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Industrial Ecology Analysis of the Potential for an Eastern Nebraska Industrial Symbiosis Network (ENISN): A Comparative Study

Bradley A. Behne
University of Nebraska-Lincoln, bbehne@huskers.unl.edu

INDUSTRIAL ECOLOGY ANALYSIS OF THE POTENTIAL FOR AN EASTERN NEBRASKA INDUSTRIAL SYMBIOSIS NETWORK (ENISN): A COMPARATIVE STUDY

by

Bradley A. Behne

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Bradley A. Behne, M.S.

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Advisor: Mark E. Burbach

The area of Eastern Nebraska north of Omaha, including the municipality of Blair is host to a collection of unique companies and industries. These industries, driven by the agricultural and urban economy of the area, as well as the geographic proximity to each other, make it an advantageous area to study the potential for a network where individual entities utilize the concept of industrial symbiosis. This potential network is referred to as the Eastern Nebraska Industrial Symbiosis Network (ENISN). Industrial symbiosis, a sub-set of industrial ecology, engages separate industries in a collaborative and collective approach, concerning itself with the flow of materials and energy, water, and/or by-products between each other. The outcome of industrial symbiosis is advantageous to not only the companies, but to the environment as well. The incorporation of ecological economic principles are at the core of industrial symbiosis. A "circular-economy" invites a more sustainable approach where efficient allocation of resources and a philosophy of an end to growth, drive this unique economy that differs from the traditional neoclassical style.

This study compares the potential of an ENISN with the existing Kalundborg Symbiosis in Kalundborg, Denmark, a long established example of industrial ecology and the use of an eco-industrial network where the by-product of one enterprise is used as a

resource by another enterprise, in a closed cycle. Industrial symbiosis is a collaboration where public and private enterprises buy and sell residual products, resulting in mutual economic and environmental benefits.

The results of this study indicate the ENISN study site has the potential for an industrial symbiosis site. The analysis of material flows and inductive themes derived from interviews with potential partners revealed the presence of collaboration and environmental stewardship. The results of the study suggest that the human capital exists to make an ENISN; however, the impetus to take on the challenging ontological barriers remains to be seen.

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Abbreviations

ENISN	The hypothetical potential network in the study area is referred to as the Eastern Nebraska Industrial Symbiosis Network.
EID	Eco-Industrial Development
EIP	Eco-Industrial Park
EIN	Eco-Industrial Network
EMS	Environmental Management Systems
IE	Industrial Ecology
IS	Industrial Symbiosis
ISIE	International Society for Industrial Ecology
OTF	Over-the-fence (customers)
TBL	Triple Bottom Line
SCM	Six Capitals Model
WWTP	Wastewater Treatment Plant

Definitions

Circular Economy: A holistic economic concept which seeks efficiency in resource use through the integration of cleaner production and industrial ecology into a broader system encompassing industrial firms, networks or chains of firms, eco-industrial parks, and regional infrastructure to support resource optimization. State owned and private enterprises, government and private infrastructure, and consumers all have a role in achieving the Circular Economy (Koenig, 2009).

Industrial Symbiosis: Describes the co-existence between diverse organisms in which each may benefit from the other. Industrial Symbiosis was first applied for the industrial co-operation that has evolved between companies and the municipality of Kalundborg in Denmark, all of which exploit each other‘s residual or by-products (Koenig, 2009).

Eco-Industrial Park: A community of manufacturing and service businesses located together on a common property. Members seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues (Koenig, 2009).

Eco-Industrial Development: An integrated system of shared resources (material, knowledge-based, social, etc,) among industries, businesses, and the local community that lead to economic gains, enhanced environmental quality, and improved human resources for the business and local community (Koenig, 2009).

Eco-Industrial Network: A set of companies in a region seeking to improve their environmental, social, and economic performance through collaboration. An EIN may include industrial parks and their companies and be supported by public sector organizations. An Eco-Industrial Network provides the context in which industrial parks and stand-alone factories can practice (Koenig, 2009).

Industrial Ecology: The science that examines the impact of industry and technology and associated changes in society and the economy on the biophysical environment. It examines local, regional and global uses and flows of materials and energy in products, processes, industrial sectors and economies and focuses on the potential role of industry in reducing environmental burdens throughout the product life cycle (Koenig, 2009).

Stakeholders: Individuals and groups affecting, and/or affected by the policies, decisions, and actions of the system at any level of society and at any level of organization (Koenig, 2009).

Sustainable Development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (Brundtland Report of the World Commission on Environment and Development, Koenig 2009)

International Society for Industrial Ecology: An international society with the aim of promoting the development and application of industrial ecology. Founded in January 2000 at the New York Academy of Sciences in a meeting devoted to industrial ecology attended by experts from diverse fields. The society formally opened its doors to membership in February 2001.

Chapter 1

Introduction

1.1 Background of Problem

Over the past one-hundred years, humankind has experienced the most impressive population and urban civilization booms the world has ever known. This unprecedented growth in our society affects many aspects of the environment, including the consumption of natural resources. Only 3% percent of the world's population lived in cities in 1800, 13% percent in 1900, and 50% today. One of the problems that arises from this urban and population shift concerns natural resource conservation and sustainability as it effects consumption of resources on a global scale.

Industrial ecology is an idea that has gained popularity in the last few decades but one that continues to face many challenges, specifically with implementation and the ability to be economically sound. Industrial ecology's main focus attempts to move industrial processes from linear "open loop" systems, where wastes leave the system, to a closed loop system where wastes are reused as inputs, often referred to as "industrial symbiosis". The city of Kalundborg, Denmark and industry in the surrounding area provides the best example of industrial symbiosis. The main issue with an open loop system is what is referred to as the "extract-and-dump" nature of many industrial systems. Natural resources are extracted, manufactured, used, and finally dumped in a continuous flow into and out of the open loop economy (Gertler, 1993). It is simple logic that this process cannot last indefinitely since earth's finite resources and the inability to integrate human pollution will eventually reach its natural limits with adverse potential consequences. While it is disputable when, if, and how this will happen, many are beginning to agree that a more sustainable form of industrial activity is required, one that can lessen the environmental load we are putting on the earth. This new standard of industrial symbiosis could also provide insights into other methods of closed loop technologies used in everyday urban living.

1.2 Objectives of Analysis

The general objective of this study is to analyze and evaluate the existing relationships and potential, for an industrial symbiosis network, eastern Nebraska near the city of Blair. Pre-selected “partners” within this area were studied for inclusion in this network. This study will utilize one of the best known and already successful “real-world” industrial symbiosis models, found in Kalundborg, Denmark, as a basis for comparison. The name given to this local hypothetical network, is the Eastern Nebraska Industrial Symbiosis Network (ENISN).

The specific objectives include the following:

1. Develop an existing material flow analysis in order to gain a better understanding of the material flow on the site.

2. Explore the existing environmental, economic, and social circumstances through qualitative research of the study area location near Blair, Nebraska, including collaboration and the synergistic possibilities offered by geographic proximity.

3. Investigate the ontologies of industrial symbiosis, specifically analyzing the successful system used in Kalundborg, Denmark, what are the reasons for its success, and what ontologies exist in the study area.

4. Discuss comparisons between the Kalundborg model and the proposed Blair study area and create similarities and differences to better understand the potential of an ENISN through environmental planning.

1.2.1 Research Questions

The following are principal questions in this study. Is there a potential or even partial industrial symbiotic relationship between the existing industries and other entities in the study area to begin the conversation of an ENISN? Are there environmental, social, and economic conditions including those involving networking, collaboration, and similar attitudes that provide evidence to suggest the possibility of an ENISN? Who are ontologically framing the industrial symbiotic conditions in the area and how are they doing so? As said by Randall Terry (nd), "He who frames the question wins the debate." This study will try to gain an understanding of these relationships and provide a starting point for future analysis.

1.2.2 Limitations

The scope of this study is limited by the depth of information provided by the potential partners in the study area. Depending on each specific situation, some contacts that answered questions in this study were bound by client and proprietary confidentiality based on their own corporate rules and standards of operation. This prevented them from sharing specific quantity and volume numbers that are directly tied to customers and their operations. In addition, another limitation was when a potential partner did not want to conduct follow up phone interviews, meaning the initial emailed survey research information was relied upon. This limited the depth of the research in that specific contact area.

1.2.3 Importance of Study

The importance of this study cannot be understated. The physical impact of current traditional industry practices, encouraged by unrelenting need for natural resources and production of waste, is no longer practical or acceptable on our finite planet. As indicated by Daly and Farley (2004), “there is only so much water, so much land, and so much atmosphere to our planet. We have finite supplies of soils, minerals, and fossil fuels. Even if we argue that natural processes make more soil and fossil fuels, the rate at which they do so is not only finite; it is exceedingly slow from a human perspective” (p. 62). The simple fact is this: infinite resource extraction is impossible on a planet with finite resources.

By investigating the potential industrial symbiotic area in Nebraska, the study will attempt to determine if the location has the necessary combination of qualities to make an industrial symbiosis network function and possibly grow, similar to what currently exists at Kalundborg Symbiosis in Denmark. An Eastern Nebraska Industrial Symbiosis Network (ENISN) will attempt to follow the Kalundborg industrial symbiosis model by addressing both the environmental and economic challenges of natural resource depletion.

Chapter 2

Literature Review

2.1 Ecological Economic Factors

The continual growth of industry and populations in relation to economics and natural resources is a connection that should be analyzed and continually re-examined. The continuous consumption of natural resources by humankind without understanding the consequences on nature's limits is an issue that we as a worldwide society must confront. Ecological economics attempts to form a base of understanding between social sciences, natural sciences, and humanities, utilizing many realities from our modern society to expose the limitations of traditional economics (Daly & Farley, 2004). The current accepted assumptions on finite resources are simply not founded. The unquenchable needs of human population and a belief that there are infinite resources that will lead to growth forever, is a modern thought pattern that lacks a sustainable solution.

2.1.1 Allocation of Resources

The study of economics is the allocation of scarce, limited resources in the middle of many competing ends of two or more available possibilities (Daly & Farley, 2004). Traditional neoclassical economics attempts to perceive the market as the mechanism of allocation, depending on what people want or need. Market transactions disclose what people desire by what goods and services are bought and sold. Ecological economics uses different methods and identifies the market as only one possible process for allocation. Efficient allocation is important, but not the only factor as with neoclassical economics. Ecological economics insists on remaining within "natural limits" that the earth can provide without causing turmoil within its ecosystem. Pollution, declining habitats such as forest or wetlands, and green-house gases are a few components that must be incorporated into the ecological economic market model.

2.1.2 Development Without Growth

One of the more difficult, controversial, and yet the most important characteristics of ecological economics is a realistic end to unsustainable growth. As stated by Daly and Farley (2004), the term "growth" is characterized as an increase in "throughput," which is the flow of natural resources from the environment, through the economy, and back to the environment as waste. The First Law of Thermodynamics states that neither matter nor energy can be either created or destroyed, that throughput is subject to a balanced equation: Input equals output plus accumulation (Daly & Farley, 2004). In addition, the law of entropy, or Second Law of Thermodynamics, discusses the transition of energy and matter from an ordered state to a less ordered and less useful state (Daly & Farley, 2004). This is the description of the natural resource throughput, a linear economy, representing a physical, quantitative, increase in the dimensions of the economy and/or of the waste stream produced by the economy. This kind of growth cannot continue indefinitely, as the Earth and its resources are not infinite (Daly & Farley, 2004).

Ecological economics strives for an end to quantitative growth while promoting the continued development of the economy through qualitative changes. Research into techniques and potential advancement toward better systems will augment the quality of goods, services, and products allowed by a given throughput. The continued development to end growth can only result in a more sustainable future.

The idea of "sustainable development," is development without growth, or qualitative improvement in the ability to satisfy wants (needs and desires) without a quantitative increase in throughput beyond environmental carrying capacity (Daly & Farley, 2004). Carrying capacity is the population of humans that can be sustained by a given ecosystem at a given level of consumption, with a given technology (Daly & Farley, 2004). Limits to growth do not necessarily imply limits to development (Daly & Farley, 2004).

2.1.3 The Basic Market Equation

Economics has been defined as "the study of how humans use scarce resources to fulfill competing objectives" (Desrochers, 1999, p. 20). In order to understand if the Industrial Ecology model connects to the principles of the basic market equation, one must first understand what is being communicated economically within the system and how or if that outcome is sustainable.

The market, driven by its own specific set of spontaneous logic, shapes the lives of millions of people and events on a daily basis. This extraordinary set of processes that comes from the interaction of the supply and demand of goods between entities has an unstructured order. As stated by Daly and Farley (2004, p. 128), determining how this process exists is the basic market equation, which is defined by five definitions and three principles. The five definitions are; first, marginal utility of a good x to consumer n, which is the extra satisfaction one gets from consuming one more unit of the good, other things being equal; second, the market price of good x; third, the market price of factor a or what factors go into the production of the good; fourth, the marginal physical product of factor a when used to make good x, meaning the marginal physical product is the extra output produced as a result of using one more unit of a factor as an input, all other inputs remaining constant; and fifth, a competitive market, which is a market in which there are many small buyers and sellers of an identical product with "many" meaning enough that no single buyer or seller is sufficiently large to affect the market price. The three principles are; first, the law of diminishing marginal utility, where as one consumes successive units of a good, the additional satisfaction decreases so total satisfaction increases; second, the law of diminishing marginal physical product, meaning as a producer adds successive units of a variable factor to a production process, other factors constant, the extra output per unit of the variable factor diminishes with each addition or total output increases at a decreasing rate, sometimes called the law of diminishing returns; and third, the equi-marginal principle of maximization, referred to as the "when to stop" rule meaning when a consumer stops reallocating income among different goods because they have found an allocation that maximizes total satisfaction or total utility (Daly & Farley, 2004).

In the end, the pieces of this intricate market language are important to industrial ecology, and how industrial ecological entities are allocated in relation to each to provide a supply and demand of resources that keep each industry satisfied. As indicated earlier, in the basic market equation industries strive for optimal allocation of resources. Suboptimal allocation means lower profits so industries want to relocate any factor resulting in lower profits to other uses.

It is one issue to analyze the market equation and yet another to see how it works in real life as in Kalundborg. As stated by Jacobsen (2006):

> Kalundborg is a highly differentiated picture of the economic stimuli for the selected industrial ecology exchanges thus appears, stressing the need to understand the context in which the industrial ecology exchanges find their relevance and motivation. In general it can be observed that low-value by-product exchanges are often motivated by indirect economic benefits, where as high-value

> by-product exchanges are often motivated more by direct economic benefits related to the value of the by-product itself. (p. 255)

Jacobsen (2006) continues to describe the intermediate stages within the extremes that move from low-value status to high-value status because upgrading provides more direct economic benefits. He states:

> This sequence is followed by increasing contractual complexity and a tendency toward a redefinition or re-conception of the exchanged materials from waste/by product status to commercial product status. In sum, these findings raise the question of whether industrial ecology relationships can be viewed as solely market-driven arrangements that evolve spontaneously, or whether the initiation of industrial ecology relationships require something beyond pure market forces. (p. 252)

As Jacobsen (2006) points out, the market equation is only a part of a larger extent, an extent that Allenby (2006) discusses as multiple ontologies that the industrial ecology system represents.

2.1.4 A Circular Economy

A "circular economy" is one that provides a restorative base system where materials flow in a balanced system, providing equilibrium between economic development and environmental resource protection. A circular economy also returns any materials back to environment benevolently. All synthetic nutrients in the system remain without entering the biosphere. The circular economy has three basic elements. The first is biomimicry, or the study of the natural environment's best ideas and imitating the designs to be used to solve human problems (Benyus, 1997). It is innovation inspired by nature. The second is industrial ecology, or the study of material and energy flows through industrial systems. And finally the cradle to cradle concept, that all materials involved in industrial processes (either synthetic or biological) are returned to soil without any negative impact to nature, or they remain in a system and flow through industry forever (Braungart & McDonough, 2002).

The economic part of industry is important to how the market manifests itself within the system driving many interactions, but industrial ecology raises even more complex ideas and realities. As stated by Allenby (2006),

> industrial ecology raises even more complex questions, in particular the possibility that in some senses, industrial ecology is one-of the first post-modern fields of study, in that, unlike most traditional disciplines, it embodies not a single ontology, but a set of complex and, in some ways, mutually exclusive ontologies. How such multi-ontological field can be conceptualized, and represented coherently through traditional institutional forms is not clear, (p. 34)

that includes the microeconomic and market theories based on these forms.

2.1.5 Empathy Conservation

While the efficient allocation of resources within a circular economy is a significant step towards reducing throughput, understanding human motivations beyond simple market factors and equations cannot be understated. One of these motivations, empathy, is the ability to place oneself in another's position and to understand and feel what another is experiencing from their frame of reference (Wikipedia, 2016). This can be a motivational factor in the conservation of finite natural resources and the reduction of throughput.

In an article about empathy conservation, Czap, Czap, Lynne, and Burbach (2014), state that the metaeconomics framework (MEF) and dual-interest theory (DIT), suggest an important and substantive role for empathy in the design of conservation policy to achieve sustainability. They state:

> MEF and DIT posit that individuals are motivated by two inseparable, yet conflicting interests: self interest and other (shared with others)-interest. This

> conflict gets resolved through empathy tempering self-interest, resulting in a balanced decision, in which neither of the interests is maximized, but we rather observe sacrifices in both interests. Empathy is based on imagining the struggle of others, on "walking-in-the-shoes-of-others" and, as a result, perhaps joining in sympathy with a shared cause like conservation and sustainability. Conservation is one of the domains of economic decisions where empathy potentially plays a very important role (p. 1).

This conclusion would be beneficial in an industrial symbiotic relationship of companies, as collaboration and "sharing" of interests for the benefit of the whole is at the core of an industrial symbiotic network. Placing the "we" before the "I" is a substantial and yet difficult task, as basic economic market factors are typically the over-riding factor in company decisions. People pursue at least two main utilities, pleasure and morality. The former reflects the pursuit of self-interest, the latter of the common public interest, the "I-utility" and the "we-utility" which link the sympathy, commitment and meta preferences (Etzioni, 1986).

Empathy conservation, therefore, can have a role in establishing a framework of trust, collaboration, and sustainability by providing balance between self-interest and the basic economic realities of competing companies. It can be stated that unless regulated or controlled, sustainability can only be achieved through empathy tempering ego, as represented in the shared other-interest tempering and otherwise restraining the self-interest only orientation (Lynne, Czap, Czap, & Burbach, in press). Seeking balance between the dual interests of "we" and "I," can create a path to sustainability, and utilizing empathy as a motive could provide a way to that path.

2.2 Introduction to Industrial Ecology

Industrial ecology is the scientific study of material and energy flows through industrial systems. Industrial ecology as a framework tries to give guidance toward the transformation of industrial systems. The basic philosophy is to change linear production processes (raw materials are converted into products, by-products and wastes) into loops (used products, byproducts, and wastes of one process are used as resources for another) by imitating the cyclical use of resources in natural eco-systems. The goal is "bringing the industrial system as close as possible to being a closed-loop system with near complete recycling of all materials" (Lowe, 1993, p. 2). The worldwide industrial economy is a network of industrial processes that extract resources from the Earth and convert those resources into commodities that can be bought and sold to meet the needs of the economic market. Industrial ecology seeks to quantify the material flows and document the industrial processes that make modern society function. Industrial ecologists are often concerned with the impacts that industrial activities have on the environment regarding use of the planet's supply of natural resources and waste disposal. Industrial ecology is a young but growing multidisciplinary field of research that combines aspects of engineering, economics, sociology, toxicology, and the natural sciences.

Industrial ecology has been defined as a "systems-based, multidisciplinary discourse that seeks to understand emergent behavior of complex integrated human/natural systems" (Allenby, 2006, p. 33). The field approaches issues of sustainability by examining problems from multiple perspectives, usually involving aspects of sociology, the environment, economy and technology.

However, there is still no generally accepted definition for industrial ecology. The main characteristics are made up of comparable characteristics with contrasting prominent information. These characteristics include the following: 1) A systems view of the interactions between industrial and ecological systems: 2) The study of material and energy flows and transformations. 3) A multidisciplinary approach. 4) An orientation toward the future. 5) A change from linear (open) processes to cyclical (closed) processes, so the waste from one industry is used as an input for another. 6) An effort to reduce the industrial systems' environmental impacts on ecological systems. 7) An emphasis on harmoniously integrating industrial activity into ecological systems. 8) The idea of making industrial systems emulate more efficient and sustainable natural systems. 9) The identification and comparison of industrial and natural systems hierarchies, which indicate areas of potential study and action (Garner & Keoleian, 1995). The final three characteristics and their correlation to natural systems is significant, and should not be overlooked in discerning how to design and develop sustainable industrial systems.

2.2.1 History of Industrial Ecology

Industrial ecology is rooted in systems analysis and is an approach to sustainably frame the interaction between industrial systems and natural systems (Garner & Keoleian, 1995). This systems approach strategy can be linked to the research of Jay Forrester at MIT in the 1960s and 70s. His studies were centered on viewing the world as a series of entwined systems connecting to each other. The book "Limits to Growth" (New York: Signet, 1972), featured Donella and Dennis Meadows and others developing his work using systems analysis. Their research simulated the prevailing degradation of the environment in the world, accentuating the unsustainable direction of the then-current industrial system.

In 1989, Robert Ayres developed the concept of industrial metabolism: the use of materials and energy by industry and the way these materials flow through industrial systems and are transformed and then dissipated as wastes (Ayres, 1989). By tracking energy flows and materials, while performing mass balances, researchers could identify inefficient products and processes that result in industrial waste and pollution, as well as determine steps to reduce them. Frosch and Gallopoulos (1989) developed the concept of industrial ecosystems, which led to the term industrial ecology. Frosch and Gallopoulos' conceptual idea for an industrial ecosystem would exist as “an analogue” of its biological counterparts. This metaphor between industrial and natural ecosystems is essential to industrial ecology. In an industrial ecosystem, the waste produced by one company is used as a resource by another. No waste would leave the industrial system or negatively impact natural systems (Garner & Keoleian, 1995).

To further the development of industrial ecology as a field of study, in 1991, the National Academy of Science’s Colloquium on Industrial Ecology promoted this theory. Since that initial step, members of industry, government, and academia have attempted to promote, define, and apply it. In early 1994, The National Academy of Engineering published a book entitled: "The Greening of Industrial Ecosystems" (Allenby & Richards), which brought together many initiatives and efforts to use systems analysis to solve environmental problems. It incorporated tools of industrial ecology, such as design for the environment, life cycle design, and environmental accounting. The late 1990's saw the advancement of industrial ecology as the field gained increased international recognition through the creation of the Journal of Industrial Ecology and the establishment of an academic degree-giving program at the Norwegian University of Science and Technology (NTNU). This growth continued in the 21st century when in January 2000 a group of leaders from many diverse fields, and who shared an interest in promoting industrial ecology, gathered at the New York Academy of Sciences with the hope of creating an international society. They formed a committee to begin planning the formation of a new society dedicated to supporting research, applications, and communication related to the rapidly growing field of industrial ecology. This led to the formation of the International Society for Industrial Ecology in February 2001. Its mission is to promote the use of industrial ecology through research, community developments, education, policy, and industrial practices. This is done by rallying support through community interest and promoting social change.

2.2.2 The Relationship between Ecology and Industry

As stated by Garner and Keoleian (1995), the term “industrial ecology” implies a relationship to the field(s) of ecology. A basic understanding of ecology is useful in understanding and promoting industrial ecology, which draws on many ecological concepts. Ecology has been defined by the Ecological Society of America (1993) as:

> The scientific discipline that is concerned with the relationships between organisms and their past, present, and future environments. These relationships include physiological responses of individuals, structure and dynamics of populations, interactions among species, organization of biological communities, and processing of energy and matter in ecosystems.

In addition, Eugene Odum (1993) wrote:

> The word ecology is derived from the Greek oikos, meaning “household,” combined with the root logy, meaning “the study of.” Thus, ecology is, literally the study of households including the plants, animals, microbes, and people that live together as interdependent beings on Spaceship Earth. As already, the environmental house within which we place our human-made structures and operate our machines provides most of our vital biological necessities; hence we can think of ecology as the study of the earth’s life-support systems.

In industrial ecology, one of the main focal points of study is the interrelationships between firms, as well as among their products and processes, at the local, regional, national, and global system level. These overlapping layers of connections resemble the complex web of interrelatedness that is characteristic of organisms in natural ecological systems. It would appear, possibly, that there is a close relationship between industrial ecology, applied ecology, and social ecology. According to the Journal of Applied Ecology (2016), applied ecology is:

> The application of ecological ideas, theories and methods to the use of biological resources in the widest sense. It is concerned with the ecological principles underlying the management, control, and development of biological resources for agriculture, forestry, aquaculture, nature conservation, wildlife and game management, leisure activities, and the ecological effects of biotechnology.

The Institute of Social Ecology's (2016) definition of social ecology states that:

> Social ecology integrates the study of human and natural ecosystems through understanding the interrelationships of culture and nature. It advances a critical, holistic world view and suggests that creative human enterprise can construct an alternative future, re-harmonizing people's relationship to the natural world by re-harmonizing their relationship with each other.

Ecology as a whole can be defined as the study of the interactions between the biotic and abiotic components of a system. Thus, industrial ecology is the study of the interactions between industrial and ecological systems; in addition, it conveys the environmental outcomes on both the abiotic and biotic elements of the ecosphere. Discovering where industrial ecology fits into the field of ecology is a future endeavor that will occur while efforts to better define the discipline and its language are explored (Garner & Keoleian, 1995).

2.2.3 Objectives of Industrial Ecology

The primary goal of industrial ecology is to encourage sustainable development at the global, regional, and local levels (Garner & Keoleian, 1995). Sustainable development has been defined by the United Nations World Commission on Environment and Development as "meeting the needs of the present generation without sacrificing the needs of future generations." (United Nations as cited by (Garner & Keoleian, 1995, p. 5). Key principles inherent to sustainable development include the *sustainable use of resources*, preserving *ecological and human health*, which includes the maintenance of the structure and function of ecosystems, and the promotion of *environmental equity*, spanning between generations and society cultures (Garner & Keoleian, 1995).

The first goal, *sustainable use of resources*, is the promotion of industries that are sensitive to the sustainable use of renewable resources, while minimizing the consumption of nonrenewable resources. Given the continuous nature of supplying industry with raw materials, it becomes imperative that an efficient system is used. Besides solar energy, the supply of Earth's resources is finite. This fact only strengthens the position that in order for industrial activity to be sustainable in the long term, the depletion of non-renewables and degradation of renewables must be minimized.

Human beings are only one element of a larger network of different ecological actors. The second goal, *ecological and human health,* addresses this connectivity, reliance, and responsibility humans must have towards the environment. Their anthropomorphic actions are part of the overall ecological system. Since the well-being and health of people is dependent on the health of the other components of the ecosystem, ecosystem structure and function should be a focus of industrial ecology. Awareness of industrial activities and their potential to disruptive degrading of the ecosystem should be a goal priority.

The third goal, *environmental equity*, summarizes an important and very challenging task associated with any "sustainable development." The task of achieving equity on both an intergenerational and inter-societal level. This goal is distinguished from the others simply by the moral stance it takes. Having the awareness and insight to foster genuine care in creating an industrial system that balances the depletion of resources in order to meet the needs of future generations is a difficult one in a present day economically driven world. The unequal sharing of resources between cultures and countries as well as between developed and undeveloped countries. These "inter-societal inequities" are a definitive problem as developed countries currently use a disproportionate amount of resources in comparison with developing countries. Inequities also exist between social and economic groups within specific countries, such as the United States. Many studies have shown that low income and ethnic communities, for instance, are often subject to much higher levels of human health risk associated with certain toxic pollutants and resource sharing (Keoleian & Menerey, 1994).

2.2.4 Industrial Ecology Success - Fundamental Concepts

In order to establish a starting point for an industrial ecological system, key concepts have been developed to facilitate the creation of such a system. According to Garner and Keoleian (1995) the inclusion of systems analysis, material and energy flows, energy transformations, a multidisciplinary approach, analogies to natural systems, and open- vs. closed-loop systems are crucial to an industrial ecology system. The first concept, *systems analysis,* is the systems perspective of the connection between human activities and environmental issues. As specified earlier, industrial ecology is a higher order systems method to framing the interaction between industrial and ecological systems. There are different system levels that may be selected. For instance, when centered on the product system level, it is important to review relationships of both higher-level corporate or institutional systems as well as lower levels, such as the individual product life cycle stages. Another example is reviewing how the product system affects various ecological systems varying from entire ecosystems to individual organisms. A systems view enables manufacturers to develop products in a sustainable fashion. Important to the systems approach is the recognition of the interrelationships between industrial and natural systems.

In using systems analysis, a certain level of caution is necessary in order to avoid the mistake described by Kenneth Boulding. In his paper referencing the general systems theory, Boulding (1956) describes, "Seeking to establish a single, self-contained ‘general theory of practically everything’ which will replace all the special theories of particular disciplines. Such a theory would be almost without content, for we always pay for generality by sacrificing content, and all we can say about practically everything is almost nothing” (p.197). The same is true for industrial ecology. If the scope of a study is too broad, the results become less meaningful; when too narrow they may be less useful (Garner & Keoleian, 1995).

The second concept, *material and energy flows and transformations*, is a primary part of industrial ecology, including the transformation of products, byproducts, and wastes throughout industrial systems. The depletion of resources is recorded along with environmental releases to air, water, land, and biology. Figures 1, 2, and 3 are examples of these types of material flow diagrams:

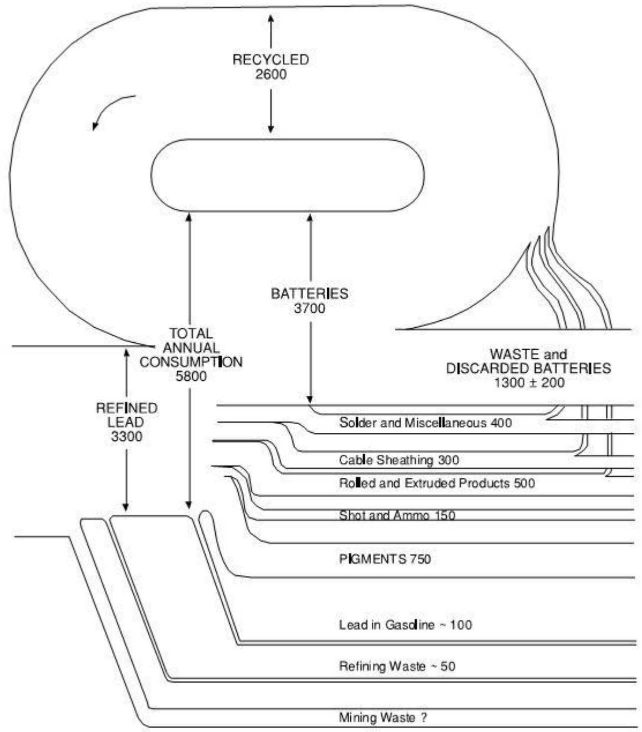


FIGURE 2: WORLD EXTRACTION, USE, AND DISPOSAL OF LEAD, 1990 (THOUSAND TONS)

R. Socolow, C. Andews, F. Berkhout, and V. Thomas, eds., *Industrial Ecology and Global Change* (New York: Cambridge University Press, 1994). Reprinted with permission from the publisher. Data from International Lead and Zinc Study Group, 1992.

Figure 1: Material flow diagram example 1 (Andrews, Berkhout, Socolow & Thomas, 1994).

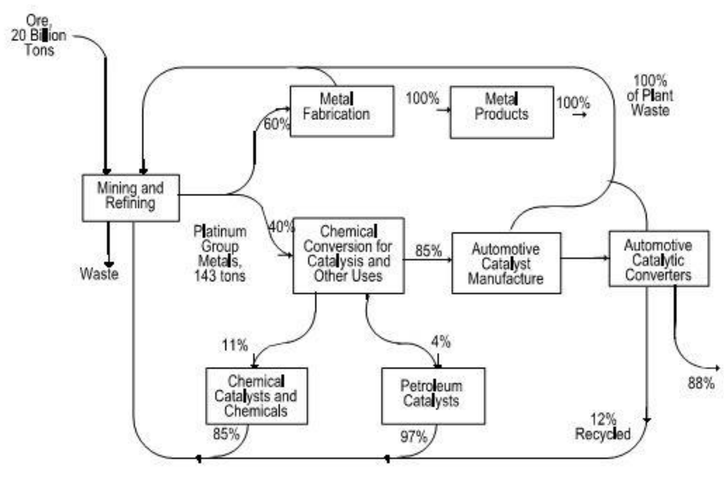


FIGURE 3: FLOW OF PLATINUM THROUGH VARIOUS PRODUCT SYSTEMS

Source: R. A. Frosch and N. E. Gallopoulos, "Strategies for Manufacturing" *Scientific American* 261 (September 1989), p. 150.

Figure 2: Material flow diagram example 2 (Frosch & Gallopoulos, 1989).

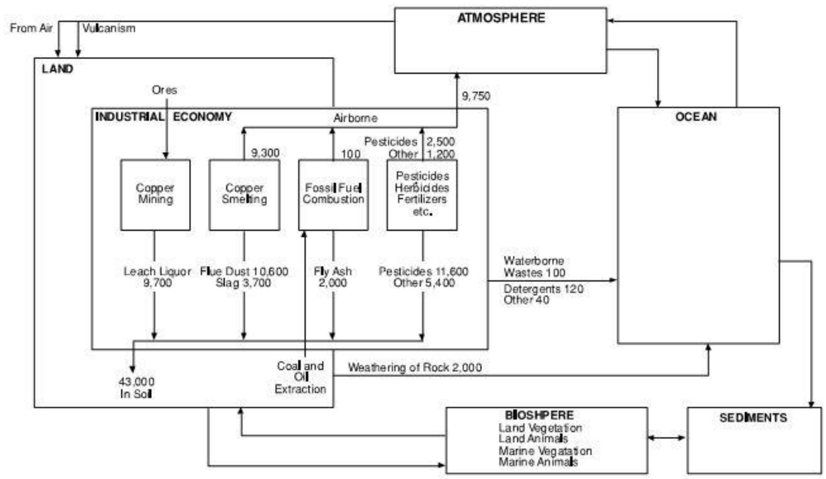


FIGURE 4: SIMPLIFIED REPRESENTATION OF ARSENIC PATHWAYS IN THE U.S. (METRIC TONS), 1975.

Source: Ayres et al. (1988).

Figure 3: Material flow diagram example 3 (Ayres, 1988).

Industrial ecology strives to reduce the amount of waste material and energy that is produced and leaves the industrial system, subsequently impacting ecological systems adversely (Garner & Keoleian, 1995). As shown in Figure 2, the flow of platinum is captured through a variety of product systems; eighty-eight percent of the material in automotive catalytic converters leaves this product system as scrap. Efforts could be made to increase recycling or other uses found for the scrap to decrease this waste. By utilizing waste as a material input or energy source for some other entity within the industrial ecology system, can potentially improve the overall efficiency and reduce negative environmental impacts. Of course, the challenge of industrial ecology is to reduce the overall environmental stress of an industrial system that provides products for the community and society. When identifying target areas for reduction, a system must realize how materials and energy dissipate and change into pollutants. A system must verify how these flows interact, intersect, and affect natural systems. Being able to discern between natural material and energy flows and those caused by human activity can beneficial in recognizing the scope of human-produced impacts. This table illustrates that the anthropogenic sources of some materials in the environment are greater than the natural sources. Industrial ecology attempts to alter industrial actions into a more closed system by reducing the spreading of used materials, pollution, or wastes into the environment by human activity.

A third concept, *multidisciplinary approach,* describes the need for participation and input from a variety of different disciplines. Considering industrial ecology is established on a holistic, systems view, the intricacy of most environmental issues requires expertise from a variety of fields such as, natural resources, public health, law, ecology, business, engineering, and economics, which all contribute to the development of industrial ecology and the resolution of environmental problems caused by industry. In order to amend impacts to the environment, the development of new technologies, changes in individual opinion, behavior, public policy and law are all relevant disciplines that should be addressed for maximum results. The prevailing notions of industrial ecology are mainly centered on engineered, technological solutions. Being able to balance the many facets of industrial ecology will be the challenge ahead.

The fourth concept, *analogies to natural systems,* cannot be understated based on the efficient and sustainable evidence that the natural ecosystem presents. There are several useful analogies between industrial and natural ecosystems. The natural system has evolved over many millions of years from a linear (open) system to a cyclical (closed) system in which there is a dynamic equilibrium between organisms, plants, and the biological, physical, and chemical processes vary in nature. Virtually nothing leaves the system, because wastes are used as substrates for other organisms. This natural system is characterized by high degrees of integration and interconnectedness (Garner & Keoleian, 1995). Industrial ecology draws upon similarities between industrial and natural systems and suggests that a goal is to stimulate the evolution of the industrial system so that it shares the same characteristics as described above concerning natural systems. As will be described forthcoming in this thesis, a well-known eco-industrial park in Kalundborg, Denmark represents the best attempt to model an industrial park after an ecological system. The companies in this industrial park are highly integrated and utilize the waste products from one firm as an energy or raw material source for another.

Lastly, the fifth concept, *linear (open) versus cyclical (closed) loop systems*, refers to the evolution of linear industrial systems, where resources are consumed and harmful wastes are dispersed into the environment, to a closed loop system, resembling that of ecological systems, a central concept to industrial ecology. As shown in Figure 4, Allenby (1992) describes this evolution from a Type I to a Type III system.

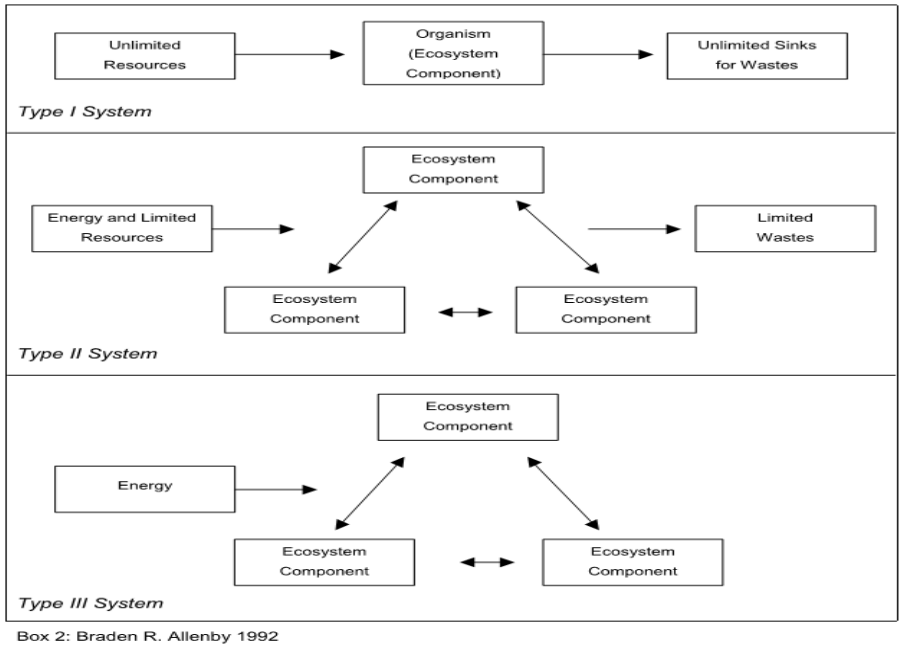


Figure 4: Evaluation from Type I to Type III industrial ecology system (Allenby, 1992)

In Figure 4, the Type I system is represented as a linear process. Materials and energy enter one part of the system and then exit either as products or as by-products/wastes. Because wastes and by-products are not reclaimed or recovered, this system relies on a large, constant supply of raw materials. A Type I system is linear in explanation, where energy and resources enter the system and products and wastes leave it. Unless the supply of materials and energy is infinite, this system is unsustainable. In addition, the ability for natural systems to assimilate wastes is also finite. Many of the industrial developments we currently have are based on this system (Allenby, 1992).

In a Type II system, there is a partial recycling of wastes and the reuse of materials in a system. A reduction of input resources, combined with a limited amount of waste exiting the system, contribute to this type. In addition, a collaboration of ecosystem components utilizing the exchanging of energy and materials between multiple entities. This type characterizes some of our present-day industrial ecology systems.

A Type III system represents ecological systems in a progressive equilibrium where energy and wastes are continually recycled and reused by other organisms and processes within the system. This is an exceedingly unified, closed system. In a totally closed industrial system, only solar energy would come from outside, while all by-products are constantly reused and recycled. “A Type III system represents a sustainable state and is an ideal goal of industrial ecology” (Garner & Keoleian, 1995, p. 12).

It is obvious that a Type III System appears to be the best, ideal situation to strive. However, this level of a closed cyclical loop system is not achievable at the level of eco-industrial parks. The fact that consumable products must leave the eco-park diminishes the amount of materials circulating within the system, and then would require new material inputs. "The goal is not hermetically sealed "biospheres" but real world solutions to improving business and environmental performance simultaneously." (Cohen-Rosenthal, 1996, p. 3).

Kalundborg, where interconnections are highly developed, is the most often cited example of a well working industrial ecosystem (apart from water-steam loops); there are no real cyclical material flows between the collaborating companies (according to schematics of Ehrenfeld & Gertler 1997; Lowe et al. 1998; Manahan 1999) as cited by Fleig, 2000). The achievement within the "Kalundborg Symbiosis" is that companies communicated and co-operated so that all main by-product flows could be directed forward to further users converting them into products, which then leave the system (Fleig, 2000).

2.3 Introduction to Industrial Symbiosis

As the study and realization of industrial ecology moves forward, practical applications, such as industrial symbiosis are being applied. Industrial symbiosis is the manifestation and practical application of industrial ecology, as exemplified by the real life success provided in Kalundborg, Denmark. This model includes stress reduction on the environment by diminishing the amounts of raw material inputs required for industry.

The word "symbiosis" is a biological term referring to 'a close sustained living together of two species or kinds of organisms' (Encyclopedia Britannica, 1992). The term was used as early as 1873 by a German botanist, H. A. De Bary, to describe the intimate coupling of fungi and algae in lichens. While nature's living arrangements can be beneficial or harmful, the specific type of symbiosis known as mutualism refers to the situation in which at least two otherwise unrelated species exchange materials, energy or information in a mutually beneficial manner (Ehrenfeld & Gertler, 1997). Industrial symbiosis has been defined as engaging "traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity" (Chertow, 2000, p. 314).

Industrial symbiosis is an industrial ecosystem where unused or residual resources of one company are used by another. This results in mutual economic, social, and environmental benefits. It is a process involving several companies – firms that complement one another provide mutual benefit through efficient use of raw materials, technology, services and energy. Based on this, industrial symbiosis consists of place-based exchanges among different entities. It stresses collaboration, because by working together, businesses strive for a collective benefit greater than the sum of individual benefits that could be achieved by acting alone. This collaboration can also cultivate social values among the participants, which can extend to the surrounding areas within close proximity to the system.

The term industrial symbiosis first originated commercially in the small municipality of Kalundborg, Denmark. Here, this term was first used to describe the collection of industrial entities collaborating together. These "partners" in the Kalundborg symbiosis had effectively "self-organized" into a working industrial ecosystem, or to use the term, industrial symbiosis. Residual products of one enterprise are used as a resource by another enterprise, in a closed cycle. Local collaboration between entities where public and private enterprises buy and sell residual products, resulting in mutual economic and environmental benefits.

In spite of the fact that industrial symbiosis may seem to have materialized as a revolutionary sustainable solution, this idea is far from a comprehensive solution. As stated by Chertow (2007), "Scrap dealers, charities organizing clothing drives, and companies buying and selling left over materials are, technically, exchanging resources." (p. 12) In order to distinguish industrial symbiosis from other types of exchanges, Chertow (2007), has adopted a “3–2 heuristic” benchmark for industrial symbiosis. Within this industrial symbiosis analysis, three different entities must be involved in exchanging at least two different resources to be counted as a basic type of industrial symbiosis. By involving three entities, none of which is primarily engaged in a recycling oriented business, the 3–2 heuristic begins to recognize complex relationships rather than linear one-way exchanges. In general, three primary opportunities for resource exchange are considered: (1) By-product reuse—the exchange of firm-specific materials between two or more parties for use as substitutes for commercial products or raw materials. (2) Utility/infrastructure sharing—the pooled use and management of commonly used resources such as energy, water, and wastewater. (3) Joint provision of services—meeting common needs across firms for ancillary activities such as fire suppression, transportation, and food provision.

2.3.1 Industrial Symbiosis and Sustainability

It is clear that as part of the ontological analysis of industrial symbiosis that certain aspects, or dimensions, shape how industrial symbiosis is framed and organized within the context of sustainability. According to Kurup (2007), sustainability has different dimensions and most people think that achieving the economic dimension is all about sustainability. However, the proponents of this dimension do not go any further to explain how addressing economic dimensions alone can bring holistic sustainability. There is an increasing trend in recognizing the importance of environmental and social sustainability to achieve and maintain true economic sustainability. This has led to examining the definition of environmental and social sustainability, and how to redefine sustainability in terms of environmental, economic, and social dimensions (Gertler, 1995; Posch, 2002). The Global Reporting Initiative (GRI), an official collaborating center of the United Nations Environmental Program (UNEP) has the goal of enhancing the quality and utility of sustainability reporting. The GRI initiative is grouped into the three dimensions of sustainability, namely, environmental, social, and economic (Kurup, 2007). The GRI then organizes performance indicators according to category, aspect, and indicator. Results are shown in Table 1.

Table 1: *Category and aspects used in GRI reporting system*. (Derived from GRI 2002)

Category	Aspects	
Environmental		
Environmental	Materials Energy Water Biodiversity Emissions Effluents, and waste	Suppliers Products and services Compliance Transport Overall
Social		
Labour practices and decent work	Employment Labour/management relations Health and safety	Training and education Diversity and opportunity
Human rights	Strategy and management Non-discrimination Freedom of association and collective bargaining	Child labour Forced and compulsory labour Disciplinary practices Security practices Indigenous rights
Society	Community Bribery and corruption	Political contributions Competition and pricing
Product responsibility	Customer health and safety Products and services	Advertising Respect for privacy
Economic		
Direct economic impacts	Customers Suppliers Employees	Providers of capital Public sector

The definitions shown in this table are aligned with international standards, and the GRI Reporting System (2002) documents the impacts of direct and indirect economic performance (Kurup, 2007). While the indirect impacts can be measured with the GRI model, the system itself does not identify the indicators for measuring indirect impacts.

2.3.2 Triple Bottom Line

As stated previously by Chertow (2007), industrial symbiosis involves separate industries realizing that a collective approach will provide a competitive advantage. Typically, these entities have a close physical distance to each other in order to have a minimum 3/2 material flow exchange including energy, water, and by-products.

Collaboration through utility/infrastructure sharing, and joint provision of services is key to creating these synergistic possibilities.

The resulting dimensions formed because of these industrial symbiosis collaborations have roots in an accounting framework called the triple bottom line (TBL), first discussed by Elkington (1994). This framework provides an organizational method to evaluate a broader business perspective of sustainable development. This framework expands the environmentalist agenda of those working towards sustainability so that it more explicitly incorporates a social dimension (Elkington, 2004). The TBL refers to the three bottom lines of “economic prosperity, environmental quality, and social justice”. This is attributed to growing demands from stakeholders for more extensive information on the operations and financial standing of businesses, thus necessitating that managers include information on sustainability related issues (Jackson, Boswell, & Davis, 2011). The most frequently seen factors used in performance measurement of the TBL are economic, environmental, and social (Global Reporting Initiative, 2006, Wang & Lin, 2007). In the literature, there is no real consensus as to the exact dimensions used for the performance measures (Jackson, Boswell, & Davis, 2011).   Figure 5 describes the triple bottom line model:

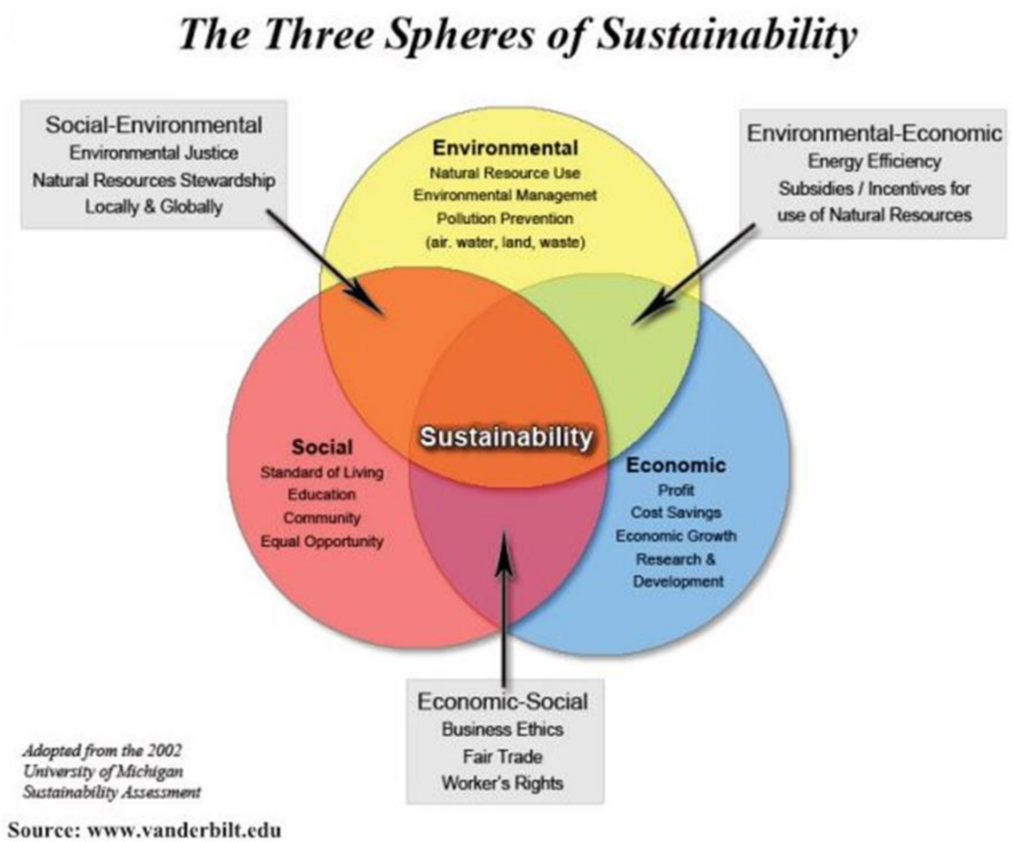


Figure 5: Triple bottom line framework (Sustainability Assessment, 2002).

Some other dimensions used are community improvement, environment, entrepreneurship, and education (Sher & Sher, 1994), and stakeholder engagement, organizational integrity, and stakeholder activism (Painter-Morland, 2006). In all instances, performance is measured based on the impact of companies on society as a whole, both now and into the future (Jackson, Boswell, &Davis, 2011). In the words of Elkington (1994), “Triple bottom line focuses corporations not just on the economic value they add, but also on the environmental and social value they add – and destroy. At its narrowest, the term ‘triple bottom line’ is used as a framework for measuring and reporting corporate performance against economic, social and environmental parameters” (p. 3). In review, sustainability is regarded as the integration of three performance areas:

economic, social, and environmental; and is viewed as a necessary practice for modern corporations wishing to attain sustainability. According to (Middlebrooks et al., 2009) "the triple bottom line of fiscal, social and environmental success considerably alters how organizations (and stakeholders) measure sustainable success" (p. 32).

2.3.3 Industrial Symbiosis Benefits

As stated previously, industrial symbiosis has been defined as engaging "traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity" (Chertow, 2000, p. 314). Because of this definition, industrial symbiosis can imply many potential benefits. Eco-industrial parks (EIPs) are complex forms of industrial systems, communities of manufacturing and business located on the same properties. Members are motivated by the potential for enhanced environmental, economic, and social collaboration through resource efficiency (Koenig, 2009). Depending on the local stakeholders, the benefits of EIPs can expand to include the local community, neighboring businesses, and additional human capital as an integrated system of shared resources (material, knowledge-based, social, etc.) that can lead to economic gains and enhanced environmental quality. These types of industrial symbiosis systems, which the ENISN would be part of, are referred to as an eco-industrial development (EID) (Koenig, 2009). The benefits of applying an industrial symbiosis approach are numerous and go beyond the simple and often exclusive raw material exchange. The following table lists some of the important benefits:

Table 2: *Potential benefits of an EID*, (Deppe & Schlarb, 2001, p. 9).

Communities	Environment	Business
1. Expanded local business opportunities 2. Improved tax base 3. Community pride 4. Reduced waste disposal cost 5. Improved environment and habitat 6. Recruitment of higher quality companies 7. Improved health for employees and community 8. Partnership with business 9. Minimised impact on infrastructure 10. Enhanced quality of life near Eco-industrial park 11. Improved aesthetics 12. Good jobs	1. Continuous environmental improvement 2. Reduced pollution 3.Innovative environment solutions 4. Increased protection of natural ecosystems 5. More efficient use of natural resources 6. Protection and preservation of natural habitat	1. Higher profitability 2. Enhanced market image 3. Higher performance workplaces 4. Improved efficiency 5. Access to financing 6. Regulatory flexibility 7. Higher value for developers 8. Reduction of operating costs(i.e. energy, materials) 9. Reduction in disposal costs 10. Income from sale of by-products 11. Reduction of environmental liability 12. Improved public image 13. Increased employee productivity

2.3.4 Six Capitals Model (SCM) Indicators

For this study, the six capitals model (SCM) was reviewed and used as a source of TBL indicators. The researcher used a method developed by Kurup (2007) to assess the broader implications such as the tangible and intangible benefits of industrial symbiosis projects. The method assesses the broader benefits of industrial symbiosis to the participants by measuring various capital benefits achieved. The Kurup method draws on the World Bank's Capital Centered approach. The World Bank developed the 'Capital Centered' approach for its assessment of sustainability of the funding they provided for developing nations. Development of various dimensions and indicators for measurement was based on the concept that even though natural resources were counted as wealth, human resources were more important and should therefore also be counted as wealth. The World Bank identified that in addition to natural capital, and produced assets, human capital and the not so well-explained social capital may well contribute to economic capital if properly protected. Table 3 illustrates each capital:

Table 3: *Capital definitions derived mainly from* The World Bank (1997).

Name of capital	Definition
Natural capital	Includes the resources necessary for industries to perform business operations
Ecosystem capital	Includes the ecosystem services needed for restoring or regenerating the environment where industries operate with sufficient air, water and soil quality (Cork et al. 2002) and biodiversity
Human capital	Skills and capabilities of people who are related to industry's operations directly or indirectly for example, employees, contractors, suppliers
Community capital	Communities of interest as place based which involves communities reside nearby industrial area as well as employees
Manufactured capital	Includes produced capital, infrastructure established for efficient running of the business like construction of pipelines, laboratory facilities, shared treatment facilities and water and energy utilities, sewage treatment systems, transport services such as roads, rails
Financial capital	Includes investment, income generated through sale of by-products, savings achieved through avoided landfill cost, treatment cost, regulatory and legal cost, storage cost, intangible cost and benefits

In order to measure the broader benefits of industrial symbiosis, which are more than just environmental, social, and economic benefits, the TBL framework had to be expanded to cover the values regenerated or restored in natural and ecosystem, human, community, financial, and manufactured capitals (Kurup, 2007). The concept of assessing various capitals delivers more outcomes since it gives an opportunity to not only look at environmental and economic values but also of skills, networks, and individual and societal assets which are identified as important aspects of social benefits (Kurup, 2007). Figure 6 shows the expansion of the TBL framework for measuring broader implications of industrial symbiosis.

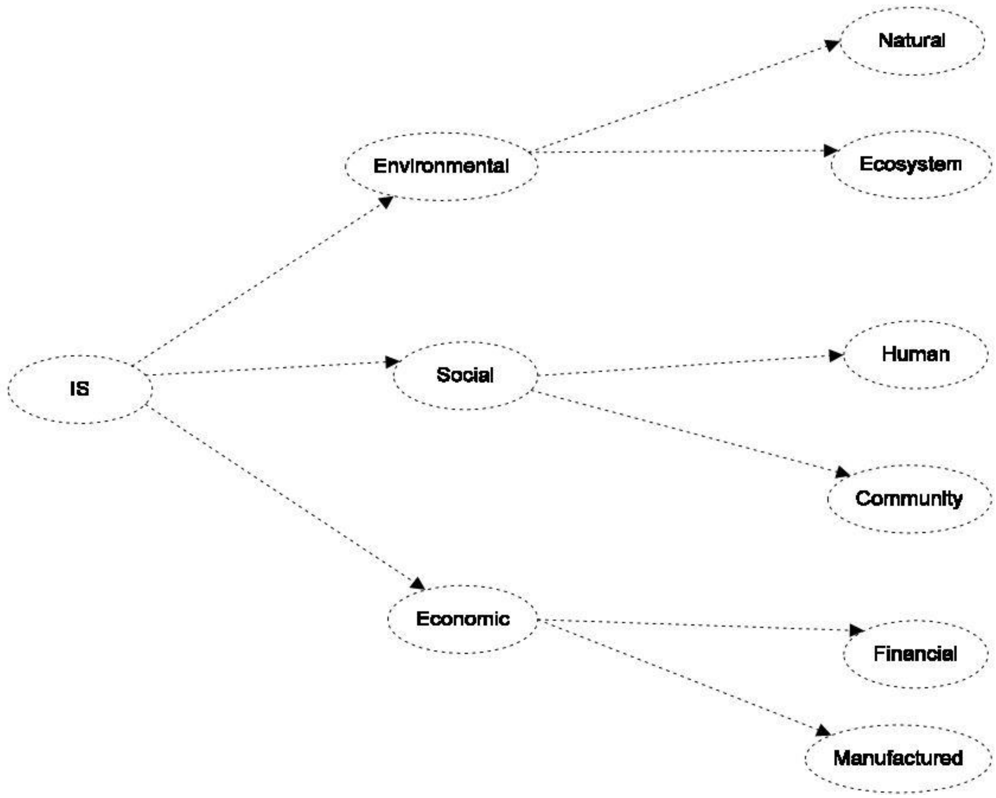


Figure 6: Expansion of TBL framework into the six capitals model (SCM) (Kurup, 2007).

A total of 38 indicators were used in the SCM model to identify the value of all the capital gained. Indicators have been selected based on the potential implications of this project on the natural capital, ecosystem capital, human capital, community capital, manufactured capital, and financial capital. Table 4 illustrates the category, criteria and indicators used in the SCM model (Kurup, 2007).

Table 4: *Indicators to measure values of capitals* (Derived from the SCM model) (Kurup, 2007).

Category	Criteria	Indicators
Environmental benefits	Natural capital (NC)	resource conservation
		resource security
	Eco-system capital (ES)	water contamination
		dust emission
		impact of noise
		air emission
Social benefits	Human capital (HC)	productivity
		retention of employees
		job security/creation
		sharing occupational health & safety programs
		investment in research & development
		sharing of infrastructure & technology
		sharing of human resources
		Employee management relations
		information sharing between companies
	Community capital (CC)	Perception of communities in regards to environmental health
		Communication about the project in the community
		Opportunities of educational partnership for school children
		Employment opportunities
		Complaints from community
		Sharing of information between community and industries
		Level of understanding about IS projects among community
		Opportunities of public relations
		Networking between industries and communities
Economic benefits	Manufactured capital (MC)	Business opportunities
		Infrastructure facilities for industries
		Public infrastructure
	Financial capital (FC)	Labour costs
		Equipment costs
		Raw material costs
		Compliance costs
		Permit costs
		Cost of penalties/fines
		Cost of future liabilities

2.3.5 Industrial Symbiosis and the Closed Loop

Industrial symbiosis promotes a "closed-loop" system of sustainability, which is similar to natural ecosystems. It makes use of a balanced flow of energy similar to ecological economic principles that reduce growth, where growth is defined as an "increase in throughput, which is the flow of natural resources from environment, through the economy, and back to environment as waste" (Daly & Farley, 2004, p. 6). It is efficient allocation, where "no other allocation of resources would make at least one person better off without making someone else worse off" (Daly & Farley, 2004, p. 4). In addition, it is resilient and adapting, where "ecological economic resilience enhances self-organization of the system and ensures the system has the capacity for learning and adaptation" (Daly & Farley, 2004, p. 5). The term symbiosis relates to the idea of a mutually advantageous relationship in biological communities where at least two otherwise unrelated species exchange energy, materials, or information in a method that benefits both. Industrial symbiosis takes advantage of this key element in nature, by connecting organizations together for mutual benefit both environmentally and economically. It is concerned with the flow of materials and energy through systems at different scales. It focuses on these flows through networks of businesses and other organizations in local and regional economies as a means of approaching ecologically sustainable industrial development. Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products.

2.3.6 Ontologies of Industrial Symbiosis

Industrial symbiosis is referred to as a systems-based, multidisciplinary engagement that attempts to understand the behaviors of complex integrated natural and human systems. Understanding the nature of industrial symbiosis collaborations is a serious challenge. As Allenby (2006) states, "a complexity that is simultaneously static, dynamic, and ontological" (p. 34). Industrial symbiosis and its systems, suggests that it is very different from traditional fields or disciplines of study, integrating many mutually exclusive ontologies, increasing the complexity. Ontologies, or groups of certain assumptions about the nature of being and reality in this case, concern how the entities within the industrial closed loop system exist, are grouped, and relate to a certain hierarchy. This is imperative for a sustainable system to work and operate. The ability to address the complexity of such a system is at the center of success. This involves economies, cultures, natural cycles, biological systems, and the dynamic structure of their internal and external philosophies, unfurling over time as a networked system. As the Kalundborg model shows, this technological advancement reveals a resilient, efficient use of resources, which can adapt to new members, and uniquely exemplifies the closed loop process. This process is an important one, as its core theories and beliefs can be utilized in many other applications in order to reduce the strain on the natural environment.

The mutually exclusive ontologies of industrial symbiosis, with its complex adaptive systems, involves a level of sophistication and integration that people will need to deal with as the literature of the field expands. Industrial symbiosis concerns not only static and dynamic issues, but also scientific and technological facets that involve dissimilar ways of thinking about the earth and concepts of nature. As said by Isenmann (2002):

> Nature does not automatically or clearly speak to humans. Nature appears to humans only by several ways of mediation...humans must translate nature with language and into language...Reading in the 'book of nature' requires an understanding of both the reader (representing human self-experience and self-awareness) and the reader's perspective representing the process of reading (p. 38)

Industrial symbiosis is focused on translating detailed conclusions acquired from natural and engineering sciences into practices involving human cultures and societies, asserting that intersecting these boundaries requires distinct suppositions about ontologies. Clearly, the boundaries of industrial symbiosis run much deeper than what would be initially thought. The practical issues are apparent, institutional relationships coupled with other disciplines and interdisciplinary endeavors to the level where industrial symbiosis grows beyond engineering and natural sciences. These lead to a comprehension of the spontaneous nature of industrial symbiosis, "not just in terms of the industrial system - the traditional activist approach - but the identification of significant intellectual challenges arising from the existence and structure of the field itself" (Allenby, 2006, p. 36). Key among these challenges are the demands of applying developing work in complex adaptive systems, and confirming that the field becomes advanced in understanding its own language of the potential implications of a complicated system of different and mutually exclusive ontologies. The existence of these is not an accident of industrial symbiosis evolution, but rather comes forth from the core of the subject material of the field itself. (Allenby, 2006)

2.3.7 Discovering Industrial Symbiosis

According to Chertow (2007), industrial symbiosis can be summarized in two stylized models that have contrasting points of view, a planned approach model and a self-organization symbiosis model. The *planned EIP model,* is a "conscious effort to identify companies from different industries and locate them together so that they can share resources across and among them. Typical U.S. planning for these systems has involved the formation of a stakeholder group of diverse actors to guide the process and the participation of at least one governmental or quasi-governmental agency with some powers to encourage development, such as land use planning and/or zoning, grant giving, or long-term financing" (Chertow, 2007, p. 21).

The *self-organizing symbiosis model*, is an:

> industrial ecosystem that emerges from decisions by private actors motivated to exchange resources to meet goals such as cost reduction, revenue enhancement, or business expansion. The individual initiative to begin resource exchange faces a market test and if the exchanges are successful, more may follow if there is on-going mutual self-interest. In the early stages there is no consciousness by participants of "industrial symbiosis" or inclusion in an "industrial ecosystem," but this can develop over time. The projects can be strengthened by post facto coordination and encouragement (Chertow, 2007, p. 21).

An important theory suggesting how industrial symbiosis emerges was created by Boons and Berends (2001) and Baas and Boons (2004). It is based on the idea of an economic driving force of an all-win situation among area firms that can potentially lead to collaboration between industries and thus sustainability. Their three-part figure is shown in the Figure 7 below:

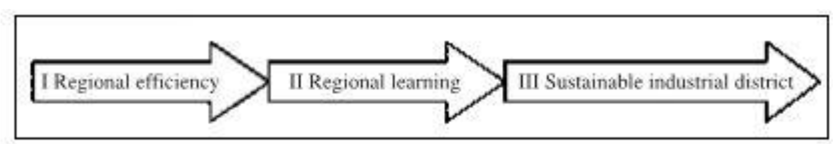


Figure 8 by Boons and Berends (2001) and Baas and Boons(2004)

Figure 7: Industrial symbiosis emergence (Boons & Berends, 2001 & Baas & Boons, 2004)

The first stage, regional efficiency, is characterized by self-governing decision-making by companies; coordination of local firms to increase utility sharing by decreasing inefficiencies. The second stage seeks to augment the goals of the group by promoting regional learning. This is where leaders strive for mutual recognition and trust. The firms and other partners exchange knowledge, and broaden the definition of sustainability on which they act. The third and final stage, displays a further progression toward a vital insight into collaborative action based in sustainability. Figure 7 brings out two questions about the collaborative effect of industrial symbiosis: What do symbiotic relationships begin to look like in their early stages and at what point are they “discovered” in industrial ecosystems? In the first stage, companies cooperate for reasons of economic efficiency. Once regional proficiency gains the initiative and growth it needs, based on self-governing decision-making, it may continue to thrive and enter the more advanced stage of wisdom denoted in the second stage. Companies will typically be aware of the environmental benefits they are gaining from working together; however, they typically cannot “discover” their linkages before exchanges are stable. With respect to awareness by the companies of the environmental benefits being gained, by definition, they cannot be “uncovered” before the exchanges are established, which is why attempts at creation outside of the market are likely to fail. Figure 7 does not offer a physical explanation of this, when the collection of companies involved at the regional efficiency stage might move to the subsequent stages illustrated (Chertow, 2007).

Using the case of Kalundborg symbiosis as an example, there were well-developed regional efficiencies already in place (as described in stage 1 of figure 7). By the time the symbiosis was brought to broader attention, it may have already entered stage II as demonstrated by the informal informational networks and regional learning already happening there. In order to understand the influence and success of Kalundborg, it is necessary to see it as having moved closer to stage III than other relevant stage II industrial symbiosis projects throughout the world. Burgeoning symbiosis found earlier in their possible projects and networks are potentially less stable and, therefore, their futures are more uncertain. Kalundborg was well developed at the time of its discovery.

As stated by Chertow 2007:

> Rather than seeing Kalundborg as chance or a historical accident, a fuller explanation would be to recognize that it is built on existing scarcities (in the case of groundwater), opportunities (in the case of by-product use by new entrants), regulatory changes (in the case of reuse of organics and impetus to pursue flue gas desulfurization), and other locational advantages (including the port and the availability of industrial land). (p. 23)

2.4 Profile of an Industrial Symbiosis Model: Kalundborg, Denmark

Kalundborg, Demark is the location of the longest established industrial symbiosis network that serves as a model for research and as a prototype for other potential closed loop systems. This model is used as a point of comparison in this study. The municipality of Kalundborg is a smaller sized city of 20,000 residents on the north-west coast of Zealand, the largest island within Denmark. It is 105 kilometers from Copenhagen, the largest city in Denmark (Figures 8, 9, and 10).

2.4.1 Site Specific Maps

Figure 8: European map (Google Maps, 2016).

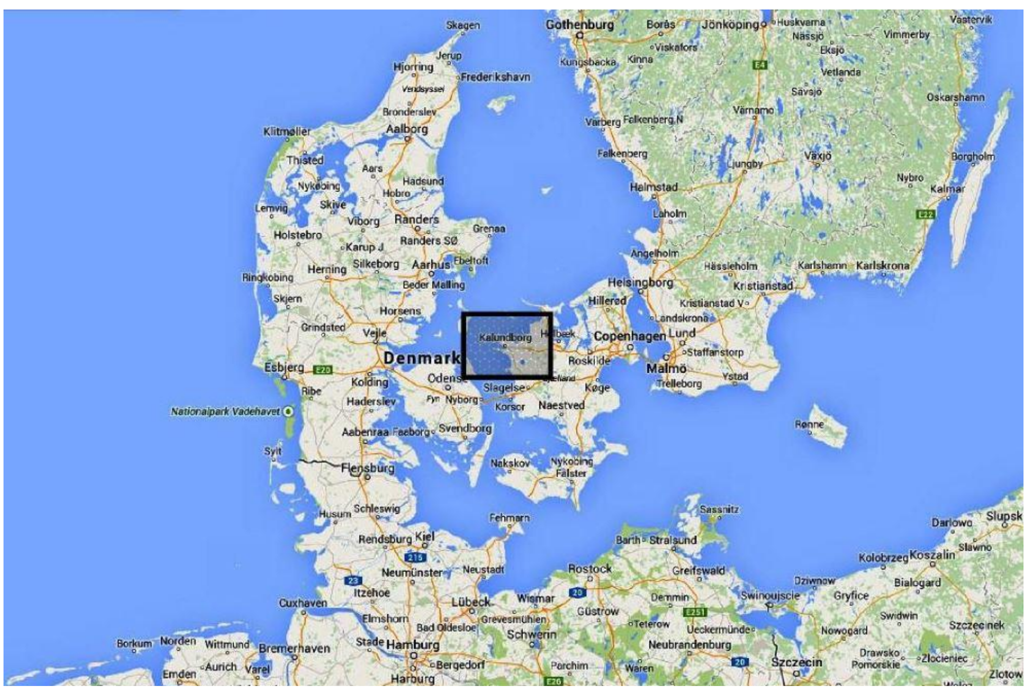


Figure 9: Denmark regional map (Google Maps, 2016).

Figure 10: Kalundborg site study map (Kalundborg Symbiosis, 2016).

2.4.2 Partner Companies in the Kalundborg Network

The Kalundborg symbiosis includes nine primary member companies, some of which are some of the largest enterprises in Denmark. The partner companies in Kalundborg symbiosis are, first, Novo Nordisk, the world's largest producer of insulin. They have about 2600 employees in Kalundborg. Second, Novozymes, the worlds' largest producer of enzymes. They employ 500 people in Kalundborg. The third company, French-owned Gyproc, produces gypsum board. They have around 165 employees in Kalundborg. The fourth partner, the municipality of Kalundborg, handles the water and heat supply for Kalundborg's approximately 20,000 inhabitants. The fifth partner, the Asnaes Plant, owned by DONG Energy, is the largest power plant in Denmark. They have around 120 employees in Kalundborg. The sixth, Statoil, is Denmark's largest oil refinery. They have around 350 employees. The seventh partner is Kara/Novoren, a waste treatment company that employs 15 people in Kalundborg. The eighth is Kalundborg Forsyning A/S, which supplies the people of Kalundborg with water and district heating, included the disposal of wastewater for the entire municipality. They have 66 employees in Kalundborg. The ninth member is RGS 90, a Danish soil remediation and recovery company.

A pair of secondary companies, Inbicon and Pyroneer, are owned by the DONG Energy and are part of the network. Inbicon is a lignocellulosic biomass conversion company, using technology to convert non-food biomass to second-generation bio-ethanol and other renewable power and biochemical products. The Pyroneer plant specializes in biomass gasification as an endothermic thermal process where solid biomass is converted into gaseous fuel. The produced gas can be used to replace part of the coal used in the existing boiler, and the ash can be used in large-scale fertilizer. Included in this dense formation of linkages are secondary connections to additional uses, such as pig farms, a fish farm, the fertilizer industry, and the cement industry.

2.4.3 Development of the Kalundborg Network

The development of industrial symbiosis in Kalundborg, Denmark has been described as an evolutionary process in which a number of independent by-product exchanges have gradually evolved into a complex web of symbiotic interactions among five co-located companies and the local municipality of Kalundborg (Ehrenfeld & Gertler 1997, Ehrenfeld & Chertow, 2002). The motivation for resource exchange began as a mutual effort to reduce costs and finding ways to gain income-producing benefits from "waste" products. Over time, the companies involved realized that carefully managing their network of exchange of energy and materials could produce economic advantages while concurrently reducing environmental impacts. Their geographical proximity played an important part in their connection and collaboration. The Kalundborg Symbiosis Institute was created as a managing entity, facilitating open communication and mutual trust between partners.

The Kalundborg industrial park was not originally planned for industrial symbiosis. Its current organization of waste heat and materials sharing developed over a period of 25 years. The early collaboration at Kalundborg mainly involved the sale of waste products without significant pretreatment. Additional links in the system were negotiated as independent business deals, which were created and established only if they were expected to be economically beneficial.

The history of the Kalundborg industrial symbiosis began in 1959 with the start-up of the Asnæs Power Station. A project was started in 1961 to use surface water from Lake Tissø for a new Statoil oil refinery in order to save the limited supplies of ground water (Christensen, 1999). The city of Kalundborg took the responsibility for building the pipeline while the refinery financed it. Starting from this initial collaboration, a number of other collaborative projects were subsequently introduced and the number of partners gradually increased. In 1972, Statoil entered into an agreement with Gyproc, a local gypsum production plant, for the supply of excess gas from Statoil's production to Gyproc. Gyproc used the gas for the drying of the produced plasterboard in their ovens. A pipeline from the Statoil refinery to the Gyproc facility is constructed to supply excess refinery gas. The following year DONG Energy (then, the Asnæs Plant) expanded, and a connection to the Lake Tisso-Statoil water pipeline was created. In 1976, Novo Nordisk, an insulin producing industry, started delivering biological sludge to neighboring farms.

Three years later in 1979, the Asnæs power station started supplying fly ash to cement manufacturers in northern Denmark.

The municipality of Kalundborg, in 1981, completed a heating distribution network that captures waste heat from the Asnaes power plant and uses it to heat the city. In 1982, Novo Nordisk and the Statoil refineries constructed pipelines connecting themselves to the Asnaes power plant. These pipelines are used to collect process steam from the power plant allowing Novo Nordisk and Statoil to shut down their inefficient steam boilers. Then, in 1987, the Statoil refinery then begins to pump its wastewater into a newly constructed pipeline to the Asnaes power plant to be used as raw boiler feed water. The power plant began to use waste heat from its own salt-water cooling tower to produce trout and turbot at its local fish farm in 1989. In the same year, Novo Nordisk made an agreement with the municipality of Kalundborg, the Asnaes power plant, and the Statoil refinery to connect to the pipeline supply grid from Lake Tisso (Christensen, 1999).

As the collaboration and linkages continued for the Kalundborg symbiosis, in 1989 the term ‘industrial symbiosis’ was first used to describe this collection of entities collaborating together. By the end of the 1980's, these "partners" had effectively "self-organized" into a working industrial ecosystem, or to use the term, industrial symbiosis. Between 1990 and 1993, the Statoil refinery completed a series of new linkages and sustainable programs, including the construction of a new sulfur recovery plant that takes recovered sulfur and sells it as raw material to a sulfuric acid manufacturer. The refinery then commissioned the construction of a pipeline to supply biologically treated effluent water from the refinery to be sent to the Asnaes power plant for cleaning use and for fly ash stabilization. It then constructs another pipeline to the power plant to supply flare gas as a supplementary fuel. In 1993, the Asnaes power plant began a desulfurization project from stack flue gas. The resulting calcium sulfate is sold to Gyproc, which uses this to replace imported natural gypsum used in manufacturing gypsum wall boards. These initial linkages were the catalyst for the current symbiosis. Since 1993, an additional fourteen connections have been established, and as of 2012 there were thirty-three total connections in the Kalundborg symbiosis network.

2.4.4 Kalundborg Circular Exchanges

The Kalundborg symbiosis is an industrial ecosystem, where unused outputs of one company is used as a resource by another company, in a closed cycle. An industrial symbiosis is a local collaboration where public and private enterprises buy and sell residual products, resulting in mutual economic and environmental benefits (Jacobsen, 2006)

As shown in Figure 11, the assorted material flows among the companies are based on either water, solid waste, or energy exchanges. As stated by Jacobsen (2006):

> In this system, wastewater and cooling water from the refinery are reused at the power plant: the wastewater for secondary purposes, the cooling water as feeder water for the boilers producing steam and electricity, and also as input water for the desulfurization process. The desulfurization process in turn produces industrial gypsum used in the production of plasterboard at the co-located Gyproc factory, thereby partly replacing the use of natural gypsum. The cogenerating power plant also produces heat for the town of Kalundborg and steam for the Novo facility and the Statoil refinery. The Novo facility is only supplied with steam from the power plant, whereas the refinery has production-related in house steam generation capacity, partly supplied by preheated boiler water from the power plant in a total-supply-security system. In addition, heated cooling water from the condensation process at the power plant is piped off to a nearby fish farm, thereby increasing the efficiency in the farm, as the heated cooling water ensures full-scale production of the fish throughout the year. Finally, solid by-products such as fly ash from coal combustion, sludge from public wastewater

treatment, and biomass from biogenetic fermentation at the Novo facility are recycled in various ways, both locally and non-locally. (p. 241)

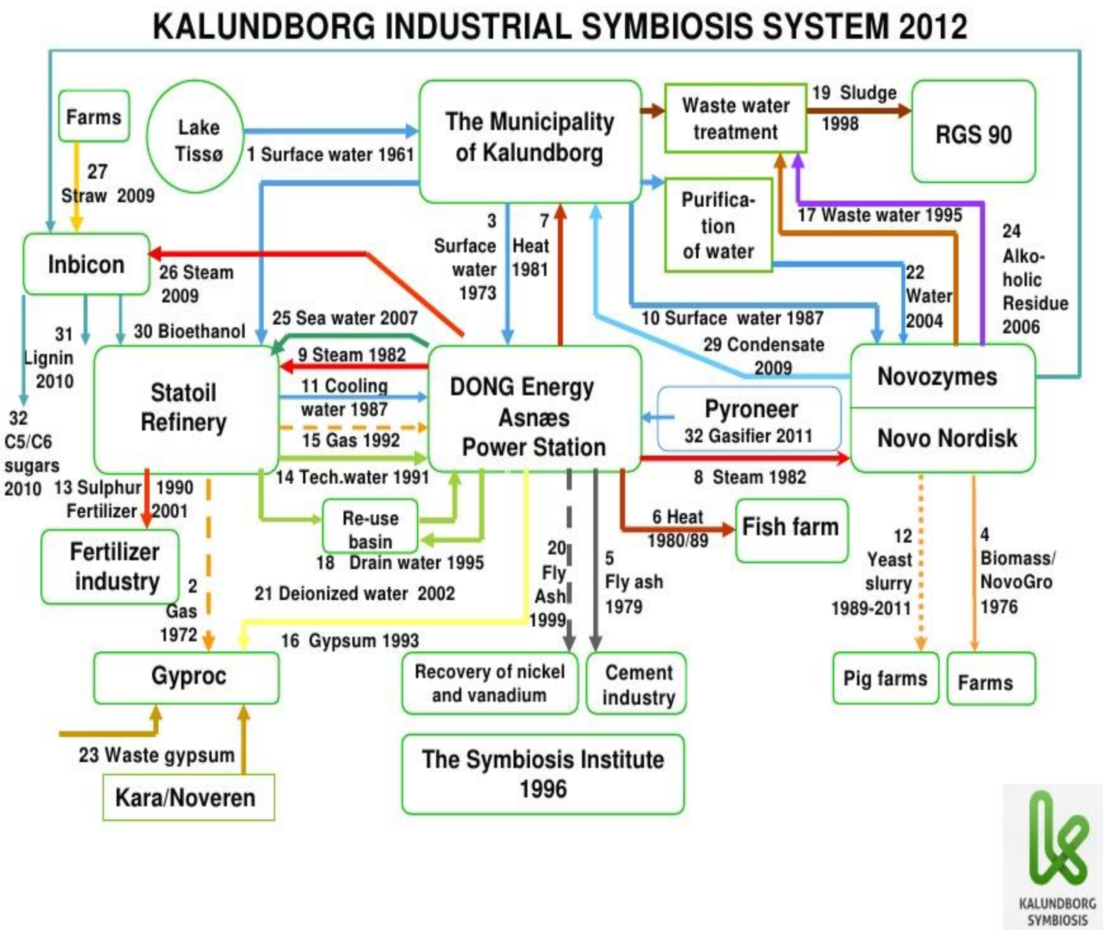


Figure 11: Kalundborg symbiosis circular exchanges (Kalundborg Symbiosis, 2016).

The circular exchanges as illustrated in Figure 11 demonstrate the intimate connection between the major companies involved and the Kalundborg community. All of them share ground water, surface water, wastewater, steam, and fuel. Most importantly, they are constantly adapting in their symbiotic processes through self-organization.

2.4.5 Kalundborg - Factors for Success

Through an analysis of Kalundborg symbiosis, we see that there can be triple bottom line advantages from the material flow exchange opportunities generated by collaborating through geographical proximity. Industrial ecology concepts are utilized. As stated previously by Garner and Keoleian (1995), the success of Kalundborg begins with a foundation of initial industrial ecology concepts. The fundamental concepts are ecology systems analysis, material and energy flows, material and energy transformations, a multidisciplinary approach, analogies to natural systems, and open- vs. closed-loop systems (Garner & Keoleian, 1995). These concepts are being utilized in Kalundborg in some form or another.

Kalundborg symbiosis is a self-organizing symbiosis model. Kalundborg evolved over time. It's a partner network adapting as the economic situation arose. It has the benefit of history on its side as companies slowly realized the economic benefits of their proximity to each other. This method is the complete opposite of a planned EIP model, where a conscious effort is made to identify specific companies and locating them together so they can share resources immediately, eliminating "the wait time" that self-organizing models like Kalundborg have endured over many decades.

Ultimately, the Kalundborg success primarily derives from the physical exchange of materials. In the 3/2 heuristic model three different entities must be involved in exchanging at least two different resources to be counted as a basic type of industrial symbiosis (Chertow, 2007). From that starting point, we expand into the three primary opportunities for exchange, namely by-product reuse, utility/infrastructure sharing, and joint provision of services. The glue that holds these three together is collaboration.

From this foundation, triple bottom line concept of sustainability is the result. This includes the six capitals model (SCM) indicators of sustainability and benefits gained as stated previously. Figure 12 shows the flow of elements to establish a baseline for factors of success:

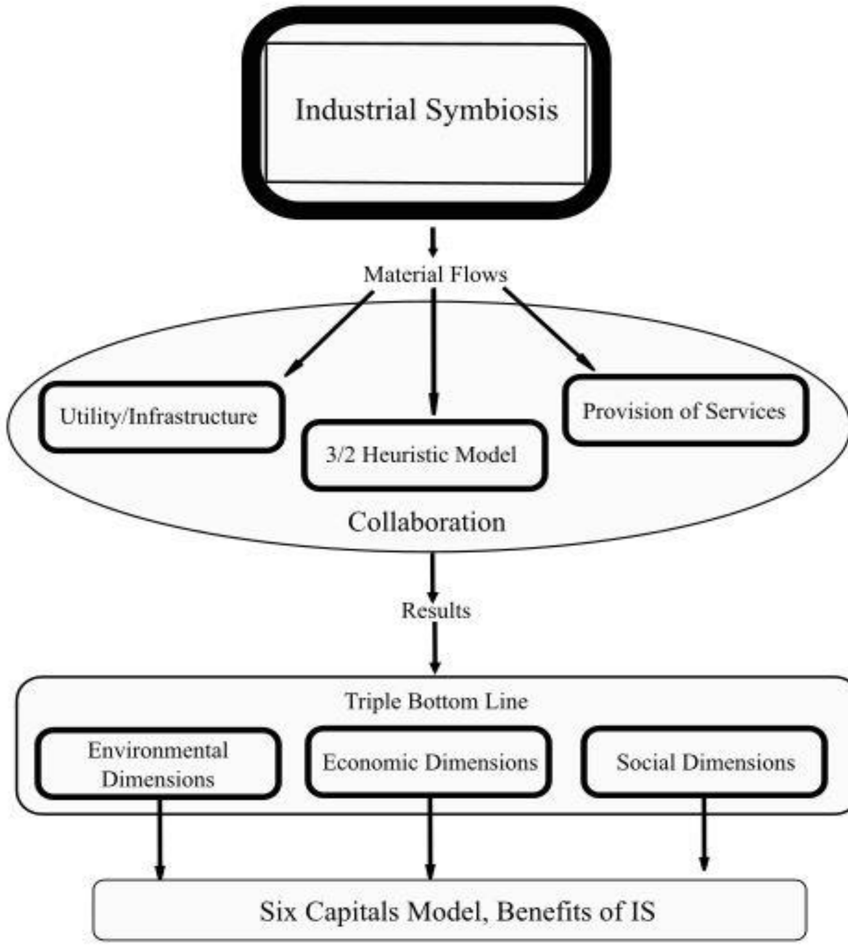


Figure 12: Kalundborg factors for success. (Derived from Chertow, 2007, Elkington, 2004)

With Kalundborg, the industrial potential existed with several large industries, limited physical distances, and good cultural fits. In addition to economic incentives, very small to no legal barriers and good communication exist. Plant managers were familiar with each other over a long period, and had the awareness, the willingness, and feasibility to trigger industrial symbiosis to happen spontaneously.

The motivation for most of the exchanges was to reduce costs by seeking income-producing uses for "waste" products. Slowly, the managers and residents of Kalundborg realized that through their transactions they were creating environmental benefits as well. The environmental benefits, resource savings, and economy all go together within the industrial symbiosis process. Figure 13 illustrates this process.

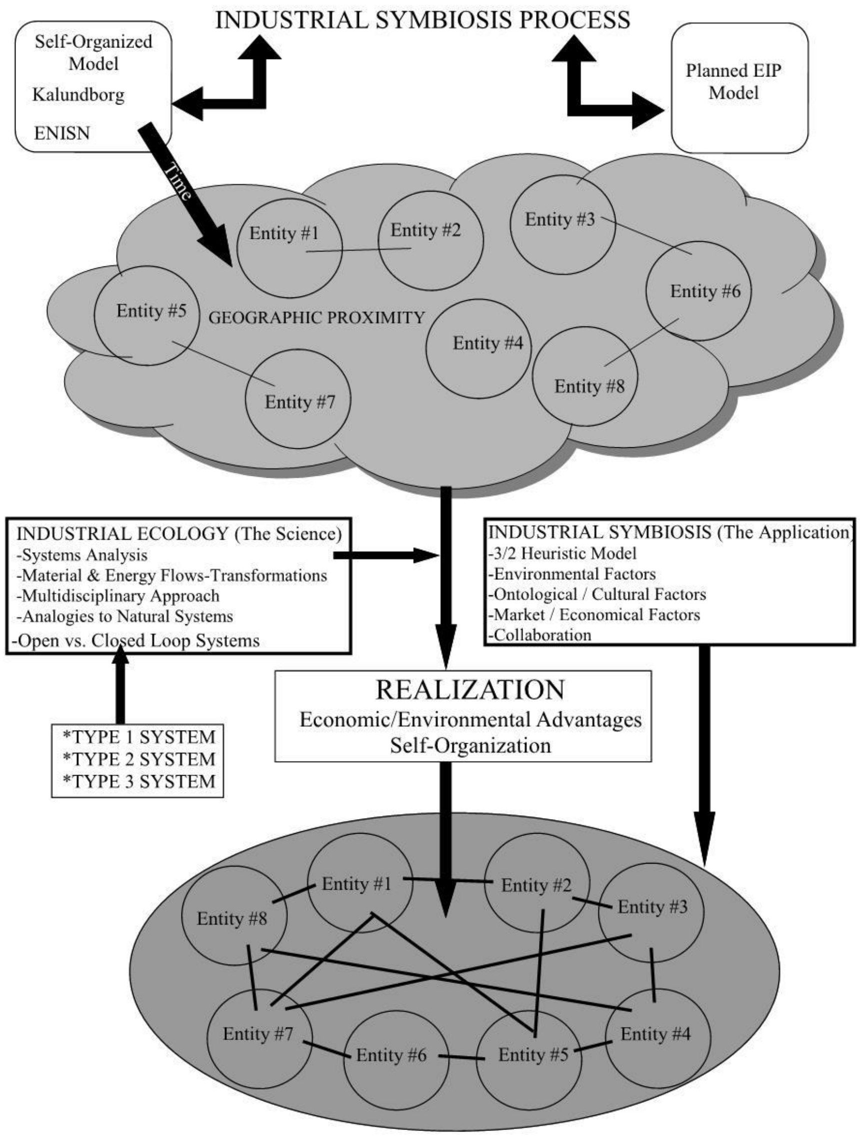


Figure 13: Industrial symbiosis - summary of concepts (Derived from Allenby, 1992, Chertow, 2007).

2.5 Profile of study area: Blair Nebraska and Surrounding Area

The selection of the area to be studied was determined by an advantageous set of circumstances, driven by an already successful bio-campus and the recent completion of the Novozymes enzyme plant built in Blair, Nebraska in 2011. As in the Kalundborg model, proximity was the initial determining factor for the ENISN model, where eight potential partners in the ENISN network are within one mile of each other (Figure 14 and 15).

2.5.1 Site Specific Maps

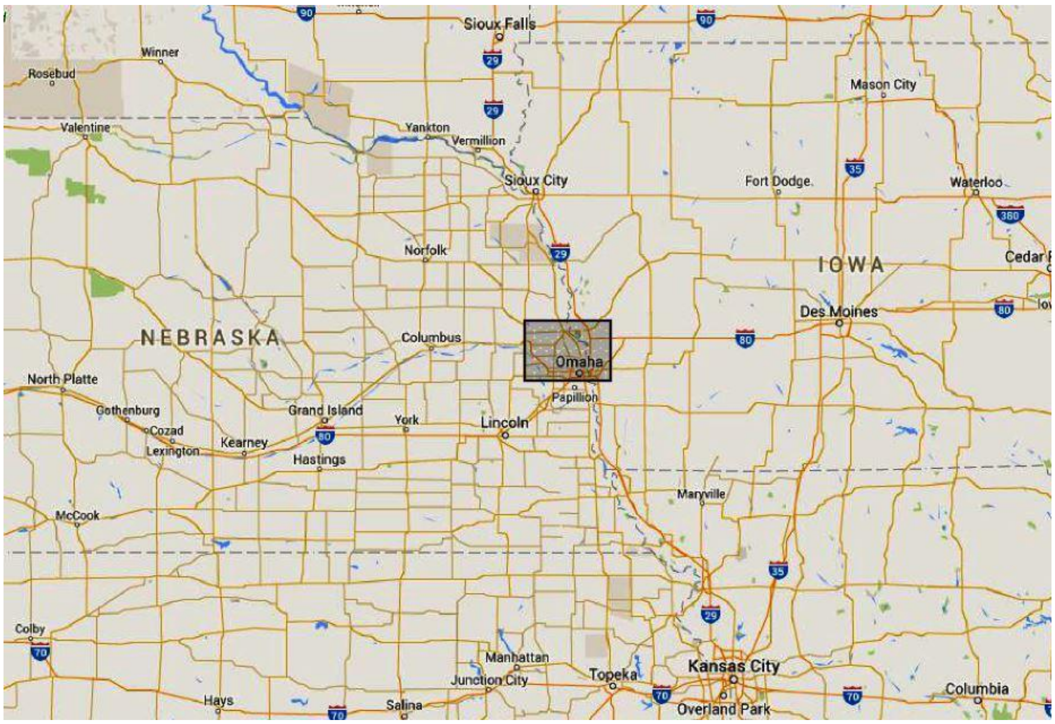


Figure 14: Nebraska state map (Google Maps, 2016).

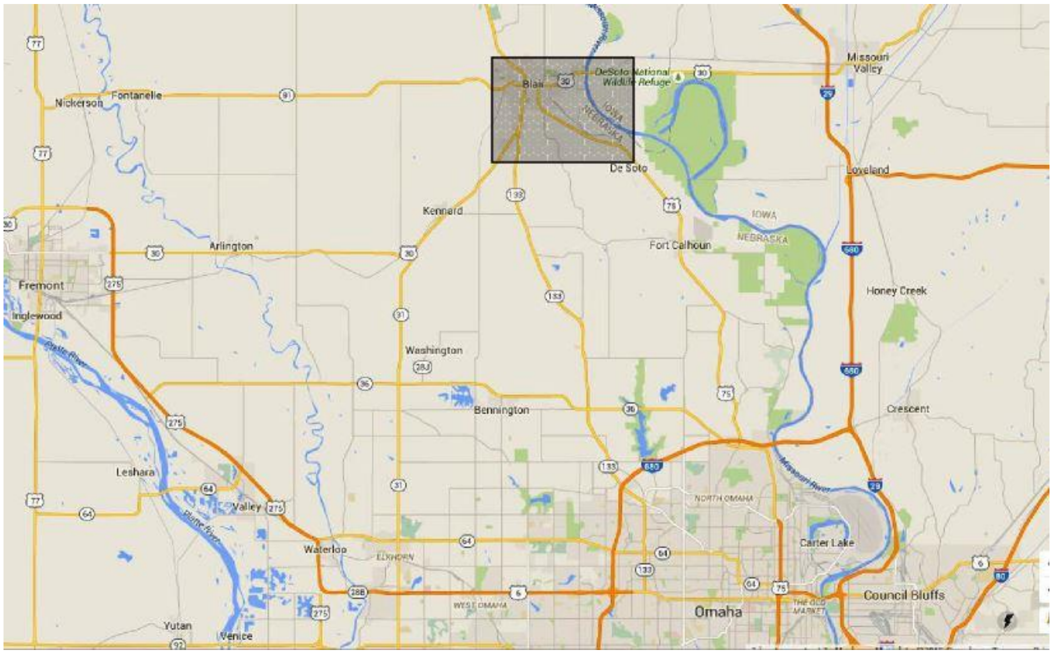


Figure 15: Eastern Nebraska regional map (Google Maps, 2016).

2.5.2 Economy of Region

The economy of the region is relatively strong, supported by a low unemployment rate of 2.7% in 2010 (US Census, 2010). Even though rural commodity industries have struggled in a global economy, the unemployment rate has remained steady. One of the major contributors to this trend is the new opportunities that Blair has embraced in the global economy, namely the industrial park that is home to both Cargill and Novozymes, two major players in the global market. As stated by Henderson (2004),

> New demand-driven technologies that create new products are emerging in agriculture. They cover a broad spectrum ranging from new uses for existing commodities to the creation of new "high-value" products. Ethanol represents a new use for agricultural commodities that is boosting demand. In Blair, Nebraska, the manufacturing of bio-plastics from corn is another example of a company using new technology to boost demand for agricultural commodities. At the other end of the spectrum, the production of proteins for human drugs in agricultural crops is an example of new technologies creating new "high value" products. U.S. export activity clearly demonstrates the ability of product agriculture to compete more effectively than commodity agriculture in a global economy. (p. 2)

Table 5 illustrates the top Blair occupations that represent the Blair economy.

Table 5: *Top Blair Nebraska occupations* (US Census, 2010).

Top Blair Occupations

View occupation data for Blair, NE below. The largest occupations are listed first.

Occupation	City	State	USA
Sales and office occupations	23.9%	25.0%	25.4% National Average
Service occupations	16.6%	16.2%	17.1% National Average
Management, business, and financial occupations	15.7%	15.0%	14.3% National Average
Production, transportation, and material moving occupations	14.7%	13.8%	12.4% National Average
Education, legal, community service, arts, and media occupations	10.9%	10.0%	10.6% National Average
Natural resources, construction, and maintenance occupations	7.0%	10.1%	9.8% National Average
Computer, engineering, and science occupations	5.8%	4.3%	5.2% National Average
Healthcare practitioners and technical occupations	5.5%	5.5%	5.2% National Average

Notes

City rating based on comparing Blair to other Nebraska cities.
State rating based on comparing Nebraska to other U.S. states.
All ratings are segmented into quintiles (very low, low, average, high, very high).
Data provided by the 2010 U.S. Census.

2.5.3 ENISN Partner Summaries

Identified potential partners that are part of this study are described below. These companies/municipality are identified as "Partners" since they would be working together in a symbiotic form. The partner summaries provide a brief description of each companies/municipality examined in the hypothetical ENISN network. The summaries give a background of the partners as they exist as a corporate entity and as a branch location in the study area in Eastern Nebraska.

2.5.3.1 Partner #1-Cargill

Cargill, a privately held, multinational company is based in Minnetonka, Minnesota, a suburb of Minneapolis. Cargill provides food, agriculture, financial, and industrial products and services throughout the world. Its major businesses include the trading, purchasing, and distribution of grain and other agricultural commodities, such as palm oil; trading in energy, steel and transport; the raising of livestock and production of feed; producing food ingredients such as starch and glucose syrup, vegetable oils and fats for application in processed foods and industrial use. Cargill also operates a large financial services arm, which manages financial risks in the commodity markets for the company. It employed 152,000 people in 67 countries in 2015 (Wikipedia.com, 2015).

For this study, the Cargill plant in Blair will be examined. The Blair facility began construction in 1993 and was operational in 1995, employing 400 people. The plant specializes in producing high fructose corn syrup, ethanol, crude corn oil, corn gluten meal, and feed products. Cargill also supplies dextrose and utility services to several on-site partners including Evonik, Novozymes and NatureWorks among others.

2.5.3.2 Partner #2-Novozymes

Novozymes, a Danish global biotechnology company, is headquartered in Bagsvaerd outside of Copenhagen, Denmark. Its primary focus is the research, development, and manufacturing of industrial enzymes, microorganisms, and biopharmaceutical elements. It employed 6,300 people worldwide in 2013 (Wikipedia.com, 2015).

This study examined the Novozymes plant in Blair. This plant began operations in 2012, producing enzymes for all major North American Biofuel Producers. These enzymes accelerate the biological processes of breaking down corn kernels into starch, then sugar, then ethanol. Although Novozymes' technology is used in more than 30 industries around the world, the Blair facility primarily focuses on the production of enzymes for ethanol. This was the main factor for Novozymes to select Blair as the site for this production facility, and its close proximity to the Cargill ethanol plant and its consumers in the Midwest. The Midwest region is home to the largest concentration of current and proposed ethanol plants in the U.S., which puts Novozymes closer to its customers and the vital raw materials necessary to produce ethanol.

2.5.3.3 Partner #3-Corbion

Corbion, originally known as CSM (Central Sugar Company) is the global market leader in lactic acid, lactic acid derivatives, and lactides. It also is a leading company in the production of functional blends containing enzymes, emulsifiers, minerals, and vitamins. It employees 1,893 people in 20 countries worldwide with its base of operations in Amsterdam, Netherlands. Corbion exists within two main market segments, biobased food ingredients and biochemicals. Biobased food ingredients is built around natural solutions that enhance the consumer experience of products from creation to consumption by extending freshness and providing safe and healthy food. Biochemicals are made from renewable resources like sugar, starch, or carbohydrates, and are a sustainable alternative to fossil-based chemicals (Corbion.com, 2015).

This study examined the Corbion plant in Blair. The facility in Blair was completed in 1998 and is a joint venture between Cargill's North American Corn Milling

Division and the PURAC Group, part of CSM's Ingredients Division. Corbion's PURAC is the brand name of its pharma-grade lactic acid solution. supplying a wide range of lactic acid derivative products.

2.5.3.4 Partner #4-Evonik

Evonik Industries is an industrial corporation headquartered in Essen, Germany, one of the world's leading specialty chemicals companies. Owned by the RAG Foundation, Evonik started in 2007, and united the business areas of chemicals, energy, and real estate within the RAG Foundation. Evonik employs 33,000 people worldwide and has interests in over 100 countries. In 2006, RAG acquired Degussa AG which was later renamed Evonik-Degussa GmbH.

This study examined the Evonik Degussa's Midwest Lysine plant in Blair. The Evonik Degussa plant in Blair began production in 2000, and it is one of the most successful of its kind in the world. Its main market product is the production of its market-leading amino acid product Biolys, an animal feed additive that benefits food production and increases sustainable methods. Through biotechnology, Evonik produces and markets all four essential amino acids that are used in modern animal nutrition: Biolys (L-lysine), MetAMINO (DL-methionine), ThreAMINO (L-threonine) and TrypAMINO(L-tryptophan).

2.5.3.5 Partner #5-NatureWorks

NatureWorks LLC is a company that produces bioplastics, polymers derived entirely from annually renewable plant resources, creating a market alternative to traditional plastics which are based on petroleum. The commercial grade polymer is made from carbons located as simple sugars in plants, such as cornstarch. The proprietary brand name of this product under Natureworks is called Ingeo, which covers the monomer, lactide, and a polylactic acid polymer, or PLA. Natureworks is headquartered in Minnetonka, Minnesota and is jointly owned by Cargill and PTT Global Chemical.

This study examined the Natureworks manufacturing plant in Blair, Nebraska. The plant began production in 2001, and it is the first and largest of its kind to produce PLA's to all worldwide markets. NatureWorks has roughly 130 employees worldwide with approximately 40 of those in Blair.

2.5.3.6 Partner #6-OPPD Pressurized Water Reactor (Nuclear Power)

The Fort Calhoun Station (FCS) is a pressurized water reactor (PWR) that generates about 35% of the retail energy produced by the Omaha Public Power District (OPPD). The plant is located on a 660-acre site along the west bank of the Missouri River between the cities of Blair and Fort Calhoun approximately 19 miles north of Omaha, Nebraska. The plant originally broke ground for construction in 1968, began initial fuel loading in 1973 and reached initial criticality in August of 1973. The plant reached full power output for the first time on May 4, 1974. In 2013, OPPD received an operating license extension from the U.S. Nuclear Regulatory Commission that extended the current operating license from 2013 through 2033. The unit is in the process of upgrading several key components to gain an additional 75-80 MW electric by the end of 2012 (Utilities Services Alliance, 2015).

This study examined the OPPD pressurized water reactor for its potential as a process heat source for the proposed ENISN. The reclamation of industrial waste heat is a largely untapped type of energy utilizing two different processes. One process is combined heat and power (CHP), which is the use of a single fuel source to generate both thermal energy (heating or cooling) and electricity. Another process, waste heat to power (WHP), is the process of capturing heat discarded by an existing industrial process and using that heat to generate power. In addition, excess heat and steam can be used as a source of energy in other bio-refinery applications, such as biochemical fermentation, or thermochemical conversion.

2.5.3.7 Partner #7-Blair Wastewater Treatment Plant

The Blair wastewater treatment plant utilizes an activated sludge treatment process. Activated sludge is a process for treating sewage and industrial wastewaters using air and a biological floc composed of bacteria and protozoa. Activated sludge refers to a mass of microorganisms cultivated in the treatment process to break down organic matter into carbon dioxide, water, and other inorganic compounds. The activated sludge process has three basic components; 1) a reactor in which the microorganisms are kept in suspension, aerated, and in contact with the waste they are treating, 2) liquid-solid separation, and 3) a sludge recycling system for returning activated sludge back to the beginning of the process. There are many variants of activated sludge processes, including variations in the aeration method and the way the sludge is returned to the process (Wikipedia, 2015).

This study examined the Blair Wastewater plant as a potential partner within the ENISN, utilizing the need to clean wastewater within a system and potentially using the waste sludge for other environmental purposes.

2.5.3.8 Partner #8-Municipality of Blair

The City of Blair is located in eastern Nebraska on the Missouri River, approximately 20 miles north of the metropolitan Omaha area. Highways that run through Blair include Nebraska Highway 133 (Blair High Road), US Highway 30, US Highway 75 and Nebraska Highway 91. Interstate 29 is fifteen minutes east on Highway 30, and Interstate 680/80 is twenty-five minutes south on Highway 133. As of the 2010 U.S. census, Blair had a total population of 7,990. Blair is the county seat of Washington County (2010 population of 20,234). The city covers a total area of 5.5 square miles. Blair has an advantageous location near the Missouri River and the city of Omaha. Yet, since it is outside the Omaha city limits, it is self-governed and provides benefits to companies who locate their industry there.

Chapter 3

Methodology

3.1 Introduction

As stated previously in Section 2.5, the area studied has an advantageous set of circumstances that at first glance appear to have many of qualities similar to the Kalundborg symbiosis. A collection of industries and the municipality of Blair, Nebraska were chosen primarily because of their already established local proximity to one another, one of the most important factors of industrial symbiosis.

3.2 Study Area

The research portion of this study includes gathering information from potential ENISN partners in this study area, shown in Figure 16:

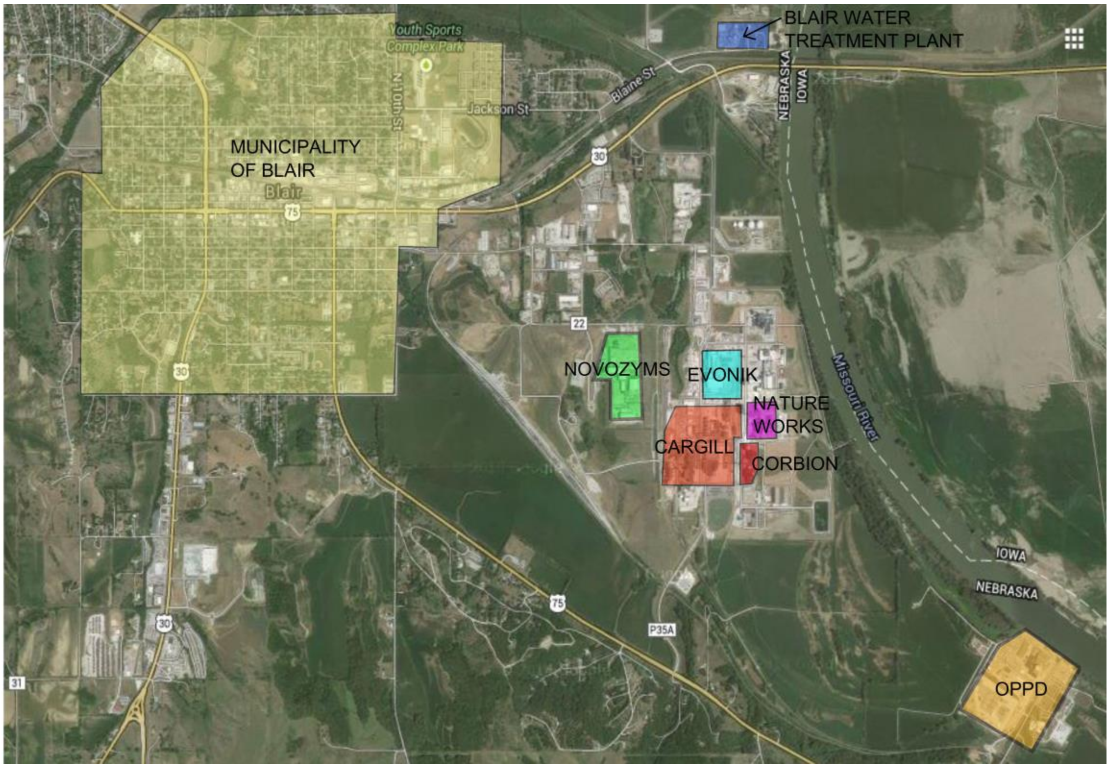


Figure 16: ENISN site study map (Google maps, 2016).

3.3 Research Sequence

The information required for this study requires interactions with the industries and public entities located in the study area. Understanding any current linkages between the companies or municipalities, water uses and treatment, waste generation, and production processes all factor into the research methodology. In addition, attempting to understand the ontologies at work within this area is also important. Driving forces such as institutional, policy, market forces, and trade and legal requirements for the creation of the ENISN are also important for a more comprehensive grasp of the area and if it has the potential as an industrial symbiotic network.

An overall research methodology is illustrated in Figure 17. This highlights the main points of emphasis beginning with the study objectives, the body of information deriving from the qualitative field study and the ancillary data sources; this will facilitate the survey document, comparison, data results, and conclusions.

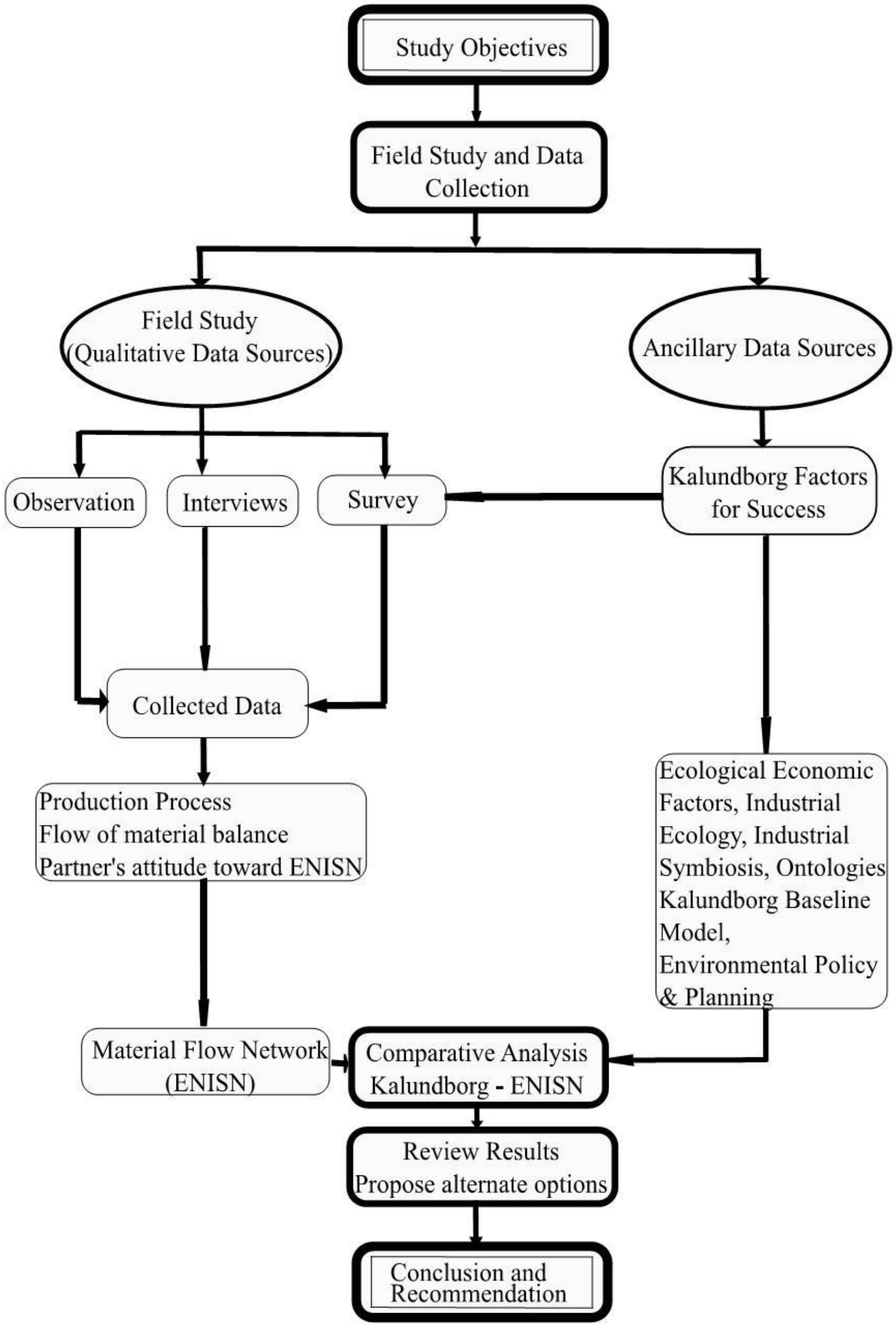
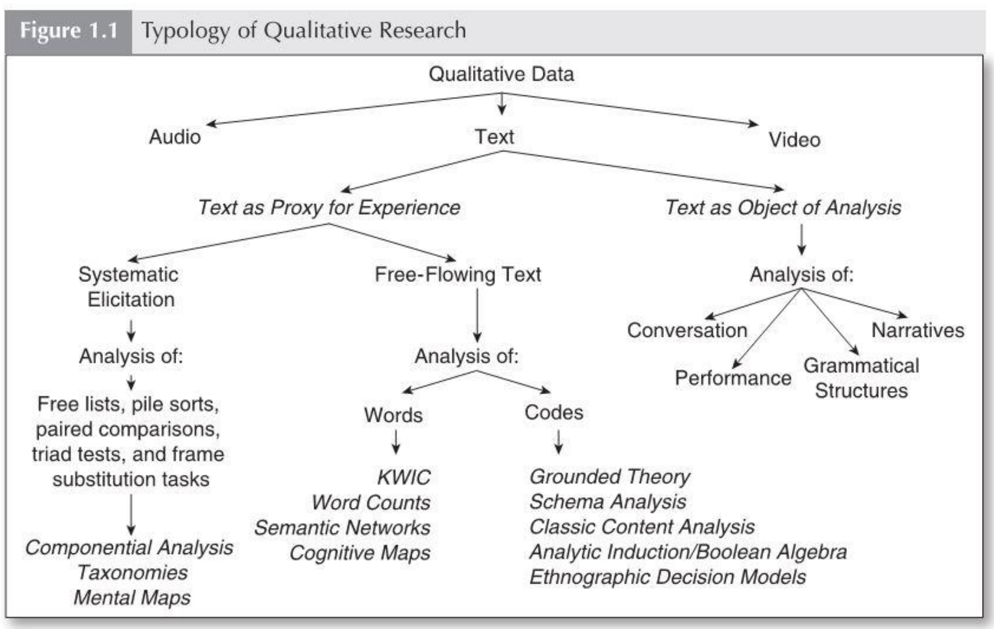


Figure 17: Overall research flow chart.

3.4 Qualitative Research Design

This study used a qualitative method of information collection. Qualitative research is primarily exploratory research. It is used to comprehend the underlying reasons, motivations, and opinions of the study participants. It provides insights into the ontologies of the ENISN potential partners. “Qualitative researchers are interested in understanding the meaning people have constructed, that is, how people make sense of their world and the experiences they have in the world” (Merriam, 2009, p. 13). As shown in Figure 18, the typology of qualitative research that divides qualitative data into three main forms, which are text, images, and sounds. Qualitative data was gathered from interviews with representatives of potential ENISN partner industries and the city of Blair. This data was augmented by information derived from a survey of potential partners detailing characteristics of their operations, a material flow analysis of a potential network, and personal observations.



Source: Ryan and Bernard (2000).

Figure 18: Qualitative research typology (Ryan & Bernard, 2000).

The data collection methods used in this study produce textual data as a proxy for experience and as a means to understand the social, economic, and environmental frames that currently exist in the ENISN study area. A common thread throughout almost all forms of qualitative research is its inductive and flexible nature, utilizing an open-ended and inductive style of questioning and observation. The use of surveys and interviews in this study as well as continuing contact via emails or phone questions has provided the necessary “follow up” in response to participants’ answers (Maxwell, 2013).

3.5 Data Collection

As stated previously, the researcher assumed the scope of this study would be limited by the depth of information provided by the potential partners in the study area. Proprietary concerns regarding confidentiality based on corporate restrictions, client agreements, competitive reasons, and standards of operation limits the study to some degree. Client/customer confidentiality drives proprietary concerns.

These factors led the researcher to conclude that a level of trust needs to be established with the contacts of the potential partners in the study. As stated by Eschrich (2002, p. 1),

> The researcher's job is to unearth attitudes, values, motivations, and behaviors in relation to certain subjects - often in spite of respondents' contention that they've never thought about it, they have no opinions, or they have nothing of value to report. Establishing and maintaining rapport is the foundation upon which all interactive research is based. It is the root of qualitative research.

Based on this the researcher felt that given the nature of the potential partners being investigated, that it was important to go through all the proper channels to identify the proper contacts and develop a sense of trust with each of these contacts. Once the contacts were established, the field study portion of the study was started. There were nine total participants answering questions for the ENISN partners. There were 8 males and 1 female. Contact was made through email to the potential partners and the researcher verified what form of discussion would be preferred.

For the study, it was decided to use two survey methods of data collection. A survey is a research method for collecting information from a selected group of people using standardized questionnaires or interviews. While many people think of a questionnaire as the "survey", the questionnaire is just one part of the survey process (Innovation Insights, 2006). First, an initial email survey questionnaire was sent to the potential ENISN partners in an attempt to gain an overarching collection of initial data regarding characteristics of their operations. The questions posed were both open-ended and closed questions. This method was preferred for the ease of delivery through email and the ability for the contacts to review the questions and determine what was acceptable to answer based on their company confidentiality. This also provided additional time to build trust with the partner, who would contact the researcher if needed to go over what could be answered or not. There were relatively no time constraints placed on the contacts to complete the survey, although follow up emails about the status of the survey were sent until the surveys were completed.

Second, phone interviews were conducted as part of the data collection survey. A separate collection of questions was developed in order to gain a better understanding of the human dimension frame of the study. Questions on this part of the survey were all open-ended questions allowing for potentially deeper answers. The open-ended questioning allowed for deeper analysis of thematic elements discussed later.

Third, a site visit was conducted with Partner #2, Novozymes. The Novozymes tour was conducted to gain an overall geographical perspective of the site and the complexity of the operations from a personal view.

3.5.1 Data Instruments

The researcher identified three different types of potential partners within the study. Bio-campus/industrial plants, Blair municipality, and the OPPD nuclear power plant. Because of this, the initial survey questionnaire and phone interviews were developed based on who was being interviewed. The "style" of questions pertained to the same study goals, namely, the ENISN potential, but the wording was customized for the specific type of partner for clarification. In addition, the University of Nebraska-Lincoln Institutional Review Board (IRB) reviewed the survey instruments and data collection procedure. It was determined that this project is not human subjects research and therefore does not require IRB approval (see Appendix F). The following is a list of the survey collection instruments and which participating partner received it based on the participant's desired level of survey interaction. Each was preceded with a descriptive cover (see Appendix A).

Instruments of Data Collection:

1) Bio-campus/industrial plant survey questionnaire (see Appendix B). The grouping of industries on the Cargill industrial site used this questionnaire.

   Used for:
   Partner #1-Cargill,
   Partner #2-Novozymes
   Partner #3-Corbion
   Partner #4-Evonik
   Partner #5-NatureWorks
   Partner #7-Blair wastewater treatment plant was also included in this grouping because of the similar nature of operations.

The Bio-campus/industrial plant survey questionnaire is grouped into five main question group categories. The questions were designed to engage the three primary organization parts of industrial symbiosis, economic, environmental, social, as well as develop background information on the companies and material flow. Group one questions are about the potential partner, employee numbers, and size. Group two questions focus on production process and flow data. Group three questions are asking about waste generation and management. Group four questions ask about sustainable perspectives, goals and collaboration. Group five questions focus on the social aspects of industrial symbiosis, connections to the community, and the environment. A total of 29 questions were asked. The primary reason for the survey with the potential ENISN partners is to gain specific information about their operations, materials flow connection to the environment, raw materials (inputs & waste), wastewater and solid waste; both generation and treatment water consumption, energy consumption, transportation methods, collaborative interests, and any economic information.

2) Municipality of Blair survey questionnaire (see Appendix C). Since the nature of the questions for an ENISN were different for the City of Blair, in lieu of an industrial plant survey, a separate survey was emailed to a Blair city official to gain an understanding of the connection the city could have in the ENISN.

   Used for:
   Partner #8 – City of Blair

The city of Blair as an ENISN contact is a special partner. It does not fall within the typical bounds of a standard industrial park or industrial plant. The dimensions of the city of Blair fall more within the human capital side of the study and therefore require a separate set of questions.

3.) Phone Survey Interview-OPPD (see Appendix D). The OPPD Fort Calhoun Nuclear Power Plant is a unique partner as it is separate from the city of Blair and not part of the Blair Bio-Campus, yet it's geographic proximity to the other partners qualifies it for this study.

Used for:
Partner #6 - OPPD

The main contact at OPPD wanted to perform the survey over the phone. The contact felt that would be a better way to describe the potential that the nuclear plant could have within a potential ENISN.

4.) Phone survey interview (see Appendix E). In addition to the emailed questionnaire, phone interviews were conducted with any ENISN partners that wanted to participate.

Used for:
Partner #1-Cargill,
Partner #2-Novozymes
Partner #3-Corbion
Partner #5-NatureWorks
Partner #7-Blair Wastewater Treatment

In addition to the survey as a source of field information detailing operational characteristics, a telephone interview was conducted with all partners. The phone interview was designed to gather information on human dimension aspects of the study area. Social elements of industrial symbiosis are an important aspect that includes how the culture, values, cohesion and norms of the proposed partners function together. Phone interviews were conducted. These were digitally recorded at the time of the interview. The next level of analysis involved the transcription process. The researcher transcribed verbatim each of the contacts answers onto another form for use in the thematic analysis portion of the data analysis described in section 3.6.3.

3.6 Data Analysis Approach

In order to analyze the returned data, the researcher reviewed the initial objectives and formulated analysis methods. This provided a foundational scientific basis from which to draw upon to answer the initial questions of material flows; environmental, economic and social circumstances; ontologies of the study area, and then draw comparisons between Kalundborg and the proposed ENISN as conclusions and recommendations are formulated.

3.6.1 Survey Questionnaire Exploratory Analysis

The initial survey questionnaire data will be separated into two groups of information based off the main two main types of analysis, material flows and inductive themes. In addition, information from the group one survey questions will be used in the ENISN partner summaries. The other purpose for the survey questionnaire is exploratory in nature. It provides a pre-analysis of the potential partners and what information they will be able to provide. It gives insight as to what additional questions should be asked in the phone interviews, which were conducted after the survey questionnaires. Exploratory data analysis (EDA) means looking at the data, sometimes before all the data has been collected and entered, to get an idea of what is there. It can lead to additional data collection if this is seen to be needed (Statistical Services Center, 2001).

3.6.2 Material Flow Analysis

To gain an overall understanding of the operations involved, including what was being produced as the final products, the inputs (natural resources), and the outputs (by-products), concepts from material flow analysis (MFA) was completed and shown through value chain mapping. A value mapping chain creates a visual representation of the connections between businesses as well as other market players.

From this data, the researcher attempted to identify what outputs, or waste products, that could be used as potential inputs for another partner in the study area, or a potential member partner being inserted into the ENISN as a hypothetical situation.

As stated previously, industrial ecology strives to reduce the amount of waste material and energy that is produced and that leaves the industrial system, subsequently affecting ecological systems adversely (Garner & Keoleian, 1995). The second concept of industrial ecology is material and energy flows and transformations, is a primary part of industrial ecology, including the transformation of products, byproducts, and wastes throughout industrial systems (Garner & Keoleian, 1995).

The researcher then created a “Study Area – Inputs & Outputs” excel spreadsheet to organize this data. From this information, an MFA diagram was created to visually identify the current circulation pattern of materials within the study area. Research into the MFA model was done by (Hinterberger, Giljum, & Hammer, 2003) whereby a historical precedent of MFA had been built on earlier concepts of material and energy balancing, as introduced, for example, by (Ayres, 1978). The first material flow accounts on the national level have been presented at the beginning of the 1990s for Austria (Steurer, 1992) and Japan (Environment Agency Japan, 1992). Since then, MFA has been a rapidly growing field of scientific interest and major efforts have been undertaken to harmonize the different methodological approaches developed by different research teams (Hinterberger, Giljum, & Hammer, 2003). This study drew upon the methodological foundations of this research by drawing upon the principle concepts discussed by Giljum, Hammer, and Hinterberger (2003),

> underlying the economy-wide MFA approach is a simple model of the interrelation between the economy and the environment, in which the economy is an embedded subsystem of the environment and – similar to living beings – dependent on a constant throughput of materials and energy. Raw materials, water and air are extracted from the natural system as inputs, transformed into products and finally re-transferred to the natural system as outputs (waste and emissions). (p. 2)

3.6.3 Inductive Thematic Analysis

Industrial symbiosis' main themes, or factors for success can be divided into three main divisions, namely the environmental, economic and social implications. The human dimension relationships as they overlap these three parts are a driving motivation in the study area. In order to begin to understand this part of the ontological equation, the researcher used thematic analysis of interview transcripts that involves the reading of textual data, coding those themes, identifying themes, and then interpreting the structure and content of the themes. Themes are the abstract constructs that investigators identify before, during, and after data collection (Ryan & Bernard, 2003).

Words that occur often are seen as being salient in the minds of respondents (Ryan & Bernard, 2003). The use of certain words throughout the surveys can indicate certain perceptions and indicators of how the contacts perceive industrial symbiosis terms and the "frame" of the study area. "Perhaps the simplest and most direct indication of schematic organization in naturalistic discourse is the repetition of associative linkages" (D'Andrade, 1991, p. 294). D'Andrade (1991) observed that "indeed, anyone who has listened to long stretches of talk, whether generated by a friend, spouse, workmate, informant, or patient, knows how frequently people circle through the same network of ideas" (p. 287). As surmised by Miles and Huberman (1994), there are at least three reasons for counting words in qualitative data analysis: (a) to identify patterns more easily, (b) to verify a hypothesis, and (c) to maintain analytic integrity.

The information was returned as written text either on the survey form, or through written email by the contact describing what could be answered or not. Phone interviews were also conducted. These were digitally recorded at the time of the interview. The next level of analysis involved the transcription process. The researcher transcribed verbatim each of the contacts answers onto another form for coding analysis. The coding analysis grouped themes into the three main divisions of industrial symbiosis, environmental themes, economic themes, and social themes.

Chapter 4

Results

4.1 Summary of Results

As described in section 3.1.3 Data Collection Design, eight potential ENISN partners were identified for this study and were surveyed based on the data collection design process. Once all the information was provided through the emailed survey and phone interviews, the information was analyzed. The following are the results.

4.1.1 Survey Questionnaire of Potential Partner Characteristics Results

The returned survey questionnaires provided information that was beneficial to the study; however, some questions were not answered based on confidentiality concerns. The group one questions were answered and provided basic background information on the partners. This information was used in the ENISN partner summaries in section 2.5.3. The group two questions that focused on production process and flow data, were answered based on specific company confidentiality. Typically, specific quantities or water and electricity that are consumed could not be provided. Volumes and names of clients could not be provided.

The Blair wastewater treatment plant did provide quantities. The flow information, names of inputs, names of outputs, names of products produced, and transport of goods and services were provided. The information gathered in these were used in the material flow analysis portion of the data results. The group three questions pertaining to waste generation and management also did not provide any quantities from the Blair bio-campus partners, but the Blair wastewater treatment plant did provide actual quantities. Flow data and how wastes were treated and disposed of were provided in the survey. The group four questions asked about sustainable perspectives, goals and collaboration, which were answered. The group five questions that focused on the social aspects of industrial symbiosis, connections to the community, and the environment were also answered. The information gathered in the question groups four and five were used in the thematic analysis portion of the study. By using exploratory data analysis of the survey questionnaire results, additional questions were created for the phone interviews that provided necessary human dimension analysis.

4.1.2 Material Flow Results

The material flows reveal the inputs, outputs, and products produced on the site and within the study area. The results are limited because of the confidential nature of the information. For primarily competitive reasons, the study contacts are restricted from providing actual quantities or volumes. A general response from the contacts was that no specific quantities of inputs, outputs, or final products could be provided. The flows of inputs could be given however. The general wastes that are generated is provided but not quantities. The lack of volumes and quantities will not allow the creation of any quantitative analysis. However, the input-output data and flow chain mapping data will provide information for a qualitative analysis. See Table 6 and Figure 24.

Moving from linear throughput to closed-loop material and energy use is a key theme in industrial ecology (Ehrenfeld & Gertler, 1997) and is also one of the characteristics of what is discussed as a "mature" Eco-Industrial Park. This process, described as a change from a Type I to a Type III System (Allenby, 1992) is seen as the evolution towards industrial ecosystems (Fleig, 2000).

In reviewing the material flow diagram, it would appear that the current ENSIN area frames between a Type I system and the beginnings of a Type II system. Materials and energy enter clearly enter parts of the system, are partially recycled, reused, and then exit either as products or by-products/wastes. A partial collaboration of ecosystem components utilizing the exchanging of energy and materials and infrastructure occurs.

Table 6: *Study area – inputs and outputs*.

Facility/Partner	Products Manufactured	Inputs	Outputs (By-products)
Cargill (Partner #1)	High fructose corn syrup Ethanol Crude corn oil Corn gluten meal Feed products Dextrose Others: *Steam *Waste water treatment	Corn Water Electricity Natural Gas Steam Other Chemicals	Wastewater Lactic acid bottoms Other solid wastes
Novozymes (Partner #2)	Spirizyme Achieve Spirizyme Fuel Avantec CTEC 3 CTEC 4U	Heat/Steam Electricity Water Dextrose Protein Mineral Salts Vitamins	Wastewater Biomass
Corbion (Partner #3)	Lactic Acid Derivatives	Dextrose Nutrients Potassium Hydroxide Sodium Hydroxide Acetic Acid Water Steam Electricity	Wastewater Gypsum Biomass Stillage
Evonik (Partner #4)	Lysine Sulfate (Biolys)	Dextrose Sulfruric Acid Ammonia Water Electricity	Wastewater
Nature Works (Partner #5)	Polylactic Acid *PLA (Ingeo) Lactide	Lactic Acid Process Catalyst Polymer Catalyst Catalyst Deactivator Water for Cooling Only Electricity	Wastewater Solid Waste
OPPD - Ft Calhoun Nuclear Power Plant (Partner #6)	Electricity	Water	Excess Steam Excess Heat (*Do not count spent nuclear fuel)
Blair Waste Water Treatment Plant (Partner #7)	Purified Water	Waste water	Activated Sludge
Municipality of Blair (Partner #8)	N/A	Human Capital	Wastewater Trash

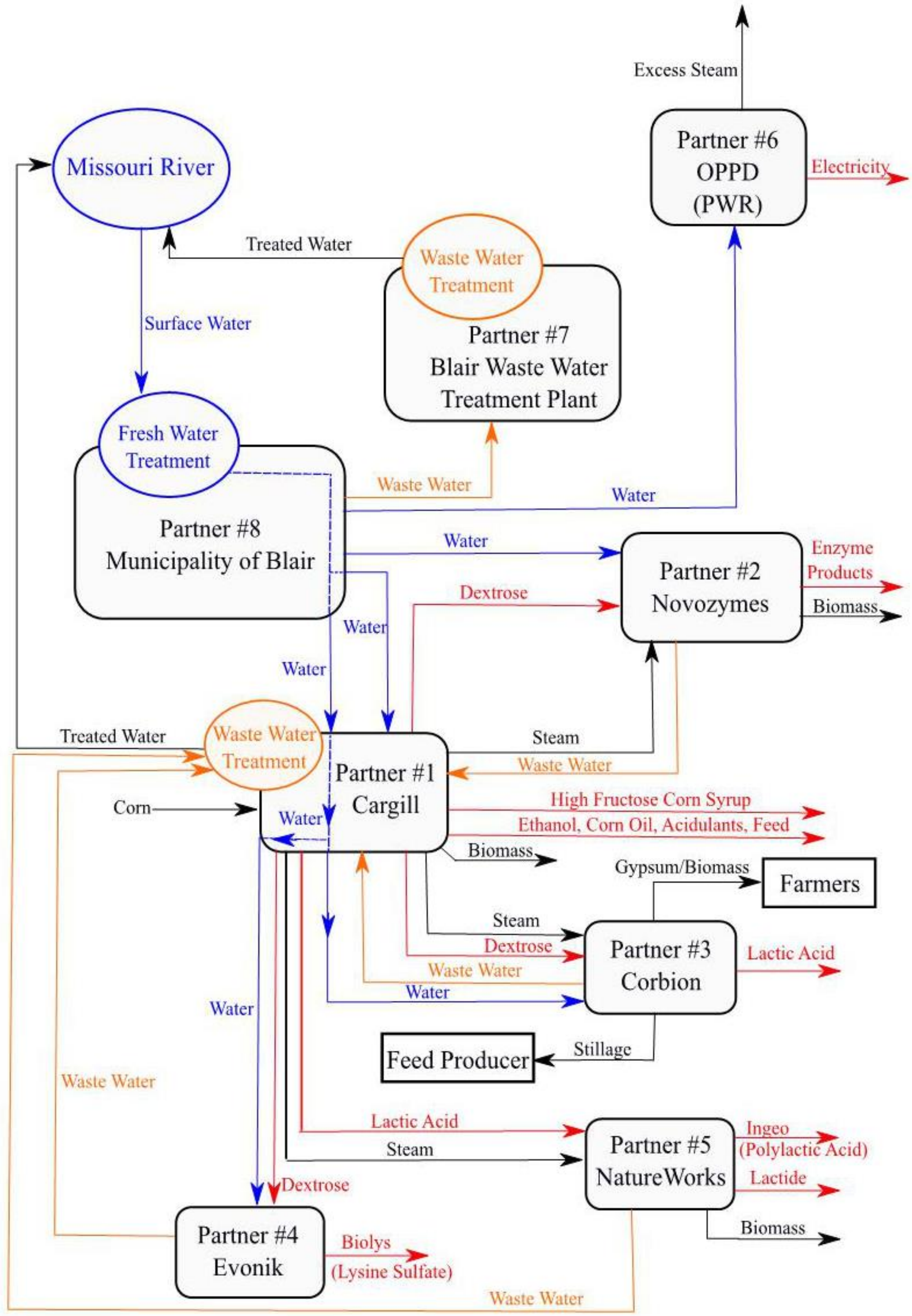


Figure 19: Study area material flow diagram.

4.1.3 Inductive Thematic Results

As shown in Table 7, nine themes emerged over the course of the survey interviews. The table includes identifying research. In addition, descriptive paragraphs summarize each theme with supporting anonymous quotes to back up the theme coding.

Table 7: *Themes from partners in the ENISN study area.*

Theme	Definition	Supporting Research
Environmental		
1) Environmental Stewardship	Environmental stewardship refers to responsible use and protection of the natural environment through conservation and sustainable practices.	Chapin, M.C., Chapin, S., Folke, Kofinas, 2009
2) Resource Efficiency	Allocating the Earth's limited resources in a sustainable manner while minimising environmental impact.	Daly & Farley, 2001
Economic		
3) Economically Viable	The current economic model is commercially sound, feasible, & profitable.	Chertow, 2007; Desrochers, 2000
Sub-theme-Geographical Proximity	Advantages of being near fellow business partners.	
Sub-theme-Utility/Infrastructure	Common use of facilities for economic gains as a whole.	
Sub theme-Competition between partners	Companies sharing site also compete for part of market.	
Sub theme-Intellectual Property	The company specific trade secrets, both technological and human based.	
4) Regulatory Responsibilities	State & Federal requirements for operational permits.	Martin, Weitz, Cushman, Sharma, & Lindrooth,1996
5) Liability Concerns	Risk to a company arising from the possibility of liability for damages resulting from the purchase, ownership, or use of a good or service offered by that company.	Martin, Weitz, Cushman, Sharma, & Lindrooth,1996
Social		
6) Collaboration	The communication and cooperation between partners through the sharing of information to make strong relationships.	Chertow, 2000
7) Human Capital	Human capital is a collection of resources—all the knowledge, talents, skills, abilities, experience, intelligence, training, judgment, and wisdom possessed individually and collectively by individuals in a population.	Olayemi, 2012
8) Community Connection	A sense of pride in and around the city of Blair that assists the social benefits and social capital of area.	Kurup & Stehlik, 2006
9) Anchor Tenant	A partner that is willing to take on the responsibilty and leadership to move the ENISN forward-A "visionary champion."	Koenig, 2009; Gingrich 2012

Theme 1: Environmental Stewardship

Environmental stewardship refers to responsible use and protection of the natural environment through conservation and sustainable practices (Wikipedia, 2016). The term has gained a stronger sense of ecological resilience based on the prevalence of sustainable activities in all areas of society. Resilience-based ecosystem stewardship emphasizes resilience as a basic feature of the changing world as well as ecosystems that provide a suite of ecosystem services rather than a single resource, and stewardship that recognizes resource managers as an integral part of the systems they manage (Chapin, Chapin, Folke, & Kofinas, 2009). This theme was prevalent throughout the survey process. Examples of this theme include:

> "Positive stewardship and sustainability results from the potential opportunities of resource exchange."
>
> "You can have a business that's good for the environment and good economically."
>
> "Our companies are very environmentally attuned to what is going on."
>
> "We believe in protecting and conserving the environment."
>
> "We have the "Flagship for the State" in a volunteer recycling group"

Theme 2: Resource Efficiency

Effective use of raw materials is an important part of industrial symbiosis. The study of economics is the allocation of scarce, limited resources in the middle of many competing ends of two or more available possibilities. Economics has been defined as the science of the allocation of scarce resources among alternative ends. This means that the three tasks of the economist, in order of importance, are to determine what are the desired ends, what are the scarce resources required to meet those ends, and finally how these resources can best be allocated among those ends (Daly & Farley, 2004). Examples of this theme include:

> "Positive outcomes around resource efficiency would be an important part of it."
>
> "I think there's the potential for shared energy optimization."
>
> "We are developing ways to reduce our environmental impact to help conserve natural resources."
>
> "The potential for shared energy optimization."

Theme 3: Economically Viable

The economical dimension of industrial symbiosis is a major driving force within any potential industrial symbiosis model. Markets are spontaneous orders sustained by an institutional framework dominated by the pricing process and private property rights. Private planning through a market relies heavily on decentralized decision-making and a trial-and-error process of discovery and improvement (Desrochers, 2000). The theme of being economically viable was an important one in the ENISN discussion with the contacts. Examples of this theme include:

> "The existing business model as it currently exists could be a barrier."
>
> "Purchasing power of raw materials is biggest positive."
>
> "We believe that you can have processes and products that are economically viable and sustainable"
>
> "We see economic development as part of our lifeblood and the lifeblood of this region of the state too."
>
> "The "over-the-fence" concept allows each of the businesses to achieve economies of scale they would not enjoy on a stand-alone basis."

"Not very interested in additional tax burdens for our citizens."

"We are constantly looking at those opportunities and evaluating the economics."

"The different business models to compete globally"

"You have to look at the cost/benefit analysis."

"I guess within this business structure, I don't see us ever getting to that point"

"Everything always comes down to economics"

"The site hasn't been designed that way from the start, so it's going to be much more of a challenge to convert it into such a place (referring to the ENISN) since it already exists under a certain business model"

"Although we would charge accordingly for whatever steam we peel off"

"Unfortunately when you do introduce the economic part of it, it really limits you quite a bit."

Economic sub-themes were also prevalent. Examples of the sub-theme of *geographical proximity* are:

"The geographical proximity is a huge deal with all of this stuff."

"There is an economic benefit to be located on the Blair bio-refinery campus."

"The key benefit of our location is the close and large volume of feedstocks."

A second economic sub-theme is *utility/infrastructure sharing.* Examples of this sub-theme are:

"Shared safety resources."

"Wastewater is treated by Cargill."

A third economic sub-theme is *competition between partners*. Examples of this sub-theme are:

"A barrier is we are competitors in some of our markets."

> "Different business models that are trying to compete nationally."

> "Competing market interests."

> "I see how hard it is to draft a simple non-disclosure agreement among parties sometimes."

A fourth economic sub-theme is *intellectual property*. Examples of this sub-theme are:

> "An inherent difficulty in creating this network from a business standpoint is intellectual property."

> "I think intellectual property and just assigning proper values so that everyone is making the right amount of capital and deriving value off of each of these would be very difficult."

> "Because in many cases we are competing against one another, a lot of the conversations are more about things that are going to impact the overall site and not collaborations about intellectual property."

> "One of the obstacles to overcome is intellectual property"

> "Sharing intellectual property would be difficult"

> "Biggest thing is the economic and intellectual property issues"

> "It would lead to some intellectual property concerns we would have."

Theme 4: Regulatory Responsibilities

State and Federal regulations play a very important role in the decisions of the partners in the study area. Meeting these requirements influence the direction of decisions both currently and for possible future actions. Although not the primary intention of most existing legislation, many regulations (or the language used in regulations) can prohibit or discourage reusing and recycling waste and by product materials (Martin, Weitz, Cushman, Sharma, & Lindrooth, 1996). Or, in many cases, companies find discarding their waste materials more profitable than undergoing a lengthy and costly process to modify existing permits to allow for constructing and using equipment to transform waste into usable inputs to other applications (Martin et al., 1996). Examples of these responsibilities discussed by the contacts are:

> "Often times though sustainable projects are put in place to meet certain regulatory requirements."
>
> "The existing regulatory paradigm is very hard to shift"
>
> "The regulatory part of it is like moving a great big huge rock"
>
> "It would depend on the regulatory issues"
>
> "The treated water, we could actually capture, instead of outflowing it into the Missouri River with a permit from the NDEQ and EPA."
>
> "We would have to get the NDEQ and EPA to sign off on that"
>
> "And that violates discharge permits."

Theme 5: Liability Concerns

Eco-industrial parks (EIPs) must contend with a number of possible liability concerns. Any potential concerns with public safety will be at the forefront of review and scrutiny. Many companies cited liability as a major concern when asked about their willingness to exchange waste materials with other potential EIP members. They were concerned that, if the production or use of a product containing secondary materials had a serious health or environmental concern, the company that supplied the secondary materials also could be held liable for damages (Martin et al., 1996). Examples of contacts in the study area commenting on this theme are:

> "From a public safety and their point of view, it is an area they would not want to go."
>
> "Take the chance that their name could someday be tainted because of what another company did."

> "You'll need some companies to figure out a way to separate that risk."
>
> "There's too many risks that could go wrong, to potentially ruin or compromise a food source"
>
> "Have a risk of cross contamination"
>
> "Causes tremendous amounts of scrutiny when it comes to that quality of water."

Theme 6: Collaboration

Industrial symbiosis stresses collaboration and exchange among its different entities. Working together, in theory, a collective benefit can be better than individual benefits by acting alone. This collaboration can also cultivate social values among the participants, which can extend to the surrounding area. "The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity" (Chertow, 2000, p. 314). Examples of this theme are:

> "I think we collaborate well with the city, the water plant, and the local community."
>
> "I think we have a close connection on the bio-campus as well"
>
> "We do open up the corporate barriers to share more challenges and strategies for success on the bio-refinery campus."
>
> "We are very functional about our relationship on campus"
>
> "Try to understand each other's needs as best we can and try to work with each other"
>
> "We're not looking out for each other from a business operations standpoint."
>
> "We all have the same fight regarding safety and environmental issues because there is real gain by helping each other. So those two subjects are subjects I would say we gain the most collaboration."
>
> "We talk about site services, security, janitorial services, mechanical contractors, and campus shutdowns."

Theme 7: Human Capital

Human capital is a collection of resources—all the knowledge, talents, skills, abilities, experience, intelligence, training, judgment, and wisdom possessed individually and collectively by individuals in a population (Wikipedia, 2016). Industrial symbiosis has a holistic approach, which needs to include the people, and their talents, within the ENISN. Of all the contributory variable or factors to economic growth and increased productivity, human capital stands out as a major catalyst. To this end, effective investment in human capital is a key component of long run economic growth and improved productivity (Olayemi, 2012). Examples of human capital discussed by the contacts are:

> "Human capital exists in Blair. The challenge is how it's currently being used."
>
> "The challenge is channeling human capital in the right direction than making sure it was there"
>
> "If you have the right people and you have the right support the network can happen."
>
> "Certainly here on this site, and in this community, I do think we have enough human capital to make something like this work, if the parties would all come together and agree how that would look and what it would take, I think they could make it happen."

Theme 8: Community Connections

A strong community benefits the individual, the community, as well as society as a whole. Humans tend to feel a greater sense of belonging in a community with strong connections. A strong community also contributes to more social benefits and capital. Globally, social capital is understood as a concept that enables a more detailed appreciation of what can be considered as a "flight from community" over the past two decades (Kurup & Stehlik, 2006). Specifically, evidence suggests as individualism has strengthened, communality is in decline and evidence is drawn from a decrease in volunteering; demands on governments for services and heightened lack of trust overall In Australia, the Federal Government implemented a Stronger Families and Stronger Communities Strategy in 2000 with the express aim of placing a greater focus on community building. The Stronger Families and Stronger Communities Strategy have policies that encourage the building of partnerships within communities between individuals, businesses, industry and all levels of government (Kurup & Stehlik, 2006). Examples of contacts discussing the community as part of their answers in the survey are:

> "The people in the community appreciate what's going on here and they get value from what we do here too."
>
> "We are fortunate in Blair that our companies are very environmentally attuned to what is going on."
>
> "We want to maintain the Blair identity; it's the Blair Bio-Campus."
>
> "I think we collaborate well with the city."
>
> "The city of Blair is very supportive of the bio-campus"
>
> "Charitable things they've done here and for the community"
>
> "The city of Blair has been very helpful in helping us solve issues"

Theme 9: Anchor Tenant

The idea of an anchor tenant or "visionary champion" is not a new concept. In many eco-industrial parks, this is the catalyst for success. An anchor tenant involves having a large industrial user, often a power plant, sugar refinery or other types of operation with large-scale material flows, that the industrial park will be developed around (Koenig, 2009). In Kalundborg the anchor tenant is the Asnaes coal fired power plant, which sits within the center of the circular material flows and has a significant number of exchanges go through the plant. The history of Kalundborg Symbiosis began with the start-up of the plant in 1959, and continued from there. A project champion usually starts an initiative or project. A champion best comes from the government, businesses, or the community to get the development process up and running. If possible, champions should be found in each of these arenas. Leadership usually takes the form of an individual or small group of people who are respected for their advocacy of specific business, environmental or community concerns or who simply value the idea (Koenig, 2009). Industrial symbiosis develops in many different ways. It is interesting to note, however, that one of the most common case studies, Kalundborg, evolved spontaneously over time (Chertow, 2007). The key to its development was an anchor tenant: a core, stable business that motivated and encouraged the development of the industrial symbiosis (Gingrich 2012). Examples of this theme are:

> "A potential barrier would be, to a degree, who would be responsible for helping put some of this together, whether the other partners would be willing to engage in this kind of cooperative effort."

> "A formalization of this type of network would be a super challenge, not that it couldn't necessarily be out of the question, but it would just be really, really challenging."

> "The biggest barrier is who's going to do it, who's going to figure out the connections, and who's going to implement it. Getting someone on board to say "yes," we're going to designate resources, time, money, and people to make it happen."

> "Any company is going to jump on an opportunity that's economically advantageous for them. They're not going to spend time and resources on something just to say they're doing it."

> "I think an ENISN is very possible, I don't see why it couldn't be done. It would take time to find the right companies who both had the needs to balance whatever

by-products you're making. It would just take a lot of work, and someone would take some time to put all that together and make sure everyone is comfortable."

Chapter 5

Discussion

5.1 Discussion of Study Objectives

In reference to sections 1.2, objectives of analysis, and 1.2.1, research questions, chapter 5 discusses these through the results of the research. After reviewing the results of the data, the researcher has a better understanding of the ontological "frame" that the partners in the ENISN study area operate under (objective 3). This is especially evident in the thematic results, and in the material flow analysis. The results are interesting to the researcher, although not surprising based on the importance of economic driving dimensions on the site. There were three economic related themes and four economic sub-themes. In addition, the thematic results provide insight into the environmental, economic, and social circumstances (objective 2) which, refers to the triple bottom line of sustainability. The material flow results (objective 1) revealed the basic materials that are coming into the site and leaving, which provides a starting point to begin to ask questions about what resources can or cannot be reused in some capacity. These ENISN "frames" were compared to Kalundborg and summarized into common factors and deficiencies (objective 4). The remaining discussions provide ENISN planning analysis and describe the potential of the site.

5.1.1 Survey Questionnaire Discussion

The most important result from the initial survey questionnaire was the flow data of the inputs and outputs. This provided the information needed to generate a material flow analysis diagram and input-output chart. While specific quantities were not provided for a quantitative analysis, the data given was useful enough to illustrate the adjacencies and movement of materials throughout the ENISN.

The initial survey questionnaire also provided insights into thematic elements that provided an additional cross-references to the phone interviews. The thematic elements derived from the group three, four, and five questions.

5.1.2 Material Flow Discussion

At first glance, the main sources of output reuse would be the wastewater that is treated and returned to the Missouri river. The Blair water and wastewater treatment plant has an activated sludge plant. Cargill has an industrial style plant with a different set of treatment regulations. The two water waste streams are incompatible with each other, with today's technology, and therefore need to be separate from each other. That however does not mean there is not potential for reuse. The treated water from the Blair plant could be captured and instead of being sent to the Missouri River, could circulate back to the water treatment plant for reuse in the municipality of Blair or be reused at the bio-campus. The three obstacles to overcome with this is the economics of providing the infrastructure required, the necessary permits, and public perception. It was interesting to learn how public perception plays a key role in any new developmental idea. In this case, the public's idea of reusing water from a sewage plant is difficult to overcome. In reality, however, the water that is treated at the Blair plant is actually cleaner than the treated water that is pulled from the Missouri river for public consumption.

Another output source is any remaining bio-mass, gypsum, or waste solids. Some of these are partially reused as animal feed and fertilizer. The largest by-product is the gypsum, which costs to put into a landfill. Currently, not many options existing for the gypsum by-products. Most of the contacts spoke of being very, interested in an economic solution to recycle or reuse this gypsum.

The last major by-product that was examined was any excess steam or excess heat that could be re-directed into the network for reuse. Cargill currently captures steam at various points in their process to re-use themselves and to send to customers within the bio-campus itself. The OPPD Ft. Calhoun Nuclear Power plant with its advantageous location near the other partners seemed like a logical choice as an additional supplier of a continuous and large source of excess steam. It was discovered, however, that because of the risk of any radiation passing from the steam to the bio-campus site, reuse would be much too large of a liability to overcome. However, the possibility exists to reuse excess process heat to generate electricity through waste heat recovery. This process captures excess heat that would normally be discharged at manufacturing facilities and converts it into electricity and steam. A "waste heat recovery boiler" contains a series of water-filled tubes placed throughout the area where heat is released. When high-temperature heat meets the boiler, steam is produced, which in turn powers a turbine that creates electricity or another form of steam. Excess heat could be used to heat commercial or residential buildings in addition to other processes. In the end, the current system falls between a Type I system and a Type II system, probably closer to a Type I, as described by Allenby (1992).

5.1.3 Theme Discussion

The inductive theme analysis was interesting because it revealed some insights into the ontological frame of the study area. The themes that emerged seemed to follow similar industrial symbiosis frameworks in the "triple bottom line" distinctions of environmental, economic, and social.

One of the main items that stood out were in the number of important economic themes and sub-themes. This would suggest the importance of the economic dimension to any business model, sustainable or not. The number of economic sub-themes was an interesting, though not surprising outcome. The "competition between partners" was an interesting sub-theme that was not expected in the initial parts of the study. Partners in the bio-campus are actually competitors with each other based on global markets. Commonly referred to over-the-fence (OTF) customers, their geographical proximity to each other is economically motivated, and conveniently advantageous. They share infrastructure, primarily in the treatment of wastewater and sharing of steam through Cargill. The products produced by Cargill supply inputs to the other partners depending on the plant. They share some interests, like collaboration of campus wide initiatives. Site management meetings occur to coordinate power shutdowns, security, and safety issues or problems. Better ways to function on the site together are discussed at the meeting; however, any collaboration regarding competitive market interests are limited. Intellectual property is kept confidential between partners and would be a challenge to overcome for a potential ENISN.

Despite the competitive nature of the current business model on the study site, many themes had sustainable and social dimensions. The level of environmental stewardship, based on the surveys, was extremely high. The encouraging part was a prevalent theme with all the partners of the ENISN study. From a philosophical standpoint, all the companies shared to desire to be good stewards while operating at an efficient and profitable level.

In addition, the connection to the community of Blair was another positive. An appreciation and mutual respect from the municipality of Blair and the bio-campus was evident. Despite the competitive and business aspects of the bio-campus and the city, the common environmental interests and synergistic examples were prevalent throughout the themes. An interesting development in the study was the recurring theme that if an ENISN were possible the name be reflective of the city of Blair or the bio-campus itself. In lieu of the hypothetical name "Eastern Nebraska Industrial Symbiosis Network" as used in this study, the contacts expressed a desire for a name that reflected the "identity" of the site. This researcher felt that was an important development in this study, that there are the beginnings of an ingrained "frame of pride" in what they are trying to do in Blair and the surrounding communities. The idea that the bio-campus site and Blair have potentially moved to a higher level of philosophical thinking to include a site-identity than just simply supply, demand, and profits.

The final observation from the thematic portion of the study includes the prevalence of the need for an "Anchor Tenant" to provide the drive required to move the ENISN or potential industrial symbiosis network forward. Obviously, such a step would be an enormous challenge. Currently the bio-campus site is owned by Partner #1-Cargill. Hypothetically, it meets many of the criteria for an anchor tenant in this study area. It has physical property either sold or leased to current over-the-fence customers on the site. It provides water treatment, various utilities, and the dextrose supply as part of the corn processing to the other partners on the bio-campus site.

Cargill has a lot of influence on the site, but also bears additional regulatory and liability risks as well. It is clear that the other partners near Cargill chose to be there because of the benefits and "economies of scale" that the Cargill plant brings to the site. Ayres (1994) revealed that experts are already considering proper integration of the “anchor tenant” principle during planning of eco-industrial park development. For example, Vigon (2002), indicated that certain types of processes or industries are well suited to becoming “anchor” facilities around which other industries might congregate. Industries that provide a large amount of waste heat or those that can serve as long-term sources or users of raw materials appear to have the potential to serve as anchors. Similarly, Chertow (1998) suggested establishing an eco-industrial park around one or more primary “anchor” tenants as a way to create a more definable set of possible inter-connections.

Based off the inductive themes, surveys, and interviews there is a consensus that Cargill is a valuable and respected partner in the city of Blair and provides leadership and support within the community. The bio-campus partners have a very functional and open connection to Cargill within their business model and existing agreements. As stated by one contact, "Cargill is great and has been great in listening to consider our ideas."

The biggest obstacle for any anchor tenant, and the other partners in the industrial symbiosis network, is finding the economic balance to justify a sustainable project, process, or new industrial member. Nothing is free, so to speak, and the industrial businesses on the bio-campus, OPPD, and the city of Blair must operate within efficient economic means. The economic barrier is an enormous challenge. The inductive thematic results section discusses how economic themes and sub-themes were at the forefront of the contact's considerations. Another major item of discussion is that the current economic model was created over twenty years ago when the site was planned. If the ENISN concept was discussed initially, given the increased support in sustainability and stewardship in society now, it may have been an easier idea to convince others to follow.

5.1.4 ENISN Barriers and Potential Summary

Table 8 lists barriers and potentials for the ENISN concept based on analysis of the themes and material flows analysis.

Table 8: ENISN barriers and potentials.

ENISN
Barriers
Existing Business Model
Existing Business arrangements
Infrastructure Costs
Public Perception of Water Treatment
Liability Concerns
Regulatory Hurdles
Intellectual Property
Competition between partners
Potential
Environmental Stewardship
Human Capital
Geographical Proximity
Community Connections
Utility/Infrastructure Sharing
Philosophical Similarities
Anchor Tenant
Resource Efficiency
Collaboration

The greatest challenges come from the economic dimensions, which include all the regulatory, liability, and competition factors. In contrast, it would appear that the environmental and social dimensions have most of the potential. The right people, community support, sustainable attitudes and a general positive “want to” direction of thinking exists. However, implementing ideas under the current economic model and business arrangements and agreements would prove to be a difficult challenge.

5.2 Comparative Analysis – Kalundborg and ENISN

In comparing Kalundborg to the ENISN study site, is clear that the study site has elements in common with the Kalundborg industrial symbiosis model. In contrast to that, there are certain deficiencies that stand out as well. The researcher used the material flow analysis and thematic analysis, plus additional research from the surveys to develop the following summary comparison. Results of the literature review of Kalundborg focusing on what makes it successful will be compared to results of the ENISN study analysis.

5.2.1 Common Factors

One of the more important factors that is present between Kalundborg and the ENISN is the sharing of utilities and infrastructure. Pooling use and management of commonly used resources such as energy, water, and wastewater is occurring, although it could be further developed. In addition, a joint provision of services, thereby meeting common needs across firms for ancillary activities such as fire suppression, transportation, security, and safety needs is also present in some form or another. The exact depth of economic cost sharing of both of these is not known.

The advantageous geographic proximity is another common factor. It provides a unique ability to deliver goods to the over-the-fence customers, which provides a foundation for economic success. Being close to your neighboring partners is ideal.

The next biggest common factor that is the partners in the ENISN have an initial concept of collaboration present. At Kalundborg, this is the glue that holds the triple bottom line dimensions together. While the collaboration between the ENISN partners is strictly motivated by economics, there is a common ideological belief in the well-being of the community of Blair and the mutual practical functioning of the bio-campus itself. Partner #1-Cargill has established itself as the primary candidate under the "anchor tenant" definition with the current site business model, although to be an anchor tenant under industrial symbiosis, there are many challenges and obstacles to overcome.

Finally, the environmental stewardship and sustainable aspirations are similar to the Kalundborg model that results in triple bottom line aspects. The prevailing opinion is that the ENISN study site has, and will continue to strive for better resource efficiency and environmental sustainability if possible under economic dimensions. The current material flows suggest a good reuse of water prior to being sent back to the Missouri river. The recycling of as many wastes as possible, considering that landfill costs are a major expense, is in the industries best interest.

5.2.2 Deficiencies

Probably the biggest deficiencies is that there is not a true 3/2 heuristic benchmark as described by Chertow (2007) where three different entities must be involved in exchanging at least two different resources to be counted as a basic type of industrial symbiosis as in Kalundborg. Currently the ENISN study area recycles and reuses water for as long as possible within the system, but eventually it is treated and returned to the Missouri river. Excess steam circulates in a one-way direction between

Cargill and other partners. In addition, partial biomass wastes are recycled and used to create feed and fertilizer, but not reused in a circular loop within.

Another interesting deficiency is the current self-organized model that the ENISN has become. The researcher originally thought this would be a potential strength, since it appeared that both the Kalundborg and ENISN sites are "self-organizing symbiosis models" (Chertow, 2007) where the sites adapt and change over time, and because of this, have a much higher chance of succeeding versus the other type of industrial symbiosis model, the planned EIP model.

The results of the research suggest that while the ENISN site has changed and adapted over time similar to Kalundborg, it has done so under a specific business model that was started over 20 years ago. According to theme 3 results (economically viable), this theme explains that the current business model could be a barrier to any potential ENISN. As said by one contact, "the existing business structure and existing business relationships with everyone on campus, there would be a lot of work to figure that out. If it was originally built as the model in Kalundborg model, it would be an entirely different endeavor. However, the fact it was not built that way and would need to be converted into such a thing when it is such a huge business enterprise. The site hasn't been designed that way from the start, so it's going to be much more of a challenge to convert it into such a place (referring to the ENISN) since it already exists under a certain business model."

Based on these comments, the ENISN site self-organization in the last 20 years may have been different if the sustainability frame of thinking in 1995 was as strong as it is today. As described by one contact, "if this was a concept that maybe came to us 20 years ago after we've built the place and started building the place given the increased support in sustainability and stewardship it may have been an easier sell." Because of these factors, the ENISN self-organization over time has become a deficiency that would be difficult to change, in lieu of a strength. However, while Kalundborg certainly operates under its own business model, it also has the advantage of more time on its side for self-organizing; more than double that of the ENISN. This would allow more adaptation towards a circular model of flows allowing for a diversified set of industries within its network, and that would potentially lead to changes in its own economic business model.

Another deficiency is a possible lack of diversity in the industries on the ENISN site. Industrial symbiosis is an industrial ecosystem where unused or residual resources of one company are used by another. It is a process involving firms that complement one another and provide mutual added value through efficient use of raw materials, technology, services and energy (Chertow, 2007). The Kalundborg companies are very diversified in their individual processes allowing for a broader set of waste to input relationships. There is evidence to suggest that clusters of diverse industry types provide greater opportunities for localized materials based industrial symbiosis (Jensen et al. 2011). This is can be seen in Figure 11, the Kalundborg MFA, where waste gas from Statoil refinery is used by Asnaes, steam from Asnaes is used by Statoil and the pharmaceutical company Novo group. Heating steam from Asnaes is used in the municipality of Kalundborg, hot water from Asnaes is used for a fishing farm, ashes from Asnaes used by Portland cement and gypsum from the desulphurization process of

Asnaes for the gypsum board company Gyproc. These are some of the main process flows at Kalundborg that illustrate the diversity of materials and entities.

When compared to the Figure 19 ENISN site study MFA, we can see that most of the process flows and outputs are agricultural in nature, consisting of wastewater, biomass, excess steam, and final products. Unlike Kalundborg, where a variety of material outputs and circular flows exist. Cargill however, is comparable to the Kalunborg Asnaes plant, as providing a "heart" for the site, an "anchor tenant" as discussed earlier, supplying a starting point for many of the site processes.

The final set of deficiencies is the competition between partners on market level, the sharing of intellectual property, potential liabilities, and regulatory responsibilities. At some point Kalundborg realized that carefully managing their network of exchange of energy and materials could produce economic advantages while concurrently reducing environmental impacts. The Kalundborg Symbiosis Institute was created as a managing entity, facilitating open communication and mutual trust between partners. The institutionalization of the network only took place in 1996 when the companies decided to create the Symbiosis Institute as a platform to diffuse their experience and also contribute to the identification of new potential areas of cooperation (Domenech & Davies, 2011).

The ENISN site, however, has a more distinct competition between partners as said earlier in the theme discussion. The number of important economic themes and sub-themes were prevalent as partners in the Blair bio-campus are, in some situations, competitors with each other based on global markets. The over-the-fence (OTF) economic profile and separate responsibilities in regards to regulatory issues also plays a part in this deficiency.

5.2.3 Closure of Material Loops

In order to facilitate the beginnings of a 3/2 heuristic model of resource exchange at an ENISN, the first material flow that was identified was the treated water from the wastewater treatment plant in Blair. The technology exists to re-circulate this water either back to the city of Blair or to the bio-campus as an initial water source or potentially for cooling. Another source of clean water is the by-product of the NatureWorks Plant. The plant itself does not use any freshwater as an input, but rather creates water as part of its lactic acid process. It is considered a by-product and is sent to the Cargill water treatment plant. It must be noted that the partners looked at this option but could not find an economical use for it.

The biggest source of an input was identified from Partner #6- the OPPD Ft. Calhoun Power Plant. While the excess steam is abundant, it carries too much of a radiation risk for use as a steam source at a food plant such as Cargill or around the bio-campus site itself. However, the excess process heat could possibly be used to generate electricity through waste heat recovery. This process captures excess heat that would normally be discharged at manufacturing facilities and converts it into electricity and steam. The electricity could be used throughout the campus and excess heat could be used to heat commercial or residential buildings in addition to other processes. This is similar to the municipality of Kalundborg that completed a heating distribution network in 1981 that captures waste heat from the Asnaes Power Plant and uses it to heat the city (Christensen, 1999).

Another solution would be the addition of a new core partner member within the ENISN site. Future studies of current site material waste volumes may provide a baseline of information that potential new members could use to study the economic benefit of locating in the ENISN. In addition, a potential new member could provide an output, supplying some material that the current members could use within the ENISN network, providing an opportunity to make the material flows more diverse in its attempt to close material loops. The challenge, of course, is working out the economics of any new member, including the regulatory requirements that they may have.

Any potential solution to close material loops require a continued collaborative effort including more trust in sharing intellectual capital, while difficult and remote, could provide a common sense of purpose to elevate the site to a deeper ontological level of synergy and connectedness. Of course, this sounds wonderful in theory, but practical applications in the market driven world are more difficult to achieve.

5.3 Industrial Symbiosis Policy and Planning Discussion

Any difficult or challenging project, such as the ENISN, requires organization and planning to achieve. The comprehensive planning portion of any environmental project requires many stakeholders, including their motivations, decisions, thoughts, and communications. Outlining strategies, specific goals, and objectives should be clearly defined. While results of this study revealed some useful insights, further research is needed to overcome barriers to creating a comprehensive industrial symbiosis plan. Environmental planning refers to the decision making process required for managing the relationships between human systems and natural systems. These planning and eventual policy making ventures attempt to manage these processes in an orderly, effective, transparent, and equitable manner that benefits all the entities within for both the present and future. Continuous refinement of policies and scope expansion are essential to this process.

Eco-industrial parks (EIPs) are a complex form of industrial system, a community of manufacturing and business located on the same property (Koenig, 2009). The benefits of EIP's can expand to include the local community, neighboring businesses, and additional human capital as an integrated system of shared resources (material, knowledge-based, social, etc.) that can lead to economic gains and enhanced environmental quality. These types of industrial symbiosis systems are referred to as eco-industrial developments (EID).

In the case of the ENISN, some of the main elements that could be part of this planning process are social and economic development, regional development, natural resource management, infrastructure systems, and solid waste management, including disposal, reuse and recycling. Table 9 lists some other important development strategies:

Table 9. *EID Strategies* (Schlarb, 2001)

Eco-industrial development strategies
• Resource recovery, pollution prevention and cleaner production
• Materials and energy interchanges
• Integration into natural ecosystems
• Industrial clustering
• Sustainable/green design
• Anchor tenant
• Life cycle assessment
• Job training
• Environmental management systems
• Deconstruction and demanufacturing
• Technological innovation and continuous environmental improvement
• Public participation and collaboration

Source: Schlarb (2001).

5.3.1 Typical Planning Challenges

Despite its compelling logic, industrial symbiosis developments face a range of challenges. Three primary ones emerge, namely: (1) sharing of information on material, energy, water and other resource flows between different operators in the same industrial area; (2) establishing operational and contractual arrangements to secure management skills, the technical "know how" and finances for the implementation of industrial symbiosis projects; and (3) estimating the environmental, social, and economic benefits (i.e. triple bottom line) of resource exchange networks (Harris, van Berkel, & Kurup, 2008).

Greater application of industrial symbiosis can be achieved through the following three 'enabling mechanisms'. *Facilitating structures* encourages collaboration among industries operating in same area. *Operational and contractual arrangements* enable commitment of required resources for industrial symbiosis projects. *Evaluation methods* track and quantify the economic, environmental, and social benefits (TBL) of industrial symbiosis projects (van Berkel (2006).

It must be noted that when planning for industrial symbiosis, knowing the type of project and its goals are important. The circumstances associated with implementing a planned EIP model versus a self-organized symbiosis model differ greatly. While Kalundborg Symbiosis provides a template for industrial symbiosis methods, simply copying what was done previously does not always guarantee success. The planning required for a "start from scratch" EIP will have different challenges to overcome than a self-organized model that emerges over time.

Many efforts to create planned EIP models to achieve the benefits of industrial symbiosis as at Kalundborg have failed. Gibbs and colleagues (Gibbs, 2003, Gibbs, et al., 2005) investigated 63 “eco-industrial” sites, 30 in the United States and 33 in Europe. They found little success in the United States and somewhat more success in Europe. After carefully examining the data, Gibbs et al. (2005) concluded that “initiatives based upon the interchange of wastes and cascading of energy are few in number and difficult to organize” (p. 178). In order to reverse this trend, organized project planning will need to occur.

Planning considerations include: 1), if industry is to take the role of a proactive ecology-oriented partner co-operating with markets and authorities, management will require new social insights, new tools for decision-making, new industry technologies, and a higher general understanding of environmental issues. 2), if we are used to thinking in terms of single companies competing in the market, that viewpoint will persist, but we need to add new dimensions to our thinking. The car user wants the car to function, but society wants the car to be produced, used, and recycled with a minimum use of resources and generated waste. This will require new co-operative alliances that will exist alongside traditional competition. Three, in industrial companies we have developed cultures which deal with challenges in the field of economics, technology, and an improved environment. We must develop this culture further to achieve a proactive ecology-oriented participation from our organizations. Training systems and techniques for organizational development must be created for this purpose (Marstrander, 1992). Other barriers to the closed loop consists of both external and internal as Figure 25 illustrates:

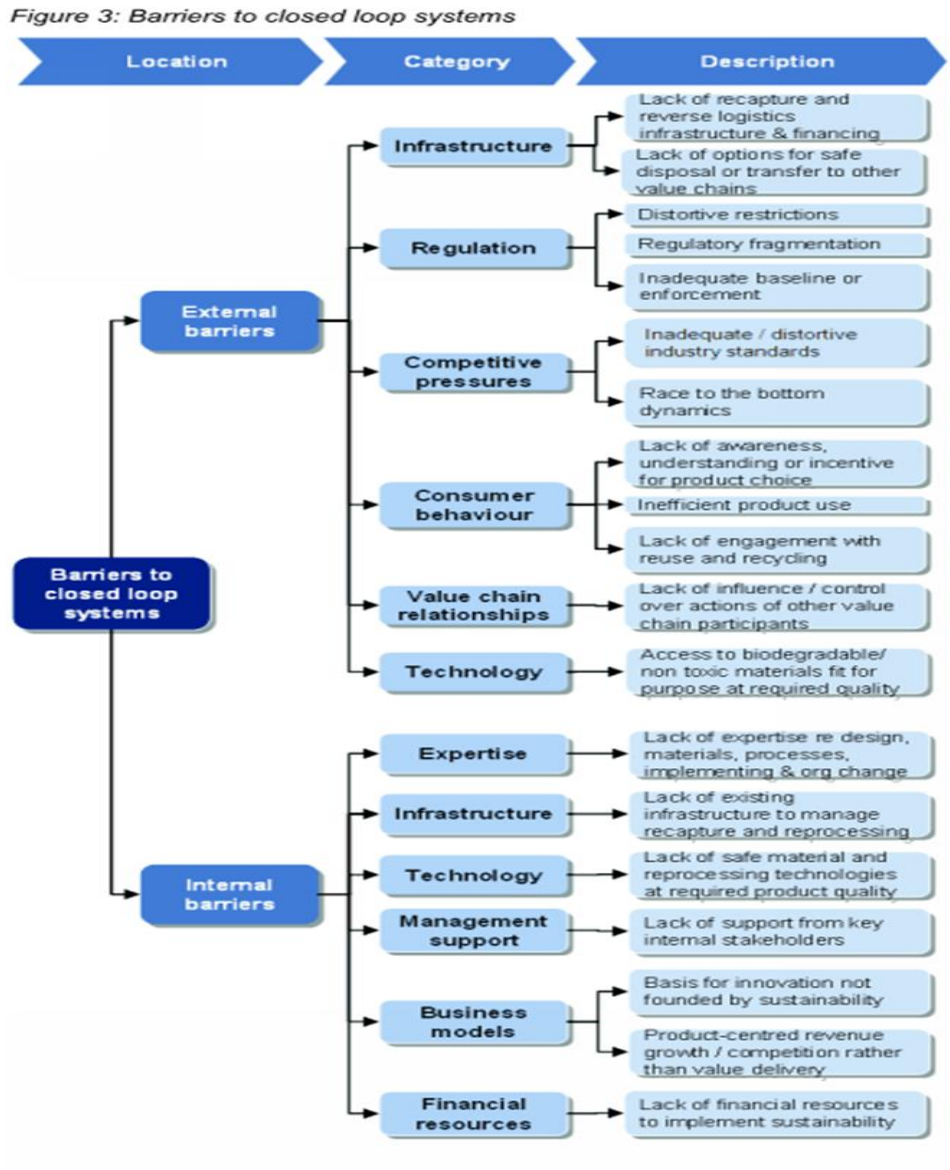


Figure 20: Barriers to industrial symbiosis planning (World Economic Forum, 2009).

5.3.2 Typical Planning Stakeholders

The challenges of an industrial symbiosis closed loop system must also be reviewed from many different perspectives depending on what stakeholders are included in the decisions and solutions to implement the system. As stated by Chertow (1999), there are four major groups of stakeholders that have a vested interest in the closed loop system either on an industrial level (EIP) or an industrial / community (EID) setting:

The first is the community level where some of the challenges include:

- Building local support for the EIP/EID setting
- EIP/EID performance objectives
- Determining the appropriate EIP/EID ownership strategy
- Developing EIP/EID financing strategies
- Local politics and governmental issues

The second is the Potential EIP/EID Member Units where some of the challenges include:

- Need diverse industry- a mix of by-products
- Estimating EIP/EID benefits and costs
- Determining the right mix of EIP/EID partners
- Developing appropriate technologies
- Reducing regulatory uncertainty and liability

The third is the Developers, Designers, and Builders where some of the challenges include:

- Choosing a site that will maximize EIP/EID benefits
- Designing EIP/EID infrastructure that incorporates the needs of the EIP/EID members for specialized services
- Designing industrial facilities that provide the flexibility that allows the EIP/EID to grow and evolve
- Designing buildings that maximize the efficiency of energy and materials
- Using construction practices that are consistent with the EIP/EID vision

The fourth is the EIP/EID Mangers or Eco-Community Mangers where some of the challenges include:

- Managing the design and development process
- Recruiting companies for the EIP/EID
- Maintaining relationships between companies or local eco-business

In the case of planning the ENISN stakeholders, this list can be modified to include:

ENISN Community level:

- Building local support in Blair Nebraska and Washington County for the ENISN setting
- ENISN performance objectives
- Determining the appropriate ENISN ownership strategy
- Developing ENISN financing strategies
- Local politics and governmental issues

ENISN Member Units:

- Need diverse industry- a mix of by-products
- Estimating ENISN benefits and costs
- Determining the current mix of ENISN partners
- Developing appropriate technologies
- Reducing regulatory uncertainty and liability

ENISN Developers, Designers, and Builders:

- Existing site modifications that will maximize ENISN benefits
- Designing ENISN infrastructure that incorporates the needs of members for specialized services
- Designing industrial facilities that provide the flexibility that allows the ENISN to grow and evolve
- Designing buildings that maximize the efficiency of energy and materials
- Using construction practices that are consistent with the ENISN vision

ENISN Mangers or Eco-Community Mangers:

- Managing the design and development process
- Recruiting future companies for the ENISN
- Maintaining relationships between companies or local eco-business

5.3.3 Typical Planning and Development Strategy

A typical strategy for the ENISN might be the development of an EIP or EID that follows four phases (Koenig, 2009). The first phase is project identification. The initial idea for an eco-industrial development project will often emerge as the result of a particular area, either with existing industry or for development. Initially an anchor tenant or champion will emerge with the idea to initiate the project. A champion typically will come from the government, existing businesses, or the community to get the development process up and running. Support then must be mobilized by the champion, who usually is recognized in the community and must promote the EIP/EID idea to important stakeholders, including local community and government leaders, decision makers, interested and affected businesses or in the case of this study, existing industry partners in the proposed ENISN. A crucial part of this are the partners and stakeholders that are part of the project. The partners are those who have the means of changing the industrial system while the stakeholders are those who have an interest in changing (or not changing) things in an industrial system (Koenig, 2009).

The next phase is preparation. Typically, there will be a particular site or region (e.g. a brownfield site, existing industrial area or a dedicated industrial site open for development. As stated by Koenig, (2009),

> If the development is on a particular site, it needs to be considered whether to think outside the legal boundaries of the project, at the municipal or district level. Preferably an ecosystem or bio-regional approach or a larger watershed should be considered for ecological and resource allocation issues. If the project allows, connecting with the larger overall region even if it is limited in size, because the likelihood of addressing environmental issues through eco-industrial development increases as the project accounts for the various connections within and between industries and the community. In addition, the project should have a big picture view of their operation. The standard industrial park has a defined boundary and area of jurisdiction. Often times this means that the thought process ends there. Materials and products move in and out of industrial sites, causing countless implications and effects outside the industrial area. The most affected are usually the immediate neighborhood, where workers live, and suppliers and service businesses set up shop. But in a global economy the effects of an industrial park are also truly global." (p. 16)

Once the region or site is determined, identifying the project scale and interests is the next step in phase two. Within the target region, there are a number of interests, often conflicting, among the various stakeholders involved pertaining to economic development, the environment, and social issues. The project will also need to address several markets, both regional and beyond, including manufacturers, agriculture, service, government, and the need for resources, such as natural, cultural, human, financial, and product markets (local, regional, national, international), government agencies, political will, community groups, and individuals. All these might affect the design and performance of the industrial project (Koenig, 2009).

The next step in phase two is identifying potential partners. In most cases, EIP/EID projects that establish a broad base of support from the outset are usually the most successful. There are a variety of potential stakeholders and partners in the ENISN who may have an interest in the project. Some of these include, municipal government departments, industry associations, Chamber of Commerce, business clubs, Industries as potential customers for the EIP/EID site, non-profit organizations, academic and research institutions, consultants, resident associations, and farmer’s groups. Once these are identified, a stakeholder survey should be conducted to find out who has any concerns of specific interests in project. Communicating ideas through stakeholder roundtables begins to form the project. The involvement of these groups from the very beginning is important for their motivation to support the project and contribute with ideas and information. Early in this preparation process, it must be communicated to the different stakeholders what the concept and opportunities for the EIP/EID are. (Koenig, 2009).

Understanding the concept and what the ENISN is trying to achieve is important since all the different groups will have their own understanding of what is an EIP/EID. If the champion, stakeholders, and community do not speak the same language, the initiative will not go beyond the communicating of ideas (Koenig, 2009).

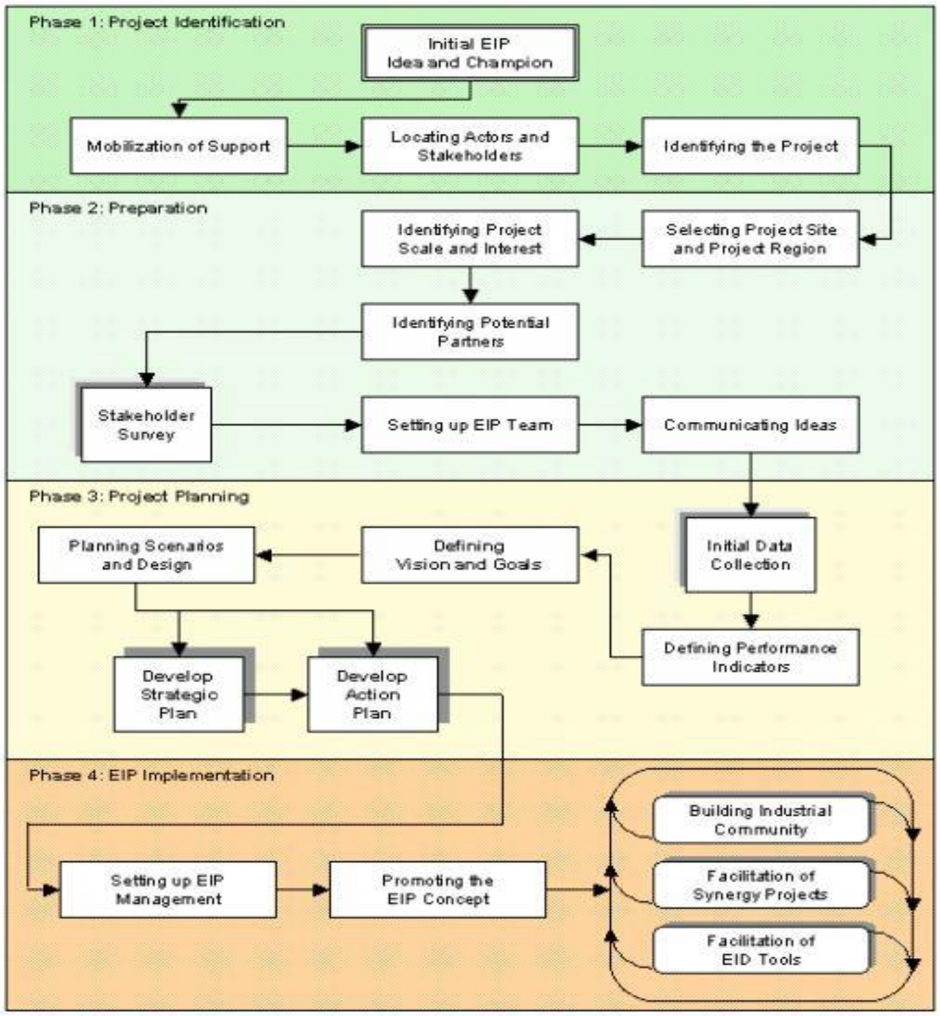
The third phase is project planning. The planning stage needs to be well designed and based on a broad consensus between stakeholders and existing / potential partners. Taking the nature of eco-industrial development as a process, the site development needs to be planned as a process. This will include the local government as a supervising body or administration It helps to ensure that all available ideas, resources, and regulations are in place to enable the project. Data collection will need to be done as an initial survey of the area and region is needed to identify resources, features, and development issues and create a benchmark for measuring development against the goals. This will assist to defining performance indicators, which are based on the initial data collection from the stakeholder survey. A benchmark for the performance of the EIP/EID needs to be defined. This should be based on a set of performance indicators that both reflect the improvement of individual companies and the industrial park as a whole (Koenig, 2009).

Once all the interests of stakeholders and actors, including the potential investors, are included in the planning process, there will be a strong ownership within the project design allowing for participatory planning and future vision and goals. This will be beneficial in meeting expectations and create the most synergies between the partners. Once all available data, issues, interests, different scenarios, and initial designs are communicated for the industrial system, the phase three culminates with the strategic action plan, where future decisions and action are summarized.

The last development phase is EIP/EID implementation. Implementation of an EIP/EID project can start depending on how the project or process is defined by the local team. An EIP/EID project will usually start if all parties are committed to implement a plan and the first synergies are created. Many projects have not gone beyond the planning process because of a lack of commitment. Early in the process of implementation, the regular industrial park management and the EIP/EID development team will need to be merged, and in the case of this study, merged into the ENISN. Some projects, especially expansions of existing industrial parks, create separate management groups with parallel management structures. This prevents synergies between the existing and new EIP/EID development groups and prevents a smooth integration of EIP/EID management into local government structure after the project is finished. Once concept and plans are available, promoting the new EIP/EID through multiple media outlets and promotional tools should be done. Potential investors and collaborators need to be informed and committed to the project since they will be the ones using the ideas and designs. As stated by Koenig (2009),

> whether the EIP project builds upon an existing industrial park or develops a Greenfield site or phase, existing and potential investing companies need to be formed into an industrial community. Synergies can only be created if the companies know each other and have the trust to work together without giving up their market independence. Project management needs to use specific tools and work with individual companies. A major part of an EIP project is to facilitate the implementation of individual projects to create synergies between the companies and provide added-benefit services through the management or joint-venture partners.(p. 20)

These strategy phases for EIP/EID's can be adapted not only to industrial parks / eco-industrial parks, but in general to any larger development project with a variety of stakeholders and multiple economic, environmental, and social effects that involves industrial or commercial development. In Figure 26, Koenig (2009) illustrates these EIP/EID strategies in a flow chart:



Source: EMCP Industry Development and Andreas Koenig, 2005

Figure 21: EIP/EID strategies flow chart (Koenig, 2005)

5.3.4 ENISN Motivation and Planning

Every industrial concern, regardless of time frame or size, is interested in understanding and improving its manufacturing processes (Kastner, Lau, & Kraft, 2015). The specific aspects that are the focus of such attention can change over time or location, but the motivational drive to get the most finished product in the best way, using the least amount of materials, cost and expenditure of effort, is universal (Kastner, Lau, & Kraft, 2015).

Based on this, the "motivational factor" should be included in determining the framework of any future network such as the ENISN. The research in this study confirms the self-interest of the potential partner companies. Company competition (study sub-theme #3) and intellectual property (study sub-theme #3) are examples of this. These economically viable reasons could motivate the self-studying and improving of a company plant within the study area. Concepts such as an EIP, EID, or industrial symbiosis, "will raise questions regarding activities between individual companies. Inter-company integration forms a new area of inquiry with respect to describing the interaction between various separately owned component plants" (Kastner, Lau, & Kraft, 2015, p. 3).

In regards to planning an ENISN from a bio-campus point of view, the points of interest center on the use of shared or collective resources, inter-plant recycling and collective benefits, as opposed to the traditional individual company profit viewpoint. These points relate to another motivational theme, resource efficiency (study theme #2). For example, if the ENISN partner's interest is water usage, one could measure the amount of water an individual unit operation requires and ascertain if it is possible to reduce that amount, perhaps by upgrading the equipment (Kastner, Lau, & Kraft, 2015). Alternately, on a plant scale, one can discuss the amount of water used by all processes and if it is possible to reuse or recycle the water from processes to minimize total plant water intake (Kastner, Lau, & Kraft, 2015). In either case, changes could be implemented to make the plant more profitable and/or lessen the environmental impact of operating the plant. From a park perspective, these same questions are applicable, but the potential solutions become more complicated, as inter-company interests for profitability may not align with optimal water conservation methods (Kastner, Lau, & Kraft, 2015). If the wastewater can be directly used between one company and another, it seems clear that both could benefit by its reuse, but if the water requires some form of treatment prior to reuse, the issue becomes less clear (Kastner, Lau, & Kraft, 2015).

Based on the research of (Kastner, Lau, & Kraft, 2015),

> the modeling and optimization of the network is the first consideration in creating inter-plant connections and to establish any potential connection, if it does exist. If a potential connection exists, then the second consideration is to establish if creating a connection would be economically or environmentally beneficial. For example, if waste heat from Plant A can be used in Plant B, a potential connection theoretically exists. However, if the distance between the plants is such that the heat will have dissipated before it arrives, such a connection is not viable. In addition, as industrial concerns are first and foremost profit-making enterprises, any reuse/recycling scheme which will incur substantial additional costs is unlikely to be adopted unless there is motivation for a favorable pay-back period. (p. 6)

In the case of the ENISN, a "retrofit" type of modification of the existing bio-campus and surrounding partners, would convert it into an EIP. However, the thirty eco-industrial project sites studied in the United States that have attempted such an endeavor have had little success (Gibbs, 2003). The success rate tends to be dependent on occupants' acceptance of ideas (Kastner, Lau, & Kraft, 2015). In the industrial parks that have been developed, economics and profits (study theme #3) are often mentioned to be the primary motivation for the building of exchange networks (Kastner, Lau, & Kraft, 2015). One obstacle to introducing changes in an already existing system are the costs and the question of how costs will be distributed is fundamental to establishing if the alterations will occur (Kastner, Lau, & Kraft, 2015). As the exchanges effect more than one party, it becomes more complicated because if all parties concerned do not deem the potential future savings and the capital costs acceptable, the scheme may not be adopted (Kastner, Lau, & Kraft, 2015).

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

The existing site at the Blair bio-campus and surrounding area was reviewed for the potential of being retrofitted into what has been coined as an eco-industrial park utilizing industrial symbiosis. The hypothetical name Eastern Nebraska Industrial Symbiosis Network (ENISN) was used to describe this area of study. The ontological challenges of such an endeavor were evident in the results of from the survey questionnaire, interviews, and resulting material flow and thematic analysis of potential partner considerations. Clearly, the positivity surrounding the prevalence of the environmental and collaborative elements of the emergent themes indicate that the frame of the partners studied lends itself to at least an engagement of industrial symbiosis techniques. The current recycling and reuse of some materials within the study area suggest elements in an initial Type II level of partial recycling of wastes and the reuse of materials in the area (Allenby, 1992).

However, the current system is mainly a Type I system representing a linear process, with limited Type II characteristics. Materials and energy enter one part of the system and then exit either as products or as by-products/wastes. Wastes and by-products are partially reclaimed or recovered; however, this system relies on a large, constant supply of raw materials. A Type I system is linear in explanation, where energy and resources enter the system and products and wastes leave it (Allenby, 1992).

As it is, the potential of an ENISN depends on if the current business model can economically justify and support such an endeavor. Based on the study results the human capital is present to at least begin to discuss such a plan; however, the challenge and uncertainty of such a change in the way the site has operated for the last twenty years seems too difficult to overcome. This conclusion should not minimize the reality that these partners currently operate a highly complex system of industrial businesses, which suggests that any future industrial symbiosis ambitions could be engaged if the stakeholders are on the same path.

Compared with Kalundborg, Denmark, the ENISN site shares common factors and deficiencies. The ENISN site does not have the benefit of the longer time frame from which Kalundborg grew and adapted. It also has a current economic, regulatory, and infrastructure arrangement that is difficult to change. There are, however important indicators that Kalundborg and the potential ENISN site share, which offers some possibilities for future synergistic adaptations that will contribute towards industrial symbiosis that frames the network before the partner.

6.2 Recommendations

Taking a "slow-but-steady" approach to increase industrial symbiosis techniques and awareness will be beneficial to accomplishing what is perceived as an overwhelming challenge economically and simply to improve what is perceived as "currently doing all we can do." The study site appears to be utilizing all avenues of resource efficiency and reuse under the economic circumstances. The stakeholders may at some point decide on a "masterplan" of what they will want to accomplish. A few suggestions include:

1. Studying the cost-benefit of the solutions outlined in the study. Some of these ideas may have been studied in the past, but other private sector avenues may exists for financing or examination.

2. Studying the current linkages between industries and investigating ways to strengthen or expand connections.

3. Utilizing the media and social networking to generate interest and support both financially and socially in creating the first industrial symbiotic network in Nebraska or specifically Blair. As stated by Peter Lowitt (2012), the area of the proposed ENISN has already been recognized by the International Society for Industrial Ecology as an "Eco-Industrial Development and Industrial Symbiosis in Practice." (p. 7)

4. A study of the economic benefits that Kalundborg has gained from its status would be beneficial.

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Appendix A

Survey Descriptive Cover

Industrial Ecology Analysis of the Potential for an Eastern Nebraska Industrial Symbiosis Network (ENISN) : A Comparative Study

Survey Form
by
Brad Behne
University of Nebraska-Lincoln
School of Natural Resources

Introduction

Study Goal

The purpose of this thesis is to determine if an Industrial Symbiosis network could possibly exist in Eastern Nebraska. The base comparison to be used will be the original network developed in Kalundborg, Denmark. I have identified the Blair/Omaha area as having the potential for a similar network.

What is Industrial Symbiosis?

The term 'industrial symbiosis' was first used in the small municipality of Kalundborg, Denmark, where a well-developed network of dense firm interactions was encountered. These companies share ground water, surface water, wastewater, steam, and fuel, and they also exchange a variety of by-products that become feedstocks in other processes.

Industrial symbiosis, also called industrial ecology, is mainly concerned with the flow of materials and energy through systems at different scales. Industrial symbiosis focuses on these flows through networks of businesses and other organizations in local and regional economies as a means of approaching ecologically sustainable industrial development. Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity.

Thanks for your assistance

While I will provide some questions below as part of my study, I would ask that if you have any other information that you feel is important and would like to share, please share it with me for the benefit of this thesis study. I understand the propriety nature of this business, and hope you can share your information with me. Thank you for your time and let me know if you have any questions.

Appendix B

Bio-Campus Survey Questionnaire

Research Survey Questions

Respondent: (Name of Participant) (Blair, Nebraska)
Date:_________________
Name of contact individual:______________________
Job Title:_____________________
Contact information:
Phone #______________________________
E-mail:_______________________________

Terminology: Please answer using whatever standard quantity terminology is used for the Blair plant (i.e. tons, metric tons, pounds, kilograms, etc)
Method of Return: Through email or Interview
My information is listed below:

Brad Behne
3825 Everett Street
Lincoln, NE 68506

Email: bbehne@huskers.unl.edu
Phone: (402) 570-8585

Question Group #1 - (Name of Participant) Blair Plant Summary:

A. Please provide general information of company plant in Blair.
    1. How many employees
    2. Size of plant
    3. What bio-solutions are specialized at this plant?

Question Group #2 - Production process and flow data:

A. Please provide a breakdown of all types of raw materials (inputs) used in production on a per week average. (or typical cycle)
    1. Include quantities
    2. Include how much water is used
    3. Energy (electricity) consumption
    4. Include how these inputs are delivered to plant, and from where?
    5. Flow information of resources within plant system to produce final product
B. Please provide a breakdown of all types of (outputs)products/enzymes/microorganisms
   Bio-polymers, etc produced at this plant on a per week average.(or typical cycle)
    1. Who are your major consumers?
    2. Include quantities to each consumer.

3. Who are they delivered to?
4. How are they transported?

Question Group #3 - Waste generation and waste management:

A. Please provide a breakdown of all types of waste materials produced by this plant on a per week average. (or typical cycle)
    1. Wastewater and solid waste; generation and treatment
    2. Include quantities
    3. Include how these wastes are treated/transported/delivered.
    4. Where are they delivered?
    5. Are they recycled?

Question Group #4 - Sustainable perspectives, goals, regulations, and collaboration:

A. Would you be willing to be part of an industrial symbiosis network sharing inputs and outputs with other neighboring industries?
    1. If no, why?
    2. If there were economical and environmental benefits, would you?
    3. What do you see as inherent difficulties in creating this network from a business perspective?

B. What are the motivations, drivers, and philosophies being used to organize production at (name of participant) plant?
    1. What are current and future sustainable goals for this plant?

C. Do you have any sustainable relationships with current industries locally?

D. What are local, state, and national (EPA) regulations you have to follow?

Question Group #5 - Connections to the Community and Environment:

A. What are current methods used by (name of participant) in Blair that are "environmentally friendly?"

B. What are the benefits of your current location in Blair?

C. Community Support?

D. Any sustainable collaborations with Municipality of Blair?

Appendix C

Municipality of Blair Survey Questionnaire

Research Questions – Municipality of Blair, Nebraska

1) What relationships does the city of Blair currently have with other companies (if any) involving sustainability measures, and are there any exchanges of information or knowledge that take place as part of these relationships?

2) Do any of these relationships involve take back product exchanges used in the inputs for other production processes?

3) What do you see as opportunities(pros) and barriers(cons) for cooperation in a symbiotic network of natural resource exchange?

4) What factors influence the successful implementation of sustainable projects, and are these factors driven by environmental or economical drivers?

5) What efforts is the city of Blair making to reduce CO2 emissions, water usage, and reducing waste products?

6) What are the impacts of legislation on recycling of wastes and reuse or the take back of products?

7) If existing industries near Blair began a sustainable network of resource reuse and exchange, would the city of Blair be interested in joining this network if it was economically and environmentally viable?

Appendix D

Phone Survey Interview - OPPD

Research Questions - OPPD

1) What relationships does the OPPD Ft Calhoun Plant (or other OPPD locations) currently have with other companies (if any) involving sustainability measures, and are there any exchanges of information or knowledge that take place as part of these relationships?

2) What are the natural resources (inputs, such as water) and the waste products (outputs, such as the spent nuclear fuel) that are part of the circular process of electrical energy production at the OPPD Ft. Calhoun plant? Please list.

3) What efforts does OPPD make to reduce CO2 emissions, water usage, reducing waste products and to participate in any recycling programs?

4) Does the OPPD Ft Calhoun plant produce excess heat or steam that could be reclaimed or diverted for other sustainable heat process applications? Examples of these applications are for heating homes, a source of energy for bio-refinery applications, such as biochemical fermentation, or thermochemical conversion.

5) If existing industries near Blair began a sustainable network of resource reuse and exchange, would OPPD be interested in joining this network if it was economically and environmentally viable?

6) What do you see as opportunities(pros) and barriers(cons) for cooperation in a symbiotic network of natural resource exchange?

7) What factors influence the successful implementation of sustainable projects, and are these factors driven by political, environmental or economical drivers?

Appendix E

Phone Interview Questions

Phone Survey Interview

1) What do you see as:

   A.) Opportunities(pros) for cooperation in a symbiotic network of resource exchange? Why?

   B.)Barriers(cons) for cooperation in a symbiotic network of resource exchange? Why?

2) Do you believe an ENISN (Eastern Nebraska Industrial Symbiotic Network, of natural resource exchanges in a closed loop) can exist within your current state of operations? Yes or No, and why?

3) **Currently, most of the operations in the Blair industrial park are linear in nature, meaning raw resources are brought in and products go out. Water is recycled.** What do you see as a way to promote a "closed loop" method of product exchange between you and your neighboring companies?

4) What factors influence the successful implementation of sustainable projects, and are these factors driven by environmental or economical drivers?

5) **One of the key factors of an industrial symbiosis network is the "realization" that there is a current exchange of resources and ideas already happening.** How do you see you and your current eco-industrial partners "formalizing" an Eastern Nebraska Industrial Symbiotic Network? (ENISN) that will exist publically?

6) Please describe (in general terms) what is typically discussed at the quarterly Site Management Team (SMT) meetings and if discussions could focus on a management of an ENISN type structure (i.e. regular exchange of information sharing challenges, strategies and successes?)

7) Do you believe your industrial business can improve performance and save money (eco-efficiency) by participating in an industrial symbiotic network based on synergies, economies of scale and reductions in risk and liability offered by eco-industrial parks?

8) **Human capital is a collection of knowledge, talents, skills, abilities, experiences, training, judgment, and wisdom possessed individually and collectively by individuals in the community.** Describe the human capital necessary to make an ENISN successful. Does this human capital currently exist in the community of Blair and its surrounding areas? If, no can you describe what is missing?

9) Would you be more willing to participate in an ENISN if private financing was provided by the private sector financial market?

Appendix F

IRB Review – Not Human Subjects Research

Nebraska
Lincoln

Reviewer: Becky Freeman
Date: 12/23/2015 1:12 pm
Comment: Dear Mr. Behne and Dr. Burbach,

Thank you for submitting IRB protocol #15755 titled Industrial Ecology Analysis of the Potential for an Eastern Nebraska Industrial Symbiosis Network (ENISN): A Comparative Study. Based on 45 CFR 46; we have determined that this project is not human subjects research which does not require IRB approval.

Project #15755 does not fall under the IRB definition of research as defined in the Federal Regulations at 45 CFR 46. The reason is the results cannot be generalized outside of the study population. Also, the questions being asked do not meet the definition of human subjects data based on the regulations.

This decision was based specifically on the protocol description, the survey, and the interview questions submitted via NUgrant for project 15755.

Based on this assessment, the project will be administratively closed and no further oversight is required at this time; however, should the scope of your project change (including revisions to the questions), please contact the IRB office at 472-6965 to discuss future procedures.

Cordially,
Becky Freeman
Research Compliance Services Specialist
Human Research Protection Program