials for production processes and necessities for controlled and optimal conditions, i.e. respectively processes and utilities. Many attempts to classify synergies and flows in industrial symbiosis have been produced by van Berkel (2006), Wolf (2007) and van Beers (2006). The subsequent definitions have been altered slightly in an attempt to provide a classification which represents the biofuel industry better.

5.3.1 Process/Product

In the production of biofuels, there are many inputs and outputs to the system. These byproducts have recently gained importance for synergies in subsequent biofuel production as well as synergies with other industries. Work produced by van Berkel (2006), Altham et al. (2004) and Bossilkov et al (2005) have taken synergies developed from the direct employment of by-products and labeled these as “by-product synergies.” Interestingly, there is some debate on this labeling, as by-products can be classified as a by-product synergy, yet also be a primary energy carrier, thus classified by another 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 to in this report. Biofuels, and products are are directly related to the core business of producing them will be referred to as biofuel *products.*

“Product” in this case 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 simply to better the process. If byproducts and synergies with these byproducts do not involve the core concern of biofuel production at a particular biofuel actor, they shall be classified subsequently as a “utility.”

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

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

5.3.2 Utilities

The following classification goes 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. *Utilities* in this report shall be classified as those previously mentioned, but additionally 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 generally this will be classified as a utility.

Examples of the *utility* classification are as follows:

- Waste heat from ethanol fermentation process
- Waste water from biodiesel cleaning process

5.3.3 Classification Example: Biodiesel Classification

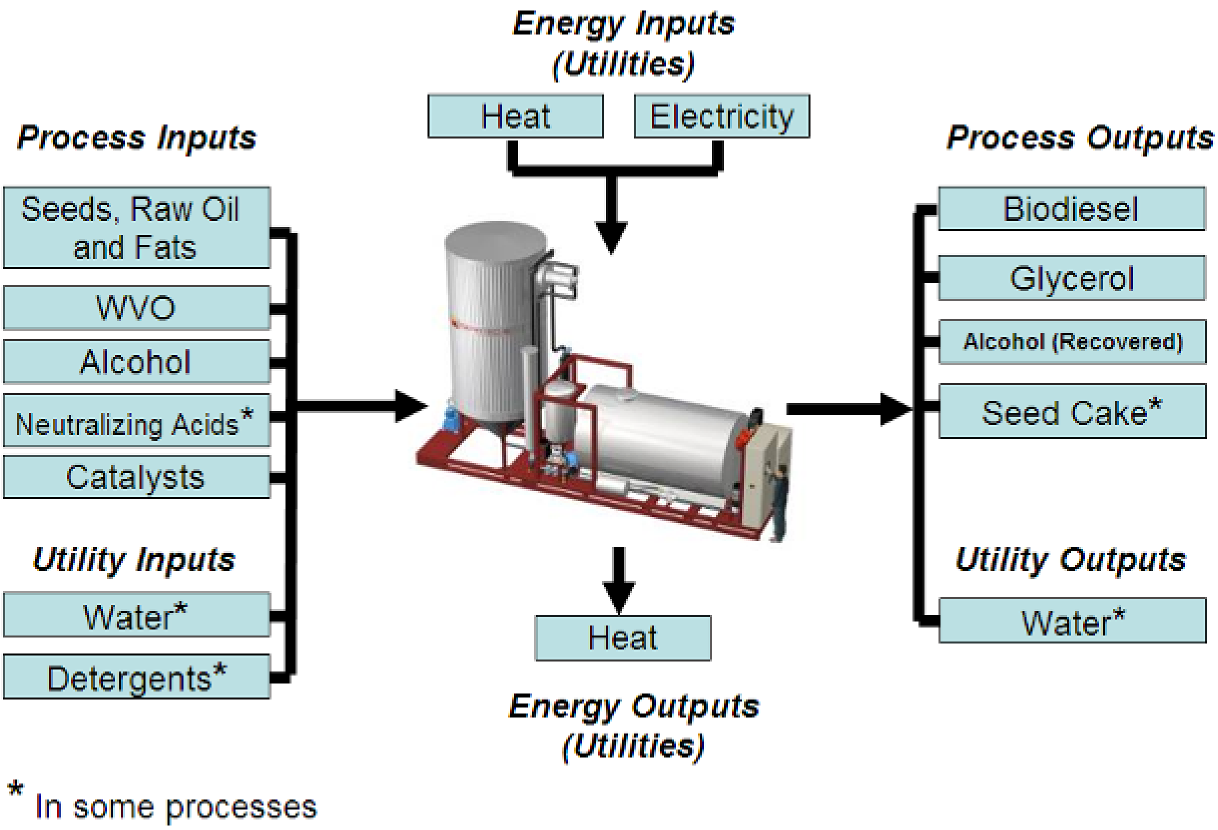

Figure 6: Biodiesel Process Overview
Source: Author

Figure 1 above depicts the inputs and outputs to a small scale biodiesel production process using an Ageratec AB processing unit. Some inputs and outputs are general, and occur in many common processes, but not particularly in this case; they are thus marked with a (*)

symbol. For this process unit, water is not used for cleaning biodiesel and detergents are used in their stead. Moreover if waste vegetable oil is used, many times neutralizing acids are used to lower the free fatty acid content of the biodiesel and thus produce high quality biodiesel, and not soap. (Ageratec, 2008) The key raw materials in this process are the fats and oils, which can be derived from a number of sources i.e. those labeled "Seeds, Raw Oil and Fats" and "WVO-Waste Vegetable Oil."

From the figure, the core materials and inputs can be seen under the heading *process inputs.* Thereafter energy and other utilities are listed under the *utilities* headings; both utility and energy inputs are classified as utility inputs for this particular case. The process inputs, once again, are those needed to carry out the transesterification process, with the main outputs being the process outputs. Utility inputs and outputs are important, but vary between biofuel production processes and are not involved directly with the core process here, i.e. transesterification.

6 Classification Models

The following sections help to define the classifications outlined in previous text as applied to the synergies produced for biofuel and external synergies. First off, a classification method to define synergies with a symbol representation based on their characteristics is presented based on the preceding text and terminology. Thereafter, a representation of the biodiesel production process flows is reexamined to develop upon classification terminology from preceding text for further clarification.

6.1 Classification Model

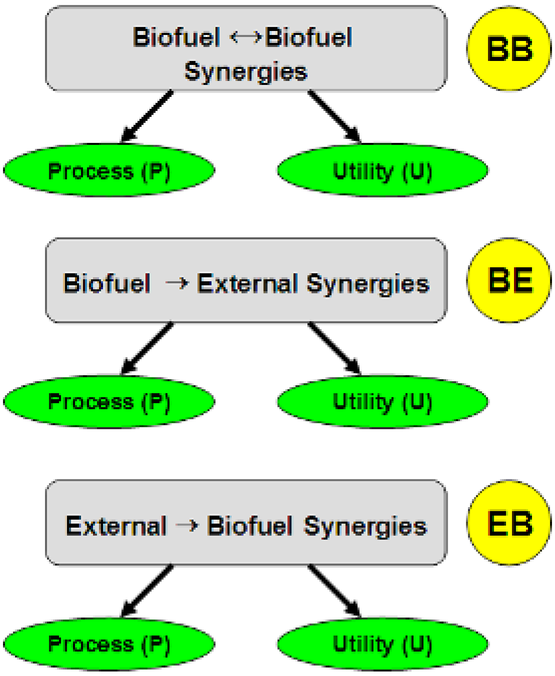

Figure 7: Classification Notation Model
Source: Author

Above, Figure 6 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 biofuel and external industries respectively , will be attached to the relative industry collaboration, and combined with the resource input and output classifications, i.e. Ps and Us, 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
- BE- An interaction between biofuel to external industries
- EB- An interaction between external industries to biofuel industries.

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. The following text portrays a classification example for further clarification.

6.2 Classification Examples

In succeeding sections the synergies will be classified with symbols in order represent the type and flow for each synergy. The following two synergies are used as examples for explanatory purposes, and more detail into the classification for each number and letter will be explored respectively.

6.2.1 Waste Water Treatment gas at Ethanol production industry for Biogas upgrading (*BP-UP*)

Ethanol production industries in many countries use water to mix with cereals in the fermentation reaction to ultimately produce ethanol. In the process, a large portion of the water is recycled in the waste water treatment facilities within the industrial site. As this water contains organic material, during the treatment it produces gases, i.e. methane and carbon dioxide. The current amount of gas produced is unknown, though the throughput of ethanol and production volumes at many ethanol industries are expanding, thus the potential for this gas is also increased. Moreover, this raw gas could be trapped and thus sent to biogas production facilities for upgrading to vehicle fuel or cleaning.

A synergy is thus created between ethanol and biogas producers. This type of synergy is classified as a *Biofuel Production Synergy*, due to the fact that it occurs between the biofuel industries and therefore this gives it a “**BB**” for the synergy type. Gas production at ethanol facilities is not part of the core business, and is a side effect of the waste water treatment plant. The origin of this synergy is thus classed as a utility, by a “**U**.” Thereafter, the destination of this synergy is that of a product for biogas producers. A major concern at biofuel production facilities is upgrading the raw gas produced for vehicle fuel, thus this raw gas from ethanol producers can be classified as a product/process. Finally the synergy can be wholly classified as a **BB-UP** type of synergy.

6.2.2 Potato Chip Factory 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 shear magnitude of supplies, very interesting for biodiesel production. It is natural therefore to produce a synergy with snack food companies. This synergy can therefore be labeled as coming from an external industry and being applied to a biofuel company, i.e. a *External → Biofuel Synergy*. The corresponding classification comes with a "**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 a "**EB-PP**" synergy.

6.3 Synergy Classification

Based on preceding terminology and theories, the symbolization methods for the synergies were thereafter applied. Each synergy is thus represented with its symbolization in order to classify its origin, destination and nature of its interaction with other biofuel industries and external industries.

Table 1 below represents the synergies classified with symbol notation.

Table 1: Synergies Classified by Symbol Notation
Source: Author

Biofuel ↔ Biofuel Synergies	
Synergy Description	**Classification**
Exhaust emissions from Biogas Producer sent to Ethanol Producer for combustion/Odor Control	BB-UU
Sulfur is a bad input for biogas production. Need a better way to control pH at Ethanol Producer. Biogas Producer prefers Nitrogen instead of Sulphur	**BB-UP**[1]
Biogas used for electricity production for biodiesel production	BB-PU
Refine the digestate to extract fatty acids and phosphor	BB-PU
Gas produced at Ethanol Producer - Sent to Biogas Producer for upgrading	BB-UP
Gas produced at Ethanol Producer - Used for odor control/combustion process	BB-UU
Exhaust emissions from Ethanol Producer used to dry biogas digestate	BB-UU
Fusil/Other Alcohols from Ethanol Still used for biodiesel production	BB-PP

[1] This particular synergy is labeled with a red classification. It is done so to identify its nature as a "contra-synergy as described in subsequent text.

Ethanol used for Biodiesel Production	BB-PP
Oil from Wheat/Corn/Other starch crops for ethanol, pressed, oil expelled and used for biodiesel before crops sent for fermentation to ethanol	BB-PP
Pelletizer at Ethanol Producer employed with Digestate from Biogas Producer to make biomass pellets for fuel or feed	BB-UU
Biomass from ethanol production (other than stillage) used for biogas production	BB-PP
Use stillage for biogas production only	BB-PP
Glycerol produced from biodiesel production for biogas production	BB-PP
Glycerol (Biodiesel by-product) + Fatty Acids (Biogas by-product) used for creation of monoglycerides --> More Biodiesel Feedstock	BB-PP
Seed cake and shells from biodiesel processing could contain starch and thus make ethanol	BB-PP
C02 used for algae production --> Biofuel Production	BB-UP
CO2 from production, used for production	BB-PU
Waste heat from ethanol and biogas facilities used in biodiesel production	BB-UP
Pinch Analysis for possible excess heat & cooling (Biorefinery/Cooperation)	BB-/ BE-UU
Waste heat from ethanol production used for pre-heating of materials	BB-UU
Biofuel → External Synergies	
Synergy Description	**Classification**
Digestate and CO2 used as fertilizer/nutrients in greenhouses	BE-PU
Dry digestate and use it as fodder	BE-PP
Digestate used as bio-fertilizer	BE-PU
Separate nutrients in digestate for chemical processing	BE-PU
Gases other than methane and CO2 captured and stored (e.g. H2)	BE-PU
C02/Water from Ethanol production for Algae Production	BE-UP
Wet Stillage used for Animal Feed Direct (no drying)	BE-PP
Dry stillage for biofertilzer	BE-PU
Waste water used for algae cultivation	BE-UP
Use stillage for pellet production (energy)	BE-PU
Glycerol used as binding agent for wood pellets	BE-P-U/P
Glycerol for healthcare and cosmetics industry	BE-PP
Glycerol combusted at other industries for energy	BE-P-U/P
Glycerol from Swedish biodiesel used for "Swedish Eco-Soap"	BE-PP
Glycerol used as a carbon source in biological cleaning steps	BE-PU
C02 trapped from Ethanol, Biogas production for Greenhouses	BE-PU
C02 trapped from Ethanol, Biogas production used for synthetic fuel production	BE-PP
C02 capture at Ethanol and Biogas Plants	BE-UU
Waste water from biodiesel or ethanol production used for Salix production	BE-P/U-P

Waste heat from ethanol, biodiesel and biogas production used in swimming pools/swim halls	BE-UP
Waste heat from ethanol, biodiesel and biogas used in nearby greenhouses	BE-UP
Build an animal (pig) farm close to Ethanol Producer and use stillage for fodder	BE-PP
Biofuel → External Synergies	
Synergy Description	**Classification**
Other fatty acids for biodiesel production, MeOH, Prop-OH, etc	EB-PP
Potato Chip/Snack Food WVO used for biodiesel production	EB-PP
Potato Chip/Snack Food by-products (organic) used for biogas production	EB-PP
Potato Chip/Snack Food by-products (Potato Skins) used for ethanol production	EB-PP
Animal fats from slaughtering at nearby farm used for biodiesel	EB-PP
Animal Wastes from farm used for biogas production	EB-PP
Algae used for oil press, oil extracted for biodiesel production	EB-UP
Algae used for oil press, oil extracted for biodiesel production, algae then used for later ethanol fermentation and subsequent biogas processes	EB-UP
Synthetic diesel Production produces alcohol as a by-product, this can be used for biodiesel production or biogas production	EB-PP
Norrköpings Fett, possible collaboration for biodiesel production	EB-PP
Use fat separators from car washes, restaurants, etc for biodiesel production (if quality is low, for biogas production)	EB-PP
Flour production must separate all oil in flour to increase shelf-life. Used for biodiesel.	EB-PP
Algae from Baltic used for biogas production (Basically a free raw material)	EB-UP
Household wastes for biogas production (organic material --> Biogas)	EB-UP
Household wastes for ethanol production (fruits, shells, etc. --> ethanol production)	EB-UP
Other industries with WVO --> Biodiesel	EB-PP

7 Brainstorming Session Results

Table A of Appendix A shows the extent of synergies produced during the brainstorming session. Descriptions of each synergy are given along with the number of times they were suggested during the session by participants. Together with Table 1 above, these results will be presented as well as an analysis in the following text.

In retrospect many synergies between biofuels industries and other industries have been identified. Table 4, below shows a representation of the quantity of these synergies with respect to the relative quantity in each type of synergy, as well as the quantity originating from processes, utilities and destined for further processes or utilities. In some cases synergies have been counted twice, e.g. a synergy with the classification BE-P/U-P can be classified with an origin of either a product or service depending upon the context. The following sections provide an analysis of the results based on categories and the magnitude of synergies encompassed.

7.1 Source of Synergy Ideas

Table A of Appendix A describes the source of the synergy production, i.e. whether they were developed by researchers (R) or industry (I), as well as those developed during discussions (D) of other synergies are noted with respective letters to identify their origin. Table 2 below shows the number of suggestions for synergies by researchers, industry and those during discussions. In total 67 synergies were suggested, though there were some overlaps which produced 60 total synergies.

Table 2: Synergy suggestions by Researchers, Industry and those developed during discussions
Source: Author

Origin of Suggestions	Research	Industry	Discussion
Total	33	24	10

7.2 Synergy Grading/Potential

Once the synergies were identified, discussed and grouped into subject classes, questions were posed on the participants, in this case only industrial actors, to identify the synergies with the largest potential. This was done by denoting the largest overall potential with a small orange sticker and those synergies with the largest regional potential with blue stickers. Only 4 of the 5 industry participants participated in the final grading. They were each given 3 orange stickers and 3 blue stickers for the grading process.

The following synergies were identified as those with the largest potential from the industrial actors participating in the event.

Table 3: Synergy Grading to Judge the Feasibility and Potential Overall and Regionally
Source: Author

Synergy Description	Largest Potential Overall	Largest Potential in Region
	Number of Votes	
Gas produced at Ethanol Producer - Sent to Biogas Producer for upgrading		2
Gas produced at Ethanol producer - Used for odor control/combustion process	1	2
Fusil/Other Alcohols from Ethanol Still used for biodiesel production	1	2
Oil from Wheat/Corn/Other starch crops for ethanol, pressed, oil expelled and used for biodiesel before crops sent for fermentation to ethanol	2	1
Dry stillage for biofertilzer	3	
Waste water used for algae cultivation		1
C02 capture at Ethanol and Biogas Plants (Combined)	1	1
C02 used for algae production --> Biofuel Production	1	
CO2 from production, used for production	3	
Pinch Analysis for possible excess heat & cooling (Biorefinery/Cooperation)	1	2
Use fat separators from car washes, restaurants, etc for biodiesel production (if quality is low, for biogas production)	1	
Household wastes for ethanol production (fruits, shells, etc. --> ethanol production)	1	

7.3 Biofuel Industry Synergies and Cooperation with External Industries

Biofuel actor/production synergies have been identified by a number of participants at the brainstorming session. Interestingly, a large number of these synergies have been identified directly between biofuel processes or utilities. Process interactions between biofuels produced 8 synergies, while those between biofuel utilities produced 6. Three synergies were identified, originating as a utility from one biofuel industry which can be used as a process/product in the target biofuel industry. Moreover, the largest quantity of synergies was found to be apparent between biofuel industries and external industries. The total number of synergies between biofuel industries comes out at 22 out of 62 possible synergies, again a few extra due to overlapping partnerships. Those synergies between biofuel industries and external industries, and vice versa, total 40.

Table 4: Synergies Quantified
Source: Author

	Origin-Destination Classification				
Type of Synergy	***PP***	***PU***	***UP***	***UU***	**Total**
Biofuel Production Synergies (BB)	8	4	4	6	22
Biofuel to External Synergies (BE)	8	12	3	2	25
External to Biofuel Synergies (EB)	11	0	5	0	16
Totals	27	16	12	8	

8 Analysis of Synergies Results

8.1 Synergies Between Industries

As the underlying goal of the project is to identify synergies and industrial symbiosis options between biofuel actors, it is fascinating to view Table 4 as an indicator of possible synergies. It is quite apparent that more synergies were identified between biofuel and external industries than those directly between the biofuel industries. Why is this the case however?

Inputs and outputs into the biofuel industries, although abundant, are quite limited in regards to other material and energy flows from external industries. Moreover, external industries and speaking of synergies to use wastes offers an eye-opening view of the potential for biofuel industries. Simply by viewing the synergies listed, one can see that a large imaginative effort was provided for the use of wastes and energy streams from external sources. These were thus labeled as essentially “free” raw materials and could benefit the biofuel industries to a larger extent than they could through cooperation.

However, the synergies between the biofuel industries are not overlooked or even disregarded. By viewing the synergies which the biofuel industry actors viewed as having the most potential, nearly half of these synergies are direct biofuel to biofuel synergies. This thus shows that industrial symbiosis is accepted and applicable in this area. There also seems to be much enthusiasm between the companies in regards to cooperation and making use of their wastes between each other which could help their view, essentially benefiting their marketing potential.

8.2 Product and Utility Synergy Trends

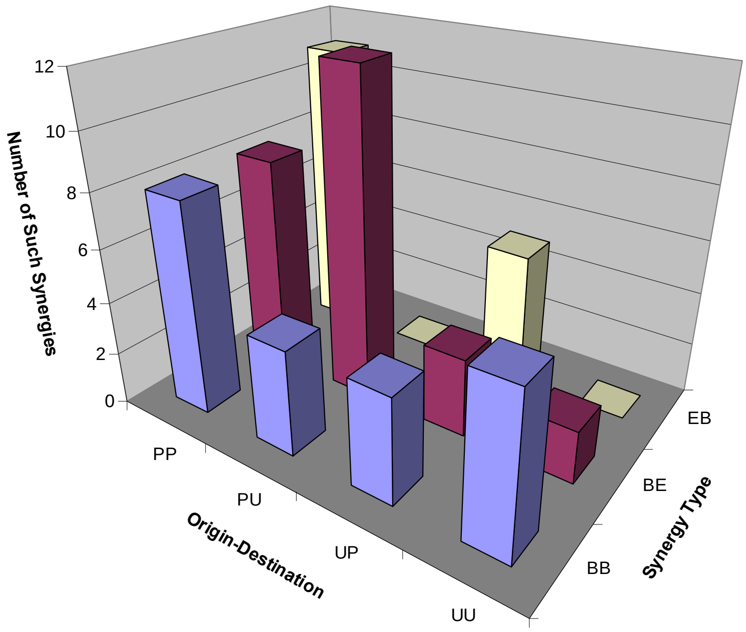

Figure 8: Synergies Quantified Visually
Source: Author

Figure 8 above shows another representation of Table 4. In this table it is apparent that the largest number of biofuel synergies occurs with origination and destination as a product process. It is quite interesting to point that the largest proportion of synergies is those between biofuel actors. Thereafter a slight trend is apparent where there are a total of 27 synergies which originate and are delivered from one process to another, i.e. starting as a product/process and destined as a product/process between biofuel and external industries. Moreover, those synergies coming from a process/product and ending as a utility for the target industry amount to 16 synergies. Synergies originating as a utility and ending as a process input are a bit lower, 12 synergies. Finally, synergies which originate as a utility and end as a utility input amount to 8 synergies.

It seems that during this brainstorming session, products and processes were given more thought than utilities. But why? In this case, it could be pointed out that the participants were posed with the questions on their material and energy use and excess, and how these would correlate between biofuel and external industries. Having a regional focus in the original question seemed to have levied the participants to choose material flows over energy flows.

In the case of these industries, the bioethanol and biogas process are attached to a neighboring utility provider for both electricity and steam, thus utilities could have been excluded in thinking regionally. However some utility sharing is also shown, and it is proven for the case of biodiesel production, in which several synergies were identified in which energy from one process is used for biodiesel.

8.3 Contra-Synergy

Interestingly, a synergy concerning ethanol production and biogas production with regards to pH control for stillage at the ethanol plant destined for biogas input can be classified as a *Contra-Synergy.* This originates from the fact that there is a synergy currently in place; in a process where the biogas processor digests the stillage from an ethanol industry to produce methane. However, the interests of ethanol production are to use sulfuric acid as a means to control pH levels, while this disturbs the processes at the biogas processor and they therefore wish for more nitrogen used in its stead. Such a "synergy" exists curiously, and the solution to this is not, and possibly will not be realized anytime in the near future due to the economic issues with acids.

9 Conclusions

Upon completion of the synergies session with the reference group, much was learned from the industrial and academic participants. The brainstorming workshop approach generated a wide variety of ideas; above all the chance to have participants write their ideas and then discuss these ideas generated several very important synergies which will be very relevant to several industries in the near future. Thereafter, the session gave participants a better understanding of processes of further industries as well as a chance to meet each other on a personal level. This has thus resulted in a number of subsequent contacts between the industries and further synergies being discussed.

Scientifically this activity has resulted in an approach toward the generation of innovative synergies between biofuel industries and external industries. Listing the synergies produced trends, and thus a categorization model being produced. This categorization method is useful for future synergies research, and is adapted toward an improved understanding of the synergies. Furthermore, categorization and presentation of the synergies and idea generation produce important issues for implementation of synergies, not only academically but also at the production sites themselves. Finally, the production of possible synergies opens for negotiation and dialogues between the industrial actors to implement ideas for improved environmental and economical benefits.

10 References

Ageratec, 2008. Personal Communication with Ageratec AB, Norrköping.

Althman, J. & van Berkel, R., 2004. Industrial Symbiosis for Regional Sustainability, an update on Australian initiatives. 10th International Sustainable Development Research Conference, Manchester, UK, ERP Environment.

Ayres, R.U. & Ayres, L.W., 2002. A handbook of industrial ecology. Edward Elgar, Cheltenham, U.K.

Bosilkov, A. et al., 2007. Regional synergies in the Australian minerals industry: Case-studies and enabling tools. Minerals Engineering, Vol. 20, Issue 9, August 2007, Pages 830-841.

Börjesson, P., 2007. Environmental effects of energy crop cultivation in Sweden—II: Economic valuation. Biomass and Bioenergy, Volume 16, Issue 2, February 1999, Pages 155-170.

Börjesson, P. & Mattiasson, B., 2007. Biogas as a resource-efficient vehicle fuel Trends in Biotechnology, Volume 26, Issue 1, January 2008, Pages 7-13.

Börjesson, P., 2007. Förädling och avsättning av jordbruksbaserade biobränslen. (Swedish: Processing and marketing farm-based biofuels) IMES/EESS Rapport nr 62, Miljö- och energisystem, Lund, Sweden.

Börjesson, P., 2007. Resource Efficiency and Biofuels: Clean Vehicles and Fuels. Presentation: 8 November 2007, Stockholm.

Chertow, M.R., 2000. Industrial Symbiosis: Literature and Taxonomy. Annual Review of Energy and the Environment 25: 313-337.

Garner, A. & Keoleian, G., 2000. Industrial Ecology: An Introduction. University of Michigan School of Natural Resources and Environment.

Heeres, R.R. et al., 2004. Eco-Industrial park initiatives in the USA and Netherlands: First Lessons. Journal of Cleaner Production, Volume 12, Issues 8-10, October-December 2004, Pages 985-995.

IEA, 2005. Biofuels for Transport : An International Perspective. Organization for Economic Co-operation and Development (OECD) and International Energy Agency (IEA).

Mittelbach, M. & Remschmidt, C., 2006. Biodiesel - A comprehensive handbook. Martin Mittelbach.

Svensk Biogas, 2008. Svensk Biogas i Linköping AB, Homepage. [Online] Available: www.svenskbiogas.se [Accessed: 14 September 2008]

van Berkel, R., 2007. Regional Resource Synergies for Sustainable Development in Heavy Industrial Areas: An Overview of Issues and Opportunities. Chapter 2.

Wolf, A., 2007. Industrial Symbiosis in the Swedish Forest Industry. PhD Disertation: Linköping Studies in Science and Technology, Dissertation No. 1131. Division of Energy Systems, Department of Mechanical Engineering, Linköping Institute of Technology, SE-581 83 Linköping, Sweden, 2007.

Appendix

Table A: List of Synergies including the frequency and Origin of Development
Source: Author

Synergies Grouped		
Synergy Description	**Number of Suggestions**	**Researcher (R), Industry (I) or Discussion (D)**
Exhaust emissions from Biogas Producer sent to Ethanol Producer for combustion/Odor Control	1	D
Sulphur is a bad input for biogas production. Need a better way to control pH at Ethanol Producer. Biogas Producer prefers Nitrogen instead of Sulphur	1	I
Digestate and CO2 used as fertilizer/nutrients in greenhouses	3	I/ R (2)
Dry digestate and use it as fodder	1	I
Digestate used as bio-fertilizer	1	I
Separate nutrients in digestate for chemical processing	1	R
Gases other than methane and CO2 captured and stored (e.g. H2)	1	R
Biogas used for electricity production for biodiesel production	1	I
Refine the digestate to extract fatty acids and phosphur	2	I/R
Biogas production produces NH4-N. Ethanol needs Urea. If the digestate is refined, there could be a "clean source" of concentrated NH4	1	I
Gas produced at Ethanol Producer - Sent to Biogas Producer for upgrading	2	I
Gas produced at Ethanol Producer - Used for odor control/combustion process	1	I
Exhaust emissions from Ethanol Producer used to dry biogas digestate	1	R
Fusil/Other Alcohols from Ethanol Still used for biodiesel production	1	I
Ethanol used for Biodiesel Production	1	D

Oil from Wheat/Corn/Other starch crops for ethanol, pressed, oil expelled and used for biodiesel before crops sent for fermentation to ethanol	1	R
Pelletizer at Ethanol Producer employed with Digestate from Biogas Producer to make biomass pellets for fuel or feed	1	D
C02/Water from Ethanol production for Algae Production	1	R
Wet Stillage used for Animal Feed Direct (no drying)	1	R
Biomass from ethanol production (other than stillage) used for biogas production	2	I/R
Use stillage for biogas production only	1	R
Dry stillage for biofertilzer	1	R
Waste water used for algae cultivation	1	R
Use stillage for pellet production (energy)	1	I
Glycerol from biodiesel production for biogas production	1	D
Glycerol (Biodiesel by-product) + Fatty Acids (Biogas by-product) used for creation of monoglycerides --> More Biodiesel Feedstock	1	I
Glycerol used as binding agent for wood pelets	1	I
Glycerol for healthcare and cosmetics industry	1	R
Glycerol combusted at other industries for energy	1	I
Glycerol from Swedish biodiesel used for "Swedish Eco-Soap"	1	R
Glycerol used as a carbon source in biological cleaning steps	1	I
Other fatty acids for biodiesel production, MeOH, Prop-OH, etc	1	I
Seed cake and shells from biodiesel processing could contain starch and thus make ethanol	1	R
C02 trapped from Ethanol, Biogas production for Greenhouses	4	I (2)/R (2)
C02 trapped from Ethanol, Biogas production used for synthetic fuel production	1	R
C02 capture at Ethanol and Biogas Plants (Combined)	1	I
C02 used for algae production --> Biofuel Production	2	R
CO2 from production, used for production	1	I

Waste heat from ethanol and biogas facilities used in biodiesel production	1	D
Waste water from biodiesel or ethanol production used for Salix production	1	R
Waste heat from ethanol, biodiesel and biogas production used in swimming pools/swim halls	1	R
Waste heat from ethanol, biodiesel and biogas used in nearby greenhouses	1	R
Pinch Analysis for possible excess heat & cooling (Biorefinery/Cooperation)	2	I/R
Waste heat from ethanol production used for pre-heating of materials	1	I
Pototo Chip/Snack Food WVO used for biodiesel production	1	R
Pototo Chip/Snack Food by-products (organic) used for biogas production	1	R
Pototo Chip/Snack Food by-products (Potato Skins) used for ethanol production	1	R
Build an animal (pig) farm close to Ethanol Producer and use stillage for fodder	1	R/D
Animal fats from slaughtering at nearby farm used for biodiesel	1	R
Animal Wastes from farm used for biogas production	1	R
Algae used for oil press, oil extracted for biodiesel production	1	I
Algae used for oil press, oil extracted for biodiesel production, algae then used for later ethanol fermentation and subsequent biogas processes	1	R
Synthetic diesel Production produces alcohol as a by-product, this can be used for biodiesel production or biogas production	1	D
Norrköpings Fett, possible collaboration for biodiesel production	1	D
Use fat separators from car washes, restaurants, etc for biodiesel production (if quality is low, for biogas production)	1	R
Flour production must separate all oil in flour to increase shelf-life. Used for biodiesel.	1	D
Algae from Baltic used for biogas production (Basically a free raw material)	1	R
Household wastes for biogas production (organic material --> Biogas)	1	R

Household wastes for ethanol production (fruits, shells, etc. --> ethanol production)	1	R
Other industries with WVO --> Biodiesel	1	D