

**Efficiency Options for a Focus Company:
Comparison and Analysis of Potential Industrial Ecology and
In-House Process Change Initiatives**

by

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Authors Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Industrial ecology is a popular option in the literature for improving the efficiency of industrial facilities, most notably through the eco-industrial park (EIP) concept. Relatively little attention has been paid to overall efficiencies achievable at the local factory scale through in-house process changes (IHPCs) - efficiency improvements that are undertaken in a factory to improve their processes, without the aid of their neighbours. This thesis compares the EIP model to IHPCs using a case study of an existing factory (the focus company) in an industrialized zone and answers the question: what are the drivers, barriers, and opportunities to encourage a promising company to participate in industrial ecology in an existing industrial cluster and how does the industrial ecology option compare with more conventional in-house environmental efficiency opportunities? An analysis of the focus company's major operating parameters, as well as data from interviews with the focus company, the local municipality, and the local utility provider are used to compare what the literature says about the implementation of industrial ecology in a case study setting to the results found through this study. The results from this study confirm a number of the barriers to implementing industrial ecology as found in the literature, and further emphasize that improved education and a more grass roots, consultant-led committee for the local industrial site would help with the implementation of industrial ecology principles. In a general sense, EIP projects are on a larger scale than IHPCs and therefore capable of greater efficiency improvements, whereas IHPCs are easier to manage due to being internally managed initiatives. It was found that for this particular case study, EIP options seem to be limited to a collaborative energy production plan, whereas a structured IHPC plan is best for the focus company's continued efficiency improvement. It was also found that the focus company has begun to tackle the higher hanging fruit in terms of energy efficiency, while leaving the comparably easily accessible lower hanging fruit options untouched. This leaves a myriad of low and/or no cost options to further improve the efficiency of the facility.

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List of Abbreviations

EIP: Eco-Industrial Park
IHPC: In-house Process Change
PV: Photovoltaic
FIT: Feed in Tariff
INES: INdustrial EcoSystem
CHP: Combined heat and power

Chapter 1: Introduction, Methods and Options

1.1 Introduction

1.1.1 Origins

This research project began through a combination of my interest in environmental protection and stewardship and my introduction to industry. The heart of this case study is a company that I have a connection with and became, “the focus company”, for this thesis research. Their facility is located in a small to mid sized North American city and is one of several processing facilities the focus company operates world wide.

I have always been very interested in improving efficiency and lowering costs, and I had developed a few methods for doing this in the areas I worked in previously. These efficiency improvements resulted in higher yields and decreased production time, and were of benefit to the company and the process; however, it is now widely recognized that small improvements in efficiency are not enough, and that what we need, especially in industry, are large scale improvements (Europe INNOVA, 2012; UNIDO, 2010; Weizsäcker, 2009).

The focus company produces a high quality final product, along with a large volume of liquid waste and a relatively small volume of solid waste. This liquid waste accounts for a large percentage of the focus company’s operating costs, and it is currently transported off site for disposal. The focus company has recently undertaken a water use reduction plan aimed at reducing water consumption, thereby also reducing liquid waste volumes. The focus company does not have a formal plan for reducing electrical or natural gas demand.

I enjoy figuring out how things work and how they could work better. At my undergraduate convocation one of the guest speakers said, “find something in this world and fix it”. This was a very simple, yet powerful statement and has definitely been something I have kept in mind since. With this mindset I looked upon the focus company with a perspective different from that of their employees, aiming to increase efficiency, decrease costs, maintain product quality and employment and generally assist progress towards sustainability. Although these are lofty goals, any contribution to this line of thinking and practice should be a positive one.

This thesis reflects a combination of general commitment to progress towards sustainability and a focus on what can be accomplished through industrial energy and resource efficiencies, and involves a more particular interest in examining the potential of, barriers to, and opportunities for implementing industrial ecology options (through eco-industrial parks) in comparison with more conventional in-house process change opportunities.

1.1.2 Background

At the global scale, it was estimated in 2002 that we were using upwards of 1.2-1.3 times the Earth’s sustainable capacity for accommodating human demands (Wackernagel et al., 2002). Recently this has been updated by the World Wildlife Fund (WWF) to 1.5 times (WWF, 2014), and although there may be some debate about these numbers, the fact remains that we are overusing the Earth’s

resources in our unsustainable way of living. Industry is what powers much of the economy, and it is one of the most important venues for changes to deliver more sustainable behaviour if we want to leave future generations with the level of sufficiency and opportunity we have had available to us (Gibson, 2005).

In Canada, industrial manufacturing jobs make up 10.2% of labour force employment, ranking third overall, behind trade (15.1%) and health care and social assistance (12.15%) (Statistics Canada, 2013). Natural Resources Canada states that as of 2013, Canadian industry “accounts for 38% of our nation’s energy use and 34% of related GHG emissions” (<http://www.nrcan.gc.ca/energy/efficiency/industry>). With respect to the economy and social wellbeing, keeping the Canadian industrial manufacturing sector at least at its current employment level is essential, and from an ecological standpoint lowering the Canadian industrial manufacturing sectors impact is also important. This intersection of economical, social, and economic pressure calls for “deliberate design and redesign of our present industrial systems” (Côté, Tansey & Dale, 2006, p. 4) in order to achieve long term sustainability and economic prosperity.

1.1.3 Why Industrial Ecology?

The basic idea of industrial ecology was first presented in a paper entitled *Strategies for Manufacturing* by Frosch and Gallopoulos in 1989. It has since become prevalent in the literature as an analogical concept depicting industrial energy and material flows as behaving as an ecosystem would (Allenby, 2006; Ayres & Ayres, 2002; Côté et al., 2006; Côté, Tansey & Dale, 2006; Erkman, 1997; Gibbs & Deutz, 2007; Norton, 2012; O’Rourke, Connelly & Koshland, 1996; Roberts, 2004; and ISIE, 2005). At the most basic level industrial ecology is an approach to improving environmental conservation and resource efficiency in industry by applying ecological principles, especially those related to cycling of materials and energy through multicomponent systems. Industrial ecology incorporates several schools of thinking in a transdisciplinary approach aimed at increasing the sustainability of traditionally inefficient and unsustainable industrial practices. Industrial ecology focuses on complex conglomerated sets of industrial and natural systems and their components. These cannot be studied adequately as individual pieces without missing the complexity of real world industrial ecology (Allenby, 2006).

Allenby (2006) defines industrial ecology as follows: “a systems-based, multidisciplinary discourse that seeks to understand emergent behaviour of complex integrated human/natural systems” (pg. 33). This definition captures the essential multidisciplinary nature and mirroring of ecological systems however industrial ecology is not merely about understanding behaviour, it is also about promoting change. Ayres and Ayres (2002) state that the goal of industrial ecology is to improve and maintain environmental quality, but that too is only part of the story because industrial ecology rests on a broader recognition of the links between environmental, social, and economic objectives.

The goal of industrial ecology is to reduce environmental impacts caused by industrial processes, maintain sociological benefits associated with industrial

processing, and increase a company's (or group of companies) market competitiveness. The combined goal-oriented definition of industrial ecology is the mirroring and incorporation of ecologically based multidisciplinary complex systems thinking in industrial practices to reduce adverse environmental impacts and maintains the sociological benefits of processing, while increasing a company's (or group of companies') market competitiveness and resilience in a sustainably focused economy.

Industrial ecology has been a conceptual idea for decades now, and although there were sporadic appearances of the concept in the literature prior to Frosch and Gallopoulos (1989), that paper is considered a fork in the road for industrial ecology, which has largely continued on in two directions: eco-industrial parks (EIPs) and dematerialization and the service economy (Erkman, 1997).

EIPs are integrated, internally self-cycling industrial clusters that share and reuse waste and energy resources more efficiently and effectively than the participating factories would be able to do on their own. The poster child for this concept is the EIP in Kalundborg, Denmark, which has been a celebrated, although never quite duplicated achievement. EIPs will be a focus for this paper due to the nature of the case study, and will be defined and assessed in detail in subsequent sections.

Dematerialization and the service economy have been identified as important contributors to an economically viable sustainable society, which according to Gibson (2005, 106) involves a shift to "the less materially and energy intensive satisfactions (more massages, fewer Mercedes)". The economics focused dematerialization literature connects industrial and consumer based ideas, holding that industry must be more efficient and use less material and energy per unit of production, while consumers must use things more efficiently, such as shared ownership of tools, cars, etc., and spending on less materially demanding activities (service based) (Ekins, Meyer & Schmidt-Bleek, 2009; Gibson, 2005; Schmidt-Bleek, 2009; Weizsäcker, 2009).

It is important to note that although industrial ecology is touted as a solution for industrial efficiency advancement, it is not yet widely recognized and utilized in industrial development. In Industry Canada's 2013 Sustainable Development Strategy industrial ecology isn't even mentioned, and the focus is more on improving air quality than reducing energy and material use (Industry Canada, 2013). If Industry Canada is not encouraging the use of industrial ecology, it points to a lack of understanding and use of the concept in the senior levels of government in Canada; hence the practicality and applicability of industrial ecology need to be evaluated with respect to barriers and opportunities aimed at educating and disseminating the information in an inclusive way to the scientific community, industry, government officials at the federal, provincial and municipal levels, as well as, the community at large.

Barriers are realities that inhibit the implementation of industrial ecology, and they will be discussed in this paper. Barriers will be determined through the different methods utilized in this work, primarily through literature search and survey questions. Opportunities and drivers will be looked at as well, as they

provide launching points for these industrial ecology based concepts to become a reality.

For individual companies in existing or proposed industrial parks, the main alternative to EIPs for efficiency enhancement is internal-to-the-company pursuit of efficiency gains. In-House Process Changes (IHPCs) are to some extent competing approaches to industrial efficiency enhancement. EIPs require collaborative planning of and investment in exchanges of materials and energy between firms, and continued cooperation to maintain these exchanges at economically favourable levels. It is at the scale of the whole EIP system that overall efficiencies are obtained. In contrast, IHPCs are all about efficiency improvements at the smaller scale level of the individual company.

In principle, EIPs and IHPCs are at least potentially complementary. However, companies with limited capital for efficiency investments and limited administrative capacity for organizing the initiatives, may find it impractical to participate in a traditional EIP focused on material and energy exchanges, while undertaking IHPC initiatives. Participation in more modest EIP efforts (e.g. where only energy is exchanged) might more often allow for concurrent IHPC initiatives aimed at improving material use efficiency.

1.1.4 Statement of Problem

Most current industrial practice relies heavily on energy and material throughput resulting in products and wastes. This practice is a linear process and relies on a constant stream on incoming and outgoing material, which is contradictory to the principles of sustainability, limiting the practicality of this method in times of limited resources and/or sanctions on waste volume/disposal. In order for industry to be more sustainable these 'loopholes' need to be closed with a goal of high energy and material autonomy.

As stated by Ayres and Ayres (2002), industry is an important focal point for ecological improvement because it is a large contributor, albeit not the only one, to environmental damage and at the same time it is a large economic provider. Most industrial facilities operate in this linear environmentally detached framework that tends to neglect social and environmental needs and requirements for sustainability, while focusing the majority of their attention on narrowly conventional approaches aimed at economic viability and profit making.

There is room for advancement in efficiency and sustainability, and although many of these avenues have been previously explored, this paper will focus on the applicability of these solutions using a real life case study in an industrial grouping that currently does not have formal plans for efficiency, sustainability and ecologically focused improvements.

1.1.5 Research Questions

This thesis explores the following question: what are the drivers, barriers, and opportunities to encourage a promising company to participate in industrial ecology in an existing industrial cluster and how does the industrial ecology option compare with more conventional in-house environmental efficiency opportunities? I will also be looking at the pros and cons of development of

combined heat and power plants, incineration plants, and renewable energy plants in a cooperative based initiative that would sit half way between an EIP and in-house only efforts.

The objectives of this thesis are as follows:

- What are the drivers, barriers and opportunities to implementing industrial ecology?
- What can eco-industrial parks offer in comparison with what can be achieved through in-house process changes in a single facility?
- What rationale is there for industry to consider a more holistic approach to environmental, social and economic gains?

1.2. Analytical Approach

This research uses a case study analysis of the focus company and experiential literature EIP and IHPC cases, through an analytical framework that was developed from the broader literature on desirable qualities of industrial ecology. This framework will be developed and used in chapters 2 and 3.

1.2.1 Development of Analytical Framework

The analytical framework for this thesis is primarily focused on the developed from a synthesis of the literature on the key factors in improving the efficiency of industrial operations for sustainability purposes. The main areas of literature consulted were industrial ecology, industrial efficiency, sustainability, and company specific information related to operating parameters and efficiency improvements. The framework for analysis which is discussed in chapter 2, incorporates attention to seven factors: energy use, material use, cost savings, job stabilization and/or creation, ease of implementation, long term viability, and public image and relations. These factors were chosen to represent economic, social and environmental aspects of sustainability, as success in all three is essential to a sustainably focused company. The framework is the looking glass through which the case studies are viewed, and allows them to be numerically graded and compared based on the above criteria.

1.2.2 Review of Basic Foundations and Industrial Ecology Literature

This research is principally founded in sustainable manufacturing and the greening of industry. At its very basic level it looks at environmentally focused efficiency improvements based on industrial ecology principles and practices.

The primary industrial ecology literature studied for this thesis was Allenby, 2006; Ayres and Ayres, 2002; Côté et al., 2006; Côté, Tansey and Dale, 2006; Erkmann, 1997; Frosch and Gallopoulos, 1989; Gibbs and Deutz, 2007; Norton, 2012; O'Rourke, Connelly and Koshland, 1996; Roberts, 2004; and ISIE, 2005. As mentioned in section 1.1.3, the goal-oriented definition of industrial ecology is the mirroring and incorporation of ecologically-based multidisciplinary complex systems thinking in industrial practices to reduce adverse environmental impacts and maintain the social and economic benefits of processing, while increasing a company's (or group of companies') market competitiveness and

resilience in a sustainably focused economy. This definition combines ideas from the industrial ecology literature, and more straightforwardly it is a definition that underlies the implementation of industrial ecology. It would be difficult or impossible to convince industry professionals to implement 'improvements' that would hurt their bottom line, or disrupt their labour force, or place them in a bad position to be competitive in the market. The future of sustainable industry depends on the transition to these practices in the real world.

1.2.3 Initial Framework

The initial framework for analysis, which is set out in Table 1 in section 2.5.3.1, allows for numerical ranking of case studies using a scale of 1-4 for each of the seven factors mentioned previously. This can then be compared to the focus company in the case study site, which will help guide the improvements and recommendations for them.

1.2.4 Review of Related Cases and Revision of the Framework for Analysis

This research is centered on a case study of the focus company and surrounding industrial cluster in a mid sized North American city. In the literature there are numerous examples of the implementation of industrial ecology, mostly through eco-industrial parks; however there is little information concerning the process of deliberation on suitability of the concept, and implementation prior to planning and construction. I will be reviewing the literature available on implementation of industrial ecology, as well as several case studies from around the world to extract insights for expanding and adjusting the initial framework to produce a stronger foundation for analysis, prior to application to the focus company and the industrial cluster.

1.2.5 Case Application of the Framework for Analysis

The primary case of the focus company and neighbouring industrial facilities is evaluated using the framework for analysis. The analysis examines and compares in-house efficiency improvements that are obtainable given the company's current and short-term future situation with what may be possible through more collaborative industrial ecology initiatives with other firms in the industrial cluster.

1.3 Methods Used in Case Study of In-House and Industrial Ecology Options

The core case study in this research is of the focus company and the immediate industrial cluster surrounding the focus company's facility. Interviews were conducted with employees at the focus company in management roles, and data concerning their major operating energy and material uses was obtained for this thesis. These data have been masked to protect confidentiality of the focus company. Representatives from the local electrical utility, and the local

municipality were also interviewed, and can be seen along with the focus company interviews in chapter 7.

1.3.1 Participant Observation

For this case study, direct participation with the focus company, was a key means of gaining familiarity with the company's operating environment, and its relations with surrounding firms, and in earning the understanding and trust necessary for access to the data needed for the analysis. I was at the focus company for three months during the summer of 2013, engaged in many process related activities. As a result I have reasonably detailed knowledge of their operations.

Being a participant observer has certain advantages and disadvantages over other methods of data collection; however, in this case study at the focus company it was the most effective method for obtaining data used in this thesis and allowed for immersion into the working world of the focus company. Key advantages of participant observation are that it allows the researcher access to 'backstage culture', and opportunities to witness and record unplanned incidents (Kawulich ,2005). Some disadvantages of participant observation are the risk of bias since information comes from key informant colleagues, which makes repetition difficult given the relationship of the observer to the informants (Kawulich ,2005). This closeness to key informants can distort the view of the observer to only see from the perspective of these informants. I acknowledge these advantages and disadvantages of participant observation and I have conducted this research as an ethical unbiased researcher to the best of my ability.

1.3.2 Review of Focus Company Data

After discussions with the focus company I signed a contract with them giving me access to data on their primary energy, material, and waste flows. These data will be presented in Chapter 4, in addition to discussion of potential improvements and recommendations. In accordance with the terms of the contract, the data have been masked to preserve confidentiality of the focus company.

1.3.3 Interviews

Interviews with employees from the focus company, the local utility provider, and the local municipality were undertaken to provide valuable information for this research; they were primarily held with employees of the focus company. Interviews with representatives of neighbouring firms in the case study industrial cluster were also sought through several means but they were unwilling to participate. The interview asked questions focused on company profiling, such as equity, material and energy use, assets, cash flow, employment, and environmental policies. The aim of the interviews within the focus company was to determine what the company has been able to accomplish through in-house

initiatives, to gain a basis for judging the ability and willingness of the company to participate in further in-house process changes for energy and material efficiency improvements as well as other environmentally desirable gains related to industrial ecology, and to find out if the company would be interested in collaborations with other firms in the industrial cluster including participating in eco-industrial park activities. The aim of the interviews with representations from other facilities in the industrial cluster, the municipality, and the utility provider was to gauge their level of interest and willingness to participate in a project partnership with any companies in the case study area.

1.3.4 Document Search

Published information for this paper comes primarily from a document search of peer reviewed and grey literature sourced through the University of Waterloo's Primo search engine and sites such as Google Scholar. Search terms included "industrial ecology", "eco-industrial parks", "sustainability", "efficiency", and "industry". All documents that had relevant information were examined from journals to sustainability reports published by the case study companies.

Information from the focus company was obtained by going through their invoices for utilities from January 2011 until December of 2013, month by month. This was done at the focus company and all records remained on site. The information gathered from these invoices was used to generate the figures in chapter 4 showing usage trends over this period.

1.3.5 Application of Framework for Analysis

The framework for analysis discussed in section 1.2.1 above was used as a 'measuring stick' for the determination of success of cases reviewed in this study. The framework is initially proposed in Chapter 2 section 8, and is then applied to different case studies in Chapter 3. At the conclusion of Chapter 3 the framework for analysis is reviewed in light of its performance in evaluating the case studies from the literature, and then adjusted to address deficiencies. This adjusted framework for analysis is then used in subsequent chapters to evaluate the focus company and potential implementations of industrial ecology within the case study area.

1.4. Outline of what is to come

The following chapters of this thesis begin with the basic theoretical and experiential foundations of this research (Chapter 3), and provide a detailed overview of the case study site and focus company (Chapter 4). These are followed by discussions of in-house improvements (Chapter 5) and eco-industrial parks (chapter 6) and a comparative analysis of the two (Chapter 7). I then analyze the realities of the focus company facing a possible role in industrial ecology (Chapter 8) and finally provide conclusions and suggestions for future work for this research topic (Chapter 9).

The basic theoretical framework is built on complex systems thinking, corporate social responsibility, environmental awareness, sustainability, and life

cycle assessment. The experiential foundations focus on in-house process changes compared to eco-industrial parks and show what lessons can be learned from the literature. The case study overview provides more information about the focus company and what improvements have been made there in the last few years, and what next steps may be planned. The analyses compares in-house process changes to eco-industrial parks, in light of the focus case study information to provide some guidance as to future steps for that case and industry in general.

Chapter 2: Basic Concepts and Theoretical Literature

This chapter looks at broad concepts from the literature that are essential building blocks for sustainability. I have chosen complex system thinking, corporate social responsibility, environmental awareness, sustainability, and life cycle analysis as these are key motivators for industrial ecology found in the literature and concepts that businesses have to be aware of and stand behind if they are to make any progress towards sustainability (Ayres & Ayres, 2002; Baas & Boons, 2004; Bakshi & Fiksel, 2003; Cohen-Rosenthal, 2000; Ehrenfeld & Gertler, 1997; Fiksel, 2003; Garner & Keoleian, 1995).

The literature review aims to answer the following questions about industrial ecology:

- What are the ideas that underline the conception of industrial ecology: why was it developed with the characteristics it has; and why is it needed in and appropriate for the world, including the world of industry these days?
- What are reasons industrial companies should be motivated to adopt and apply industrial ecology?

These questions will be reflected on at the end of section 2.1. Following that this chapter will look at in-house process changes, industrial ecology and eco-industrial parks, the initial framework for analysis, which is the basis for the framework for analysis used for the assessment of the examples from the literature and the focus company.

2.1. Basic Conceptual Foundations

2.1.1 Complex Systems Thinking

Complex systems thinking is defined as “research concerned with understanding systems characterized by nonlinear behavior, feed-backs, self-organization, irreducibility, and emergent properties, in which the whole is not only more than but also different from the sum of its parts” (Baynes, 2009, pg. 215). Kay and Schneider (1994) state that through the lens of systems thinking, ecosystems are complex and that the conventional scientific method of quantification and analysis oversimplifies this fact, creating a synthetic frame of analysis upon which many theories are based.

Complex systems are importantly categorized as ‘self organizing’. Self-organization can be described through sudden changes (or flips) occurring from a novel actions developing among sections and/or the system as a whole (Kay & Schneider, 1994). Kay and Schneider (1994) also point out that self-organizing systems occur in the buffer zone between receiving enough energy of good quality (to support self-organization), and too much energy, which results in chaos due to overwhelming the dissipative abilities of the system.

Kay, Regier, Boyle and Francis (1999), describe complex systems as self-organizing and thermodynamically open which has become a prominent stream of complex systems thinking, especially when looking at ecosystems and social systems (Francis, 2005). Some important properties about complex systems are that they are non-linear, hierarchical and dynamically stable; that they have internal causality, a window of vitality, and multiple steady states; and that they

can exhibit catastrophic and chaotic behaviour (Kay et al., 1999). Being non-linear indicates holistic “system” behaviour that cannot be understood by fractional analysis; being hierarchical is a system contained within a system, which is made up of systems and the whole must be studied from different types and scales. Being dynamically stable suggests that the system is in flux and may not have equilibrium points (Kay et al., 1999). Having internal causality suggests a self-organizing system illustrated by goals, feedbacks, autocatalysis, emergent properties and surprise, having a window of vitality gets back to the earlier point that self-organizing systems exist in the zone between too little and too much energy (chaos), and having multiple possible steady states indicates that there are multiple system states that can occur without preference for one over another (Kay et al., 1999). Finally, exhibiting catastrophic behaviour is shown by divergences, rapid system flips, and the Holling four box cycle (exploitation, conservation, release and reorganization (Holling, 2001)); chaotic behaviour is shown by a limited ability to predict, or forecast, with certainty over a long duration of time (Kay et al., 1999).

The understanding of complex systems has been incorporated into industrial ecology as a core feature that recognizes a key reality of the complex nature of the world, one that industry must unavoidably operate in. Complex systems thinking has been uncommon and represents a window into new fields of innovation, including the pursuit of efficiencies that could benefit industry finances as well as environmental stewardship.

2.1.2 Corporate Social Responsibility

Corporate social responsibility can be defined as actions that appear to further some social good, beyond the interests of the firm and beyond that which is required by law (McWilliams & Siegel, 2001). McWilliams and Siegel (2001) state that corporate social responsibility goes further than what the law requires and that some examples are recycling, minimizing pollution, supporting the local community and advanced human resources programs. Corporate social responsibility is a concept that was developed in the 1950’s and has progressively evolved throughout this ‘modern era’ to what it is today (Carroll, 1999). Corporate social responsibility includes attention to issues such as: human rights, workplace and employee wellbeing (including occupational health and safety), unfair business practices, organizational governance, environmental aspects, marketplace and consumer issues, community involvement and social development (Leonard & McAdams, 2003).

Using Willard’s (2005) five stages of sustainability (pre-compliance, compliance, beyond compliance, integrated strategy and purpose and passion) we find that corporate social responsibility fits in at stage three: beyond compliance. When a company is at this stage of progress towards sustainability it is going to be investing heavily in a proactive corporate social responsibility plan, realizing that there are significant cost savings associated with eco-efficiencies, a competent engaged work force, cleaner processes, and better waste management (Willard, 2005). Unfortunately many companies are stuck in the

compliance stage and it is only once they realize the benefits of corporate social responsibility that they move beyond this stage.

The International Organization for Standardization (ISO) defines corporate social responsibility as “a balanced approach for organizations to address economic, social and environmental issues in a way that aims to benefit people, communities and society” (Leonard & McAdam, 2003), and these guidance standards are a major stepping stone for corporations to adopt higher levels of sustainability-enhancing behaviour. Leonard and McAdam (2003) state that an organized method to corporate social responsibility actions is ISO 14000. ISO 14000 is the environmental and management standard, and was updated in 2004 as ISO 14001; it includes methods for reducing waste management costs, savings in consumption of energy and materials, lower distribution costs, and improved corporate image (ISO, 2009). Perhaps showing the increasing importance of corporate social responsibility in the world today, a new ISO 26000 standard has recently been developed that guides businesses through corporate social responsibility as a way to operate that meets social and environmental expectations (ISO, 2014).

Corporate social responsibility is increasingly well recognized, through programs like ISO, as an expectation, perhaps even an obligation of companies wishing to gain and retain a desirable reputation in the eyes of investors, consumers and others. This can be seen as a reason why companies could be motivated to apply industrial ecology to their business practice.

2.1.3 Environmental Awareness

Applied environmental awareness, or environmentalism has the simple goal of protecting the environment, and providing stewardship (or gardening) to the Earth through environmental protection (Dreher, 2011). Falkner (2012) argues that society, on an international scale, has been gradually ‘greened’ over the past century in an effort to restore the relationship between the natural environment and society. The modern environmental movement beginning in the 1960’s was arguably initiated by Rachel Carson’s *Silent Spring*, and it has led to an era of international political environmentalism where environmental protection is a global issue (Falkner, 2012). Industry as an important part of the international economy, present in almost every country in the world, needs to participate in encompassing environmental awareness on an international scale.

In the last hundred years, Falkner (2012) reasons, there have been three major features of the greening of society at an international scale: environmental issues have transitioned from domestic to international concerns, concepts of global environmental responsibility have emerged and led for example to increased practice of environmental diplomacy, and finally, actual firm diplomatic commitments lag far behind procedural commitments. These three arguments can be seen clearly in international political relations regarding the environment. One obvious example concerns the Kyoto Protocol, in which countries tackled an environmental issue on a global scale, and about which countries met regularly at different subsequent meetings on implementation around the world, but which has been much less successful in driving effective emission abatement action

than hoped, in part because many signatory countries including Canada failed to meet their obligations (Canada eventually pulled out of the agreement). Effective commitment to environmental stewardship is the essential first building block to environmental protection. The failures of governments to act on environmental stewardship add to the expectations for businesses to take the lead, and these expectations will surely rise as the costs of unsustainable behaviour (including climate change effects) mount.

We are in a new age of consumer environmentalism. Consumers are increasingly demanding products and services that are environmentally friendly, and favouring companies that believe in these principles (Fineman & Clarke, 1996; Hainmueller & Hiscox, 2012). Being green is the new trend in business, and consumers want to know what the products they are buying are made from, where they came from and how that business is being environmentally friendly (PWC, 2010). Industry that does not produce directly for the consumer retail market often gets a backstage pass in consumer awareness, as it's the market companies that are the branded face of the product; however consumers are starting to consider life cycle assessment and truly green companies must have a green supply chain in order to meet these expectations. This consumer environmentalism gives industry a growing motive to be environmentally aware, and to act on this awareness in tangible ways.

2.1.4 Sustainability

Sustainability can be found at the place where social, economic and ecological welfare convenes, with each dependent on one another in ways that maintain lasting viability and desirability (Gibson, 2006). Nowadays sustainability is most often viewed unevenly, with the economy assigned utmost importance, social provisions measured by how they aid the economy, and the environment viewed in a utilitarian ecosystems services approach focused on what resources and services it can offer us (Gibson, 2005).

The concept of sustainability overlaps with the concept of sustainable development, first popularized by the Brundtland Commission in 1987 (WCED, 1987). Although this concept has had much scrutiny, Gibson (2006) argues that its real brilliance was in the fact that it stated that reducing poverty and safeguarding the environment are dependent on each other's success and gains cannot be made in one, without gains being made equally in the other.

Gibson (2005) argues that there are nine characteristics of sustainability: "that it is a challenge to conventional thinking and practice, that it is concerned with both long and short term well being, that it covers the core issues of decision making, that it demands acknowledgement of links and interdependencies, that precaution is necessary in a complex world, that it recognizes inviolable limits and endless opportunities for creative innovation, that it is open ended, that the means and ends of sustainability are intertwined, and that the concept of sustainability is both universal and context dependent" (pg. 57-58).

The main requirements for progress towards sustainability are socio-ecological system integrity, livelihood sufficiency and opportunity, intragenerational equity, intergenerational equity, resource maintenance and

efficiency, socio-ecological civility and democratic governance, precaution and adaptation, and immediate and long-term integration (Gibson, 2005). It is important to address these requirements together, which is a great strength of industrial ecology's combined attention to socio-ecological system integrity and efficiency.

Efficiency is absolutely paramount for industry. It is a key requirement to achieve enhanced sustainability, and this concept has been, as Gibson (2005) points out, especially popular with industry. It is this need for efficiency improvements tied to sustainability objectives that highlights the calls for factor 5 and factor 10 improvements in resource efficiency (Schmidt-Bleek, 2000; Weiszäcker, 2009). Factor 5 (50% reduction in resource use) and factor 10 (90% reduction in resource use) are essential for progress towards sustainability as we are currently overusing the Earth's carrying capacity and will be soon depleting resources and ecosystem viability catastrophically if changes are not made.

Sustainability objectives and insights underlie the industrial ecology concept and that the broad global recognition of increasingly pressing needs to move towards sustainability presents growing motives for adoption and implementation of industrial ecology.

2.1.5 Life Cycle Assessment

Life cycle assessment is essentially an effort to ensure that all environmental impacts associated with a product or services are accounted for from raw materials (cradle) to waste products (grave) (Klöppfer, 1997; ISO, 2009). Life cycle assessment is all-inclusive and considers all facets of the natural environment, human health and resource use (ISO, 2009). The U.S. EPA states that life cycle assessment consists of three parts: inventory analysis of energy, resource use and waste production, impact analysis of the consequences of inventory use, and improvement analysis of opportunities to effect environmental improvements (U.S. EPA, 1993).

Life cycle assessment was first discussed in a 1993 paper by Guinée, Udo de Haes, and Huppes and has evolved into an international standard (ISO 14040 and 14044), becoming an important and practical tool for impact assessment (Finnveden et al., 2009). Finnveden et al. (2009), describes two types of life cycle assessment analysis: attributional and consequential (sometimes referred to as descriptive and change-oriented). Attributional life cycle assessment focuses on environmentally relevant physical flows surrounding a life cycle and its subsidiaries (Finnveden et al., 2009). Consequential life cycle assessment looks at how decisions affect environmentally relevant flows (Finnveden et al., 2009).

Life cycle assessment is now part of the sustainability package for companies focused on improving their products and services in a new green economy. Consumers care about how environmentally friendly a company, and their products are, and it is an approach that taps into the new environmentally aware global consciousness (Deloitte, 2009).

Many companies now feel pressure to follow their products through the entire life cycle, which in turn puts pressure on secondary suppliers, and so on,

thus spreading the motive for greener behaviour throughout industry. This results in a motivation that rests on the advantage enjoyed by companies that adopt industrial ecology approaches, for example.

2.1.6 Answering Questions about the Literature Review

At the start of 2.1 the following questions about the literature review were posed:

- What are the ideas that underline the conception of industrial ecology, why was it developed with the characteristics it has, and why is it needed in and appropriate for the world, including the world of industry these days?
- What are reasons industrial companies should be motivated to adopt and apply industrial ecology?

The literature review shows that industrial ecology is indeed built upon the concepts of complex systems thinking, corporate social responsibility, environmental awareness, sustainability, and life cycle assessment, and that it is needed and appropriate for a world where there are calls to improve efficiency and to make progress towards enhanced sustainability. Industrial companies should be motivated to adopt and apply industrial ecology because it improves their competitive advantage in this day and age of environmentally aware consumers and investors, and is in line with the pressing need to achieve improved sustainability in industry. Industrial ecology is a crucial means to this end as it is a multidisciplinary approach that looks at the big picture of socio-ecological system integrity and overall efficiency. It is ever increasingly on the shoulders of industry to succeed where governments have not, in order to meet the needs of the ever-changing environmentally aware global economy.

2.2 In-House Process Changes

2.2.1 Scope

In-house process changes (IHPCs) encompass any efficiency improvements made to an industrial facility whether directly in production or indirectly through reduction of energy and/or material demand. Examples include upgrading electric motors to ones that are more efficient, replacing inefficient lighting with LED technology and more major changes such as improvements within the actual process line to make it more efficient. IHPCs are analogous with industrial eco-efficiency, cleaner production and corporate greening; however, the term IHPCs is used in this thesis as a more specific comparison to EIP initiatives. Eco-efficiency is the ratio between environmental impact and value of production; eco-efficiency is an attempt to produce a valuable product with less harm to the environment (Huppes & Ishikawa, 2005).

IHPCs do not include collective efficiency improvements in a development such as an EIP; however, IHPCs can include efficiency improvements among several facilities owned by the same company, within the same region, nationally, or around the world.

2.2.2 Potential

IHPCs can provide efficiency improvements in energy use as well as material consumption, independently increasing market competitiveness through cost savings and public image improvements. IHPCs are a popular option for industry because considerable gains can be achieved with minimal input, compared to other options. Efficiency improvements in industry are popular as a way to improve production practices, and calls for factor five to factor 10 improvements in material and energy efficiency using existing technology are prominent in the literature (Schmidt-Bleek, 2000; von Weizsäcker, 2009).

Cleaner production practices can result in short and long term improvements to environmental and social considerations, which can go past what is possible through regulatory compliance programs (Taylor, 2006). IHPCs can be encouraged through regulation and other encouragement from all levels of government aimed at implementing cleaner production methods, starting for example with grants for industry audits to highlight areas for improvement (Taylor, 2006). Regulatory encouragement can also take the form of carbon taxes and generally more suitable pricing of true costs of manufacturing, initiatives to decrease reliance on fossil fuels, and programs to support new job creation (Andersson & Karpestam, 2012). Andersson and Karpestam (2012, 2) report that use of “policy instruments such as environmental taxes or tradable emission permits increases innovation in “green technologies” and speeds up the diffusion process of existing technologies”. It is through this avenue that carbon taxes can encourage IHPC implementation in industry, and could be an important regulatory based incentive for cleaner production and industrial eco-efficiency improvement.

Shipley and Elliott (2006, 21) report that significant energy efficiency improvement opportunities are still present in industry, especially given the opportunities with ever improving technologies, but that the potential “opportunities for gross waste elimination may be less than they were 30 years ago”.

2.2.3 Strengths

The strengths of IHPCs lie chiefly in being governed by the authoritative figures within the company, rather than relying on significant third party input. This allows for greater flexibility within decision-making and autonomy in carrying out those decisions. Many IHPC initiatives can be undertaken with minimal capital investment and/or extended over a period of time. The flexibility may be limited where the improvements are required by law or as conditions of agreements with clients, for example as part of extended producer responsibility arrangements.

IHPCs can be broadly implemented and are applicable across industrial sectors through government regulations resulting in the implementation of cleaner production initiatives (Taylor, 2006). This allows proactive response across the industrial sector, but relies on the right regulations and incentives being implemented in government. IHPCs are accessible to industry as a whole and with the right education programs implementation can be encouraged (Taylor, 2006).

IHPCs are a lower cost, immediately available option for improving industrial material and energy use efficiency in order to make progress towards sustainability objectives and achieve factor 5 to 10 improvements as called for by Schmidt-Bleek (2000) and von Weizsäcker (2009).

IHPCs such as upgrading lighting and electric motors are replicable in many industrial facilities, which can create a cooperative learning environment showing implemented successes as well as troubleshooting potential pitfalls (Shipley & Elliot, 2006). As well, many of these improvements have rapid payback periods of 6-12 months, which are very appealing to industry management (Shipley & Elliot, 2006).

2.2.4 Weaknesses

The main weakness of IHPCs is that they typically operate on a much smaller scale than, for example, an EIP, and are limited to processes within a single factory. There is a limit to how efficient you can make an inherently inefficient process, without complete redesign built upon the foundations of sustainability, and that some improvements cannot be economically accomplished at the single facility scale (Esty & Porter, 1998; Hill, 2005; Huesemann, 2003). This is well illustrated by transportation efficiency options. Efficiency gains can be made in the use of personal automobile for commuting and travel – by ensuring the car is tuned, or investing in a hybrid, diesel, or even an electric car – but a modal shift to multi-person transportation using buses and/or trains, would permit much greater efficiency improvements. While driving the most efficient vehicle possible, and operating a factory as efficiently as possible, remain desirable, larger scale collective actions may provide much more significant benefits.

IHPC initiatives can also be victims to the ‘rebound effect’ where gains from efficiency increases are ‘spent’ on more resource consumption nullifying the gains made in the first place (Schmidt-Bleek, 2000). Efficiency gains need to be to the benefit of increasing sustainability and decreasing capital costs.

Previous attempts at corporate greening such as ISO 14001 have been criticized as largely ceremonial and superficial aimed at compliance to social standards (Boiral, 2007). IHPCs could be implemented for similar reasons but unlike a policy based compliance structure, IHPCs as defined in this thesis are a practical implementation of efficiency improvements.

IHPCs and eco-efficiency improvements do not guarantee sustainability objectives will be reached within industry and the dependence on efficiency improvements alone that are popular with industry do not relieve society of difficult future decisions surrounding global sustainability (Huesemann, 2003).

Larger IHPC initiatives involve partial or complete shutdowns of processes resulting in lost time for production and wages for employees; this could be too big of a burden for small facilities to implement (Shipley & Elliot, 2006).

2.3. Industrial Ecology and Eco-industrial Parks

2.3.1 Industrial Ecology Principles and Purposes

As discussed in section 2.1, the character and purposes of industrial ecology are grounded in the principles of complex systems thinking, corporate social responsibility, environmental awareness, sustainability, and life cycle assessment. Industrial ecology is the “multidisciplinary study of industrial and economic systems and their linkages with fundamental natural systems” (Allenby, 2000, pg. 43).

Industrial ecology, as previously defined through combining the works of Allenby (2006), Ayres and Ayres (2002) and Gibson (2005) involves the mirroring and incorporation of ecologically-based multidisciplinary complex systems thinking that reduces environmental impacts and maintains the sociological benefits of processing, while increasing a company’s (or group of companies’) market competitiveness and resilience in a sustainably focused economy. Industrial ecology usually focuses on efficiency gains through EIPs, dematerialization and/or conversion from selling products to selling services. Practically speaking there are some material goods that need to be produced even in a sustainable society, and for this reason I will focus upon EIPs and their potential contribution to a sustainable manufacturing sector.

2.3.2 Industrial Ecology Applications

The best examples of applied industrial ecology in the literature are EIPs. The EIP in Kalundborg, Denmark, has become the poster child for successful EIP projects. Kalundborg will be discussed in detail in chapter 3 as an excellent merger of traditionally unsustainable industries collectively reducing their impact on the environment while maintaining competitiveness in the market economy.

A good example of dematerialization is found in Allenby (2000) who discusses the success of applying industrial ecology concepts to AT&T, which resulted in a significant decrease in environmental degradation and capital costs through simple measures such as reducing packaging and increasing recycling.

2.3.3 Eco-industrial Parks

2.3.3.1 Goals and Definitions

The goal of an eco-industrial park (EIP) is to reduce waste volume and negative environmental impacts while increasing the competitiveness and success of companies in a collaboration of companies (Cohen-Rosenthal, McGalliard & Bell, 1996). There are several definitions of EIPs; however, they all include some mention of improved environmental, economical and social conditions achieved through the cooperation and collaboration of multiple firms in close proximity, and fall under the broader definition of industrial symbiosis. An EIP differs significantly from a simple industrial park, which Côté and Cohen-Rosenthal (1998, 182) define as “a large tract of land, sub-divided and developed for the use of several firms simultaneously, distinguished by its shareable infrastructure and close

proximity of firms,” which places no emphasis on reducing environmental impacts or increasing sustainability.

Côté and Cohen-Rosenthal (1998, 182) clarify that EIPs are not “a single by-product exchange pattern or network of exchanges; a recycling business cluster (resource recovery, recycling companies, etc.); a collection of environmental technology companies; a collection of companies making ‘green’ products; an industrial park designed around a single theme; a park with environmentally infrastructure or construction; or a mixed use development (industrial, commercial and residential)” Côté and Cohen-Rosenthal (1998) do not provide their own definition of an EIP, but rather provide several definitions from the literature, stating that just like industrial ecology, EIPs have several definitions. They provide the following complementary definitions:

An eco-industrial park is an industrial system which conserves natural and economic resources; reduces production, material, energy, insurance and treatments costs and liabilities; improves operating efficiency, quality, worker health and public image; and provides opportunities for income generation from use and sale of wasted materials (Côté and Hall, 1995).

An eco-industrial park is a community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resources issues including energy, water and materials. By working together, the community of businesses seeks a collective benefit that is greater than the sum of the individual benefits each company would have realized if it optimized its individual interests (Lowe et al., 1995).

A community of businesses that cooperate with each other and with the local community to efficiently share resources (information, materials, water, energy, infrastructure and natural habitat), leading to economic and environmental quality gains, and equitable enhancement of human resources for the business and local community (United States President’s Council on Sustainable Development, 1996).

2.3.3.2 Potential

EIPs can significantly improve efficiencies of industrial facilities, reduce waste outflow and encourage cycling of waste/resources externally from the environment (Erkman, 1997). EIPs can transfer previously unused wastes turning them into resources for another process, linking various companies together producing an efficient ‘industrial ecosystem’. By cycling waste products the

collective EIP is much more efficient than individual companies could be on their own, which increases market competitiveness (Behera et al., 2012). EIPs can transition industrial facilities into the upper echelon of efficiency improvements much more effectively than IHPC can, as EIPs as a whole are greater than the sum of their parts could achieve independently (Chertow, 2008; Côté, Tansey & Dale, 2006).

EIPs have the potential to bring companies together in cooperative ventures that may go beyond waste exchanges, to include options such as collaborative solar or wind energy generation projects, which is consistent with the latter half of the Lowe et al., (1995) definition of EIPs seen above.

EIPs do not create themselves; there is some form of planning involved at least at an economic level. Desrochers (2000), Desrochers (2004), Lowe (1997), Cohen-Resenthal et al., (1996) and Ehrenfeld and Gertler (1997) all agree that there was no holistic planning at Kalundborg. Rather the EIP was the product of economically based decisions designed to reduce waste treatment and disposal costs, as well as acquire cheaper materials and energy. There is an argument in the literature made by Desrochers (2000), Cohen-Resenthal et al., (1996) and others in the field that holistically planned EIPs could very well out perform Kalundborg and that planned EIPs should be the next phase of development.

2.3.3.3 Anchors

The concept of anchors is important within the realm of EIPs. An anchor facility is the critical mass for an EIP, and is quite often a power plant (Chertow, 2000). It is the main player within an EIP and, without it, EIP success would be severely limited. Ayres (1994) argues that every EIP would need at least one anchor firm that produced raw or processed material and that was connected to several other industries able to utilize this 'waste'.

In the Kalundborg EIP, the anchor is the 1,500 MW Asnæs coal fired power station, which provides heat, steam, gypsum (via sulphur removal in the flue gas scrubber), as well as fly ash (airborne ash captured by the scrubber) and clinker (heavier soot like material) (Ehrenfeld & Gertler, 1997).

At Burnside Industrial Park there is a lack of a traditional anchor, such as the case with Asnæs at Kalundborg EIP; however, the integration of the eco-efficiency center with Dalhousie University, and the networking of small manageable inter-firm connections seems to provide the equivalent of a collaborative anchor to hold the park together. A similar collaborative anchor could be an option for similar small to medium sized pre-existing industrial parks partaking in industrial ecology projects.

2.3.3.4 Strengths

The strengths of EIPs are that they provide collective efficiency gains that are greater than the sum of what could be accomplished by the individual facilities working independently (Côté, Tansey & Dale, 2006). EIPs reduce waste outflow by utilizing materials more completely as well as integrating new options for waste use, rather than just reducing the volume of outflow. EIPs benefit more

than just industry, as seen in the Kalundborg EIP, where approximately 3,500 residents receive cheap reliable heat, eliminating the need for oil fired furnaces, and thereby reducing contributions to global warming (Ehrenfeld & Gertler, 1997). Transitioning from individual heating sources to centralized district heating is more efficient because it utilizes heat that would otherwise be wasted and it capitalizes on economies of scale from large power station boilers (Euroheat and Power, 2011).

2.3.3.5 Weaknesses

The weaknesses of EIPs are that there are significant political, technical and administrative hurdles to overcome before the benefits of such a project can be realized and redeemed. EIPs such as Kalundborg require high volumes of continuous material and energy flow to be effective. In many industries, waste flow is discontinuous and comprised of single material wastes (plastic and metal scrap, etc.) or mixed wastes (damaged product containing multiple assembled components); these wastes types are a hindrance to EIPs due to high transaction and recycling/remanufacturing costs (Ehrenfeld & Gertler, 1997). One exception Ehrenfeld and Gertler (1997) note is the reclamation of precious metals, which have high enough market value to justify their extraction. EIPs require large flows of 'waste resources' and so efficiency increases resulting in a reduction of flows are counterproductive, and instead maximum flows are desired (Ehrenfeld & Gertler, 1997). EIPs also require extensive trust between the participating companies, as success is dependent on the parts of the 'industrial ecosystem' functioning efficiently together, which is unlikely if the participating firms are completely independent parts and act as if they were immune to the failures of others.

2.4. Framework for Analysis

On the basis of the discussion above, it is possible to construct a framework for analysis for use in analyzing the IHPC and EIP case studies, as well as the focus company. The framework for analysis introduced below is built upon the literature on theory and concepts (section 2.1), the literature on IHPC (section 2.2) and the literature on industrial ecology and EIPs (section 2.3). The framework is composed of two parts: the desirable qualities and effects of industrial ecology, and the key drivers of, barriers to and opportunities for industrial ecology applications.

2.4.1 Contributions from the Literature on the Concept of Industrial Ecology and Underlying Theory

The conceptual theory indicates that the desirable qualities and effects of industrial ecology lie in the potential efficiency gains that are obtainable, and that they allow sustainable development to occur within industry. There is a large potential for industrial ecology applications to improve economic, environmental and social conditions in the industrial world, given that the right conditions are present to foster this development. Industrial ecology is built on the foundations

of complex systems thinking, corporate social responsibility, environmental awareness, sustainability, and life cycle assessment, and effective use of the industrial ecology concept requires the application of these concepts. Dissemination of these concepts to the consumer will also lead to pressures on industry to meet these demands from non-government bodies, which can be seen today through the consumer desire for green products.

2.4.2 Contributions from the Literature on IHPCs and EIPs

IHPCs and EIPs provide some intriguing opportunities to improve overall efficiency in industry independently or in conjunction with neighbouring industries. The main strengths of IHPCs are that they have lower capital investment costs, and they keep investment decisions within the company, while the main strength of EIPs is that they provide greater efficiency gains than independent IHPCs do. The main weakness of IHPCs is that it is significantly harder to achieve significant gains in efficiency, and that efficiency gains may not be feasible without greater economies of scale than are available at the single facility level. The main weakness of EIPs is that there are significant political, technical, and administrative hurdles to overcome before they can be successfully implemented.

2.4.3 The Framework for Analysis (Determination of Success Criteria)

2.4.3.1 Desirable Qualities and Effects

Chapters 3 and 4 below examine IHPC, EIP and the focus company cases to see how their current operating parameters stack up when examined and compared through the framework for analysis presented in this section. The discussion and examination of these cases will involve identification of the strengths and limitations of their operating initiatives and results. The analysis will involve application of the framework, which sets out the key criteria for success in IHPC and EIP initiatives. Each case study will be analyzed using these criteria and the cases will be ranked using a scale of the different stages of success for each category and then provide a final score out of 28. The four stages of each category have been compiled from the various literature sources discussed above. This scale will rank IHPCs and EIPs using six categories and four stages of success within each category.

The key insights from sections 2.1 to 2.3 are summarized in the following adjusted list based on Kurup et al., (2005) providing economic, environmental and social indicators for industrial ecology analysis:

Economic:

- Generation of local business opportunities
- Generation of capital works
- Increases to sales and profit
- Wages paid
- Continued taxation revenue for governments
- Reduction or elimination of tangible environmental costs

- Reduction or elimination of transport costs

Environmental:

- More environmentally friendly land use
- Reduction of energy, water and material consumption
- Reduction and/or elimination of air, land and water emissions

Social:

- Job creation and security for skilled workers
- Continued health and wellbeing of employees
- Community stability through employment opportunities
- Reduction or elimination of sensory stimuli (aesthetic or visual, noise, dust, odour)

The framework for analysis was created as an attempt to compare and quantify IHPC and EIP project successes, noting that it is not possible to evaluate each and every component due to the limitations of the data that are publically available. The framework aims to recognize both overall steps towards sustainability in the broad public interest, and the importance of corporate willingness to concentrate on matters recognized in the corporate eco-efficiency literature. The framework is not an attempt to present a full set of considerations that would move industrial practice to full adoption of commitments to maximize positive contributions to sustainability, but lists and extends key accepted considerations for enhanced corporate greening. Traditional stage models for corporate greening are insufficient in addressing the multidimensional complexities of real world corporate greening as analyzed by Schaefer and Harvey (1998), and they recommend that future research use “broader, multi-dimensional theoretical frameworks” (119). The following framework categories represent quantifiable selections that broaden traditional corporate greening structures and take into account key insights from the literature to produce a working framework progressing towards enhanced sustainability.

Desire for efficiency gains (and associated cost savings) is the main driver of IHPC and EIP projects and a goal of significant (factor 10) improvements is the desired outcome in terms of energy and material use. Material use covers both waste and new material usage, as these are extremely important to industrial ecology. Waste reduction covers air emissions, water discharge, as well as, solid/liquid and hazardous wastes.

Cost savings have been ranked from no change to substantial change (millions saved per year). These cost savings are taken from conventionally reported data, usually from sustainability reports, and do not include currently externalized costs, such as the cost of climate change. This leaves the cost savings category as a fraction of what it should account for, but due to a lack of carbon taxing and other accounting for important environmental and social effects it is impossible to quantify this cost at present, and so, analysis in this category does the best it can do with readily and publically available conventional

economic data. An important note is that given that this table compares IHPC and EIP, it does not specifically distinguish cost savings that are associated with industrial ecology, from cost savings that were achieved in more conventional applications of good business practice. The cost savings from the EIP cases come directly from the application of industrial ecology principles; however, the IHPC cost savings can come from a variety of actions initiated for various purposes and it is impossible to determine where they originate from at the inception and application stage of their development.

The job stabilization and/or creation category has been ranked from no change (given economic uncertainty) to job stabilization (current positions) and creation of greater than 10% new jobs and/or positions. This range was chosen as an attempt to rank both IHPC and EIP using the same framework, and is based on industrial ecology success criteria from Agarwal and Strachan (2006), Ayres and Ayres (2002) Kurup et al., (2005) and Kurup (2007). Job creation is considered broadly in this framework, and includes temporary construction and consulting jobs that would be needed in order to complete some aspect of the project. Some efficiency improvements are a result of job cuts, as processes are streamlined and excesses are cut. Perhaps a job can be more effectively completed by a robot, as is seen commonly in automobile manufacturing, or perhaps there are more employees than needed and positions that could be eliminated and redistributed. This is where economic and social concerns are at opposite ends of each other, and the release of an employee for economic reasons has negative impacts on social wellbeing. It is to be assumed though that some released employees will find work elsewhere, perhaps in a different field, or even after going back to school for a new career. The elimination of less efficient human-tended tasks must be weighed against the environmental and economic efficiencies that come with that elimination. Job creation in that sense could be (using the example of robots in the automotive industry) come in the form of the technician who works on the robot, or the whole new company that designs and builds these robots.

Ease of implementation ranks from impossible/impractical to active development and/or cooperation is being initiated. This is an important category for the framework for analysis as there are significant technical hurdles to overcome while implementing new technologies and concepts, as well as administrative challenges that could hinder progress. If a solution for industry cannot be implemented then it cannot practically be considered a realistic goal.

Long term viability would rank from unviable (no change) to viable and resilient to change given an uncertain future. Long term viability is important as it relates to sustainability and the need for efficiency increases in industry, in order to continue progress towards a sustainable society (Schmidt-Bleek, 2000; Weiszäcker, 2009). Long term viability is the extension of efficiency in resources towards the global challenge of improving environmental stewardship.

Public image/relations ranks from no change to newsworthy. This is primarily based on a publication level for what is readily available to the average person through traditional news channels and internet media. Public image is

important because it can potentially increase market share and equity value (Patniak & Poyyamoli, 2012).

A baseline case study of 'no change' (no progress beyond stage 1) would be given a score of 0 in total, whereas a fully successful IHPC or EIP project could receive a score as high as 21. It is also important to note three limitations of the framework. First, the framework does not provide a full set of criteria for assessing IHPC or EIP contributions to sustainability. It represents a more narrowly focused compilation of the criteria that are commonly recognized in the literature as important for success in industrial ecology, and that can be used for comparison of IHPC and EIP cases. Second, the framework is generic and intended to ensure attention to key considerations. It does not attempt to determine how heavily each of the categories of concern should be weighed or to take into account the particular concerns and priorities of applications in different places. Finally the criteria categories include some for which data may be unavailable and the indicators of success may be difficult to quantify. As Kurup et al. (2005) point out, despite such difficulties, it is important that all key considerations be listed. The framework is therefore appropriate for exploratory comparisons and indicative findings, and would need further elaboration for applications seeking greater precision.

Table 1: Desirable Qualities and Effects ranking scale for IHPC and EIP case studies.

Category	Stage 1 (0 points)	Stage 2 (1 point)	Stage 3 (2 points)	Stage 4 (3 points)	Score
Energy Use Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	
Material Use and Waste Flows Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	
Cost Savings	No change from current business as usual levels.	Minimal (thousands/year)	Significant (hundreds of thousands/year)	Substantial (millions/year)	
Job Security, Stabilization and/or Creation	No change from current levels given the uncertain economic situation.	Job stabilization at current company levels; no job creation. No change in job security.	Job stabilization at current company levels and minimal job creation (<10%) and/or enhanced job security.	Job stabilization at current company levels and significant job creation (~10%) and enhanced job security.	
Ease of Implementation	Impossible and/or impractical given involved company's current situation.	Possible, however there are significant administrative barriers.	Sensible, willingness from stakeholders to begin planning.	Development and/or collaboration is actively explored and initiated.	
Long term Viability	Unviable (no change)	Improvements in viability.	Viable but not resilient to change.	Viable and resilient.	
Enhanced Public Image and Relations	No change from current level.	Minimal improvement in one or the other.	Improvement in both public image and relations.	Significant improvement in public image and relations. Newsworthy.	
Total Score					

2.4.3.2 Drivers, Barriers and Opportunities

Drivers, barriers and opportunities are a primary focus of this thesis and insights from the literature, as well as the case study will provide a collected summary of what drivers, barriers and opportunities there are for the main case study, as well as broadly in the literature with regard to the implementation of industrial ecology principles and practices in the industrial workplace.

Drivers are key elements that facilitate the implementation of industrial ecology within industry. They could be economic, environmental, or social in nature and would be a significant pushing force to facilitate a project of this kind.

Barriers are anything economic, environmental or social that prevent industrial ecology based applications to be initiated or pursued successfully. It is hoped that the interviews will provide new content from the industrial workplace to add to the literature.

Opportunities are openings for desirable initiatives to be pushed forward. In the major case, these would be openings to increase the efficiency of the focus company and/or two or more companies at the case study site. This could

be individual for the focus company or some sort of collaborative venture, all depending on what the drivers and barriers are.

2.4.3.3 Other Considerations

This framework for analysis is open to other considerations that may appear in the analysis of the case studies (practically and in the literature). Any additional considerations not covered in this section will be incorporated into the adjusted framework for analysis at the end of chapter 3.

2.5. Chapter Conclusion

In this chapter, basic concepts and theoretical literature were presented and discussed. The theoretical concepts of complex systems thinking, corporate social responsibility, environmental awareness, sustainability, and life cycle analysis were highlighted and discussed in order to better understand the underlying foundations of industrial ecology. There needs to be understanding of these concepts, at least in a basic form for easier comprehension of industrial ecology to industry professionals.

The basic characteristics, strengths, and weaknesses of IHPCs and industrial ecology (via EIPs) were examined in order to provide the reader with a more robust understanding of them. It was found that IHPC suffers less from administrative hurdles but that EIPs operate on a different, and much larger scale, leading to potential for greater efficiency gains (Chertow, 2008).

Finally, desirable qualities and effects were examined, and the initial framework for analysis was developed and presented as a means for comparing the success of IHPCs in comparison with EIPs.

Chapter 3: Comparison of Significant IHPC and EIP Cases

In this chapter the experiential literature cases will be reviewed and assessed using the framework for analysis developed in the previous chapter. Three IHPC and three EIP projects will be examined and ranked in order to compare the successes, and shortcomings of each.

3.1. Cases: Experiential Literature

3.1.1 Methodology and Reasoning

Six cases were chosen for this chapter, three being examples of IHPCs and three EIPs. The cases of Interface and Kalundborg were chosen as prime examples of IHPCs and EIPs, respectively. Analysis of these cases permitted a test application of the framework for analysis developed in Chapter 2, and provided for a comparison of IHPCs and EIPs under this framework. The cases are globally sourced, and there was no particular emphasis put on North American companies/cases; however multifaceted companies, or chemical and/or metallurgical companies were of particular interest due to relevance to the Canadian industrial economy. The IHPCs and EIP cases were chosen for this research based on the following criteria:

- Adequacy and availability of reasonably recent publically available data for application of the framework for analysis
- Representation of best practices identified through the Corporate Knights ranking
- Relevance and comparability to the focus company case including: developed country status, reasonably large corporate players, and characteristics of industrial inputs and processing
- Relevance to the varied industrial manufacturing landscape in North America

It is important to note that the adequacy and availability of data for application of the framework for analysis was crucial in this selection of case studies, while at the same time attempting to satisfy the other criteria. For the IHPC cases there were other companies considered such as 3M and Hewlett Packard; however, after consideration of the data available, I selected the case studies seen in the following sections.

3.2. In-House Cases

3.2.1 Case 1: Interface Inc.

3.2.1.1 What did they do?

Interface Inc. is a global carpet and office textile manufacturer and distributor that was founded by the late Ray C. Anderson and is based in Atlanta, GA (Greiner, Rossi, Thorpe & Kerr, 2006; Rosenberg, 2009). They have been touted as one of the global private sector sustainability success stories, and have greatly

improved many aspects of their business over several company reinventions (Anderson, 1998; Dornfeld & Wright, 2007; Lampikoski, 2012; Rosenberg, 2009).

Prior to Anderson's epiphany in 1992 about the importance and need for environmentally sustainable companies, Interface Inc. was a successful, though, materials-intensive manufacturer of carpet tiles and office textiles for various workplace environments (Anderson, 1998). Anderson's adoption of manufacturing sustainability principles followed the concepts of industrial ecology through the mirroring of ecological system functions in industrial manufacturing; "When we understand how a whole forest works, and apply its myriad symbiotic relationships analogously to the design of industrial systems, we'll be on the right track" (Anderson, 1998, p.10). Interface can be considered a poster child for IHPC utilizing the fundamental principles of industrial ecology to dramatically increase the sustainability-related efficiencies of an individual company.

Interface improved its environmental sustainability through following seven fronts of sustainability (or seven faces of the sustainability mountain) as well as an Eco-metrics system (Anderson, 1998; Rosenberg, 2009). The seven fronts of sustainability concept is based upon The Natural Step by Karl-Henrik Robèrt and is summarized as:

1. Zero Waste (through their QUEST program),
 2. Benign Emissions (the elimination of toxins),
 3. Renewable Energy (namely solar),
 4. Closing the Loop (through waste to resource recycling),
 5. Resource-Efficient Transportation (through alternative fuels/transportation as well as virtual meetings),
 6. Sensitivity Hook-up (buy-in of business partners and employees),
 7. Redesign Commerce (through the economic notion of prices reflecting *true* costs).
- (Anderson, 1998).

The seven fronts of sustainability are effective guiding principles that have helped Interface achieve enhanced environmental sustainability, and progress has been made in three main areas: conservation/waste minimization, engineering changes, and product and chemical/process changes (Rosenberg, 2009).

Conservation/waste minimization has been very successful at Interface and the company estimates savings in excess of 40 million USD over their five U.S. plants from 1999 to 2005, and solid waste and GHG emission reductions by 60% and 78%, respectively; in particular the Guilford, Maine plant reduced solid waste by an impressive 94% from 1997 compared to 2004 (Rosenberg, 2009).

In identifying desirable engineering changes Interface's Quality using Employee Suggestions and Teamwork (QUEST) program has been essential for reducing their environmental impact, as it has allowed employees with better first hand knowledge of the process to suggest changes and improvements (Rosenberg, 2009). This formal program at Interface has been successful in part

because the workers on the factory floor have a different perspective of the process, and therefore offer different suggestions, than the design engineers. One of Interface's biggest assets in this area is that their workforce is trained to think outside the box and detect areas where efficiency gains could be made.

Interface has made good progress on their product and process/chemical changes initiative and are actively trying to "cut the umbilical cord to oil". In Europe 44% of their raw material is recycled/bio-based (Arratia, 2014, p.1). It is Interface's goal to eventually produce 100% bio-based products that can enter the food chain at their end of life; currently they are looking at corn-based fibers to fill this requirement (Rosenberg, 2009). In the time until fully biodegradable corn based fibers are fully used at Interface they are able to use 100% recycled polyester fibers in a closed loop manufacturing process (Anderson, 2009; Rosenberg, 2009). Interface is also actively working on eliminating toxic chemicals from their manufacturing process, in accordance with step two of the seven fronts of sustainability (Anderson, 1998; Rosenberg, 2009).

The Eco-metrics system allows Interface to more accurately measure energy inputs and waste outputs per yard of final product (Rosenberg, 2009). The Eco-metrics system helped reduce solid waste by 60% in pounds per yard of finished product and greenhouse gas emissions by 78% at two of their manufacturing facilities (Rosenberg, 2009). This technology can accurately show the energy inputs and outputs within a company's product line, and Interface has even made the Eco-metrics system available freely to encourage others to use it (Rosenberg, 2009).

In Europe, Interface has been able to reduce greenhouse gas emissions by 80% and water use by 87% across their manufacturing facilities, and one facility in Scherpenzeel, Netherlands, was able to operate with 100% renewable energy, near zero water use and zero waste going to landfill as of January 2014 (Arratia, 2014).

According to Interface sustainability reports for investors, their employee numbers have fluctuated mildly from 2008-2013 (down 8.88%); however, from 2004 to 2013 there have been significant job losses at Interface, with approximately 33% of their workforce being eliminated (Interface, 2004; Interface, 2008; Interface, 2009; Interface, 2010; Interface, 2011; Interface, 2012; Interface, 2013).

3.2.1.2 What didn't they do?

Interface has done an exemplary job of improving energy and materials efficiency and reducing wastes in the company's operations while maintaining or improving economic performance. Interface is a publically traded company (NASDAQ:TILE), and has to be held accountable to its shareholders, regardless of environmental initiatives.

The biggest issue with Interface is with respect to job creation, security, and stabilization, as they have cut approximately one third of their labour force in the nine years from 2004 to 2013. This labour reduction occurred during the post 1994 Eco-Metrics revolution at Interface and has helped with the economics of the business at the cost of social welfare for their employees and eliminated staff.

These job cuts at Interface occurred from 2004-2013, during which there was a 18 month depression in the US and abroad from December 2007 to June 2009, and was arguably the worst financial crisis, given its extent across the globe (Paul, 2010). During this recession the US unemployment rate was the highest it has been in 25 years (Paul, 2010). Given this economic environment, the job cuts at Interface could be justified as necessary for corporate survival, and thus fall into the 'no change given the uncertain economic situation' category.

In 2004 Interface operated 19 locations totaling 4,845,990 square feet, but in 2013 they only had 10 locations totaling 2,464,691 square feet (a 49% reduction in square footage) (Interface, 2004; Interface, 2013). Even with this large reduction in square footage, Interface managed to increase net sales by 8.88% from 2004 to 2013, indicating that they became more efficient with their manufacturing space (Interface, 2004; Interface, 2013).

Interface is also at the mercy of the corporate economy, as their carpet tile products are primarily used in corporate offices. Their Annual Reports indicate that when the economy is down and office spaces aren't being built or renovated, Interface's bottom line suffers. The Interface model is not resilient to these changes and therefore cannot adapt if the market for carpet tiles dries up in corporate office spaces.

Ray C. Anderson's 1998 book, entitled *Mid-Course Correction: Toward A Sustainable Enterprise: The Interface Model*, discusses action on the seven fronts of sustainability as well as the other tools Interface is using to achieve zero waste, yet the January 2014 press release indicates that Interface has only recently achieved this in its European manufacturing facilities.

What are the limits to Interface's contributions to sustainability? How much further can they increase production before the limits of their process start to show? Anderson's step 3 in the seven fronts of sustainability is the use of renewable energy, however only solar energy is presented as a long-term solution. Anderson states that electricity from solar panels is at best four times the cost compared to fossil fuel sources and that we shouldn't care if the product sells (Anderson, 1998). Combinations of renewable energy (wind, geothermal, biogas, hydroelectric, etc.) are not considered by Anderson as a long-term solution to Anderson, even though the combination of solar with other sources would provide a more robust energy solution than one source would. Akella (2009) notes that solar produces the largest amount of greenhouse gas emissions (g/kWh) throughout its lifecycle, compared to other renewable energy sources such as hydroelectric and wind power.

Interface has been a leader in industrial greening for two decades and its achievements have been celebrated and are influential (Rosenberg, 2009).

3.2.1.3 Application of Framework for Analysis

The scores from the application of the framework for analysis for Interface rely on the data collected from Anderson (1998), Greiner, Rossi, Thorpe and Kerr (2006), Dornfeld and Wright, (2007), Lampikoski, (2012), Rosenberg, (2009), and the Interface Annual Reports (Interface, 2004, and 2008-2013) to quantify Interface Inc.

It can be seen (Table 2) that Interface Inc. scores high marks in most categories thanks to aggressive improvements within the company, making the company a sustainability leader in most aspects. Interface may achieve a higher score in the coming years, if other units match the factor 10 improvements of their European manufacturing facilities; however, until the other global facilities reach this goal, Interface will remain at a very respectable 14/21.

Table 2: IHPC Framework for Analysis on Interface Inc.

Category	Stage 1 (0 points)	Stage 2 (1 point)	Stage 3 (2 points)	Stage 4 (3 points)	Score
Energy Use Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	2
Material Use and Waste Flows Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	2
Cost Savings	No change from current business as usual levels.	Minimal (thousands/year)	Significant (hundreds of thousands/year)	Substantial (millions/year)	3
Job Security, Stabilization and/or Creation	No change from current levels given the uncertain economic situation.	Job stabilization at current company levels; no job creation. No change in job security.	Job stabilization at current company levels and minimal job creation (<10%) and/or enhanced job security.	Job stabilization at current company levels and significant job creation (~10%) and enhanced job security.	0
Ease of Implementation	Impossible and/or impractical given involved company's current situation.	Possible, however there are significant administrative barriers.	Sensible, willingness from stakeholders to begin planning.	Development and/or collaboration is actively explored and initiated.	3
Long term Viability	Unviable (no change)	Improvements in viability.	Viable but not resilient to change.	Viable and resilient.	1
Enhanced Public Image and Relations	No change from current level.	Minimal improvement in one or the other.	Improvement in both public image and relations.	Significant improvement in public image and relations. Newsworthy.	3
Total Score					14

3.2.2 Case 2: Umicore SA/NV

3.2.2.1 What did they do?

Umicore is a metallurgical processing company based in Brussels, Belgium that recycles and recovers various metals from electronic and industrial scrap. They were ranked #1 in 2013 on the Corporate Knights 9th annual Global 100 Most Sustainable Companies in the World list (Corporate Knights, 2013; Gunther, 2013; Umicore, 2013a). Umicore deals in four main areas: catalysis, energy materials, performance materials, and recycling (Umicore, 2012a). The catalysis component of Umicore consists of catalytic converters for passenger and commercial vehicles using internal combustion engines. Umicore manufactures approximately one third of all catalytic converters used on vehicles worldwide (Umicore, 2012a; Gunther, 2013). Energy materials are another key component within Umicore and they are involved in numerous applications, from battery technology to thin film solar applications (Umicore, 2012a). Umicore produces performance materials primarily in the form of zinc and platinum based materials for engineering and technical solutions (Umicore, 2012a). Finally, recycling is a

cornerstone of their business, and they process over 20 precious and non-precious metals from industrial wastes and end of life cycle products (Umicore, 2012a).

Using 2008 as a reference year, jobs at Umicore decreased by 6.55%, energy use decreased by 6.73%, water consumption decreased by 10.17%, total waste decreased by 16.17% and CO₂e emissions increased by 12.02%(Umicore, 2012a; Umicore, 2012b). Umicore's annual reports emphasize their cost reduction program but provide little information about the full extent of these cost cutting measures. Their annual reports suggest that the environmental efficiency initiatives often result in job cuts (Umicore, 2004; Umicore, 2013). For example the 2003 annual report states that Umicore is restructuring its zinc operations in part by reducing staff by 136 people, which will result in yearly savings of €14 million (Umicore, 2003). Staff reductions as part of their restructuring program can also be seen in the 2013 report that shows reductions of approximately 2% of their total workforce directly after the 2012 cost reduction program implementation (Umicore, 2013).

In the number of jobs and cost savings Umicore is being slightly more efficient, in that it is achieving the same or better revenue targets with fewer employees, and although CO₂e emissions are up, their 2012 annual report notes that this is primarily due to increases in production and changes in their utility provider (Umicore, 2012a).

3.2.2.2 What didn't they do?

Although Umicore ranked #1 in 2013 on the Corporate Knights 9th annual Global 100 Most Sustainable Companies in the World list, they ranked #9 in 2012 and #8 in 2014 (Corporate Knights, 2013; Corporate Knights, 2014; Kho, 2012). Umicore is not aggressively targeting environmental sustainability, and this is evident in the little to no change status in several of the framework for analysis areas. Umicore has a 'sustainability policy' (mostly about material and energy use) and for a large company they are certainly more environmentally responsible than some of their competitors, but Umicore lacks the focus for improvement that other companies, such as Interface Inc., have. They are newsworthy in their efforts but it is a relatively low-profile approach compared to actively making changes within their company that positively affect their environmental impact and then spearheading a movement to encourage other companies to follow suit. For this reason, Umicore is not a leader in environmental sustainability, even though they consistently rank within the top 10 of the Corporate Knights Global 100, and making an effort for improvement.

It is also apparent that Umicore tries to reduce costs in part through the elimination of staff, which reduces job security as well as the total number of positions available. This may be good for economic reasons but has a negative effect on social welfare of their employees, and will be reflected on the framework for analysis assessment for Umicore. Again, just like with Interface, it could be argued that the job cuts were due to the US recession, which is reflected in the Stage 1 ranking for jobs.

Although not covered in the framework for analysis it is interesting to note that the number of sites having a potential environmental impact on an area of

high biodiversity is also increasing, up to 15 in 2012 compared to 8 in 2009 (no data for 2008) (Umicore, 2012b). This brings into question the sustainability effects of their mining/manufacturing sites as they have potentially serious impacts on biodiversity and ecosystem health.

3.2.2.3 Application of Framework for Analysis

Analysis using the data from Umicore (2003; 2012a; 2012b; 2013a; 2013b) gives Umicore a score of 11 out of 21. They primarily lose points under this framework for not significantly improving the company's performance in several areas, and achieving only minor (<20%) improvements in energy and material use. Umicore is frequently self-labeled in their sustainability reports as a 'great place to work' (Umicore, 2003; 2012a; 2012b; 2013a; 2013b), yet they are missing an internal program aimed at improving sustainability at a grass roots level, which would be a useful tool for improving the performance of the company in this analysis.

Table 3: IHPC Framework for Analysis on Umicore Inc.

Category	Stage 1 (0 points)	Stage 2 (1 point)	Stage 3 (2 points)	Stage 4 (3 points)	Score
Energy Use Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Material Use and Waste Flows Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Cost Savings	No change from current business as usual levels.	Minimal (thousands/year)	Significant (hundreds of thousands/year)	Substantial (millions/year)	3
Job Security, Stabilization and/or Creation	No change from current levels given the uncertain economic situation.	Job stabilization at current company levels; no job creation. No change in job security.	Job stabilization at current company levels and minimal job creation (<10%) and/or enhanced job security.	Job stabilization at current company levels and significant job creation (~10%) and enhanced job security.	0
Ease of Implementation	Impossible and/or impractical given involved company's current situation.	Possible, however there are significant administrative barriers.	Sensible, willingness from stakeholders to begin planning.	Development and/or collaboration is actively explored and initiated.	3
Long term Viability	Unviable (no change)	Improvements in viability.	Viable but not resilient to change.	Viable and resilient.	1
Enhanced Public Image and Relations	No change from current level.	Minimal improvement in one or the other.	Improvement in both public image and relations.	Significant improvement in public image and relations. Newsworthy.	2
Total Score					11

3.2.3 Case 3: BASF

3.2.3.1 What did they do?

BASF is a diversified global chemical company, based in Ludwigshafen, Germany that operates in six distinct business areas: chemicals, plastics, performance products, functional solutions, agricultural solutions, and oil and gas (BASF, 2012). The motto of BASF is “We don’t make a lot of products you buy. We make a lot of the products you buy better” (Sery, Presti, & Shobrys, 2001). BASF is a highly diversified company and a major player in the manufacturing world.

BASF has a goal of reducing GHG emissions per metric tonne of sales by 40% using a baseline year of 2002; they also want to reduce their overall carbon footprint, as well as increase energy efficiency (BASF, 2013a). These are such prominent goals for BASF that they are outlined in the first paragraph of their 2013 economic, environmental and social performance report, perhaps indicating that BASF is committed and motivated to achieve these goals with near a future target of 2020. In fact BASF is over halfway towards this, and their three other main goals to achieve by 2020, which are to (BASF, 2013b):

1. Reduce GHG emissions per metric tonne of sales product by 40% using the baseline year of 2002.
2. Improve energy efficiency in production processes by 35% using a baseline year of 2002.
3. Reduce water consumption in production by 50% using a baseline year of 2010.
4. Reduce lost time work injuries per mill on working hours by 80% using a baseline year of 2002.

As of 2012 BASF had reduced GHG emissions by 31.7%, improved energy efficiency by 19.3%, reduced water consumption by 23.2% and reduced lost time work injuries by 48% (BASF, 2013b).

BASF ranked 35th in the 2013 Corporate Knights 9th annual Global 100 Most Sustainable Companies in the World list, and impressively moved up to 12th in the 2014 list (Corporate Knights, 2013; Corporate Knights, 2014). BASF did not make it into the top 100 in the 2012 report, which indicate an even more impressive rate of improvement (Kho, 2012). BASF is on the right trend to be an environmental leader for the future.

From 2007 to 2013 BASF reduced its GHG emissions by 15.13%, and from 2011 to 2013 primary energy use decreased by 7.21% (BASF, 2008; BASF, 2013a). Waste unfortunately increased by 16% from 2011 to 2013 up to 2.5 million metric tonnes per year (BASF, 2012; BASF, 2013a). From 2007 to 2013 jobs at BASF increased by 15.18%, up from 95,175 to 112,206, indicating stable job growth within the company (BASF, 2008; BASF, 2013a). Cost savings varied due to the diversified nature of BASF. One success would be the overhaul of their distribution network in the early 2000’s, saving over \$10 million US dollars annually, while increasing speed of service by 12% (Sery, Presti, & Shobrys, 2001). Additional cost savings came through the redesign of their vitamin B2 production plant, which began utilizing fermentation technologies, resulting in a

40% cost savings and 95% waste reduction over the previous method (Jenck, Agterberg, & Droescher, 2004).

BASF has also implemented a number of cost savings programs recently, which have resulted in significant cost savings (BASF, 2014). BASF's NEXT program has reduced costs from 2012 to 2014 by €1 billion, and the STEP program will result in annual savings of €1 billion (BASF, 2014). The NEXT and STEP programs are both strategic excellence programs, with NEXT concluding and STEP taking over from 2012 on. STEP resulted in savings in 2013 of €600 million compared to 2011 (BASF, 2014). BASF has also infused its company mantra with the Verbund concept; which roughly translates from German to 'composite' with the aim to be looking at multiple aspects of how BASF does business and where they can improve from the ground up (BASF, 2014). The Verbund concept has seen cost savings of €1 billion per year, with 60% of the savings coming from logistics, 30% from energy, and 10% from infrastructure; annual revenues in 2013 were €73.9 billion (BASF, 2014). This is a significant improvement for BASF and it is resulting in major yearly savings.

3.2.3.2 What didn't they do?

BASF is making headway towards contributing to a more sustainable world, through using resources more effectively and by implementing its Verbund concept. They have gone from >100th to 12th in just two years on the Corporate Knights Global 100 Most Sustainable Companies in the World list which is to be congratulated. They have aggressively worked on achieving their four production goals on GHG emissions, energy efficiency, water use and lost time work injuries: however, all of this is not enough to surpass factor 4 improvements. BASF has some exciting prospective technologies that they are hoping to put into production soon, such as a renewable energy plant that converts atmospheric CO₂ into using products like formic acid (BASF, 2013c). BASF promotes itself as a green chemistry company from which we should expect impressive innovation in the near future. With BASF, its not so much a question of what they didn't do, but what they haven't done yet.

3.2.3.3 Application of Framework for Analysis

BASF scores well in cost savings and does much better overall than Umicore in analysis applying the framework criteria. In comparison with Interface some bigger improvements need to be made in energy and material use. Overall BASF gets a score of 14 out of 21, which is very respectable. Given that BASF has major corporate projects aimed at CO₂ conversion, the company could make the transition into an environmental leader within industry. BASF has clearer and more ambitious goals than most companies; however, material and energy reductions of 75% would needed in order to achieve factor four improvements.

Table 4: IHPC Framework for Analysis on BASF.

Category	Stage 1 (0 points)	Stage 2 (1 points)	Stage 3 (2 points)	Stage 4 (3 points)	Score
Energy Use Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Material Use and Waste Flows Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Cost Savings	No change from current business as usual levels.	Minimal (thousands/year)	Significant (hundreds of thousands/year)	Substantial (millions/year)	3
Job Security, Stabilization and/or Creation	No change from current levels given the uncertain economic situation.	Job stabilization at current company levels; no job creation. No change in job security.	Job stabilization at current company levels and minimal job creation (<10%) and/or enhanced job security.	Job stabilization at current company levels and significant job creation (~10%) and enhanced job security.	3
Ease of Implementation	Impossible and/or impractical given involved company's current situation.	Possible, however there are significant administrative barriers.	Sensible, willingness from stakeholders to begin planning.	Development and/or collaboration is actively explored and initiated.	3
Long term Viability	Unviable (no change)	Improvements in viability.	Viable but not resilient to change.	Viable and resilient.	1
Enhanced Public Image and Relations	No change from current level.	Minimal improvement in one or the other.	Improvement in both public image and relations.	Significant improvement in public image and relations. Newsworthy.	2
Total Score					14

3.2.4 Conclusions from IHPC Cases

Based on the IHPC case studies on Interface, Umicore, and BASF we can see that some companies are making huge strides towards more responsible manufacturing, whereas others are making reasonable progress, but are still far from the factor 4 or 10 improvements called upon in the literature. Interface benefitted immensely from the late Ray Anderson as their leader, visionary and enabler, and it is largely through his work that Interface became so environmentally friendly. Interface also has overwhelming employee buy in, and this combination of top down and bottom up implementation is evidently a very effective way at improving overall sustainability and environmental protection.

All three of these companies are primarily product based, and although there is a need to move towards a more service-based economy, there is still a great need for manufacturing of products. This need stems from the basics of actually needing physical products (not everything can be service based), and the need for job creation, especially in countries where manufacturing jobs have been transferred elsewhere. It is most difficult for product-based companies, such as manufacturers to achieve significant reductions in material and energy use: however Interface has, and other companies can learn from how they did it.

3.3. Eco-industrial Park Cases

3.3.1 Case 1: Kalundborg, Denmark

3.3.1.1 What did they do?

Kalundborg Eco-Industrial Park has been studied more than any other EIP project globally, and is the undisputed poster child of the concept. The initial linkages at Kalundborg were formed in the early 1970's and have evolved over time into its current state (Figure 1) (Ayres & Ayres, 2002; Desrochers, 2000; Kalundborg Symbiosis, 2010; Norton, 2012).

At Kalundborg, the main players are the 1,500 MW Asnæs coal fired power plant owned by the Danish company DONG energy, the oil refinery owned by the Norwegian company Statoil, the municipality of Kalundborg (Kalundborg Forsyning), the Danish pharmaceutical manufacturer Novo Nordisk, and the French owned drywall manufacturer Gyproc (Ehrenfeld & Gertler, 1997).

Over the whole of Kalundborg EIP, the sheer volume of energy and material savings is immense; Chertow (2000) estimates that 2.9 million tons of waste materials are exchanged per year. Chertow and Lombardi (2005) estimate that Kalundborg EIP saves 2.1 million m³/year of groundwater, 1.2 million m³/year of surface water, 20,000 tons/year of oil, and reduces Gyproc's dependence on mined gypsum by 200,000 tons/year. To get a sense of some of the volumes of water exchanges within the EIP, the water needs for Asnæs are 95% symbiotically sourced from within the EIP, while Statoil and Novo Nordisk are 98% and 20%, respectively sourced in the EIP (Jacobson, 2006). Statoil pipes approximately 700,000 cubic meters per year of water to Asnæs (Ehrenfeld & Gertler, 1997). In terms of steam requirements, Statoil receives 40% of its needs from Asnæs and Novo Nordisk receives 100% (Ehrenfeld & Gertler, 1997). The steam energy used by Novo and Statoil from Asnæs, was approximately 682,083 GJ/year based on 2002 values (Jacobson, 2006). Chertow (2000, 316) states that through the Kalundborg EIP project, "water consumption has been reduced by a collective 25%." There are certainly areas where the EIP arrangement at Kalundborg reduces a particular company's demand for raw resources, such as water needs between Asnæs, Statoil, and Novo Nordisk; however the overall EIP still needs inputs of raw resources, such as coal and water, and therefore it is not a completely closed system.

Carbon dioxide and nitrogen oxides emissions have been reduced through heat and steam exchanges in the Kalundborg EIP sourced from Asnæs, by approximately 30,800 tons of CO₂ and 77.8 tons NO_x per year (Jacobson, 2006). The substitution of fuel gas from Statoil in place of coal at Asnæs has reduced coal dependence by 2% (Ehrenfeld & Gertler, 1997). Annually about 80,000 tons of gypsum are saved through the flue gas desulfurization process, which accounts for almost 100% of the gypsum used by Gyproc (Ehrenfeld & Gertler, 1997).

As of 2002 total savings were \$200 million, and collective annual savings were \$15 million (Chertow & Lombardi, 2005). Based on this trend, and

assuming linearity, it can be estimated that the partners in the Kalundborg EIP have saved in total around \$360-380 million since its inception (as of 2014).

Since the foundation of Kalundborg, there have been several expansions and integrations into the overall structure, adding companies and jobs to the overall system, based around the core seven companies (Kalundborg Symbiosis, 2010).

Material and energy efficiencies have been significantly improved at Kalundborg, which can be seen through the energy and material savings achieved each year. Kalundborg has built in backups to allow uninterrupted production, even if major breakdowns or other issues arise from any of the players within the system. An example of this is Gyproc's gas reserve kept in place in case Statoil oil refinery shuts down unexpectedly, or needs maintenance (Jacobson, 2006). This kind of process consideration adds to the resilience of Kalundborg. Among the Corporate Knights global 100 most sustainable companies, Statoil and Novo Nordisk have consistently been in the top 10 (Corporate Knights 2013; Corporate Knights 2014).

According to <http://www.symbiosis.dk/en/partnere>, which is the Kalundborg EIP informational website, Novo Nordisk has 2600 employees at the Kalundborg facility, Novozymes (a demerger of Novo Nordisk) has 500 employees, Gyproc has 165 employees, the Asnæs power plant has 120 employees, Statoil has 350 employees, Kara/Novoren has 15 employees, and Kalundborg Forsyning A/S has 66 employees, which puts an approximate total for the Kalundborg EIP of 3,816 employees. Employee numbers for other components of the EIP were not available, but the majority of employees are included in this value.

Statoil is largely a Norwegian company, but its financial reports separate Norway from the 'rest of Europe' when reporting employees. They do not break the data down further to show just the Kalundborg facility numbers, they do report that Kalundborg is their only refinery operation in Denmark (Statoil, 2013). With that in mind, the 'rest of Europe' category reports job growth from 2009-2011 of 5.83% from 2009-2013 for their facilities in Denmark, Belgium, Germany, Ireland, Switzerland, Sweden, and the United Kingdom (Statoil, 2013). Novo Nordisk is the largest employer at Kalundborg EIP and it has seen its number of employees grow by 38% from 1999-2013 (Novo Nordisk, 2013). DONG Energy, the parent company of the Asnæs power station reports that the number of employees they have in their thermal power division was down by approximately 13% from 2012-2013, but this is across nine power stations in Denmark, not just at Kalundborg (DONG Energy, 2013). Novozymes reported an increase of employees from 2009-2013 of approximately 15% again keeping in mind that Kalundborg is not their only facility (Novozymes, 2013). According to a presentation by Pedersen (2005) of the Symbiosis Institute, Gyproc reduced its workforce by 17.5% from 2005-2013. Using a weighted average using the available employee information from these companies we can get an approximate job growth figure for Kalundborg EIP of 14.5% from 2009-2013.

As seen in the literature (Lowe, 1995; Desrochers, 2000), Kalundborg began as a series of economically based business transactions that happened to

also be environmentally beneficial. It was under this premise that Kalundborg evolved into the EIP it is today.

Kalundborg has significantly improved the public image of the companies participating in the project, as it is the most cited EIP in the literature, and there are numerous articles for a non-academic audience that feature Kalundborg.

It is important to remember that the Kalundborg EIP is not a self sufficient entity, and that it still draws on outsourced materials such as coal for the Asnæs power plant, and ground and surface waters: however, it has provided overall a much more efficient way of using those resources.

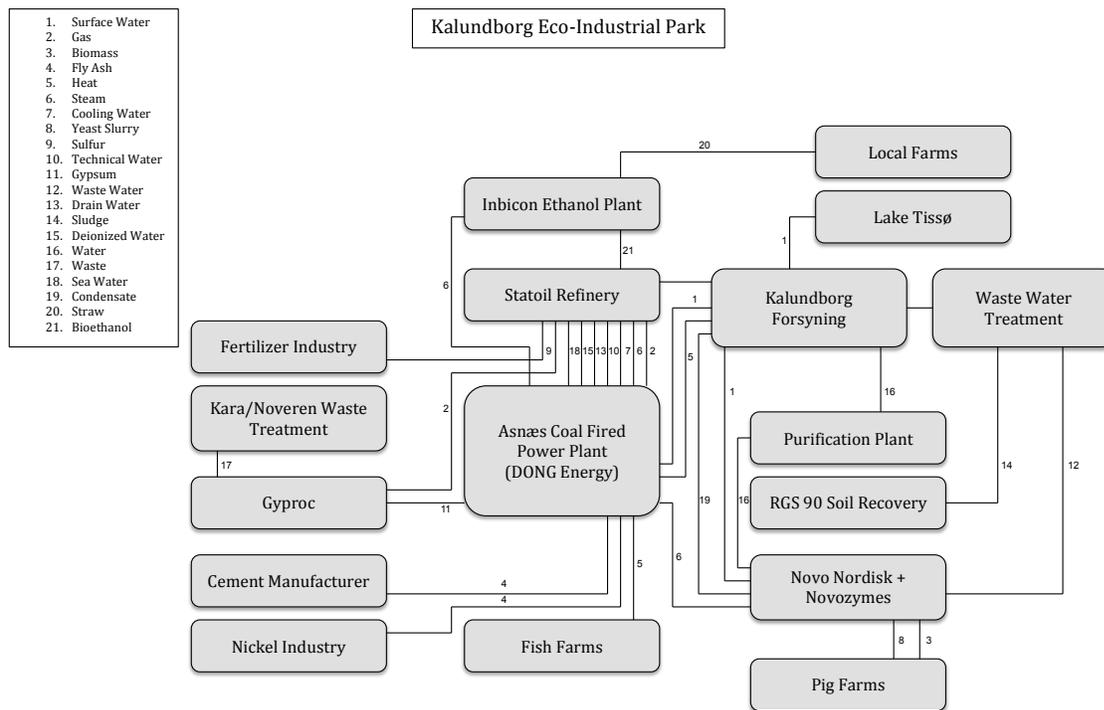


Figure 1: Kalundborg Eco-Industrial Park. Based on information from Kalundborg Symbiosis, 2010.

3.3.1.2 What didn't they do?

Kalundborg is the best known and most often cited EIP project and the participants have greatly improved the overall efficiency of the companies within the partnership. Kalundborg is an example of traditionally inefficient and environmentally unfriendly industries becoming much more efficient. However, it could be argued that starting with and phasing in more environmentally friendly manufacturing processes/companies would improve the overall EIP. Desrochers (2000) advises to not read too much into Kalundborg, and to note that it still requires significant external inputs (coal, water, oil, etc.) to function. Moreover,

major Kalundborg EIP operations refine or burn fossil fuels and contribute to GHG emissions. Kalundborg would have a better claim to sustainability contributions if the Asnæs power plant were converted to a more environmentally friendly energy fuel source, and the oil refinery subject to a heavy carbon tax.

Also of note, job growth within certain parts of Kalundborg is limited, for example at Gyproc or Asnæs power station, due to them being more or less stable entities, than compared to Novo Nordisk which is actively expanding, hiring and investing in the Kalundborg facility. This is perhaps due to the international marketing of the products from Novo Nordisk, with Kalundborg being an important production facility, whereas Asnæs power station, Gyproc and even Statoil cater to a more local consumer. That being said, job growth at Novo Nordisk seems likely to continue to grow based on company performance, whereas Asnæs power station, Gyproc and Statoil have probably reached their employee maximum. In EIP efficiency efforts as well as in individual company initiatives employee numbers may be reduced along with emissions and resource demands.

3.3.1.3 Application of Framework for Analysis

Across the board Kalundborg EIP scores high marks, and receives a nearly perfect score for what its participants have accomplished. The overall efficiency improvements have been immense, and they have resulted in less damaging, more resilient and more cost effective enterprises that have employed thousands of people in the Danish city of Kalundborg.

Table 5: EIP Framework for Analysis on Kalundborg.

Category	Stage 1 (0 points)	Stage 2 (1 point)	Stage 3 (2 points)	Stage 4 (3 points)	Score
Energy Use Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	2
Material Use and Waste Flows Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	2
Cost Savings	No change from current business as usual levels.	Minimal (thousands/year)	Significant (hundreds of thousands/year)	Substantial (millions/year)	3
Job Security, Stabilization and/or Creation	No change from current levels given the uncertain economic situation.	Job stabilization at current company levels; no job creation. No change in job security.	Job stabilization at current company levels and minimal job creation (<10%) and/or enhanced job security.	Job stabilization at current company levels and significant job creation (~10%) and enhanced job security.	3
Ease of Implementation	Impossible and/or impractical given involved company's current situation.	Possible, however there are significant administrative barriers.	Sensible, willingness from stakeholders to begin planning.	Development and/or collaboration is actively explored and initiated.	3
Long term Viability	Unviable (no change)	Improvements in viability.	Viable but not resilient to change.	Viable and resilient.	3
Enhanced Public Image and Relations	No change from current level.	Minimal improvement in one or the other.	Improvement in both public image and relations.	Significant improvement in public image and relations. Newsworthy.	3
Total Score					19

3.3.2 Case 2: Burnside Industrial Park, Nova Scotia, Canada

3.3.2.1 What did they do?

Burnside Industrial Park was first established in 1972 as a commercial and light industrial zone by the city of Dartmouth, Nova Scotia, and has since developed into one of Canada's largest industrial parks, containing approximately 1300 small to medium enterprises (SMEs) employing 18,000 people in 2002 (Côté & Smolenaars, 1997; Lambert & Boons, 2002). The number of companies and employees has recently been updated to approximately 1500 companies and almost 20,000 workers, showing an increase in the number of jobs at Burnside of approximately 11% from 2002-2014) (Moulton, 2014).

Burnside Industrial Park is situated on a 1,200 hectare (12 square kilometer, 4.6 square mile) plot, of which 760 hectares (7.6 square kilometers, 2.9 square miles) are occupied (Côté & Smolenaars, 1997; Lambert & Boons, 2002). The types of small and medium-sized enterprises present in Burnside include 36 printing companies, 21 painting companies, 19 chemical companies, 20 computer companies, 32 car repair companies, 17 metal processing companies, and other companies involved in food processing, health services,

communications, construction, retail, logistics, furniture production, plastic film production, cardboard production, and telecommunications (Côté & Smolenaars, 1997; Lambert and Boons, 2002).

Results from Burnside Industrial Park have been cited as modest in the literature in terms of material and energy use: however the establishment of the Eco-Efficiency Centre has been a great step forward for research on cleaner production and eco-efficiency (Lambert and Boons, 2002). There has been progress on a silver recovery program by the printing companies, a pallet exchange program, a cardboard recycle program, a paint swap program, and the reuse of extra polystyrene packaging (Gnanapragasam, 2013; Lambert & Boons, 2002). The exact savings from these programs are unknown. However they are numerous and easily managed by the participating companies, making them desirable incremental steps. There is also the network of knowledge being created and shared within the park, which may not lead to immediately quantifiable economic savings, but may encourage future developments in energy and material savings for the companies within the park.

It is important to note that Burnside Industrial Park is not an EIP like Kalundborg is, but rather it is a collection of smaller enterprises that participate in industrial symbiosis; the exchange of materials and energy between companies (Lambert & Boons, 2002).

3.3.2.2 What didn't they do?

Burnside Industrial Park is an application of what can be done in a typical industrial park populated by small and medium-sized enterprises. Unlike Kalundborg, it does not have the large scale material flows needed for large scale efficiency improvements. Burnside Industrial Park has essentially done what it can with its scale. However there could perhaps be further linkages between the companies to promote energy and material efficiency, and further analysis and evaluation of these linkages is needed.

3.3.2.3 Application of Framework for Analysis

The application of the framework for analysis for Burnside Industrial Park shows admirable but modest gains, well short of the success that Kalundborg has. Burnside Industrial Park and Kalundborg are not on the same scale, but both are successful applications given their situation. Based on the limited data in the literature, Burnside Industrial Park gets a score of 12 out of 21.

Table 6: Framework for Analysis on Burnside Industrial Park.

Category	Stage 1 (0 points)	Stage 2 (1 point)	Stage 3 (2 points)	Stage 4 (3 points)	Score
Energy Use Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Material Use and Waste Flows Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Cost Savings	No change from current business as usual levels.	Minimal (thousands/year)	Significant (hundreds of thousands/year)	Substantial (millions/year)	1
Job Security, Stabilization and/or Creation	No change from current levels given the uncertain economic situation.	Job stabilization at current company levels; no job creation. No change in job security.	Job stabilization at current company levels and minimal job creation (<10%) and/or enhanced job security.	Job stabilization at current company levels and significant job creation (~10%) and enhanced job security.	3
Ease of Implementation	Impossible and/or impractical given involved company's current situation.	Possible, however there are significant administrative barriers.	Sensible, willingness from stakeholders to begin planning.	Development and/or collaboration is actively explored and initiated.	3
Long term Viability	Unviable (no change)	Improvements in viability.	Viable but not resilient to change.	Viable and resilient.	1
Enhanced Public Image and Relations	No change from current level.	Minimal improvement in one or the other.	Improvement in both public image and relations.	Significant improvement in public image and relations. Newsworthy.	2
Total Score					12

3.3.3 Case 3: Rotterdam, The Netherlands Industrial Ecosystem Project (INES)

3.3.3.1 What did they do?

The INdustrial EcoSystem (INES) project in Rotterdam was a planned EIP that was initiated in 1994 (Baas, 2011). It houses approximately 80 companies in a 3,000 hectare area (Baas, 1998; Baas, 2005; Heeres, Vermeulen & de Walle, 2004). Of these 80 companies, 7 are refineries, 11 are inorganic chemical companies, and 13 are in the petro-chemical industry (Lambert & Boons, 2002). The INES project was aimed at improving water management, CO₂ emissions, utility use, and waste management (Baas, 2008). The most significant aspect of the INES project is the heat sharing network set up with the city district of Rotterdam to provide heat for approximately 50,000 houses (Baas, 2008). Heeres, Vermeulen and de Walle (2004) estimate that the realization cost of INES was greater than \$100 million US dollars, but that the yearly economic benefit is greater than \$16 million US dollars. INES also saves 157.6 MW energy, 152.2 M Nm³ gas, 272.5 ktons CO₂, 225.7 tons NO_x and 158 MW waste heat per year. As opposed to a new build, INES was developed as a brownfield,

revitalization/redevelopment of an existing industrial cluster (Heeres Vermeulen & de Walle, 2004). Baas (2005) also found that in the INES project, primary waste minimization reduced sludge amounts by 10-20%, saving between \$380,521 and 761,043 (CAD) (€ 250,000- € 500,000) per year.

Few data on job creation for the INES project are available in the literature. The Centre for Sustainable Resource Processing states that the INES project generates 14,000 direct jobs, and 66,000 indirect jobs (<http://asdi.curtin.edu.au/csrrp/database/nl/roth/>).

The success of INES has been extremely modest in comparison to Kalundborg, and INES has unfortunately had economic restrictions (see below), which limited its success (Lambert & Boons, 2002).

3.3.3.2 What didn't they do?

INES did not achieve the same level of success that other EIP projects have, mostly due to economic restraints on the project. The biggest issue with the INES project was that the stakeholders determined that the initial heat sharing pipeline, which would have eliminated and reused approximately 2200 MW of waste heat at a cost of €112,700,000, was not economically feasible, the project was reduced to smaller and smaller scales to make it feasible (Baas, 2008). This led to pockets of linkages being formed, but INES missed out on the large scale, whole project heat sharing plan that would have led to the largest resource efficiency improvements (Baas, 2008). Due to this 'watering down' of the project, the grants and subsidies kept getting reduced as well, as these were for the original larger scale project, leaving the INES project with a smaller working budget, and therefore smaller efficiency improvements (Baas, 2008).

INES should not be considered a failure as it did result in substantial material and energy efficiency improvements. However, as it was extensively modeled after Kalundborg, and as a planned attempt at recreating the success seen there, it did not meet expectations (Boons & Janssen, 2004).

3.3.3.3 Application of Framework for Analysis

INES was an attempt to mimic the success seen at Kalundborg, through a planned EIP in Rotterdam harbour. However, due to the inability of the stakeholders to reach agreement and the whittling down of the original project, the result was much less spectacular. The INES project does save a considerable amount of money per year, and does reduce energy and material demands reasonably well; it is perhaps a lack of trust between the stakeholders that prevented this agreement (Boons & Janssen, 2004). With that in mind the INES project receives a score of 12 out of 21.

Table 7: EIP Framework for Analysis on INES.

Category	Stage 1 (0 points)	Stage 2 (1 point)	Stage 3 (2 points)	Stage 4 (3 points)	Score
Energy Use Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Material Use and Waste Flows Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Cost Savings	No change from current business as usual levels.	Minimal (thousands/year)	Significant (hundreds of thousands/year)	Substantial (millions/year)	3
Job Security, Stabilization and/or Creation	No change from current levels given the uncertain economic situation.	Job stabilization at current company levels; no job creation. No change in job security.	Job stabilization at current company levels and minimal job creation (<10%) and/or enhanced job security.	Job stabilization at current company levels and significant job creation (~10%) and enhanced job security.	2
Ease of Implementation	Impossible and/or impractical given involved company's current situation.	Possible, however there are significant administrative barriers.	Sensible, willingness from stakeholders to begin planning.	Development and/or collaboration is actively explored and initiated.	3
Long term Viability	Unviable (no change)	Improvements in viability.	Viable but not resilient to change.	Viable and resilient.	1
Enhanced Public Image and Relations	No change from current level.	Minimal improvement in one or the other.	Improvement in both public image and relations.	Significant improvement in public image and relations. Newsworthy.	1
Total Score					12

3.3.4 Conclusions from EIP Cases

The EIP cases show us that there have been some great successes in these industrial ecology applications, but the overall record has been mixed, and inconsistent. Kalundborg has perhaps been overanalyzed in the literature as the 'saving grace' for industrial sustainability. However the results from Kalundborg have not been easily reproduced. It is important to remember that Kalundborg grew from a series of economically minded decisions that were not forced by a governing body, and slowly developed over time. In order for EIPs to be a successful option for the practical industrial world they may often need to develop 'organically' from economically minded decisions, as in Kalundborg. There is an argument for the pre-planning of EIPs in order to maximize their efficiency opportunities (Desrochers, 2000), and although this has not been very successful in the real world so far, as seen in the INES project, it may well be a concept that merits further testing in industrial ecology.

3.4. Conclusions from the Cases

3.4.1 How did the Cases Confirm, Elaborate or Contradict the Framework for Analysis?

The cases show varied success. With IHPC, variations are expected due to the fact that it is individual companies are deciding what improvements to pursue and how ambitious to be. The EIP cases include a very successful Kalundborg case, and two other industrial ecology projects that have not achieved the same level of efficiency improvement. This is consistent with findings in the literature that while industrial ecology is highly attractive in theory it has been a huge success only at Kalundborg. There has been a call in the literature for private planning of industrial ecology solutions, such as Desrochers (2000) *Eco-Industrial Parks: The Case for Private Planning*. However Desrochers (2000) and Desrochers (2004) found that removing barriers to reuse was likely more effective in the long run than planning EIPs.

Perhaps what the EIP case studies show us is that while important gains can certainly be achieved through such industrial ecology applications, establishing successful EIPs is difficult. Planning on single-phase development of an EIP is less likely to deliver long run success than gradual development mimicking what occurred at Kalundborg.

Together, the IHPC and EIP cases show that there is great potential at both the single firm and inter-firm levels for efficiency improvements, and having repeat success copying what Interface and Kalundborg have been able to do for their respective categories would be a good thing for global energy, material and waste reduction efficiencies all around. It is sensible then to argue that a combination of investing in intra-firm efficiency (Interface) for some cases and investing in inter-firm efficiency (Kalundborg) for other cases is needed. Certainly, there need to be efficiency improvements in global industry, whether they happen from one source or the other.

Table 8 summarizes the scores for the three IHPC and three EIP cases reviewed in this chapter. The conclusions drawn from these six cases are merely indicative. The framework components are not weighted and the cases do not fully represent what has been happening with respect to IHPC and EIPs around the world, but rather offer lessons learned from some of the more influential cases described in the literature. The main potential limitations of this scoring include incomplete data (i.e. only energy or water savings data or savings related to production levels or expenditures, imperfectly comparable data (different geographical and regulatory contexts, different time periods with different stresses such as economic outlook), and data of different levels of reliability (i.e. self-reported or third party or tested by regulatory bodies). This again means that the results from these case studies are merely indicative.

Some findings from this rough comparison of IHPC and EIP cases merit attention. The EIP cases achieved a slightly higher average score of 68%, compared to the IHPC cases that have an average score of 62%, pointing to the greater potential of EIPs, even though only Kalundborg was a celebrated success. Also, potentially significant is the much greater variability of the EIP cases. The standard deviation of the scores for IHPC is only 0.087, whereas the

standard deviation for the EIP cases is 0.191, indicating that there is greater variance in the EIP cases studied reviewed here. The IHPC cases apparently enjoyed more consistent prospects for success, whereas the EIP cases either do really well (Kalundborg), or are a modest success (Burnside and INES).

Table 8: Summary of the Results from the Framework for Analysis.

Case	Type	Location/Head Office	Product(s)	Successes	Areas for Improvement	Summary Score
Interface, Inc.	IHPC	Atlanta, Georgia, U.S.A.	Carpet Products	Motivated local champion in Ray Anderson. The seven fronts of sustainability. The Eco-metrics program.	Improved social performance and diversification of green energy sources.	67%
Umicore	IHPC	Brussels, Belgium	Catalysis, energy materials, performance materials, and recycling	Improvements in overall efficiency.	Greater scale of improvement.	52%
BASF	IHPC	Ludwigshafen, Germany	Chemicals, plastics, performance products, functional solutions, agricultural solutions, and oil and gas	Good progress on their sustainability goals.	Implementation of new RandD projects and technologies.	67%
Kalundborg	EIP	Kalundborg, Denmark	Energy, steam, petrochemical products, pharmaceutical products, plaster board, fertilizers, cement, fish, metals.	Functional EIP model.	Continued linkages and new companies added.	90%
Burnside Industrial Park	EIP	Dartmouth, Nova Scotia, Canada	Print, paint, chemical, computer, metal, food, furniture, plastic, and packaging products	Industrial ecology application within a SME dominated industrial park.	Enhanced linkages and greater efficiency.	57%
INES	EIP	Rotterdam, Netherlands	Petrochemicals, chemicals, other industrial manufacturing.	Efficiency improvements.	Enhanced linkages and greater efficiency.	57%

3.4.2 Adjusted Framework for Analysis

The original framework for analysis (Table 1) attempted to establish a common basis for evaluating both IHPC and EIP cases, and did a fairly adequate job at that. There is some room for readjustment of the wording to better accommodate the cases; however, the framework's categories have been well utilized. Minor improvements in the framework for analysis can be seen in Table 9, and this will be used going forward in this thesis.

The changes to the framework for analysis include rephrasing of the framework's descriptive language using a more consistent format, rephrasing of some of the category titles (i.e.: Energy Use to Energy Efficiency), as well as adding the maximum possible score as a denominator in the final total column.

Table 9: Adjusted Framework for Analysis.

Category	Stage 1 (0 points)	Stage 2 (1 point)	Stage 3 (2 points)	Stage 4 (3 points)	Score
Energy Efficiency	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	
Material Efficiency and Waste Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	
Cost Savings	No change from current business as usual levels.	Minimal (thousands/year)	Significant (hundreds of thousands/year)	Substantial (millions/year)	
Job Security, Stabilization and/or Creation	No change from current levels given the uncertain economic situation.	Job stabilization at current company levels; minimal job creation. Minimal change in job security.	Job stabilization at current company levels and significant job creation (<10%) and/or enhanced job security.	Job stabilization at current company levels and substantial job creation (~10%) and enhanced job security.	
Ease of Implementation	Impossible and/or impractical given involved company's current situation.	Possible, however there are significant administrative barriers.	Sensible, willingness from stakeholders to begin planning.	Development and/or collaboration is actively explored and initiated.	
Long term Viability	Unviable (no change)	Minimal improvements in viability.	Significant improvements in viability but not resilient to change.	Substantial improvements in viability and resilience.	
Enhanced Public Image and Relations	No change from current level.	Minimal improvement in one or the other.	Significant improvement in both public image and relations.	Substantial improvement in public image and relations. Newsworthy.	
Total Score					/21

Chapter 4: The Focus Company, IHPCs and Broader Potential

This chapter describes the focus company and the surrounding industrial cluster site, which serve as the core case in this thesis. In addition to an overview of the focus company, the chapter reports the company's current trends for utility use in light of recent improvements it has made to the facility; possible improvements for the focus company are also highlighted. This chapter then looks at the case study site and possible linkages between firms.

The information presented in this chapter was collected directly from the focus company, and required going through monthly account statements and operating data to gather sufficient data on electrical, water, natural gas, main process chemicals, and liquid waste figures. The monthly statements were issued directly from the provider and/or supplier from January 2011 until December 2013. This time frame was used because it provided the longest string of continuous monthly operating data that the focus company could make available to me. Monthly production values were taken directly from the focus company's operating figures, provided to me by management. The statements/invoices showed the amounts of the utility/product that were used for the billing month and those figures were recorded in Microsoft Excel, which was then used to generate Figures 2-7. As per the confidentiality agreement with the focus company, all data were masked through ratios, as described below. All of these data were stored on a secure, encrypted and password protected hard drive partition, while all paper copies remained at the focus company. I also observed the operating procedures and general functionality of the focus company over the course of the past two years, and in all seasons to gather information for this research.

4.1. The Focus Company

As previously mentioned, the focus company for this thesis research is located in a small to mid sized North American city and operates several other processing facilities around the world. It produces a high quality final product, along with a large volume of toxic liquid waste and a relatively small volume of solid waste. Managing this liquid waste, including transporting it off site for disposal, accounts for a large percentage of the focus company's operating costs.

4.2. Energy, Water and Waste Efficiencies

Production at the focus company has been maintained at a quite constant level in recent years. This provides a convenient basis for considering the company's experience with energy and water use and waste water generation over these years, during which there have been some initiatives aimed at lowering production costs, related to water use and liquid waste generation.

The focus company provided data on utilities and production from the years 2011-2013. These data were normalized to production by dividing the utility/waste value by production (i.e.: electricity use for January 2011/production for January 2011).

An increase in efficiency would be shown through a downward trend in utility use or waste water generation relative to production, as it would take less to produce the same amount of product. If for example, in month 1 a hypothetical 1,000 Kwh of electricity were needed to produce 100 kg of final product, giving a ratio of 10, whereas in month 2 only 800 Kwh were needed to produce the same 100 kg, giving a ratio of 8, which would be graphed as a decreasing or negative slope.

As per agreement with the focus company all data are being displayed here as trends without axis values.

As seen in Figure 2, the overall trend at the focus company is relatively flat, indicating that production efficiency is neither increasing nor decreasing. However, when the utilities/waste are broken up it can be seen that for some components, in particular water use and liquid waste generation, efficiency is improving, whereas for electricity use, natural gas use and chemical use efficiency is declining. The increase in electricity and natural gas use is most likely due to expansion and renovation in the production areas, which have led to better production numbers, but apparently at the cost of more energy use. However, the focus company has undertaken a recent campaign to decrease waste water volume through decreased water use and better processing, and the results can be seen in the efficiency trends, in Figures 3 and 4.

Regression analysis reveals that none of the trends is statistically significant with a 95% confidence interval; however, efficiency improvements in water use and waste water generation are evident. The focus company may not be making ground breaking improvements, but they are definitely starting to save money due to reduced water use and therefore waste water volumes. They have started improving the process and are making it more efficient, but they have yet to address the traditionally easier options based on electrical and natural gas use. Improvements in chemical use efficiencies are expected to come through further process enhancements.

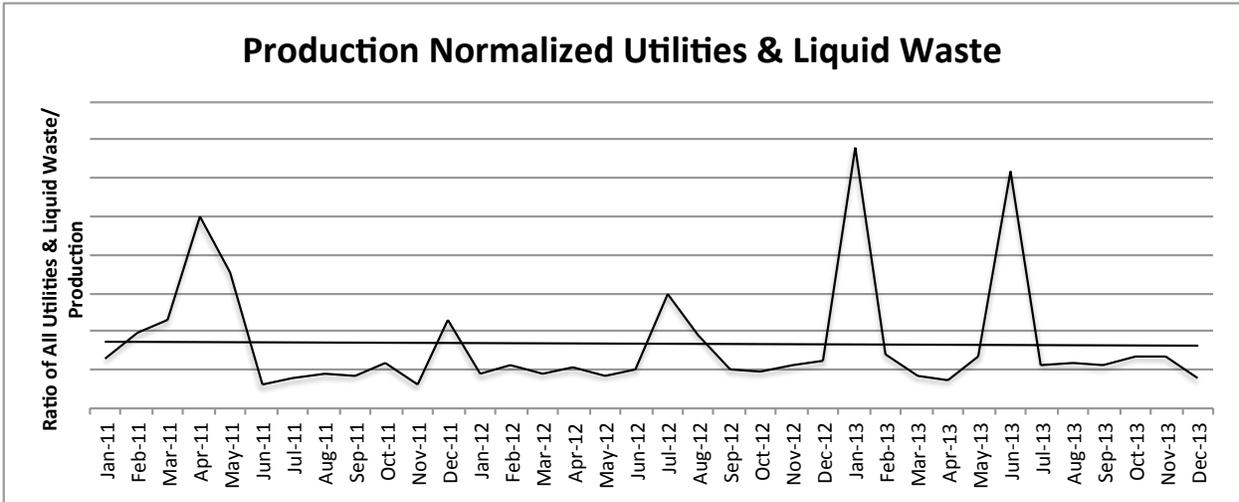


Figure 2: Overall trends in utilities and liquid waste normalized to production levels. January 2011 to December 2013. Utilities included here are water, electricity, natural gas, and chemical use, added to liquid waste values to show a

rough total material use trend. The peaks shown in this graph are due to variances in manufacturing based on normal supply and demand and in line with the trend seen in the unmasked raw data.

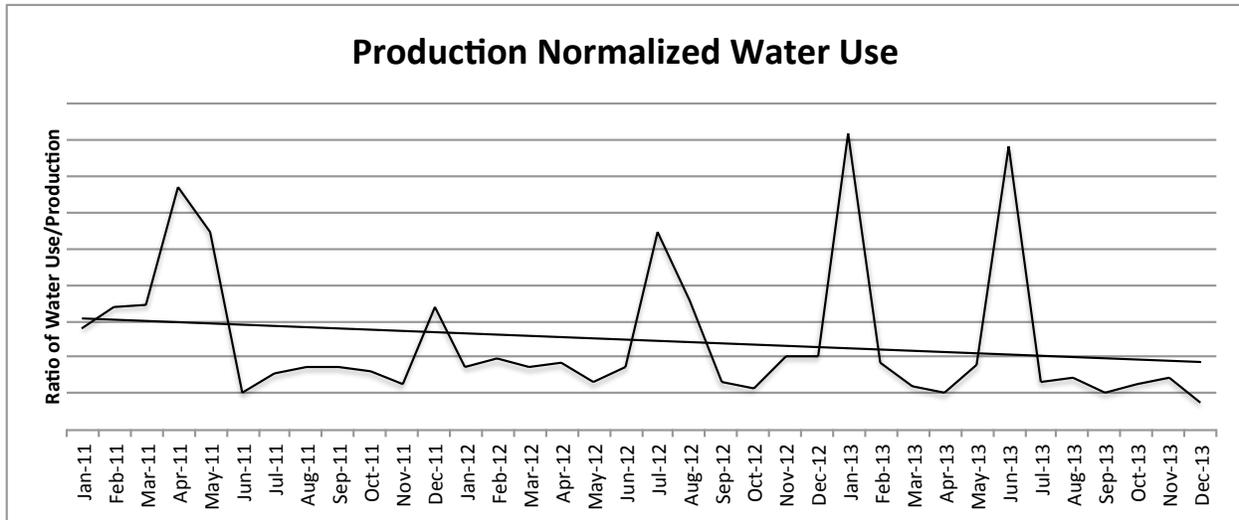


Figure 3: Water use normalized to production. January 2011 to December 2013. The peaks shown in this graph are due to variances in manufacturing based on normal supply and demand and in line with the trend seen in the unmasked raw data.

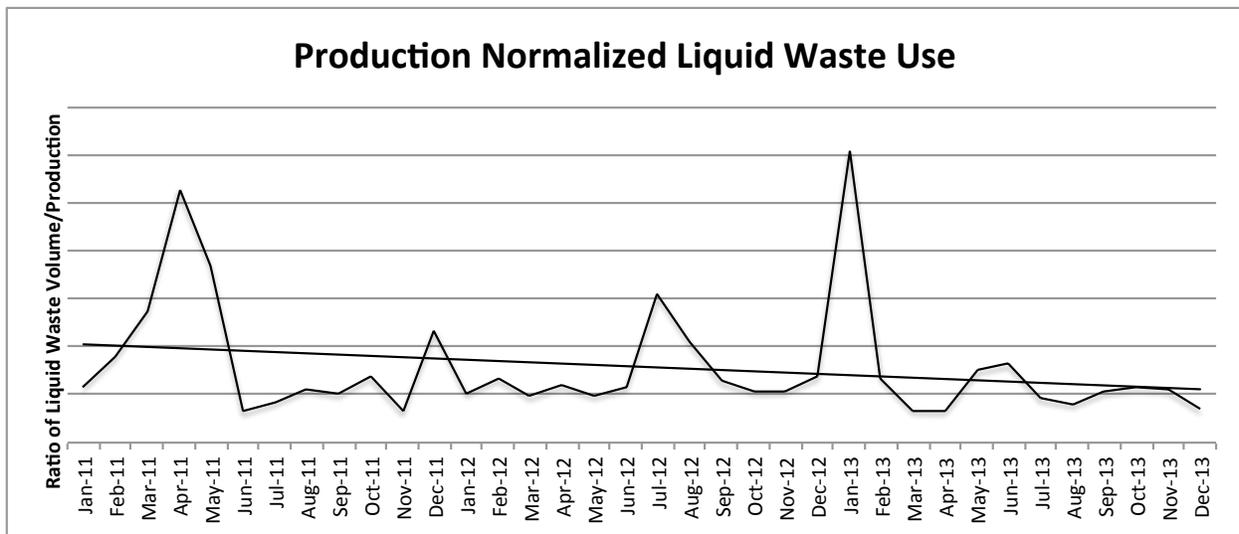


Figure 4: Liquid waste volume normalized to production. January 2011 to December 2013. The peaks shown in this graph are due to variances in manufacturing based on normal supply and demand and in line with the trend seen in the unmasked raw data.

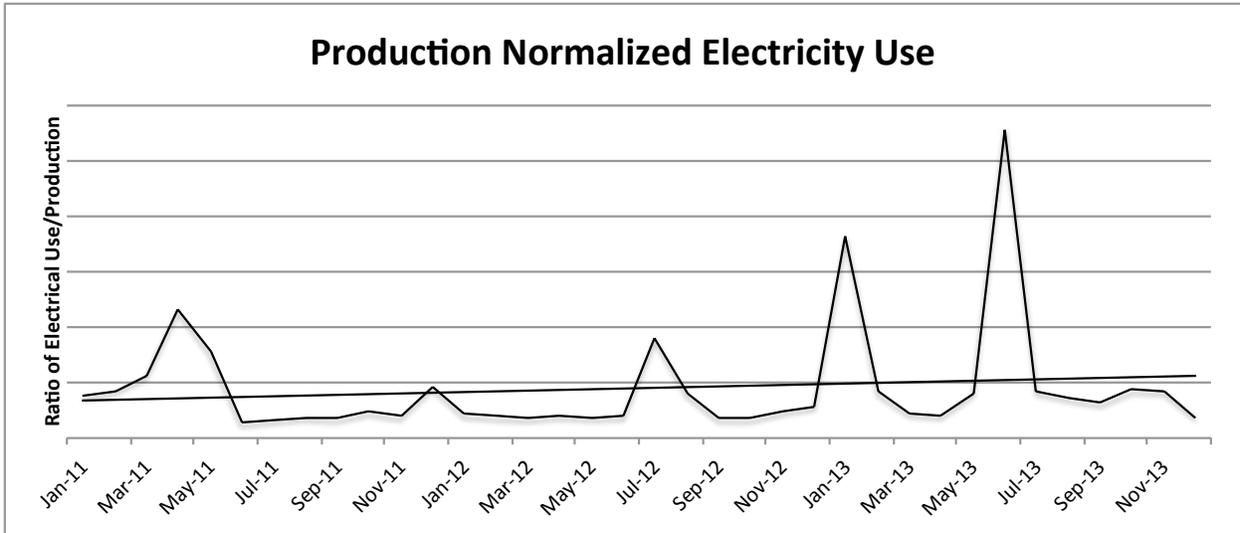


Figure 5: Electricity use normalized to production. January 2011 to December 2013. The peaks shown in this graph are due to variances in manufacturing based on normal supply and demand and in line with the trend seen in the unmasked raw data.

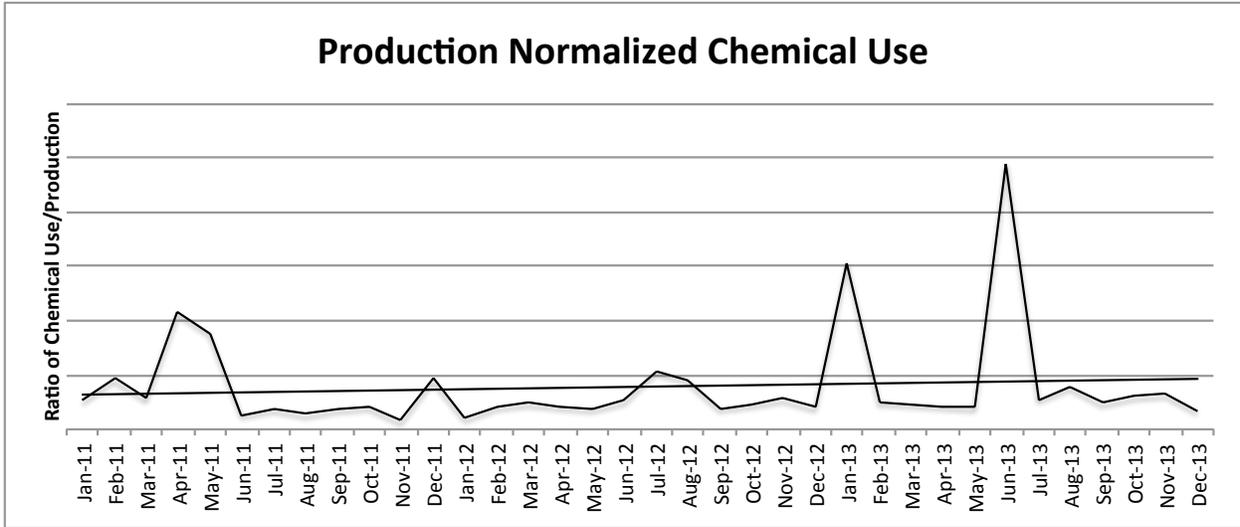


Figure 6: Chemical use normalized to production. January 2011 to December 2013. The peaks shown in this graph are due to variances in manufacturing based on normal supply and demand and in line with the trend seen in the unmasked raw data.

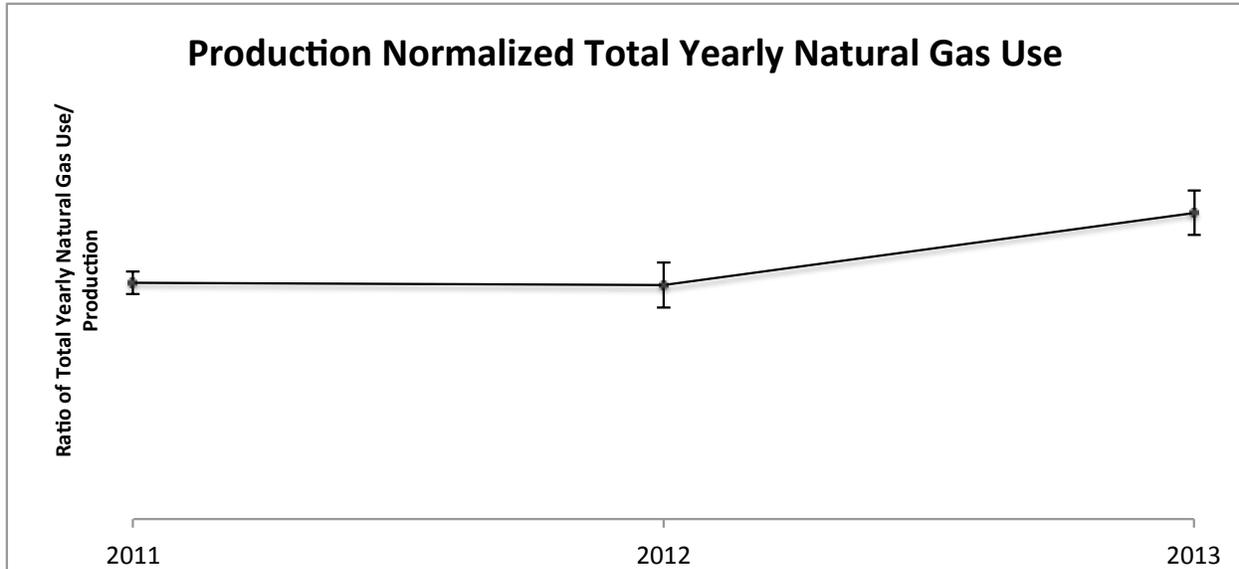


Figure 7: Total yearly natural gas use normalized to production. 2011-2013. Natural gas use was displayed as a total yearly total due to seasonal trends affecting the clarity of the trend. Error bars represent the 95% confidence interval.

The peaks seen in Figures 2-6 occur at the same times (Apr-11, Dec-11, Jul-12, Jan-13, and Jun-13) and can be considered background noise in the data due to inherent fluctuations in industrial manufacturing. The masked trends are reflective of the original trends in the raw data without disclosing absolute values in order to protect the confidentiality of the focus company.

Table 10: Regression statistics.

Statistic	Figure 2	Figure 3	Figure 4	Figure 5	Figure 6
t-stat	-0.12134	-1.12053	-1.38452	0.76069	0.56495
P value	0.90413	0.27034	0.17522	0.45208	0.57582
Trend	Negative	Negative	Negative	Positive	Positive
Efficiency	Increasing	Increasing	Increasing	Decreasing	Decreasing
Statistically Significant?	No	No	No	No	No

Statistical analysis using StatPlus shows that none of the trends is statistically significant using a p value of 0.05. However, overall use of materials and energy is changing in real numbers as per their respective trends.

4.3. Potential for Further Improvements

As seen in Figures 5 and 7, rates of electricity and natural gas use relative to production are rising within the focus company. Generally, in facility efficiency efforts, electricity and natural gas use are a rich area of 'low hanging fruit', and achieving efficiencies in those areas should be easier and/or involve less capital than a process improvement would (Granade et al., 2009). There is a range of options for improving efficiencies for these two utilities; however, a combination

of many small changes will most likely make the most economic sense, while noticeably improving efficiency and utility use. This approach is supported by Eden and Long (2014) in their book *Low-Hanging Fruit: 77 Eye-Opening Ways to Improve Productivity and Profits*. In one reported case, the US bank PNC Financial Services required employees to find and implement efficiencies, resulting in about 2,400 small changes adding up to savings of \$400 million a year.

With respect to natural gas use, the primary use at the focus company is in the winter months for heating of the factory floor and office spaces. Large overhead heaters are used on the factory floor to supply heat: however the thermostat to adjust these heaters is not easily accessible by the factory floor workers. A consequence is that when they are hot the workers just open the big bay doors to let in cool outside air. This is obviously a huge waste of heat, and a more accessible thermostat would give the plant floor workers greater control over the temperature. Also with the bay door some workers will take the forklift out and leave the bay door open while they are in the yard. This is due primarily to a lack of motivation to doing the seatbelt, get off the forklift, open the door, get back on, do the seatbelt back up, drive the forklift out, and then repeat the getting off and closing procedures on each exit and return. This is a waste of time for the floor workers. An automatic garage door system installed on the forklift would allow the forklift operator more efficient access through the bay door, thereby saving on wasted heat escaping to the outside. The plant also uses active ventilation in the process and there is a good deal of warm air sent outside every second of every day. A heat exchange system could be installed to recapture some of this wasted heat and use it for heating the plant floor, which would also cut down on natural gas use.

Electrical demand for the focus company is primarily to power lighting, air compressors, pumps, electric ovens/furnaces, mixer motors, office equipment, and air conditioning. Some options to help improve the electrical efficiency of the plant would be to improve the insulation of the office spaces and factory floor, improve windows, add caulking and weather stripping to windows and doors, turn the temperature of the staff fridges down, turn down the water heater thermostats, upgrade electrical motors to more energy efficient ones, actively check for and fix leaks in the compressed air system, upgrade the air compressors and other major electrical equipment to more efficient models, raise the air conditioning/heating thermostat temperature setting in the summer and lower it in the winter, clean/replace air filters, retrofit lighting with more energy efficient options, wrap hot water heaters with insulating jackets, and finally initiate larger projects that would reduce energy demand, such as solar panels or wind turbines. These options range in terms of pay back period, capital investment required and efficiency increases to be gained, and some may not be sufficiently attractive from a financial perspective. However, doing as many as possible would increase the efficiency of the focus company plant. A rooftop solar project would provide a large amount of electricity that would be sold to the grid, as well as provide an opportunity for green advertising in the broader community.

A combined heat and power (CHP) plant producing electricity and steam/heat for production purposes would also be an effective way to save on both electricity and heating/natural gas use, as it is a more efficient use of both resources, and can achieve efficiency ranges >90% (Angrisani, Roselli & Sasso, 2012; Mueller, 2012; Salomón et al., 2011). A CHP plant at the single facility scale is economically feasible and produces electricity at a cost that is comparable to current generation methods, as well as renewables (Cuttica & Haefke, 2009; Mueller, 2012). Capital costs for a micro-turbine CHP plant run on natural gas would be around 2,400-3,000 \$/kW, and operation and maintenance would be around 0.012-0.025 \$/kWh (United States Environmental Protection Agency, 2008). Cuttica and Haefke (2009) state that “without long hours of operation (>3,000 hrs/yr) with at least 50% usage of the recycled heat (annual basis), the viability of CHP is low”. Spark spread is the gas/electric price difference and can be used to approximately determine the feasibility of CHP; if the spark spread is greater than \$12/MMBtu then CHP has a higher potential for favourable paybacks (Cuttica & Haefke, 2009). The utility data acquired from the focus company from January 2013 to December 2013, and the worksheet in Cuttica and Haefke (2009) on spark spread, permit a calculation that the focus company has a spark spread value greater than \$12/MMBtu and therefore would be a good candidate for a CHP plant at the single facility level. A calculation using the savings and payback steps in Cuttica and Haefke (2009) reveals that an appropriately sized CHP plant at the focus company would be economically viable and have a payback period of less than two years assuming full utilization of the produced heat. If the focus company were unable to use all the heat that was produced by a CHP plant, there would be a potential to sell it to a nearby facility through a business partnership that may prove to be economically favourable.

There is also the potential for a rooftop solar project through a government incentive program, should that be feasible. In some jurisdictions, for example Ontario, there is the Feed-In Tariff (FIT) program that pays the generator of the electricity a higher than market value for electricity produced, which reduces payback time and makes the project more economically favourable (IESO, 2015). This would probably be a project best suited in collaboration with the local utility provider or a solar contractor to determine if it is a worthwhile investment for the focus company; however, it does have great potential as an environmentally friendly project, and would produce significantly less GHG emissions than a fossil fuel dependent system.

‘Lower hanging fruit’ options that the focus company could work on with minimal capital investment include installing insulating blankets (R11) on their hot water tanks, which cost around \$25 each and can save approximately 20% of the energy requirements for that tank (Casey, 2009). According to the U.S. Department of Energy (n.d.), this \$25 investment should pay for itself within a year. Given that there are several hot water tanks in the factory for process, hygienic, and safety requirements this would be a worthwhile venture.

In the summer the air conditioning is set quite low in the office spaces, approximately in the 19°C (66°F) range, with the thought that it helps cool plant

floor workers who are exposed to hot environments. If the thermostat were raised 3°C (°F) to 22°C (72°F) it would result in approximately 6-18% savings in energy costs associated with the air conditioner, and still provide a cooler environment for plant workers, especially if additional cool beverages or frozen popsicles were used in combination (Casey, 2009). Reducing heating and cooling costs through simply adjusting the thermostat to a more economical level does not cost anything and will result in immediate savings.

Hot water tanks are generally set to 60°C (140°F) however this could be lowered 11°C (20°F) to 49°C (120°F) without any significant change in performance according to Casey (2009). This adjustment requires no capital investment and would save approximately 6-10% of the energy costs associated with the hot water tanks (Casey, 2009).

Computers and office equipment are often left on, even when the operator/supervisor has gone home. These should be shut down and restarted at the start of the next shift to save on energy. According to Hostway (2015), leaving a computer in sleep mode every night and weekend for a year costs approximately \$41, whereas shutting it down for that same time period of time only costs approximately \$3 per year; that would deliver a savings per computer of 93%. This simple change in habit has no capital cost and would save the focus company \$38 per computer a year; using 20 computers as an example, that would work out to \$760 in savings per year.

Electric motors are an essential part of many industrial processes, and although replacement of existing motors would be expensive, new motors that are purchased to replace motors that have failed should be energy efficient ones. Integrating a retrofit of motors into the regular maintenance and replacement schedule would be a proactive way of improving efficiency. Energy efficient electric motors, such as the Baldor Super E are 93% efficient compared to EPA Standard motors (roughly 88% efficient), and average motor efficiency (roughly 83%) based on a 5 hp model (Figure 8). Using calculations from Keys (2007), increasing the efficiency of an electric motor from 88% to 93% would result in \$182.31 in annual electricity cost savings, operating at full load for 8,000 hours per year, with the cost of electricity at \$0.10/kWh. This adds up to considerable savings given the number of electric motors operating in industrial facilities, and motors that are used the most should be proactively upgraded first.

The compressed air system is an integral aspect of most manufacturing facilities, and a complete system inspection to test for leaks can save approximately 20-30% of the costs associated with its use (Hydro One, 2007). Leaks are commonly located in aging pipework, flanges, fittings, manifolds, flex hoses, couplings, drains, and pneumatic components (Hydro One, 2007). A full system test should be done when regular process equipment is off, so that audible leaks can be heard. Losses from even a small 1/64 inch (0.4 mm) hole in a compressed air line will cost approximately \$48.00 per year, whereas a larger 1/8 inch (3.2 mm) hole will cost an estimated \$2,981.00, based on 100 psi and \$0.22/MCF (Abdelaziz, Saidur & Mekhilef, 2011). A detailed inspection of compressed air lines could add up to significant yearly savings, considering that

in a loud industrial environment air leaks are often unheard over other process equipment noises.

Lighting is also an area that commonly offers potential for easy and profitable improvements in energy use. For example, according to NeoLumens their linear LED lamp that is designed to replace typical T8 and T12 fluorescent tube lighting is 70-80% more efficient and contains no mercury (NeoLumens, n.d.). Assuming a 24/7 lighting scenario, the payback period for this investment in LED lighting would be less than 3 years, and could be as little as just over 1 year (NeoLumens, 2014). This would provide savings of around \$50 per lamp per year based on T12 fluorescent lamps (currently in use at the focus company) running 24/7 (NeoLumens, 2014).

In Ontario, for example there are incentive grants for industry to help alleviate some of the costs associated with these initiatives (Hydro One, 2014). This program is aimed at businesses and industry and helps pay up to 50% of the cost of efficiency retrofits; this can significantly help with return on investment time (Hydro One, 2014). Opportunities such as this are available in many jurisdictions, and industrial facilities looking to upgrade to more efficient equipment should utilize this support.

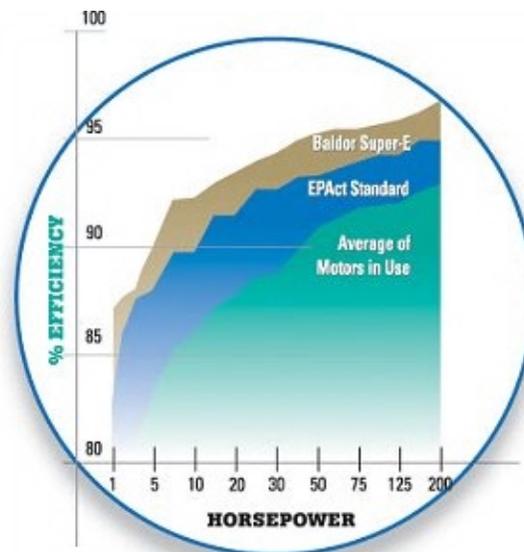


Figure 8: Baldor Super E electric motors compared to the industry standard. (Baldor, 2015).

There are evidently many options available for energy efficiency gains at the focus company facility, and a proactive approach aimed at systematically improving the efficiency of equipment would be a worthwhile pursuit for any company.

Earlier in this section CHP plants were mentioned as a way to capture efficiency through thermal and electrical energy. This could be a favourable option for the focus company based on the initial spark spread calculations.

4.4 Application of the Framework for Analysis to the Focus Company

Using the framework for analysis used in chapter 3 to rank three IHPC cases and 3 EIP cases, we examine the focus company in light of their recent IHPC improvements. The results are shown in Table 11, using the data presented in figures 2-7. Although the focus company has made improvements in material efficiency and waste reduction and therefore has lowered costs, the costs of increased energy use have negated these cost savings. Although not part of the data set in Figures 2-7, company data indicate that employment and job security at the focus company has been unchanged, with minimal job creation or loss. Ease of implementation can be considered as sensible from the focus company as it is interested in improving and being more efficient. This was clearly demonstrated throughout my personal interactions with the company, including the managers' willingness to participate in this research. Long term viability is at the minimal improvement level, as there have been few improvements towards overall sustainability goals and improvements are required to enhance the viability of the operations, given these broad sustainability improvement initiatives. Public relations remains unchanged as there has not been any sort of publication prior to this thesis on the efficiency initiative. Overall the focus company gets a score of 5/21, which is considerably lower than the IHPC cases described in the literature and in chapter 3, but recognizes useful past initiatives and identifies significant room for improvement within the focus company.

Table 11: The framework for analysis for the focus company.

Category	Stage 1 (0 points)	Stage 2 (1 point)	Stage 3 (2 points)	Stage 4 (3 points)	Score
Energy Efficiency	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	0
Material Efficiency and Waste Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Cost Savings	No change from current business as usual levels.	Minimal (thousands/year)	Significant (hundreds of thousands/year)	Substantial (millions/year)	0
Job Security, Stabilization and/or Creation	No change from current levels given the uncertain economic situation.	Job stabilization at current company levels; minimal job creation. Minimal change in job security.	Job stabilization at current company levels and significant job creation (<10%) and/or enhanced job security.	Job stabilization at current company levels and substantial job creation (~10%) and enhanced job security.	1
Ease of Implementation	Impossible and/or impractical given involved company's current situation.	Possible, however there are significant administrative barriers.	Sensible, willingness from stakeholders to begin planning.	Development and/or collaboration is actively explored and initiated.	2
Long term Viability	Unviable (no change)	Minimal improvements in viability.	Significant improvements in viability but not resilient to change.	Substantial improvements in viability and resilience.	1
Enhanced Public Image and Relations	No change from current level.	Minimal improvement in one or the other.	Significant improvement in both public image and relations.	Substantial improvement in public image and relations. Newsworthy.	0
Total Score					5/21

4.5. The Case Study Site

The case study site is a collection of light industrial facilities and small and medium-sized enterprises located within a small-medium sized city in North America. The case study site is both commercial and industrial; however, it is limited in redundancy, unlike Burnside Industrial Park. In total the case study site covers approximately 100-120 hectares, and has full electrical, water, sewer, natural gas, and fiber optic infrastructure in place. It is also located in close proximity to a major highway and rail line. The manufacturing areas in the case study site include assorted plastics, metal and chemical manufacturing. Density is approximately 0.6 facilities/hectare. There have been no previous attempts to consider an industrial ecology based project in the area, and the industrial cluster has operated as a standard industrial land development throughout its existence.

4.6. Other Companies in the Area

As previously mentioned, the case study site contains various commercial, and industrial facilities, from plastics manufacturing to electrical contactors. All the companies in the area have a demand for natural gas, electricity, water, telecommunications, and sewer services. Specialized demands include plastic pellets, various chemicals, metals, and electronics. The waste streams from the case study area include hazardous solid and liquid waste, non-hazardous solid wastes (flashings, etc.), normal garbage, and low grade heat. The focus company does not produce any significant air emissions, other than carbon dioxide from the natural gas used for heating.

Specifically the case study area has 3 plastic injection molding facilities supplying mostly the automotive industry, 2 specialty instrument facilities, 1 specialty metal products facility, 2 chemical oriented facilities, 2 vacant lots (1 with a burned down building) that used to have production facilities, 1 manufacturer of audio equipment, 1 manufacturer of pulp and paper products, 1 hazardous waste facility (municipal), 1 manufacturer of retail equipment, and 8 commercial facilities.

4.7. Potential Linkages

The following four questions cover the common indicators of potential linkages for industrial ecology purposes:

- Are there any facilities generating wastes (heat, steam or other) that could be reused, recycled or repurposed as a resource for another facility?
- Are there any materials that could be provided at a lower cost through collaboration?
- Could energy be provided at a lower cost through a collaborative generation project?
- Is there another facility that could be added to the case study site that would encourage linkages?

Looking at the case study site with these questions in mind, reveals limited but not negligible potential. There is a lack of significant levels of high grade heat such as the case with the Asnæs power plant at Kalundborg EIP, however there are common and constant needs for low grade heat for building heating and process requirements. Also, there is a need for significant amounts of electricity for production purposes in the industrial facilities. It is difficult to discern which materials could be provided at a lower cost through collaboration without a company to company discussion on this topic, but possibilities for minor initiatives such as skid sharing and mutual use of equipment. The addition of a CHP plant and/or a waste processing plant, assuming sufficient economic capital is in place to facilitate such a project, would help various facilities on the site to deal with resource production or recovery needs; however, any such plant would have to be agreed upon by a number of the companies within the case study site.

In the case study site, there is limited redundancy in manufacturing of products; however, there is high redundancy in essential requirements for electricity, water, sewer, natural gas, and telecommunications. The waste

management needs seem to be insufficiently similar to establish collaborative opportunities. Only one company generates significant volumes of liquid waste that needs further processing, whereas the other companies would have higher volumes of solid waste. It is unlikely that a linkage will emerge without outside investment in another factory site and/or a treatment facility.

The most promising linkages in the case study site would be ones that focus on water, electricity and/or heat/natural gas use. These linkages would require collaboration on some sort of capital project, such as a CHP plant, or a renewable energy project. As shown previously there is a potential for the focus company to generate some of their electrical demand using solar panels, and a successful collective application for participation in a feed in tariff (FIT) program, as is available in Ontario, would help spread responsibility for the capital investment, ensure significant revenue for PV solar electricity fed into the grid, and build collaboration among participating companies. According to the Ontario Power Authority (OPA), community engagement with the municipality or other groups is an important part of the application process (OPA, 2014). The OPA has a Large Renewable Procurement (LRP) process for proposals greater than 500 kW, and this level of electrical production would be possible with a joint venture utilizing multiple rooftop spaces in the case study area, for example. Opportunities such as this are available in some North American jurisdictions that promote renewable energy use. A structural assessment would need to be done to ensure that the roof tops in the case study area are capable of supporting the weight of solar panels prior to an application being filed with OPA. If other companies in the case study area joined in a solar energy project there would be possible savings for all involved through a group rate on the purchasing of the panels, installation, and maintenance.

A CHP plant providing heat and power for the case study site would also be a possible linkage. This could be a traditionally fueled power plant, utilizing natural gas, or it could be a more forward thinking alternative, such as waste incineration or a concentrating solar power plant (CSP).

Waste incineration is a highly debated topic, and attracts much criticism in North America; however, it is very mainstream and widely accepted in Europe (Best, 2008; Grosso, Motta & Rigamonti, 2010; Koehler et al., 2011; Pavlas et al., 2011; Renewable Waste, 2012; Saner et al., 2011). Europeans can be considered more motivated to use waste incineration, because unlike in North America, there is very limited space available for a traditional landfill. There were concerns with heavy metals, dioxin and furans when incineration technology was first introduced, but these pollutants have been largely eliminated from exhaust streams, especially through the high efficiency waste to energy (WTE) plants now in operation (Best, 2008). In North America, a CHP plant utilizing WTE technology would be a novel way of creating electricity and heat for an industrial park site, as well as the surrounding community, while dealing with the issue of municipal waste for both the local and nearby areas.

Concentration solar power uses mirrors called heliostats to reflect solar radiation into a collection device, usually through a tower or a trough and pipe system (Müller-Steinhagen & Trieb, 2004). It is estimated by Müller-Steinhagen

and Trieb (2004) that solar energy of approximately 1800 kWh/m²/year is needed for a concentrating solar power project to be economically viable, and using the map from Trieb et al., 2009, we can see that North America ranges from approximately 800-2800 kWh/m²/year range, which makes it a possibility in much of Mexico, the U.S., and parts of Canada. A CSP project an industrial site would be a very forward thinking approach that could provide electricity and heat to the local factories, while reducing the environmental impact of energy production in the area and lowering overall GHG emissions.

4.8. Chapter Conclusions

The focus company has made some good progress towards achieving greater efficiency in production, and has seen the cost associated with energy and material use to produce their finished product go down over the past years. However, it has yet to capitalize on the 'traditional' environmental efficiency savings through 'low hanging fruit' within the factory. These efficiency changes would likely be easier to implement than process changes, and could deliver significant savings. As a result, the focus company has a great opportunity to improve their efficiency as well as overall image of being a green company committed to sustainability. The process changes that the focus company has already implemented improved production efficiencies related to water use and waste water generation. However electricity, which is probably also the area in which the company has the greatest opportunities for efficiencies and financial gains through pursuit of 'low hanging fruit' possibilities.

Some broader opportunities are available for collaborative initiatives among firms in the case study site, though the cluster is not in a position to recreate the success of Kalundborg EIP. There is potential for improvement for the mix of small and medium-sized commercial and industrial facilities, similar to the scope of Burnside Industrial Park. With the right motivation and pressure the case study site could achieve an industrial ecology project that would increase overall efficiencies and lead to cost savings for the companies involved.

As we can see at this point, IHPC options are a promising option for the case study site and for similarly sized industrial clusters around the world. IHPC options will be discussed further in the next chapter.

Chapter 5: In-House Process Changes: A Closer Look, Pros and Cons

In this chapter, IHPCs are examined more closely, weighing potential efficiency gains, costs, advantages and limitations. The insights from this chapter will be used in combination with those of chapter 6 on EIPs to compare IHPCs and EIPs at the start of chapter 7.

5.1. In-House Improvements

5.1.1 A Closer Look

In section 2.2 In-house process changes (IHPCs) were first identified as any efficiency improvements made to a single industrial facility whether directly in production or indirectly in energy and/or material demand reduction. IHPCs can increase market competitiveness through cost savings and public image improvements, and in-house initiatives are a popular option with industry in comparison to industrial ecology options focused on EIP projects. IHPCs have strength in relatively small capital investment requirements and being in the sole control of the company that is undertaking them. IHPCs avoid complexities dealing with other companies and one board of directors, or other authoritative figure(s) calls the shots. IHPCs are limited in the extent of improvements that can be accomplished because they are constrained by the efficiencies of scale possible within a single facility.

IHPCs have been a mainstream choice compared to EIPs, and have been widely reported in the media in part because of the visibility of various retrofit incentive programs offered by utility providers. IHPCs are also good candidates for 'green' advertising, which is a popular advertising angle to target the ecologically minded consumer.

5.1.2 Potential Efficiency Gains

As noted in chapter 4 the focus company has achieved significant process efficiency gains and there are many easily identifiable areas for further improvement. Many of these potential improvements are 'low hanging fruit', in that they are within easy reach, and could bring savings that provide rapid payback of initial investments. Individually they may not amount to much but collectively they could make a sizeable difference, especially considering they have such low capital costs compared to other means. Some examples of different improvement opportunities can be seen in Figures 9 and 10, from Granade et al. (2009), a report prepared by McKinsey and Company entitled *Unlocking Energy Efficiency in the U.S. Economy*, and Mogren (2007), a report by Vattenfall, the Swedish state owned power company.

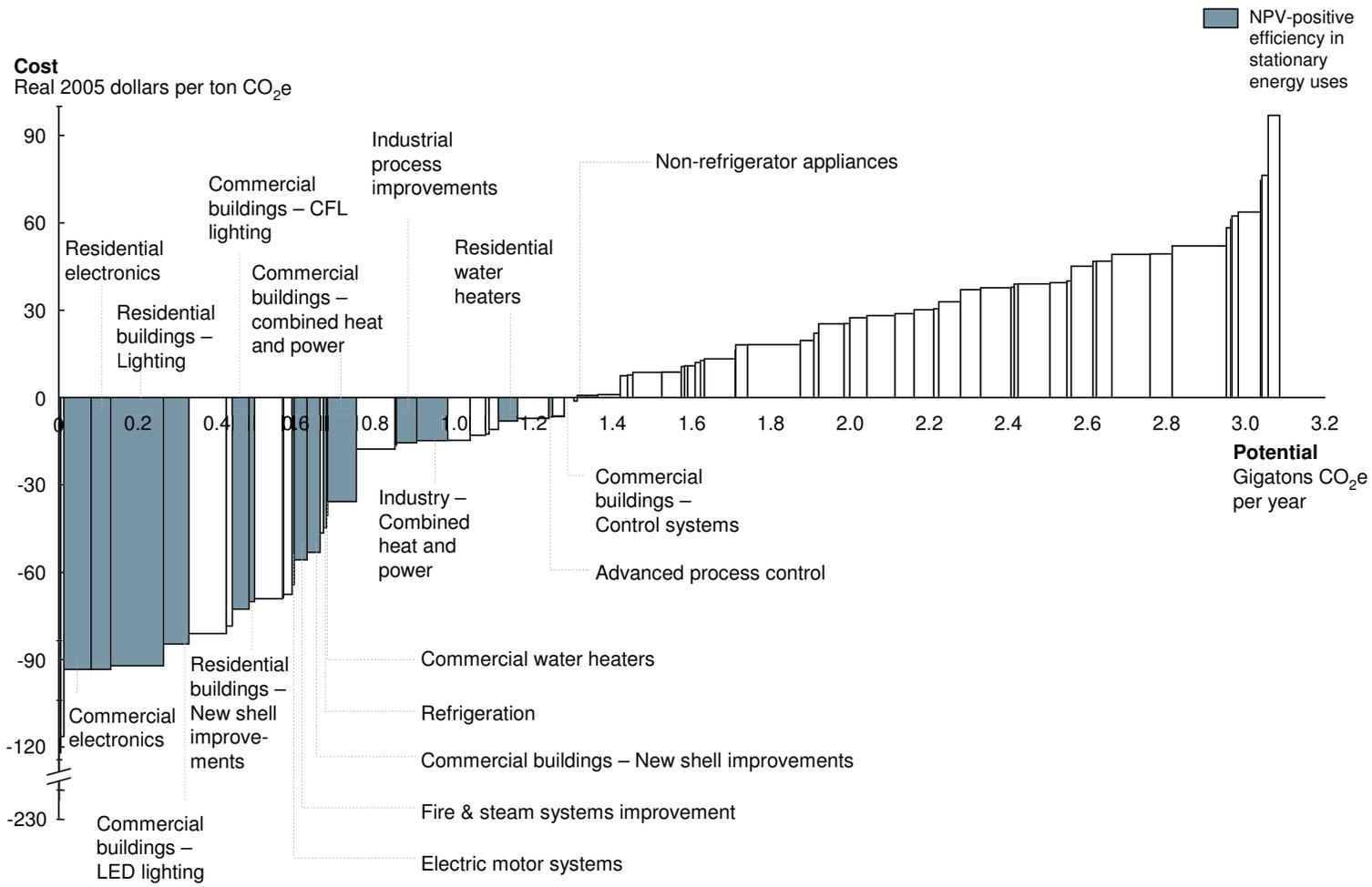


Figure 9: Abatement opportunities and costs (Granade et al., 2009).

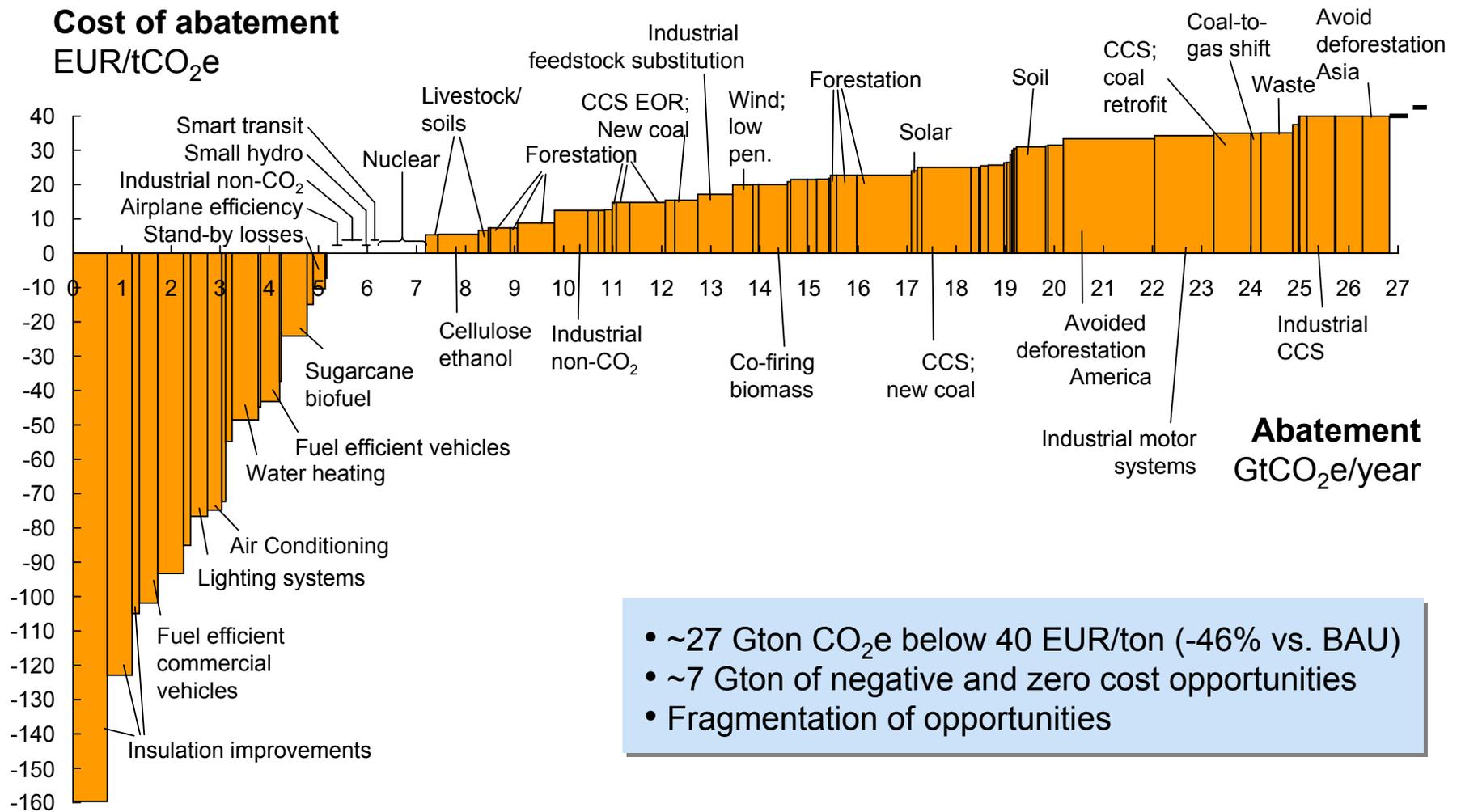


Figure 10: Abatement opportunities and costs (Mogren, 2007).

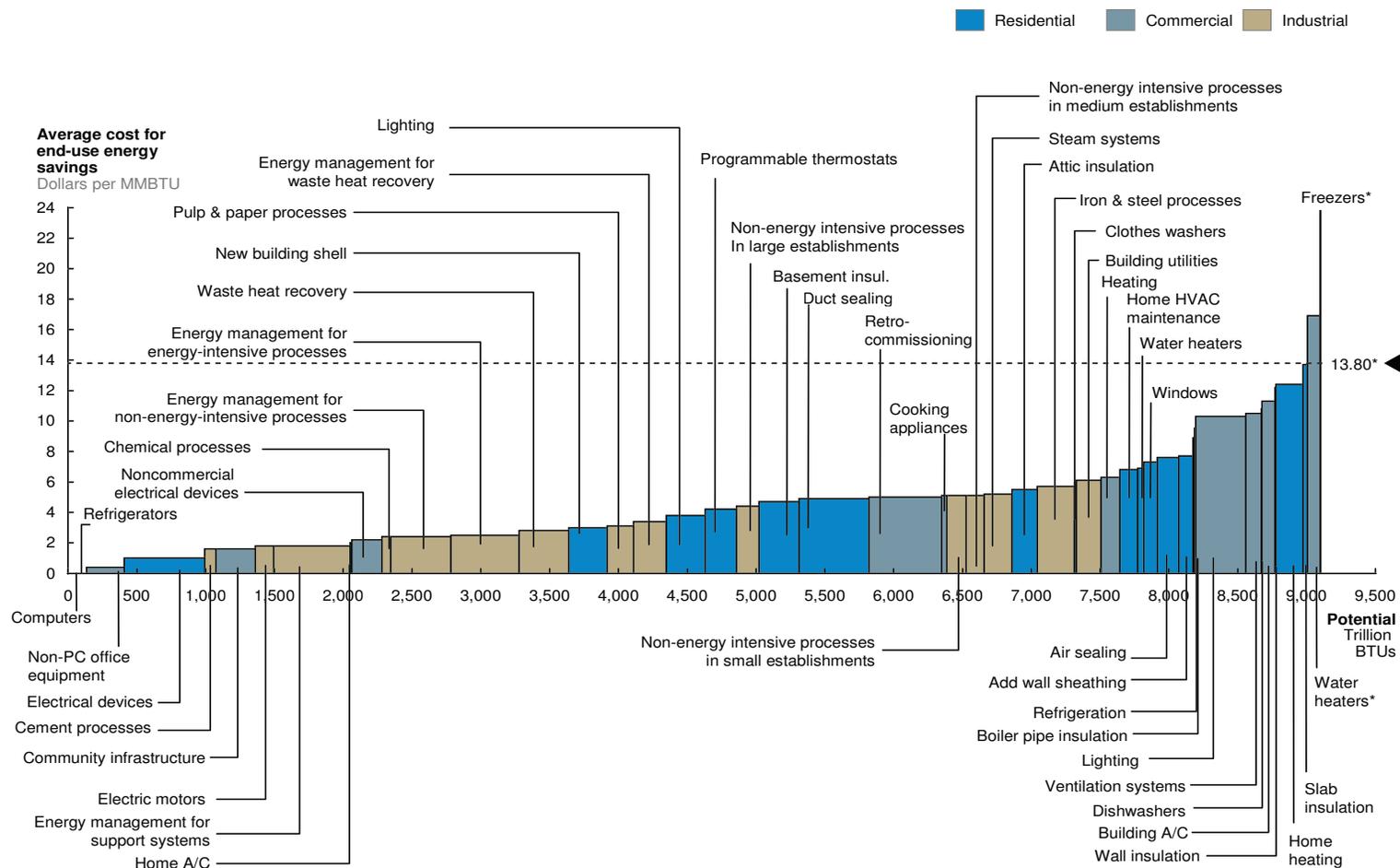
Figures 9 and 10 show the 'low hanging fruit' on the left and the higher up 'fruit' on the right. While the left side options are the more easily obtainable, they do not provide the same level of abatement that the options on the right do. Looking back at section 4.3 we can see that most of the identified possibilities for the focus company are in the left section. These include insulation improvements, and far more efficient lighting systems, air conditioning, and water heating. Solutions such as solar power cross the threshold into the higher placed 'fruit'.

In total, the economically feasible efficiency improvements from IHPCs could deliver 10-30% in savings under most applications, plus opportunities for green advertising/marketing benefits for the company (U.S. E.P.A., 2012).

5.1.3 Potential Costs

As mentioned in section 5.1.1, in Ontario there is the saveONenergy program sponsored by the provincial electrical utility: Hydro One (<http://www.hydroone.com/MyBusiness/SaveEnergy/Pages/Retrofit.aspx>). Similar incentive packages are available from other utility providers as well. For example, New York State Electric and Gas Corp., has a program called CA\$HBACK (<http://www.nyseg.com/YourBusiness/CASHBACK/cashback.html>).

Under the saveONenergy program, participating companies can receive up to 50% of the costs of the retrofits, significantly reducing the capital investment needed to make these improvements. Generally, costs associated with IHPCs are low compared to other options. Picking the higher up 'fruit' can require much larger capital investment, but still deliver an attractive return on investment.



* Average price of avoided energy consumption at the industrial price; \$35.60/MMBTU represents the highest regional electricity price used; new build cost based on AEO 2008 future construction costs
Source: EIA AEO 2008, McKinsey analysis

Figure 11: Costs and end user savings (Granade et al., 2009). Note that Figure 11 represents average situations and that in specific situations costs and efficiency savings will be different.

Unlike Figures 9 and 10, which present the 'low hanging fruit' on the left, Figure 11 does not show 'low hanging fruit' on one side or the other, but rather shows average costs of energy savings. For example, in Figure 11 lighting (a 'low hanging fruit' on Figures 9 and 10) is on the right, but it has a high potential for energy savings and a medium cost leading to good return on investment.

Figure 10 shows that insulation improvements, fuel efficient vehicles, updated lighting systems, more efficient air conditioning and water heating, and elimination of stand-by losses all have negative costs (-160 to -10 €/tCO₂e) indicating that they save the company money when they are implemented. Such improvements make the most sense for initial IHPC efficiency improvement programs as they save the company money and have good return on investment.

5.1.4 Advantages

The advantages of IHPCs are fairly straightforward, in that they have lower capital investment, they only involve one company and therefore are easier to plan and carry out. A company that has adopted an IHPC strategy for efficiency gains can autonomously chip away at easier and lower cost options, move quickly to take advantage of energy retrofit incentives, and leave more available capital for other projects, rather than having that money be tied up for years. IHPCs allow companies to take on only what they can afford, and still provide them with an opportunity for green advertising/marketing, at a much lower cost than an EIP type project.

IHPCs avoid complexities dealing with other companies, and one board of directors, or other authoritative figure(s) makes the decisions. When working in a partnership with other companies, decisions can often be held up simply through the delay associated with working with multiple partners. Also, in the event the leading authoritative figure(s) do not remain the same throughout the years of company operation, agreeing on a direction is much simpler when it remains within one company. It is important to note that improvements in efficiency are generally a step in the right direction, assuming that they do not come at the cost of social wellbeing, and that it is better to make small improvements than none at all.

In terms of capital investment one can refer back to Figure 9 and see that many of the IHPC changes suggested, such as improvements to insulation, lighting systems, air conditioning, and water heating, fall into the left side of the figure, and have the lowest costs per abatement gains.

In Ontario, the provincial electricity utility company Hydro One has incentives for financing process and system upgrades, auditing (50% of cost), and retrofits (50% of cost), and through peak shaving incentives that lower electricity costs when demand is the lowest. These can be seen at: http://www.hydroone.com/MyBusiness/SaveEnergy/Pages/Programs_Industrial.aspx.

IHPC accomplishments are prime candidates for 'green' advertising. One example comes from one of the IHPC cases: BASF, which promotes itself as a sustainable chemical company (BASF, 2014). BASF leverages this 'green' image

to consumers through integration of environmentally focused advertising; for example stating that their paint ‘contains less than 50 g/L Volatile Organic Compounds (VOCs) (BASF, n.d.)’. This statement would have been practically meaningless to the consumer 20 years ago, but in today’s society it might convince a consumer to choose the BASF brand of paint over one with higher VOCs. Green advertising can also be seen on any highway these days on the large number of transport trucks that are equipped with trailer side skirt air deflectors, usually with some slogan about how the trucking company is ‘going green for the sake of the environment’. These trailer side skirts have been proven to decrease fuel consumption by 3-7%, which is add up significantly in trucking, and it provides a great green advertising opportunity (Patten et al., 2012). IHPCs ideally will provide a green advertising opportunity while achieving cost savings through efficiency improvements.

5.1.5 Limitations

IHPCs are limited in scale compared to industrial ecology based EIPs. They tie up less capital investment, but cannot economically provide the same level of savings that a collaborative industrial ecology option can, as was discussed in the chapter 3 comparison of EIPs and IHPCs. By-product exchange, or industrial symbiosis “consists of place-based exchanges among different entities that yield a collective benefit greater than the sum of individual benefits that could be achieved by acting alone [IHPCs]” (Chertow, 2008).

A single company does not generally have (or want to tie up) significant capital investment needed for a major project that would provide bigger returns on investment, and even if it did, some initiatives are economically feasible only at a scale larger than is possible at one facility. IHPCs are by definition limited to single facilities or multiple facilities within a single company. Multifaceted companies might have the diversity to successfully perform industrial ecology like options as a form of IHPC; however, few companies have multiple facilities based within a small geographic area.

5.2. Chapter Conclusion

This chapter has examined the potential pros and cons of IHPCs for industrial efficiency improvements. IHPC is a robust and attractive option that can appeal to many companies because they require less capital investment while still providing green marketing opportunities for the company in question. It is feasible that every company could do some form of IHPC, even something as simple as changing light bulbs to more efficient LED options, and it is this ease of use that makes IHPC a great option for industry.

This chapter also confirms that the identified IHPC opportunities for further efficiency gains at the focus company are well recognized in the literature as means for single facilities to improve efficiency and lower costs profitably. The suggestions presented in chapter 4 are mirrored in the suggestions from Granade et al., 2009 and Mogren, 2007 in Figures 9-11.

Chapter 6: Eco-industrial Parks: A Closer Look, Pros and Cons

Chapter 6 examines EIP options, in preparation for the Chapter 8 comparison of IHPCs (chapter 5) and EIPs. Chapter 6 will evaluate the potential of EIP options for the focus company and case study site.

6.1. Eco-industrial Park Improvements

6.1.1 A Closer Look

In section 2.4 EIPs were first introduced with the broad goal of reducing waste volume and negative environmental impacts while increasing the competitiveness and success of companies participating in collaborative initiatives (Cohen-Rosenthal, McGilliard & Bell, 1996). EIPs have been very attractive in principle as a method for improving industrial efficiency: however, only a handful of EIPs around the world are currently in successful operation.

EIPs have an advantage over IHPCs in their scale and capacity for efficiency improvements; however, they are hindered by the need for intercompany negotiations and agreements (Chertow, 2008). The scale of an EIP operation such as the one at Kalundborg offers considerably bigger savings than what is possible for an individual company to achieve by retrofitting lighting or their internal processes for example.

In the previous chapter IHPCs were considered ‘mainstream’ compared to EIPs, as most people have heard of retrofit programs offered by utility providers. It is more apparent that savings can be had from replacing inefficient building equipment, such as air conditioning or lighting, or improving the process design to minimize wastes and/or material inputs; it is conceptually more difficult to imagine increasingly complex connections with multiple facilities involved.

6.1.1.1 Possible Forms

EIPs are a form of industrial symbiosis that relies on the interaction of multiple facilities exchanging materials and/or energy in their operations. An EIP can be built simply as collaborative energy production through renewable and/or combined heat and power (CHP), or it can adopt a much more ambitious and complex form such as at Kalundborg EIP (Figure 1). EIPs fall into the academic category of industrial ecology first introduced to the literature in a 1989 paper entitled “Strategies for Manufacturing” by Frosch and Gallopoulos.

6.1.1.2 Possible Participants

A 2004 paper by Heeres, Vermeulen and de Walle identified many potential participant stakeholders in EIPs: the companies involved, a local champion, an anchor tenant, local, regional and national governments, the local chamber of commerce, entrepreneurs association, educational institutions, consultants, labour and environmental NGO’s, and local residents. This list could be expanded to include the local utility companies, and engineering, green business and perhaps architecture consulting firms that could facilitate EIP planning.

6.1.1.3 Planning or Evolution?

Kalundborg was not pre-planned. Instead, it was an evolutionary EIP that developed through financially minded decisions rather than solely environmentally based ones (Lowe, 1995; Desrochers, 2000). Henning Gran of Statoil was quoted in Garner and Keoleian (1995, 28) saying:

The symbiosis project is originally not the result of a careful environmental planning process. It is rather the result of a gradual development of co-operation between four neighbouring industries and the Kalundborg municipality. From a stage where things happened by chance, this co-operation has now developed into a high level of environmental consciousness, where the participants are constantly exploring new avenues of environmental co-operation.

Desrocher's (2000) paper, "Eco-Industrial Parks: The Case for Private Planning," discusses the pros and cons of planned EIPs and concludes that all capital corporations are governed by the market, which keeps them constantly improving their process to reduce costs, and that rather than grand pre-planning of EIPs, there should be more of an emphasis on reducing barriers to EIPs and more encouragement of cooperative discussions and planning through which EIPs can develop on their own.

There are merits to both approaches. Pre-planning permits a large leap and the usually greater efficiencies of dedicated initial design rather than retrofitting. More gradual EIP development relies on relative baby steps, but more time and much less complexity in planning. For the numerous preexisting industrial clusters that do not follow the EIP model, the evolutionary retrofit is a more promising option, but that one should be open to a blend of both routes.

6.1.1.4 Combined Heat and Power Plants

Combined heat and power (CHP) also known as cogeneration, is a technology that harnesses electrical or mechanical as well as thermal energy produced from a single source, thereby drastically increasing the overall efficiency of the system (Mueller, 2012; Raj, Iniyar & Goic, 2011; Salomón, 2011). CHP can increase efficiency two fold, and reduce carbon emissions by two thirds (Salomón, 2011). CHP is an important, cost effective and environmentally friendly technology that could significantly lower greenhouse gas emissions from industry.

Traditionally, CHP has been fueled by natural gas, giving a clean burning electrical and thermal energy source; natural gas is now relatively inexpensive, has a lower carbon footprint than coal, and is a proven and reliable technology. However, it is still carbon based, and emits significant amounts of carbon dioxide compared to greener renewable energy sources. More desirable would be a renewable energy based CHP plant providing highly efficient green energy for industry.

As discussed in Raj et al., there are primarily four renewable energy based cogeneration technologies: biomass, solar, fuel cell and waste heat recovery. Biomass cogeneration utilizes solid or gasified organically sources fuel

such as municipal solid waste or wood byproducts to power a prime mover such as a reciprocating internal combustion engine or a gas turbine (Raj et al., 2011). Biomass is attractive because it has a low carbon footprint compared to fossil fuel based sources, and is a potentially renewable and locally supplied fuel. Solar based cogeneration utilizes photovoltaic or concentrating solar power (CSP) to provide clean heat and power from the sun. CSP is especially attractive for this as it produces a very high temperature working fluid to create steam for the turbine generator. Currently this heat is usually lost to the environment, making CSP a very attractive option for cogeneration adaptation. Although CSP is not as effective in the northern latitudes, it has still been theoretically viable in the sunnier parts of Canada that receive higher amounts of solar radiation, as proposed by Pagliaro (2014). Fuel cell technology uses hydrogen or carbonate fuel across a membrane to generate electricity (Raj et al., 2013). Finally, recovery of waste heat captures wasted thermal energy from process equipment, and reuses it for other beneficial applications.

Another renewable energy source not covered in Raj et al (2011), is geothermal, which is particularly popular in the USA (2,687 MW in 2007; 3,389 MW in 2013), the Philippines (1,970 MW in 2007; 1,884 MW in 2013), Indonesia (992 MW in 2007; 1,333 MW in 2013), Mexico (953 MW in 2007; 980 MW in 2013), Italy (811 MW in 2007; 901 MW in 2013), Japan (535 MW in 2007; 537 MW in 2013), New Zealand (472 MW in 2007; 895 MW in 2013), and Iceland (421 MW in 2007; 664 MW in 2013) (Bertani, 2007; Matek, 2013). These numbers show that the top three fastest countries that are installing geothermal capacity are New Zealand (89.62% increase from 2007 to 2013), Iceland (57.72% increase from 2007 to 2013) and Indonesia (34.38% increase from 2007 to 2013) (Bertani, 2007; Matek, 2013). As of 2013 there were 7 planned geothermal projects in Canada; however, there are no active utility plants (Matek, 2013).

Assuming an adequate source, geothermal has a great potential for environmentally friendly cogeneration and is being utilized in Iceland for aluminum production (Bertani, 2007; Matek, 2013). One of the most famous geothermal power plants is Svarstenegi due to its integration into the tourist attraction of the Blue Lagoon. Svarstenegi produces 46 MW of electricity, and 150 MW of hot water for district heating and the outdoor swimming/spa facilities of Blue Lagoon (Bertani, 2007). The Blue Lagoon is arguably Iceland's biggest must see for tourists arriving through Reykjavik, and it gives the Svarstenegi geothermal power plant additional benefits beyond electricity and heat production. This model has been copied elsewhere in Iceland, such as the case with the Bjarnarflag geothermal power plant and spa. The Hellisheidi geothermal power plant will soon be producing 210 MW, with most of that power going to nearby aluminum refineries (Bertani, 2007).

The geothermal power plants in Iceland do not come without criticism, with arguments against them ranging from the possibility of groundwater pollution to unpleasant (and potentially dangerous) hydrogen sulfide emissions (Gunnlaugsson et al., 2010).

CHP plants are a much more efficient way of utilizing resources and would provide multiple benefits if installed as part of an EIP project to provide electrical and thermal energy to the participating factories.

6.1.1.5 Waste Treatment Plants

At the opposite end of production, a possible anchor for an EIP project is a waste treatment plant. This would most likely treat liquid waste in one or more streams coming from the EIP participants. As previously mentioned, anchors are an integral part to the EIP experience, as suggested by Ayres (1994), stating that there would need to be at least one firm exporting raw or processed material connected to several other industries able to utilize this 'waste'. A waste water treatment plant would need to be able to accomplish at least one of the following: handling high liquid waste volumes, improve effluent quality, reduce demand from the EIP on freshwater resources, and create economic development in the nearby area around the EIP (Penn & Vos, 2002). The addition of a waste water treatment plant to an EIP, as an anchor or subsidiary of one would significantly lower operating costs, and lead to faster returns on investments for project financiers (Penn & Vos, 2002).

Waste water treatment plants are an essential part of the Kalundborg experience, and are integrated into several of the anchor tenants becoming subsidiary anchor components, allowing for different purity requirements to be obtained by each applicable participant in Kalundborg. The Kalundborg municipality also has a main waste water treatment plant in the EIP that serves the greater municipal area.

Depending on the participants in an EIP project the waste water treatment plant requirements could range from heavy metal, toxic compound or biohazardous waste removal, to purity up scaling for bottled consumables. The liquid waste projects in the EIP would have to have waste water treatment plant capacities and technological capabilities to deal with the various effluents in question, in one or many subsidiary operations. Having a waste water treatment plant on site significantly reduces greenhouse gas footprint by eliminating trucking, and also provides a crucial feedback loop for water and other liquids used in production.

6.1.2 Potential Efficiency Gains

The potential efficiency gains from an EIP are immense and are the main rationale for EIP initiatives. By integrating life cycle analysis and by closing loops, EIPs make clusters of independently inefficient industrial facilities into one efficient industrial ecosystem.

Kalundborg EIP had a group of traditionally inefficient facilities at the beginning: a coal fired power plant, an oil refinery, a pharmaceutical manufacturer, a Gyproc manufacturer and the local municipality (waste water treatment plant). These facilities are not usually thought of as environmentally friendly, or efficient; however by combining them into an EIP the overall result was a much more efficient entity. Linking components of an EIP involves

adaptation to the manufacturing process to integrate new flows within the larger system. In the Kalundborg example, it is estimated that the water needs of Asnæs, Statoil and Novo Nordisk are now 95%, 98% and 20% symbiotically sourced from the EIP, furthermore Statoil receives 40% of its steam requirements from Asnæs and Novo Nordisk receives 100% (Ehrenfeld & Gertler, 1997; Jacobson, 2006). This translates to approximately \$13.33-15 million dollars per year in savings (Chertow & Lombardi, 2005). The Kalundborg EIP also saves 45,000 tons of oil per year, 15,000 tons of coal per year, 600,000 m³ of water per year, and has reduced emissions by 175,000 tons of CO₂ per year, 10,200 tons of SO₂ per year while at the same time recovering and reusing 90,000 tons of calcium sulfate (gypsum) per year, and 130,000 tons of fly ash per year (El Hagggar, 2007). These material savings are very significant and result in impressive cost savings for Kalundborg.

6.1.3 Potential Costs

As the saying goes, 'you have to spend money to make money', funding an EIP is considerably more expensive than pursuing IHPC options; however, the return on investment is faster and the efficiency rewards are greater. At Kalundborg the capital cost of the energy and material exchange projects up to 1998 was an estimated \$75 million, and the savings from these projects were collectively \$160 million in the same time frame (El Hagggar, 2007). The exchange projects had a payback period of less than 5 years on average per project (El Hagggar, 2007). In 1993 the capital cost was estimated at \$60 million, and the savings were \$120 million, which shows compounding savings throughout the years (El Hagggar, 2007). From this example we can see that the capital investment in an EIP is significantly higher than an IHPC project. IHPC's can range from a few thousand dollars to a few million, but very seldom would reach the level of \$60-75 million.

6.1.4 Advantages/Drivers

The biggest advantage of an EIP is the scale of efficiency improvements that are obtainable through this method, and they are an effective and realistic stepping stone to achieving sustainable manufacturing. EIPs are robust in their implementation and can be adapted for retrofits of existing industrial clusters, or be designed from the ground up. The overwhelming success story of Kalundborg is built upon some otherwise inefficient and environmentally harmful industries, especially the coal fired power plant and oil refinery, but a really exciting possibility would be a renewable energy based EIP. A renewable energy based EIP would most likely have to rely on a combination of renewable energy sources, such as solar, wind, biomass, etc. The flexibility in the blueprints for EIPs allows them to be adjusted for future needs and opportunities, making them a very valuable tool for improving the environmental impact of manufacturing globally.

6.1.5 Limitations/Barriers

EIP projects savings are substantial, but the capital investment that would be tied up in a project like this is potentially much higher than many small and medium

sized firms want, or have the ability, to pay, and would limit investment abilities in other ventures (Fleig, 2000). EIPs are also logistically more difficult as they involve the collective agreement of several participating firms, often with several people representing each firm at the table.

EIPs are geographically limited in that they only work when the firms needed to make the system work are within a kilometer or two of each other. If an essential firm is not present in an existing industrial cluster it could be brought in and added to the EIP plan, but that represents a higher risk of failure should the necessary firms not be in place.

6.2. Chapter Conclusion

This chapter looked at the pros and cons of EIP projects with respect to industrial efficiency and the practicalities of implementation. EIP projects have the stunning success flagship of Kalundborg EIP, which has resulted in large scale industrial improvements, turning independently inefficient and environmentally unfriendly facilities into a united industrial ecosystem. Unfortunately, other than Kalundborg most other EIP projects have failed or been modest successes, quite often right from the planning stages, for various reasons. However, EIPs represent a realistic and obtainable way to achieve factor 4 improvements in efficiency, as called for from the literature, and are an important tool for industry and planners. It is hoped that future EIP projects, whether in the retrofit or new-build stages are successful and bring forth efficiency improvements for industry.

Chapter 7: Case Study Participant Views on EIP Possibilities

This chapter looks at the interviews conducted with participants in the case study area. Conclusions and take away messages from their responses are summarized at the end of the chapter.

7.1 Local (Case Study Area) Interest in the EIP Possibilities, and the Interview Methods

This section of the thesis explores the potential for collaborative action within the case study area centered on the implementation of an EIP project or broader industrial ecology based practices with the focus company and others situated in the case study site. Interviews were held with participants from the focus company, the municipality, and the local utility provider to gauge their interest and ability to participate in such a project.

There was much interest in the ideas of industrial ecology based practice from interviewed parties and they unanimously thought that trying to achieve efficiency improvements in this method was a very good idea, even if they had never heard of it before. Beyond the narrow scope of the interviews I cannot speak with certainty but I can assume based on the feedback I gathered that companies would be interested in any EIP plan that could save them money or be cost neutral.

I was unfortunately unable to set up interviews with many of the companies I had originally wanted to question, even after numerous attempts at contacting them, which leads me to believe that they have even less time available for projects such as this from a staffing perspective. I was able to conduct several interviews with employees at the focus company, and with personnel from the municipal planning office and the local utility provider.

Prior to conducting the interviews I had to obtain ethics approval via the University of Waterloo's Office of Research Ethics.

7.1.1 Municipality Interview

The municipality is responsible for city wide infrastructure (roads, water, sewer, etc.) planning, and is also the vendor of industrial (as well as commercial and residential) zoned land in the industrial park, and elsewhere around the city. The municipality sells serviced lots in the zoned industrial park, and other areas for development land they service it for utilities and oversee the acquisition of new economic activities.

Within the municipality I talked to the City Planner, and asked the following questions:

1. What is the city plan for encouraging industrial development? What are the incentives for companies to choose this city?
2. What is the primary source of electricity production for this area? What is the plan for energy production in the future? Does it place an emphasis on renewable energy sources?

3. Are you aware of co-generation technologies? Would this be something that would be considered? Are you aware of municipal solid waste incineration? Is this something you think would make sense for the case study site?
4. Have you heard of eco-industrial parks? Would this be something you would be interested in partnering in?
5. Does the municipality have the ability to participate in this sort of venture (financially or otherwise)?
6. Is there a program in place for increasing efficiency for industrial clients?
7. What barriers do you see that would inhibit the creation of an eco-industrial park in the industrial area surrounding the case study site?
8. What would you say would be the attraction to participating in an eco-industrial park?
9. Do you like the concept of an eco-industrial park? Why or why not?

The first three questions were intended to extract information on the city's plans for industrial development in the municipality and on the city's views about possible energy related initiatives in the municipality. As noted above, a collaborative energy-related project can be an EIP anchor, or at least a step towards converting a conventional industrial park into an EIP. Questions 4 to 9 are focused more directly on municipal views about EIPs.

The responses to these questions on a per question basis are as follows:

1. What is the city's plan for encouraging industrial development? What are the incentives for companies to choose this city?

This question aimed to reveal whether the municipality is making industrial development efforts, including incentives that might attract new facilities into the case study area, especially facilities might be well suited as EIP anchors.

Summary of the municipal interviewee's response:

The municipality aims to ensure "an adequate supply of the right kinds of land" ready for new companies to purchase and build on. Industrial land available from the municipality in industrial parks is priced significantly lower in this municipality than in larger cities within a 100-200 km radius, and is not subject to development charges, with the hope that this will encourage new employers to make the move.

The municipality has entered into an agreement with a local educational institution to develop a research park elsewhere in the community to facilitate new industry and start up companies. As currently envisioned, that park is not environmentally focused, and no characteristics of industrial ecology are incorporated in its design; however, the research park was originally envisioned as an environmental research park and environmental components could remain as potential considerations.

2. What is the primary source of electricity production for this area? What is the plan for energy production in the future? Does it place an emphasis on renewable energy sources?

This question aimed to gather insight into whether the municipality has plans to build future energy projects and whether they might be of a kind that could play a role in an EIP.

Summary of the municipal interviewee's response:

While most electrical energy is supplied to the municipality through the larger grid, "we have smaller generation capabilities in the city." These smaller generation facilities meet less than 10% of the municipalities needs; however, they are all renewable-energy facilities and expansion of renewable electricity generation is supported by the city. While the municipal electrical utility has lead responsibility for electrical projects in the area, the city "has a sustainability plan, with a focus on renewable energy going forward."

3. Are you aware of co-generation technologies? Would this be something that would be considered? Are you aware of municipal solid waste incineration? Is this something you think would make sense for the case study site?

This question explores the municipality's interest in a particular kind of project that could serve as an initial base for an EIP, since energy production is probably easier to implement than any sort of material exchange. One possibility would be municipal partnership or some other supportive role in collaboration with the case study area companies.

Summary of the municipal interviewee's response:

Co-generation technologies "would be considered"; however the interviewee questioned whether the city has "the right setting, the right mix of opportunities to make this feasible". The interviewee pointed out that "Sweden is big on this, and district heating, but they are at a different density than we are accustomed to." With regard to municipal solid waste as a fuel for co-generation the interviewee stated that there would be "political controversy over whether incineration is safe", and that "incineration would have local opposition."

4. Have you heard of eco-industrial parks? Would this be something you would be interested in partnering in?

This question was asked to see what level of interest and possible commitment the municipality could provide should an EIP project be proposed for the area. Cooperation with the local government is an important factor in the planning of a collaborative energy or waste management system, as seen in the Kalundborg example.

Summary of the municipal interviewee's response:

Although the interviewee stated that municipal officials "haven't specifically heard of that" with regard to EIPs, they were given a one-page summary of the concept, allowing a more informed opinion for the next questions. The research park in partnership with the educational institution mentioned in question 1 was "originally was set out as an environmental research park", which suggests the possibility that environmentally focused options might be under consideration for the park.

5. Does the municipality have the ability to participate in this sort of venture (financially or otherwise)?

This question sought some indication of the potential feasibility of the municipality participating in an EIP project.

Summary of the municipal interviewee's response:

The interviewee indicated that the city would be more interested in participation in the planning and development of a new EIP, rather than in supporting efforts to retrofit an existing industrial cluster, because "you could perhaps make some more strategic selections of industries to start the ball rolling."

6. Is there a program in place for increasing efficiency for industrial clients?

This question was meant to uncover any municipality-based incentive program for industrial clients, perhaps through some sort of competition or award.

Summary of the municipal interviewee's response:

The interviewee reported that the municipality has no such incentive program, but noted, "whether the utility provider has a program is another matter."

7. What barriers do you see that would inhibit the creation of an eco-industrial park in the industrial area surrounding the case study site?

Summary of the municipal interviewee's response:

The interviewee suggested that manufacturing facilities are better suited for this sort of option, rather than smaller commercial facilities, and that "presently there is a repatriation of jobs that have gone offshore in the past. If more traditional industry returns with large waste streams and heat requirements then this model begins to make sense."

8. What would you say would be the attraction to participating in an eco-industrial park?

Summary of the municipal interviewee's response:

EIPs provide an opportunity for municipalities to distinguish themselves; "I think municipalities are always looking for differentiation". The municipality has "always

prided ourselves as being a green community”, and the integration of an EIP is “probably much more responsible long term.”

9. Do you like the concept of an eco-industrial park? Why or why not?

This question was asked after the interviewee had been provided more information on the EIP concept though the interview.

Summary of the municipal interviewee’s response:

The interviewee liked the concept of an EIP, but reported that “we’ve never looked at something as comprehensive as this model.” As noted previously, the interviewee stated that the municipality would be inclined to participate in something that wasn’t a retrofit; however, the interviewee also indicated that perhaps the right mix of industry was presently lacking.

7.1.2 Utility Provider Interview

The utility provider provides electricity from the grid to residential, commercial and industrial clients in the city that the case study resides in. Electricity is drawn from the larger grid, as well as through several local generating stations that use renewable energy in solar, hydroelectric, and biogas facilities. This local electrical utility supplies electricity at rates based on those set for the larger electricity grid. The interviewee at the utility provider was in a management position and was asked interview questions similar to those posed to the municipality. The responses are summarized as follows:

1. What is the primary source of electricity production for this area? What is the plan for energy production in the future? Does it place an emphasis on renewable energy sources?

This question focused on differentiating the types of electrical production in the local area surrounding the case study site and to see what kind of projects the utility provider has been a part of, as well as, plans for future generation.

Summary of the utility provider interviewee’s response:

The local utility provider has experience with solar and hydroelectric projects and has installed a 10 MW solar farm in the area, as well as various smaller hydroelectric projects, “but the majority [of electricity] comes through the grid.” The utility provider’s experience with small-medium scale energy production and with solar electrical generation would be very useful in an energy generation partnership within the case study site. It is exciting to note that the utility provider is “looking for opportunities for another solar farm and water based generation”, which could possibly be a rooftop solar ‘farm’ that encompasses the case study site; however, “the utility is based all around renewable energy sources”, and “they have no plans to develop anything that isn’t renewable at this point.”

2. What is the utility's plan for encouraging industrial development? What are the incentives for companies to choose this city?

Summary of the utility provider interviewee's response:

The interviewee reported that the utility plays no direct role in promoting industrial development. Concerning initiatives, the interviewee said, "I believe there are none. There are some incentives that are offered to all industries as far as trying to reduce their energy consumption but it certainly wouldn't be provided [as an enticement] to someone who was relocating to [the city] and I think that might be in violation of the Energy Act."

3. Are you aware of co-generation technologies? Would this be something that would be considered? Are you aware of municipal solid waste incineration? Is this something you think would make sense for the case study site?

This question was intended to gauge the utility provider's interest in a highly efficient co-generation plant within the case study site as a way to generate electricity and thermal energy for the area. This, or a renewable based energy plant, could make a good EIP anchor tenant within the case study site. Municipal solid waste was brought up as an alternative fuel for a co-generation plant.

Summary of the utility provider interviewee's response:

Co-generation is "definitely something that they would consider"; however, "because our generation group is a retail, for profit organization, they typically don't share their plans until they're pretty mature."

The utility provider is currently "using methane gas collection from the landfill to generate electricity, but I doubt they'd go anywhere near an incinerator based co-gen plant based on negative attention." This echoes the response from the municipality, in that they do not want to partake in a project that would have that much negative feedback and backlash from the local community. "When you look at the scale of things that raise somebody's ire, I see a solar farm as relatively low, a wind farm as kind of medium and I would see an incinerator almost an order of magnitude higher than that, and the wind farms are getting absolutely crucified as far as public reaction, so I can't see us going there [incineration]."

4. Have you heard of eco-industrial parks? Would this be something you would be interested in partnering in?

This question was to determine whether the idea of EIPs had reached the interviewee through past educational and professional experiences.

Summary of the utility provider interviewee's response:

The interviewee had not heard of the concept of EIPs, but thought that they "would really seriously consider it. It would meet with their operating mandate and a lot of their goals." Participation in an EIP "would depend on the what kind

of role would be expected upon them”, and the scale and depth of linkages would definitely depend on who was involved and capital constraints.

The interviewee was given a one page handout explaining the EIP concept and responded very positively to the idea, indicating that there is potential for some form of industrial ecology based efficiency enhancements in the case study area in cooperation of the utility provider. “I can definitely see them doing something like this because it’s so defensible from an environmental perspective and if it makes money too, that’s icing on the cake.”

5. Does the utility have the ability to participate in this sort of venture (financially or otherwise)?

This question was meant to reveal the potential for utility participation in a project such as what was outlined in the previous question and if there might be capital, staff capacity, and motivation to take part.

Summary of the utility provider interviewee’s response:

The utility provider has “resources and capital available. That’s why they have been able to do some of the other generating projects that they’ve done. In fact, their investments in those projects have grown faster than they anticipated it would over the past several years.” The utility provider could be a key stakeholder and driver towards the realization of a project such as this.

6. Is there a program in place for increasing efficiency for industrial clients?

Summary of the utility provider interviewee’s response:

There are incentives from the local utility provider that would be similar across all utility providers in this jurisdiction. These incentives would allow less costly retrofits to existing equipment such as electric lighting, motors, hot water tanks, etc., and encourage the facility to be more energy conscious. The incentives offered to all industries are part of a rebate type program where equipment overhauls and upgrades are subsidized if they save on electrical usage. The utility provider has had success with previous solar installations and they would “certainly be interested in larger rooftop solar projects [$>50\text{kW}$]”.

7. What barriers do you see that would inhibit the creation of an eco-industrial park in the industrial area surrounding the case study site?

Summary of the utility provider interviewee’s response:

The interviewee was concerned about the cost of running things like pipes and cables between the companies as “a lot of it [the case study site] is very linear...which means everything has got to run a long way. If you had a block with some depth that would probably be less expensive.”

8. Do you like the concept of an eco-industrial park? Why or why not?

Summary of the utility provider interviewee's response:

The interviewee said "I think it's a great idea. It reminds me of some of the things they talk about from an economics perspective, where you take two distinct entities and put them together, the sum is greater than what they are separately."

7.1.3 The Focus Company Interviews

In the focus company interviews I asked the twelve questions below to each of the five interviewees. Some interviews sparked additional questions, arising from the answers that were provided. The interviewees at the focus company were all in management positions at the facility. The interview questions were as follows:

- 1) What have you identified as the areas with most potential for (or where you would most like to make) environmental and financial savings improvements?
- 2) Do you have any company plans for initiatives in these areas? If not, what are the barriers?
- 3) Would it be (more) possible to take some initiatives in cooperation with other firms in the area?
- 4) Does your company have a professional relationship with any of your neighbouring companies?
- 5) Does your company have any interest in the following collaborative project areas aimed at improving overall efficiency: material use, energy use, and/or waste management? Which is most appealing?
- 6) Does your company have the ability (financial, motivation, or otherwise) to participate in any of these projects?
- 7) Have you heard of the concept of an eco-industrial park?
- 8) What barriers do you see that prevent and/or discourage participation in projects in any of the above listed collaborative areas?
- 9) Have you heard of co-generation technology? Are you aware of municipal solid waste incineration? Is this something you think would make sense for the case study site?
- 10) What would you say would be the attraction to participating in an eco-industrial park?
- 11) Do you like the concept of an eco-industrial park? Why or why not?
- 12) Finally, do you have any questions for me about this research?

Each question and a summary of the responses to it are presented below:

- 1) What have you identified as the areas with most potential for (or where you would most like to make) environmental and financial savings improvements?

This question was intended to reveal the areas the employees of the focus company thought were the most feasible for efficiency improvements that could be gained through IHPCs or EIP initiatives.

Summary of the focus company interviewees' responses:

In response to this question, answers varied; however, the most common answers pointed to potential gains through reduction in heat used, waste produced, and the amount of chemicals used, although janitorial and labour costs were also identified. "Overall, probably having to do with heating here in the winter time...certain areas of the plant are hotter than others, and when we have the heat on and the plant doors open because other people are hot [it gets] to be a little costly". In regard to improving heating efficiency the focus company has "insulated the roof in the last few years", and the managers "have decided to install a garage door opener on the forklift." Waste water production is an area that was identified for further efficiency improvements, and that "a lot was done in the last 18 months to decrease [liquid] waste per output of material and reuse waste within the facility through major process changes and less handling and processing. It was just a smart move."

- 2) Do you have any company plans for initiatives in these areas? If not, what are the barriers?

In response to question 3, the answers showed that the focus company has a plan to reduce water use and waste water output by 10%. In terms of barriers, financial restraints and lack of education on the idea were voiced.

Summary of the focus company interviewees' responses:

The focus company "started last year with water consumption. One of the operators came forward and said we should really look at how much water we are using," and through this the focus company plans to "reduce chemical and waste water use by 10% and to use more recycled wash water over fresh water." The "improvements we have seen lately [Figures 3 and 4] have largely been driven by on site management and largely from economics".

- 3) Would it be (more) possible to take some initiatives in cooperation with other firms in the area?

In response to question 3, answers showed that interviewees were ambivalent about cooperative ventures with other companies in the industrial cluster; however they thought that initiatives that delivered gains at a reduced cost would make sense.

Summary of the focus company interviewee's responses:

One of the interviewees suggested that a "local conference" would help facilitate a project as it is "easier to get motivated with many minds involved." Any project in the case study site would need "to start at each plant and take baby steps," as there are "not many incentives to participate", and it is "unknown what other facilities make [product]". "A consultant doing research would be helpful [to profile companies and make determine linkages]".

Another thing that was mentioned was the fact that cardboard is picked up weekly regardless of if the bin is full or not, and it was suggested that perhaps a neighbour could share the bin so that it was picked up full more often. That could be one of the baby steps that were suggested by an interviewee.

- 4) Does your company have a professional relationship with any of your neighbouring companies?

This question was intended to see if the focus company had any professional relationships with other companies in the case study site, to determine the extent of the working relationships in the industrial cluster.

Summary of the focus company interviewees' responses:

In the case study site the "neighbours don't like each other [and] keep to themselves," there are "some vendor relationships with maintenance services [but] no energy/material relationships." Company relationships in the case study site are "cordial" and "very limited", i.e.: "notify of construction or smells".

Although not specifically said in the interviews I was informed on the general mistrust among companies within the case study site, which perhaps stems from environment/safety concerns, which have resulted in accusations against different companies for different odours, or other concerns.

- 5) Does your company have any interest in the following collaborative project areas aimed at improving overall efficiency: material use, energy use, and/or waste management? Which is most appealing?

Question 5 was aimed at identifying which area of improvement was most appealing to the interviewees. Not surprisingly they all answered yes to having interest in all of these aspects but were more reserved when thinking longer about the practical side of it.

Summary of the focus company interviewees' responses:

The interviewees were all interested in a collaborative project if it had "a clear incentive to save money or cost neutral for green advertising." "Waste [management] is a possibility that could be used, if it had favourable economics."

In their answers to this question, the interviewees emphasized the importance of green advertising, and how a cost neutral investment with green advertising opportunities is a desirable thing.

If "a consultant came with a plan and a fee" that could be an important facilitating factor.

- 6) Does your company have the ability (financial, motivation, or otherwise) to participate in any of these projects?

Question 6 looks past the interest in collaborative projects and towards the reality of capital investment in an industrial ecology based venture.

Summary of the focus company interviewees' responses:

Overall, the answers to question 6 were mixed, with interviewees in different positions having contradicting answers. "[The] theory makes sense [but it is a] manpower issue: who can do it?" One of the interviewees stated that "if it has decent return and helps both parties we would be interested, issue is in identifying them [and the company would be] cautious to make capital investments with payback longer than a year given the instability inherent in the market/business." If a project provided "financial gain or [was] cost neutral with green advertising, resources would be made available to do so."

7) Have you heard of the concept of an eco-industrial park?

Question 7 explores the level of awareness and knowledge of eco-industrial parks. In order to have an informed opinion for responding to question 8, interviewees were given the same one page summary as the other interviewees and a verbal explanation of eco-industrial parks following their answer.

Summary of the focus company interviewees' responses:

The interviewees had a mixed knowledge on eco-industrial parks, such as through reading "an article or two in passing over the years" and through one interviewee's "professional career in Norway [through a project] heating 6,000 homes with steam from electrical generation [the project] may not have been an eco-industrial park but it falls under industrial ecology." An interviewee stated that he "didn't learn about it in university, not so much focus on green engineering. Waste just went to the right side of the page with a picture of a truck."

8) What barriers do you see that prevent and/or discourage participation in projects in any of the above listed collaborative areas?

Question 8 is the key question into determining barriers that the interviewees think prevent industrial ecology projects such as a collaborative EIP project from being initiated or from being implemented successfully.

Summary of the focus company interviewees' responses:

Quite a few different barriers were brought up by the interviewees in answering question 8. A repeated point was that it would be "desirable to have an experienced and resourceful consultant" who could piece together the different pieces of the industrial ecology puzzle to maximize efficiency gains for all participating parties. "It is unknown what people [other companies] do and what is on site." There is also an issue with "the number of people that need to reach an agreement [on a collaborative project]" and that companies may have "dissimilar decision-making process and empowerment [and that] organizational structures do not often align." There is often a "distance between head office and local factory management [and local facilities need] head office buy in."

The need for “collaboration and education from top down” was emphasized, and “education [is] most important” in the opinion of many of the interviewees.

Some of the more unique answers noted were concerns over “lawyers and legal liability reasons [with regard to supply pipes],” and one interviewee didn’t think that “social aspects are main hurdle, as long as you can explain it and show the savings [but that] it is an engineering challenge.”

Collaboration between companies could be problematic in the U.S. according to one interviewee as “Denmark embraced socialism, but in the States it is a very bad word [and that it is] inevitable that in time we will realize this makes sense...in 10-20 years we would be having a different conversation.”

- 9) Have you heard of co-generation technology? Are you aware of municipal solid waste incineration? Is this something you think would make sense for the case study site?

Cogeneration technology and municipal solid waste incineration were raised in this question because they are possible collaborative projects that could help initiate EIP development. I asked the interviewees about hearing of these options to uncover the level of awareness and potential interest.

Summary of the focus company interviewees’ responses:

Municipal solid waste incineration was brought up in a few times, and it seems to be a solution that has multiple benefits for the case study area as well as the local community, but also faces barriers. One interviewee stated, “A waste incineration station with cogeneration [with waste] fed from the greater area via rail line would be amazing but there will be backlash.”

The interviewee’s were familiar with cogeneration and “[the focus company at another facility] owns one, although it is hard to resell steam due to local regulations.”

- 10) What would you say would be the attraction to participating in an eco-industrial park?

Summary of the focus company interviewees’ responses:

The most common answer was financial savings of some kind: “Cost savings is number 1,” “how can we save over the next 15 years?” Other attractions suggested by the interviewees included “advertising/image, sustainability reports to investors, employees, etc.,” [and] “public relations.” However, one interviewee pointed out that “if you’re making money you don’t usually get hyper vigilant about your costs.”

- 11) Do you like the concept of an eco-industrial park? Why or why not?

This question broadly explored what the interviewees thought about the EIP concept, based on prior knowledge, and the facts discussed within the interview.

Summary of the focus company interviewees' responses:
The interviewees liked the concept of an eco-industrial park. One stated:

Yes, I absolutely like it because it makes sense. We know the concept of recycling works, so introducing intermediate recycle loops cannot be a bad idea and it improves efficiency. It must make financial sense, cannot be more costly and put a place out of business.

Another interviewee said "yes, as long as it makes economic sense [an eco-industrial park project] can't be a subsidized exercise, best imbedded if government includes it in industrial zoning and infuses it in an area slated for industrial development." An eco-industrial park, as one interviewee said "brings companies and thought processes together...I am very much of the mindset that this will be integrated into the way of thinking in the future."

12) Finally, do you have any questions for me about this research?

Summary of the focus company interviewees' responses:
Generally this period in the interview led to another discussion on the topic, and most had general questions about my Master's degree; however, there were a few good quotes in responses to this discussion, such as if I "feel encouraged or disheartened looking at a case study in Canada? Does that seem insurmountable to you?" One of the interviewees stated that "they should make a documentary on Kalundborg," and that the academic community sees different stories than the industrial community does because there is a "huge divide between what [articles] academic and industry people read."

7.2. Chapter Conclusions

This chapter presented the responses from the interviews held with representatives from the local municipality, the local utility provider and employees at the focus company. The findings from these interviews show that the interviewees have mixed knowledge about industrial ecology concepts and that there are concerns about the cost of such a project. A consultant that would initiate and guide thinking on such a project would be helpful due to staffing shortages, the engineering challenges involved, the poor alignment of decision-making structures in different companies, as well as, concerns over legalities and liabilities with respect to flows of materials, wastes, and/or energy. From the focus company's perspective a cost neutral project would be worthwhile due to the green advertising potential. There does not appear to be much trust within the case study site between neighbours and some interviewees thought that a local conference on the project would be a good way of building that trust and getting companies together.

In order to facilitate an EIP in the case study area, there needs to be a clear understanding of the project by all involved parties, and there needs to be a

foundation of trust between those parties. It appears that there are shortages in staff that would be able to initiate such a project, so an outside group, such as the municipality, the local utility, or a consulting group would have to take charge of the project. All the necessary legal contracts would have to be drawn up outlining duties and expectations of the involved parties, and all parties would need to be in agreement on this. An initial step of having a local conference with the companies in the case study area, along with the municipality and the utility provider would be a good first step to explore the possibility of a project.

Chapter 8: Analysis of the Potential Implementation of Industrial Ecology by the Focus Company

This chapter will start off with a brief comparative review of the advantages and limitations of IHPCs to EIPs. It will then assess the focus company's potential for the implementation of industrial ecology principles. It will identify the drivers, barriers, and opportunities for encouraging this promising company to participate in industrial ecology in an existing industrial cluster and discuss how the industrial ecology option compares with more conventional in-house environmental efficiency opportunities in this case.

8.1. Comparative Review of the Advantages and Limitations of In-House Efficiency Improvements (IHPCs) and Eco-industrial Parks (EIPs)

IHPCs involve a combination of different efficiency improvements at a single factory, or across some or all of the facilities owned by a company. With IHPC there are no agreements or collaborations with neighbouring firms and the initiatives are independently run by the company of ownership. IHPC allows the firm to have sole control of how involved the project is and in what direction it goes, producing a more tailored efficiency improvement package for the company. With IHPCs, a company can determine what aspect of the business operations it wants to focus on, what the timeline for implementation is, how significant the changes are going to be, what resources are allocated to the project, and what kind of payback period is acceptable. IHPC strategies are more decentralized than EIP planning and many improvements can be made with a limited budget, freeing up capital for other projects and/or expansions. IHPCs look good to the consumer and provide a basis for green public relations campaigns explaining what and why the company is investing in these improvements. Interface Carpet, whose IHPC efforts were described in detail earlier, provides a prime example of what IHPCs can do for a company. IHPCs are limited in scale, however, and cannot compete with EIP solutions aimed at efficiency improvements orders of magnitude larger.

EIP projects, when successful, can provide greater return on investment and substantially larger efficiency improvements; however, they are much more complex to orchestrate and have additional parties to involve in collaborative planning and implementation (Chertow, 2008; City of Spruce Grove, 2008; GTAA, 2013). EIPs seem to be more successful when they evolve in a currently existing industrial cluster, and are based on smart financial moves that will benefit all participating parties over the long term. The pinnacle of EIPs seen in the literature is without a doubt Kalundborg; however, recreating this success has proven difficult.

EIP and IHPCs can be both complementary and competing approaches to industrial efficiency enhancement. In the case of Kalundborg EIP, IHPCs are a competing approach, as the waste exchanges present within the Kalundborg EIP structure rely on consistently large waste flows. In essence, Kalundborg EIP is an investment in inefficiency at the single facility scale, as a whole delivers the big

picture efficiencies. At Burnside Industrial Park, or in an energy based cooperative, IHPCs and EIP principles can be seen as complementary, as a reduction in energy consumption improves the big picture efficiency and does not negatively affect any other participants. Material flows at Burnside Industrial Park can even be seen as complementary to IHPCs as they are not based on large volume exchanges, but rather on improving the efficiency of use for materials, for example: the silver recovery program from print shops, and the pallet sharing program. Certain IHPCs could be complementary at Kalundborg, through energy efficiency improvements to lighting, electric motors, etc.; however, as discussed IHPCs aimed at reducing waste volumes would be a competing approach to the EIP agreements already in place.

Efficiency improvements, whether they come from successful EIP projects or broader based industrial ecology practice, are desirable for industry and called upon for enhanced sustainability and environmental stewardship for all.

8.2. The Focus Company as a Candidate for Industrial Ecology

On the surface the focus company seems to be a good candidate for participation in industrial ecology initiatives. The company is evidently committed to improvement, as seen through their IHPC efforts, and efficiency minded thinking fits with the expertise of management. The focus company has a desire for cost savings and has demonstrated this desire through economically focused initiatives that have also reduced adverse environmental effects. The thinking structure of the management leaders fits with the thinking that underpins industrial ecology, in the sense of basic economically focused efficiency improvement ideals and there is a willingness at the focus company for continued improvement. The stretch towards full fledged industrial ecology thinking then, would be for the management to embrace collaborative improvements, and branch out from initiatives only in their facility to networking and collaborating with others.

From the interview responses we can see several reoccurring themes related to the focus company's potential to be a participant in industrial ecology. The main themes can be presented as three questions:

- 1) Is there adequate awareness of and education about the industrial ecology concept?
- 2) What potential changes and improvements could be achieved collaboratively through industrial ecology initiatives? and
- 3) Do the potential participants have the inclination and ability to participate?

These three questions can be used as a general indication of the potential for implementing industrial ecology options at a case study site, and are some preliminary questions the initiating party should be considering. For example, at the focus company, the interview responses show a mix of understanding of the industrial ecology concept; however, if interviewees were not very familiar with

the concept, it was easily explained to them, and there was unanimous agreement that the concept was a good one after this education period. This likeability of the concept was also found in the interviews with the municipality and utility provider, and would hopefully be found with all other participating parties as well. This brings up the issue of collaborating with stakeholders, as any industrial ecology option will require inter-firm relationships and collaboration to successfully be implemented. All stakeholders must have adequate awareness and education about the industrial ecology concept.

One must consider what potential changes and improvements could be achieved collaboratively through industrial ecology initiatives in the development and planning stages of an industrial ecology initiative. This involves having detailed knowledge of the operating parameters of the participating stakeholders in order to determine where efficiency improvements could be made. This brings up the issue of adequate material and energy flows, and compatible industry linkages. Whether they involve electrical or heat energy, waste or raw materials, an industrial ecology initiative requires cycling and linkages between and among firms. The case study site appears to lack sufficient material compatibility between firms; however, collaborative electrical generation could be possible.

Finally, one must consider whether the potential participants have the inclination and ability to participate. Agreement of the concept is one thing, but the initiating party must determine whether the other stakeholders have the capital available for such a project, as well as the desire to be in a long lasting mutually benefitting relationship with other stakeholders into the future. At the focus company, the interview responses indicated that there is sufficient desire and available capital to participate should the project be suitable to their needs.

The efficiency campaign that the focus company undertook in the last year was centred on processes efficiencies, which are understandably crucial determinants of the facility's financial viability and are closely aligned with the expertise of management. Process considerations have already received considerable attention and the remaining efficiencies to be gained involve improvement in areas such as energy efficiency, where further gains are likely. The interviews indicate that the next round efficiency campaign is likely to be focused on these 'lower hanging fruit' items mentioned in chapter 4, some of which are possible through industrial ecology. The key areas of 'low hanging fruit' are lighting, heating, cooling and ventilation, and process equipment upgrades, to name a few.

The focus company has a good mix of material and energy demands which would play well into an EIP; however, the other companies in the case study area have largely incompatible material demands, limiting industrial ecology options to primarily energy based project.

For further analysis of the focus company's potential for implementing industrial ecology, we can roughly explore whether there are any realistic possibilities for items in the following list of things that stakeholders would incorporate into the EIP, keeping in mind that this list was designed for new build EIPs and not retrofits (Innovista, 2011):

- 1) Targeted economic development: businesses are attracted to fill product or service niches.
- 2) By-product synergy: businesses cycle material and energy (waste of one = feed for another), increasing efficiency and reducing environmental impact.
- 3) Ecological design: green buildings and sites are designed to minimize resource use. Green spaces and ecologically sensitive areas are preserved and integrated with the site design.
- 4) Green infrastructure: traditional infrastructure is replaced i.e., natural storm water management or alternative energy systems.
- 5) Networking services: businesses share services, such as: marketing, transportation, research, and monitoring services.

Looking at this list from a retrofit perspective in the case study site, targeted economic development could be something the municipality advertises in hopes of attracting new businesses to the city. By-product synergy is an important item to integrate into industrial ecology options, although material and waste synergies would be more difficult to implement than energy focused ones. Ecological design could be something that is integrated into a retrofit, through renovations to existing buildings; however, this is probably best suited to a new build. Green infrastructure could be something that is more easily integrated into the case study site, and would be favourable to the needs of the focus company, and (presumably) other companies in the industrial cluster. Networking services could be a first step to developing relationships with other companies in the area as an industrial ecology option. Overall though, none of these possibilities is currently on the horizon in the case study site, and the interviews indicate that while the focus company employees are reasonably positive about EIPs as an idea, they are not likely to initiate collaborative efforts in any of these areas. Any progress towards industrial ecology options would need some gradual networking and trust building, probably led by an outside organization.

The case study site needs leadership to initiate a collaborative project, perhaps from the utility provider, an outside consultant or the municipality. An alternative energy project could be one of the 'baby steps' mentioned as a crucial initiation process in the interview responses, and would build relationships with companies in the case study site.

8.3. Closer Examination of the Focus Company's In-House Initiatives

The focus company's recent initiatives to improve their process efficiency have proven successful. This provides a strong basis for considering whether these initiatives can be extended and complemented using industrial ecology options. Could any of the improvements be enhanced using industrial ecology options with greater savings/gains in collaboration with others? The following sections will examine options in the categories of electrical use, natural gas use, water use, wastewater generation and material consumption.

8.3.1. Electrical Use

Electrical use can be improved effectively through IHPCs, using the low hanging fruit initiatives noted in chapter 4. Options include steps to turn the temperature of the staff fridges down, turn down the water heater thermostats, upgrade electrical motors to more energy efficient ones, actively check for and fix leaks in the compressed air system, upgrade the air compressors and other major electrical equipment to more efficient models, lower the air conditioning/heating thermostat temperature in the summer and raise it in the winter, clean/replace air filters, retrofit lighting with more energy efficient options, wrap hot water heaters with insulating jackets, and finally initiate larger projects that would reduce or offset energy demand, such as solar panels or wind turbines.

So far, the focus company has not done much to improve electrical use, which can be seen to be increasing in Figure 5. Collaborative industrial ecology based electrical generation is not likely to make the internal processes more efficient but it could lower electrical demand from the grid and ensure net energy savings and heating efficiencies, such as through CHP.

8.3.2. Natural Gas Use

The focus company could improve the efficiency of their natural gas use through improving insulation of the office spaces and factory floor, upgrading windows, adding caulking and weather stripping to windows and doors, recapturing process waste heat, thermostat adjustment, and the implementation of an automatic garage door system to prevent heat being wasted when the forklift is outside. This was suggested to management prior during one of my discussions with them, and it was brought up in the interviews as something that was to be implemented in the future.

These internally scaled improvements, such as upgrading windows, or adding caulking do not have collaborative industrial ecology potential, but as noted in the electricity use section, a CHP plant could help improve the overall efficiency of the focus company, and if excess heat were sold to neighbouring companies it could be a promising industrial ecology step for the case study area.

8.3.3. Process Changes Focusing on Water Use

As seen in Figure 3, water use has been reduced at the focus company due to process efficiency changes initiated by management. This is an excellent example of an initiative well suited to IHPC, especially because of the needs to protect proprietary information about the process. However, water recycling is definitely not just limited to IHPC, and in cases like Kalundborg EIP collaborative water treatment and recycling have provided very efficient means of using the resource.

Figures 3-7 show that water use and wastewater production at the focus company have decreased, whereas electricity and natural gas use have increased, and chemical use have remained relatively constant over the past few years. The IHPCs that the focus company implemented were aimed at reducing water and wastewater use, and they have done that well. These IHPCs involved

improvements to the efficiency of the actual production process took place within the production facility, and are part of day to day operations. Given that these changes are part of the integral production methods, and given the current companies in the case study site, it would be difficult to implement these changes using industrial ecology methods. If there was a compatible company, for example one with similar process parameters, industrial ecology options in collaboration between the companies might work, and deliver greater efficiency gains. At present, available information about what the companies in the case study area produce, indicates that water process compatibilities may be limited, and that there are no collaborative links or any significant communication links among the companies in the cluster. This means that there is no established trust base or information base to proceed with industrial ecology initiatives.

8.3.4. Process Changes Focusing on Wastewater Generation

The process efficiency changes initiated by the management at the focus company have lowered the amount of wastewater being generated (Figure 4). Further wastewater efficiency improvements, at present, are limited in the case study site to IHPC due to the lack of any compatibility with a company that could use the wastewater, or collaborate in treatment; however should such an opportunity emerge, it would be worth pursuing as an industrial ecology based option. There is a potential IHPC option for treating wastewater on site at the focus company, but that would require overcoming the engineering hurdles associated with such a project.

8.3.5. Process Changes Focusing on Material Consumption

Material consumption, especially chemical consumption in this case, has increased slightly (Figure 6). As with wastewater, initiatives involving chemical use would be limited to IHPC due to incompatibility within the case study area. However, the potential for an industrial ecology based option could arise if the right company moved into the case study site.

8.4. Closer Examination of the Industrial Ecology/EIP Option

The responses to the interview questions indicate that the interviewees had very limited initial familiarity with the concepts of industrial ecology and an EIP, but had quick recognition of the attractiveness of the idea. The lack of existing cooperation among the industrial cluster's companies impedes collaboration. There is also a lack of spare staff capacity to organize any such initiative to utilize industrial ecology options. The interviewees recognized many practical barriers, including some not often mentioned in the literature. These include liability concerns, dissimilar decision-making processes and organizational structures, and the distance between head offices and local facility management.

There is an evident need for a viable initial collaborative project organized by some company/agency with established credibility and capability, perhaps the utility provider leading a collaborative for a rooftop solar PV generation project

supported by a feed-in tariff or other subsidy, or a CHP plant. Having the utility provider organize and manage a solar PV generation or CHP project makes sense because they have the experience and motivation to undertake such a project, and they are a credible organizing body that has established capacities for facilitation.

An industrial ecology based option for the focus company is most likely limited to an energy partnership, as opposed to material exchanges, which are highly unlikely due to material needs incompatibility with other companies in the case study site and concerns about proprietary knowledge.

8.4.1. Electrical Use

Implementing a PV FIT program project in collaboration with neighbouring companies would be a sensible industrial ecology based option for the case study site. A cogeneration plant would also provide valuable heat for the industrial processes occurring in the area. Electrical generation might be the best candidate for an industrial ecology based option because it is the most compatible with the needs and interests of all companies in the case study area, and the local utility provider has the needed experience to spearhead such a project.

8.4.2. Natural Gas Use

Collaborative natural gas use options are probably limited to the cogeneration plant idea for the case study site, but that being said it would be a very efficient method of obtaining heat and power for the case study site, and would be considered a successful industrial ecology implementation.

8.4.3. Process Changes Focusing on Water Use

Unfortunately, there appear to be no significant water recycling options at present in the case study area; however, if another company were to move to the case study site that had compatibilities this could be an option.

8.4.4. Process Changes Focusing on Wastewater Treatment

Treatment of wastewater within the case study site would be very favourable for the focus company; however, at present this is not a possibility in the case study site and therefore the focus company is limited to long distance solutions.

8.4.5. Process Changes Focusing on Material Consumption

There are some collaborative possibilities within the case study site to enhance efficiencies in meeting basic material needs, such as obtaining skids and janitorial supplies. However, there would need to be more cooperation among neighbouring companies even to access the potential for process specific material needs and linkages that could be implemented.

8.5. Overall Summary Analysis

A successful EIP should promote economic development, undergo material/energy synergy, be designed to minimize adverse impact on the environment, and share networking services (Innovista, 2011). It is important to keep in mind that these 'criteria for success' are based on a new build EIP, specifically the Innovista EIP project that is being designed in Alberta. A retrofit of an existing industrial cluster will not have all the green infrastructure that a new build would have, as the new build would have incorporated this into the initial design. Retrofit of existing industrial clusters to EIPs is considerably different than a new build EIP, as the majority of infrastructure will already be in place. Therefore I suggest that a modified set of criteria for EIP retrofits, based on the criteria for new EIPs by Innovista (2011), could include the following:

- 1) Economic feasibility: this is the first and foremost concern for EIP retrofits, and a foundation for the other criteria.
- 2) Targeted economic development: attraction of new companies to relocate to the retrofit EIP site if needed to fill specific synergy roles
- 3) By-product synergy: businesses cycle material and energy if favourable linkages are present, increasing efficiency and reducing environmental impact. New linkages are made with companies that move to the retrofit EIP site.
- 4) Ecological redesign: existing buildings are upgraded and retrofitted to minimize resource use. Green spaces are integrated into the retrofit plans.
- 5) Green infrastructure: traditional infrastructure is replaced or upgraded.
- 6) Networking services: trust and collaborative relationships are fostered between stakeholders and any shared services that are possible are implemented.

This modified criteria set for EIP retrofits takes into account that existing companies in a case study site may not have working relationships, and that a trust base must be fostered prior to implementation of the project. Also, there may not be a suitable anchor company, or there may be additional companies that must be brought into a site in order to fully utilize exchange synergies. Since buildings and infrastructure will already be in place any sort of ecological redesigns will have to be incorporated into renovations or other improvements to existing structures and infrastructure.

Similarly, the implementation of a successful IHPC project will have criteria that should be met as well. Criteria for a successful IHPC project can be summarized as the following:

- 1) Economic feasibility.
- 2) Implementation of a corporate efficiency plan with realistic targets and deadlines.
- 3) Improvements to material use, waste reduction and/or energy use and efficiency.

- 4) Monitoring of continued improvement in material use, waste reduction and energy use.

Implementing a plan with realistic targets and deadlines is essential to any project, and it should be included in a formal efficiency improvement plan. This first step can be neglected due a variety of reasons, including a lack of time from employees, and it is easy for more efficient process equipment to be purchased without a formal efficiency plan in place, obscured as just a part of routine maintenance. The goal of any IHPC plan is to improve efficiency and lower operating costs, so reductions in wastes produced as well as material and energy use should be accomplished with such a plan. Importantly, monitoring the success of an efficiency improvement process is important, and it is an ongoing requirement into the future. Continued improvements to efficiency and lowering operating costs should always be a priority. A formal efficiency plan similar to the seven fronts of sustainability derived from Interface, Inc., would be a very effective way to implement IHPC initiatives, as that plan has seen great success at Interface Inc. The Interface, Inc., plan involved active engagement of employees in identifying new opportunities for efficiency gains, and has been a key component of their success.

How do the potential gains from participation in IHPCs and EIPs compare from the perspective of the focus company? To begin with, we can make a rough comparison of the potential gains from IHPCs and EIPs using a similar framework for analysis, as was used to compare the case studies from the literature, but from the perspective of the focus company. Comparing IHPCs and EIPs at the focus company it would seem that both could be viable for the site, although a limited industrial ecology based option such as a solar PV project with a FIT type program support or co-generation, would be most likely and possible. This comparison is very rough and largely speculative and is based on assumptions indicated below.

Although there were concerns about the practicality of organizing an EIP for the case study area, the concept was liked by every single interviewee. The interviewees were able to identify some novel barriers to the EIP concept, even though they found the idea favourable. These conclusions were drawn from a very limited sample, and may not represent the responses of industry in North America. These responses are what was collected from the interviews with the focus company, the municipality and the utility provider, and are representative of these parties.

Table 12: Potential for IHPCs at the focus company based on the framework for analysis.

Category	Low (0 points)	Medium-Low (1 point)	Medium-High (2 points)	High (3 points)	Score
Potential for Improvement in Energy Efficiency	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Potential for Improvement in Material Efficiency and Waste Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Potential Cost Savings	No change from current business as usual levels.	Minimal (thousands/year)	Significant (hundreds of thousands/year)	Substantial (millions/year)	1
Potential for Job Security, Stabilization and/or Creation	No change from current levels given the uncertain economic situation.	Job stabilization at current company levels; minimal job creation. Minimal change in job security.	Job stabilization at current company levels and significant job creation (<10%) and/or enhanced job security.	Job stabilization at current company levels and substantial job creation (~10%) and enhanced job security.	2
Potential Ease of Implementation	Impossible and/or impractical given involved company's current situation.	Possible, however there are significant barriers.	Sensible, willingness to begin planning.	Development and/or collaboration is expected to be actively explored and initiated.	3
Potential for Long term Viability	Unviable (no change)	Minimal improvements in viability.	Significant improvements in viability but not resilient to change.	Substantial improvements in viability and resilience.	3
Potential for Enhanced Public Image and Relations	No change from current level.	Minimal improvement in one or the other.	Significant improvement in both public image and relations.	Substantial improvement in public image and relations. Newsworthy.	3
Total Score					14/21

Rationale:

The potential for improvement at the focus company through an IHPC project is 14/21 due to the following considerations. It is assumed that the IHPCs would be similar to the suggested efficiency improvement examples listed in section 4.3, such as upgrading electric motors, and lighting.

Potential for Improvement in Energy Efficiency:

Upgrading electric motors, which account for the majority of electricity consumption (~65% of electricity use), in industrial facilities, according to Csanyi (2013), from standard electric motors (approximately 83% efficient) to high efficiency motors (approximately 93% efficient) would result in an approximately 6.5% reduction in total electricity consumption. Lighting accounts for approximately 10% of electrical demand, and HVAC accounts for approximately 11% of electrical demand, according to XEnergy (2001). NeoLumens (2014)

states that their LED lighting can reduce electrical demand by 70-80%, which would result in a 7-8% reduction of the total electrical consumption. Casey (2009) states that reducing air conditioning can result in a 6-18% savings, and reducing hot water tank operating temperature by degrees can result in a 6-10% savings, resulting in 1-2% decrease of the total electrical consumption. In total this rough calculation would add up to around 14.5-16.5% savings on the total electricity consumption, which puts it in the stage 2 (<75%) category.

Potential for Improvement in Material Efficiency and Waste Reduction:

The focus company has made some significant improvements to reduce water use and therefore the amount of wastewater generated; however, these improvements have only increased water and wastewater efficiency marginally as seen in Figures 3 and 4. The potential for material use efficiency improvements are facility specific due to the nature of IHPCs, and are therefore difficult to estimate, but it can be reasonably assumed that efficiency improvements will be less than 75%. This assumption is based the fact that IHPCs do not involve material sharing outside of the facility and therefore are unable to achieve the level of efficiency improvements as seen at Kalundborg EIP, for example.

Potential Cost Savings:

Cost savings are going to be variable on a case to case basis, but for the focus company I would estimate their dollar savings could be somewhere in the thousands to tens of thousands range, again based on the limits of IHPC. An example of potential savings comes from Husky Injection Molding Systems that upgraded their air conditioning units through a Hydro One retrofit program and saved an estimated 22,604 kWh which at 0.10 \$/kWh equates to approximately \$2,260 in total savings (Hydro One, 2012). Even if all potential efficiencies were realized at the focus company I would not estimate their cost savings to be above the Stage 3 (hundreds of thousands) mark.

Potential for Job Security, Stabilization and/or Creation:

Job stabilization potential for IHPCs is estimated to be Stage 3 because saving money should help stabilize the number of employees at the company, and reducing costs in this manner should lead to enhanced job security and possibly the hiring of new employees.

Potential Ease of Implementation:

Potential ease of implementation should be very high for the focus company as they have a willingness to save money and be more efficient, as demonstrated in the interview responses, and there are many avenues for retrofit incentives for industry to take participate in in North America.

Potential for Long term Viability:

When all IHPCs have been improved to their potential there will be significant improvement to the viability of the company through the improvement of

efficiencies and social securities, therefore the potential for long term viability is for significant improvements.

Potential for Enhanced Public Image and Relations:

Fully realized IHPCs are indeed substantial improvements to public relations and image, and as seen in the case of Interface, Inc., can definitely be newsworthy. These sorts of improvements can at minimum be integrated into sustainability reports, which are very important for investor relations.

Table 13: Potential for an EIP at the focus company based on the framework for analysis.

Category	Low (0 points)	Medium-Low (1 points)	Medium-High (2 points)	High (3 points)	Score
Potential for Improvement in Energy Efficiency	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	2
Potential for Improvement in Material Efficiency and Waste Reduction	No change from current business as usual levels.	Less than factor 4 improvements in efficiency. (<75%)	Greater than factor 4 improvements in efficiency, but less than factor 10. (75-90%)	Factor 10 improvements. (>90%)	1
Potential Cost Savings	No change from current business as usual levels.	Minimal (thousands/year)	Significant (hundreds of thousands/year)	Substantial (millions/year)	2
Potential for Job Security, Stabilization and/or Creation	No change from current levels given the uncertain economic situation.	Job stabilization at current company levels; minimal job creation. Minimal change in job security.	Job stabilization at current company levels and significant job creation (<10%) and/or enhanced job security.	Job stabilization at current company levels and substantial job creation (~10%) and enhanced job security.	2
Potential Ease of Implementation	Impossible and/or impractical given involved company's current situation.	Possible, however there are significant barriers.	Sensible, willingness to begin planning.	Development and/or collaboration is expected to be actively explored and initiated.	1
Potential for Long term Viability	Unviable (no change)	Minimal improvements in viability.	Significant improvements in viability but not resilient to change.	Substantial improvements in viability and resilience.	3
Potential for Enhanced Public Image and Relations	No change from current level.	Minimal improvement in one or the other.	Significant improvement in both public image and relations.	Substantial improvement in public image and relations. Newsworthy.	3
Total Score					14/21

Rationale:

The potential for improvement at the focus company through an EIP project is 14/21 due to the following considerations. It is assumed that the EIP project would be an energy collaborative based on a solar PV project, or a CHP plant based at the focus company. A solar PV project would most likely be rooftop based and in collaboration with the local municipality and utility provider. It is assumed that it would be part of some sort of rebate incentive such as the FIT program of Ontario. A CHP plant would be at least the scale to provide the focus company with the majority of their electricity needs, with any unused heat being piped short distances to neighbouring firms. These initial linkages would then hopefully lead to more substantial energy and material exchanges if they are feasible to the participating firms.

Potential for Improvement in Energy Efficiency:

There is reasonable potential for energy savings at the focus company through a CHP plant or collaborative solar feed in tariff program; however, the net energy savings that would result from that would definitely be under 75% improvement over existing levels.

Potential for Improvement in Material Efficiency and Waste Reduction:

The case study site does not have a foundation of trust built between neighbours based on the interview responses from the case study site, and that combined with minimal potential for material exchanges due to incompatibilities leads to a medium-low potential for efficiency improvement. The integration of a CHP plant with heat exchanges between firms could result in natural gas improvements however, the potential for success is currently limited. With some improvements to relations in the case study area and/or additions of other compatible firms the potential for improvement would be higher.

Potential Cost Savings:

Potential cost savings could be higher at the focus company, and have been placed at the Stage 3 level, as a potential EIP operation would not be as sophisticated as Kalundborg, EIP and would not reach the same level of cost savings.

Potential for Job Security, Stabilization and/or Creation:

Job stabilization potential for EIPs is estimated to be Stage 3 because saving money should help stabilize the number of employees at the company, and reducing costs in this manner should lead to enhanced job security and possibly the hiring of new employees.

Potential Ease of Implementation:

Potential ease of implementation has been put at Stage 2 as within the case study site there are some significant barriers to EIP implementation through the lack of trust base and planning logistics. These barriers could be overcome and there is willingness from at least the focus company employees to look into it more, based on their interview responses.

Potential for Long term Viability:

EIPs have the potential for significant improvement to the viability of the company through the improvement of efficiencies and job security, which could provide significant improvements for long term viability.

Potential for Enhanced Public Image and Relations:

Implementation of an EIP if it proves to be possible, has a high potential for improvements to public image and relations, which the focus company interviewees identify as something that would be desirable. This is a strong point of potential for the EIP scenario at the focus company.

This comparison using an adjusted version of the framework for analysis shows no difference in overall score between the potential from IHPCs and EIPs using the adjusted framework; however, the potential for IHPCs are much higher, even if the resulting improvements are lower. The suggested IHPCs in section 4.3 could be implemented at the focus company and would be see return on investment quickly. The focus company should undertake some or all of these IHPCs, with room to transition to a more long term energy collaborative in the future. The focus company should remain open to the possibility of an EIP option, and do what they can to encourage its development, but they should focus the majority of their attention to IHPCs at their facility. Easily-at-hand IHPCs are likely to be as valuable as potentially possible EIP options that are at best some way off. Dealing with immediate improvements while keeping an eye on potential long term improvements is a good strategy to promote success into the future.

Based on the interview responses, and the analysis of the potential for IHPCs and EIPs there needs to be further analysis of some of the overlying forces acting on these decisions. These are the drivers, barriers, and opportunities for the implementation of industrial ecology in the case study site, and they will be presented in the following sections. These drivers, barriers and opportunities are focused on implementing industrial ecology initiatives as IHPCs are ubiquitous in the industrial environment, while industrial ecology initiatives such as EIPs have not been as widely implemented.

8.5.1. Drivers for the Implementation of Industrial Ecology

The most powerful driver is certainly the anticipation of cost savings. However, the interview responses also revealed that companies would be willing to partake in a green efficiency improvement project even if it was only cost neutral as it provides an advertising opportunity to make their company stand out to investors and shareholders. All interviewees who addressed this matter took this position. To elaborate, many companies that want to be at the cutting edge realize that being green is important; also most large companies publish sustainability reports, and participating in an industrial ecology based efficiency improvement project would be an attractive demonstration of commitments that could be used in advertising and messaging in these reports. The responses from the interviews saying that even cost neutral is attractive represent a positive driver that is not reported in any of the EIP literature that I reviewed.

Another important factor in this case is that the utility provider has capital ready for investment in green energy management, conservation and production, as well as incentives for industrial (as well as all other) clients that can be utilized to lower the costs associated with equipment improvements and retrofits.

Finally, the interviewees pointed to the value of a consultant to investigate and initiate such a project. This consultant could be described as a facilitator rather than a driver, but his or her role in implementing industrial ecology initiatives is still just as important. This consultant is a step further than just a local champion as identified in Heeres et al, 2004 in that he or she would be from a higher profile position, such as one at the utility provider, and actively advocate

for and facilitate the implementation of an industrial ecology based project within a given site.

8.5.2. Barriers to the Implementation of Industrial Ecology

There is a serious lack of education on environmentally focused design and efficiency among engineering professionals. One of the interviewees said, “[I] didn’t learn about [industrial ecology] in university, not so much focus on green engineering. Waste just went to the right side of the page with a picture of a truck.” Even a relatively recent graduate from a top engineering school in Canada said there needs to be more education on this topic. Another interviewee stated that there is a “huge divide between what academics and industry people read”. Lack of awareness and dissemination of industrial ecology ideas among industry professionals is a major initial barrier to implementing industrial ecology within industry.

It was more difficult than I had imagined to get interviews about industrial ecology matter with representatives of other companies in the industrial park where the focus company is located. I was told numerous times that people were too busy to meet with me, or were on holidays. Others just didn’t reply. Very few companies had administrative assistants that could help direct me to the appropriate employees; most only had a lobby with a telephone and a slot for resumes. One of the interviewees said that “if you’re making money you don’t usually get hyper vigilant about your costs”, and perhaps this is the reason companies aren’t actively seeking further efficiency enhancements.

There is an evident need for outside leadership because current employees are too busy (as one interviewee said, “manpower is short...not so much capital.”) with their day to day tasks to spearhead an efficiency improvement project. In the words of one interviewee, “if a consultant came with a plan and a fee, that would be good.” She or he would also be the person who would fit the different waste and energy requirements of the different companies together to find the most efficient and effective solution.

At present, there is a lack of awareness of what neighbouring facilities in the case study area do, and little trust among these facilities. This inhibits the creating of any sort of collaborative efficiency improvement program.

There is a lack of collaborative conference opportunities for stakeholders within the case study area, and therefore networking possibilities are limited. One interviewee suggested that a local conference would facilitate planning as it is “easier to get motivated with many minds involved.”

Organizational structures and the number of people that need to reach an agreement for an industrial ecology based project to be realized was brought up by one of the interviewees as well. As well, an interviewee brought up that there is often a physical and communicative “distance between head offices and local factory management”, preventing, or at least hindering the implementation of industrial ecology projects. The interviewee stated that implementation of an industrial ecology based project needs “head office buy in”.

One interviewee stated that “Denmark embraced socialism, but in the States it is a very bad word [and that it is] inevitable that in time we will realize

this makes sense...in 10-20 years we would be having a different conversation.” This shows the difference political landscapes in Denmark where the Kalundborg EIP is located, and the US, where EIPs have struggled in their implementation.

Engineering challenges were mentioned as a barrier, and rightfully so as there are some serious engineering hurdles that need to be overcome in order to produce economically favourable linkages between companies. One of the interviewees didn't “think social aspects are main hurdle, as long as you can explain it and show the savings; it is an engineering challenge.”

An interesting barrier that was brought up by an interviewee was legal liabilities and lawyers with respect to the linkages between firms. That interviewee was concerned about contracts and maintaining adequate flows as agreed upon, between firms.

In summary, the perceived barriers to implementing industrial ecology are insufficient education, a lack of collaborative conference opportunities, a lack of staff that companies can put towards a project such as this, not trusting and understanding what neighbouring companies do, organizational structures and the number of people that need to reach an agreement, the distance between corporate head offices and factories, different political landscapes, engineering challenges, lawyers and liability reasons, lack of an influential and resourceful consultant and poor dissemination of this concept to companies.

8.5.3. Opportunities for the Implementation of Industrial Ecology

A local conference on efficiency could be an excellent way to get the municipality, utility provider, local companies, and investors together to begin collaboration on a project, even if it were as simple as splitting the cost of a small solar farm to offset the local factory's electricity requirements. As stated due to the incompatibilities within the case study site, the most promising opportunities are limited to energy sharing and co-generation. Collaborative trust is likely to start small and there are some ‘baby steps’ that could be implemented to build up the intercompany relationships in hopes of future collaboration on a larger industrial ecology based project.

8.6. Chapter conclusions

The interviewee comments on barriers match those in the literature well. They reiterate findings from Chertow and Lombardi (2005) on barriers of education and the need for more communication, trust and knowledge among the companies involved. As well they take the concept of a local champion, seen in Heeres, Vermeulen and de Walle (2004), a step further to expecting the consultant to investigate the area and come up with an individualized site plan. Heeres et al (2004) found that in theory a local champion seemed important but in the U.S. and Dutch cases they were found to actually be largely unimportant in practical applications. In my interviews I found almost unanimous agreement that there was a lack of staff to push forward a project such as this from the company end but that resources and capital might be made available to an outside consultant who could do the leg work of profiling each company and coming up with a plan for cooperative energy usage and/or waste reduction.

The main opportunities that arise from these findings are an in-house efficiency plan at the focus company, and for a collaborative project within the case study area that includes at least the utility provider, the municipality and the focus company. Other participants might be pulled together through some form of town hall meeting/energy efficiency committee, which would engage other companies within the case study area. The interviews suggest that the most plausible opportunity for an industrial ecology based efficiency improvement project might be a combined heat and power plant, or solar project within the area. A project such as this would involve less capital investment than an EIP yet would provide green advertising opportunities and reduced overall utility costs through income from feed in tariffs for the case study area. Buy in from companies in the case study area is important and perhaps would be more likely if the initiative came from the utility provider/municipality, inviting companies in the industrial cluster to sign on to participate. Fostering pride in a local efficiency movement would hopefully be accomplished through this. A solar power generation project in the case study site would be primarily an economic gains opportunity, although it appears to be on the line between making money and saving money on electricity and it would be recognized as a contribution to more sustainable energy generation.

The interviews, the IHPC and EIP case studies, the literature, and the comparison of IHPC and EIP options using an adjusted framework (section 8.5), indicate that the best immediate strategy for the focus company is to focus on the 'low hanging fruit' options through an ongoing efficiency improvement campaign, while remaining open to potential EIP projects. A rooftop solar PV electricity generation project spearheaded by the utility could also be attractive to participate in, but not something that the focus company is likely to organize itself. A CHP plant at the focus company could be a potential first step to further industrial ecology options, and would be effective for the focus company itself. Future process changes should be thought of with the possibility of industrial ecology based options should they be favourable and available, and there is the possibility that these initial steps could attract more practical interest among other companies in the industrial cluster and lead to identification of further industrial ecology possibilities.

Chapter 9: Conclusions and Implications

9.1. Summary of Findings

This study looked at the drivers, barriers, and opportunities for an eco-industrial park (EIP), compared to in-house process changes (IHPC) using a focus company within a pre-existing industrial cluster. The focus company had recently undertaken an efficiency improvement campaign and redesigned aspects of their process to run more effectively.

The focus company is in a pre-existing industrial cluster that is home to various manufacturing facilities, producing a variety of products including plastics, chemicals and metals. The research question for this thesis was: what are the drivers, barriers, and opportunities to encourage a promising company to participate in industrial ecology in an existing industrial cluster and how does the industrial ecology option compare with more conventional in-house environmental efficiency opportunities?

In this research three IHPC cases, Interface Inc., Umicore, and BASF were compared against three EIP cases, Kalundborg, Burnside Industrial Park and INES using a framework for analysis that was included the following categories:

- Energy Efficiency
- Material Efficiency and Waste Reduction
- Cost Savings
- Job Security, Stabilization and/or Creation
- Ease of Implementation
- Long Term Viability
- Enhanced Public Image and Relations

These categories were used in the framework for analysis for evaluations and comparisons of the IHPC and EIP cases, and then for considering the focus company's performance and potential prospects. This table was adjusted to better present the categories in Table 9. Overall the EIP cases ranked slightly higher than the IHPC ones (Table 8), and the focus company showed area for improvement specifically with energy and material use (Table 11).

Analysis of data from the focus company revealed that the company's efficiency improvements, aimed specifically at water use and wastewater generation, have proven effective, but that electricity, natural gas, and chemical use was rising. The focus company has not yet addressed 'low hanging fruit' efficiency opportunities beyond the core process efficiencies that have been emphasized in past initiatives. Therefore attractive opportunities with low or no cost remain in areas such as lighting, heating and cooling, and the installation of more efficient electrical equipment.

IHPC cases from Interface, Inc., Umicore and BASF were compared to EIP cases from Kalundborg, Burnside, and INES using a framework for analysis that provided a rough quantitative score for the cases using a rubric based on criteria for success and desirable qualities of industrial ecology. IHPC and EIP options from these cases and the literature were compared to and contrasted with options for the focus company, as informed by data from the focus company

and by responses from interviews with representatives of the focus company, the local municipality, and the local utility provider. The objective was to determine which option is most appropriate for the focus company. From this it was determined that participation in an energy cooperative would be the most realistic industrial ecology based option for the focus company, and that a formal efficiency plan similar to the seven fronts of sustainability derived from Interface, Inc., would be the most effective way to implement continued IHPC initiatives. The seven fronts of sustainability concept aims to have zero waste, benign emissions, utilize renewable energy, close the loop on waste and resource use, use resource efficient transportation, have buy-in from business partners and employees, and redesign commerce to reflect the true costs of products (Anderson, 1998).

The results from this thesis show the perceived general barriers to implementing industrial ecology are insufficient awareness of industrial ecology, a lack of staff that companies can put towards industrial ecology projects, difficulties in matching existing corporate organizational structures with the demands of inter-company collaboration (internal management complexities and the number of people including the boards of directors at each company that would need to be involved in reaching a collaborative agreement), the distance between corporate head offices and factories, fear of additional government control over industry, engineering challenges, concerns about potential liabilities, and absence of an influential and resourceful consultant for dissemination of this concept to companies, while the more case study specific barriers are a lack of collaborative relations and opportunities, limited trust among neighbouring companies and limited understanding of what those companies do. The specific barriers identified are likely to also apply elsewhere.

The main perceived general drivers/attractions are potential economic savings from efficiency gains, the appeal of cost neutral advertising (green advertising potential from participation in an environmentally friendly practice, which is attractive to customers and investors) and, if available, a consultant to investigate and initiate such a project. A particular strength in the case study was the availability of utility provider capital and mandate. These drivers, barriers and opportunities are discussed further below in the section on implications.

The EIP opportunities that arise from these findings are for a collaborative project within the case study area that includes the utility provider, the municipality, and the focus company, as well as a formal efficiency plan for the focus company in order to realize continued economic savings through improved efficiency.

It was found that the best option for the focus company would be to concentrate on the in-house 'low hanging fruit' options through an ongoing efficiency improvement campaign similar to that of Interface Inc., which addressed seven fronts of sustainability, while keeping potential EIP based options open. A collaborative rooftop PV project spearheaded by the utility would be a good thing to participate in, but not something that the focus company should try to organize itself, whereas a CHP plant would be better off initiated by the focus company.

From the perspective of the focus company the previously mentioned combination of continued IHPC improvement through pursuit of low hanging fruit options, which develop into a more all encompassing efficiency improvement platform based on the seven fronts of sustainability from Interface Inc., and a collaborative energy project with the local municipality and utility provider satisfy the desirable qualities and effects listed earlier in this chapter. Continued efficiency improvements through an organized program at the focus company would not only save money, but also increase employee buy-in through the utilization of their suggestions, as seen in the Interface Inc. model. This would improve all aspects of the framework for analysis on the focus company (Table 11), through increased material and energy efficiency, cost savings, job security, stabilization and/or creation (through retention of employees that are activity committed to efficiency improvements within the company), ease of implementation, long term viability (with respect to a long term efficiency plan similar to Interface, Inc.), and public image and relations (through sustainability reports and green company advertising).

9.2 Implications

9.2.1 Implications for Theory/Analysis

The implementation of EIP-based industrial ecology principles has been difficult. Few if any initiatives have managed to replicate the success of the Kalundborg EIP. IHPCs are rarely discussed in the industrial ecology literature, especially in any detail, perhaps partly due to proprietary information concerns; however this thesis has highlighted a few examples, including the very successful case of Interface, Inc.

As noted above, the main barriers to effective industrial ecology implementation, as revealed in the literature and confirmed by the interviewees in the case study, seem to be limited knowledge about industrial ecology principles among potential participants, a shortage of available staff to work on implementing such ideas within companies, limited communication, trust and understanding among neighbouring companies, organizational structures and corporate decision making that do not often align with other companies, the distance between corporate head offices and local factories, fear of additional government control over industry, engineering challenges, a lack of a resourceful local champion/consultant and fear of legal liabilities.

The majority of these barriers are reported in the literature (e.g. Tudor et al. 2007, Taddeo et al. 2012 and Heeres et al. 2004). However, some of the barriers revealed in this thesis research, especially fear of additional government control over industry and liability/legal reasons have not previously been reported in the literature. The focus company interview responses provided more 'on the ground' responses that are not seen in the literature. Heeres et al. (2004) found that a local champion seemed important in theory; however, in practice in the US and Netherlands cases, it was judged to be less critical to the success of the project. In contrast, the interview responses in this research project featured

consistent emphasis on the inadequacy of in-house personnel resources and need for an informed consultant to spearhead any collaborative project. Both Tudor et al., (2007), and Heeres et al., (2004) agree that participation of local stakeholders is absolutely paramount to the success of the project, and in the case of this project, those stakeholders were keenly interested.

Also noted above, the main drivers of interest in collaborative industrial ecology initiatives identified by the interviewees in the focus case were economic savings, the appeal of a cost neutral EIP with regard to advertising potential and having a utility provider with capital and a suitable mandate. An additional potential driver, or key facilitator (echoing the barrier along the same lines), would be a consultant to investigate and initiate a collaborative project. The attraction of cost neutral advertising is not recognized in the literature as a driver for the implementation of EIPs, and is not mentioned in the Tudor et al., (2007) review of literature on the drivers and barriers to the implementation of EIPs. Cost neutral advertising is an important concept because it shows, from the responses gathered in this research that while economic gains from participation in an EIP are very important, the participating companies may not need to be assured of significant new revenues or cost savings; an EIP would be a worthwhile venture on a cost neutral basis. Given natural market fluctuations in commodity prices and revenues generated from the recapture and reuse of waste streams, having drivers in addition to immediately profit-based ones should enhance the stability of the EIP model.

Concerning IHPC, it is significant that the focus company began with process improvements, looking to improve overall efficiency in production, in contrast to the conventional focus on the myriad of comparably easy “low hanging fruit” improvements that could have been accomplished. In the example of Interface, Inc., tackling these higher hanging fruit improvements to the production process is absolutely necessary to achieve higher level process efficiency gains; however, the way the focus company started with these improvements while neglecting the obvious lower hanging ones is interesting, and contrary to traditional environmental thinking (Anderson, 1998; Rosenberg, 2009; Tunnessen, 2009). Pursuing these higher level efficiency gains was a favoured investment in efficiency improvements in the focus company because these actions were within the expertise of the company management and central to the focus company’s operational concerns. This is a reality that likely affects many other companies with similar engineering-based management. As mentioned, this leaves the focus company with several opportunities to continue to improve efficiencies through pursuit of these low hanging fruit options.

The data collection and analysis of this case were greatly facilitated by immersion and the relationship that I have had with the focus company and the ability to see the improvement they have made to their process. This research approach, using a focus company as a basis for comparing EIP vs. IHPC options, is not discussed elsewhere in the current literature but appears to be a fruitful means of examining options and determining the best course of action with regard to efficiency improvements that could be undertaken in the future. This research is exploratory but contributes to filling the gap between IHPC and

EIP focused efforts, while looking at real world industry options for a specific focus company. With further elaboration, this approach could prove very effective for studies involving larger industrial clusters, or strong EIP anchors such as nuclear power plants, or large manufacturing operations.

9.2.2 Implications for General Practice

Industry is an extremely important economic driver in North America and provides jobs to people of different socioeconomic levels. However, industry is also a major energy user and contributor to North America's carbon footprint. It is important to maintain the economic benefits of industry in ways that also actively minimize its detrimental environmental effects. While both IHPCs and EIPs are effective methods for improving the environmentally related efficiencies of factories, the most suitable path for efficiency improvements will depend largely on the context of the different industrial areas. IHPCs, EIPs, or combinations of the two are needed to improve the efficiency industry, and it is hoped that the lessons learned through this research, and in the wider literature are made available to the working industry professionals, and individuals still in the educational process at all levels.

One lesson from this research is that it appears to be extremely difficult to gain access to information and interviewees without personal connections to the companies, municipalities, and local utilities, which severely limits research in this field. It is also critical to ensure that information about industrial ecology principles and applications are made more widely available through education to industry professionals, and promoted in communication between companies, municipalities and utility providers.

9.2.3 Implications for the Focus Company

The focus company has a promising opportunity to further improve efficiency through low hanging fruit IHPCs, especially in lighting and process equipment, as well as the potential of an energy collaborative with neighbouring companies, the local utility provider, and the local municipality. The low hanging fruit efficiency improvements suggested in this thesis are low and no cost improvements that could add up to substantial gains in overall facility efficiency, with associated savings. An active efficiency policy that gradually implements these suggestions in the short term could lead to additional gains in the future as more accessible and refined technology and process innovations add more opportunities for savings improvements and as initial experiences lead employees to become more engaged in environmental and economic stewardship. Developing a culture fostering environmental stewardship could be accomplished by following a logic similar to that underlying Interface Inc.'s seven fronts of sustainability concept. Implementation of such a program would dramatically improve and update the focus company's environmental policy, and promote improvements from the ground up.

9.2.4 Implications for the Case Study Area

The case study area has the potential for an energy collaborative through rooftop solar electricity generation, or a co-generation plant implemented by the local utility provider, assuming the cooperation and engagement of the stakeholders within the case study site. Based on the interview responses from the focus company, there is interest in such collaboration; however, the project would have to be spearheaded by the local municipality and local utility provider, which have sufficient credentials to get the other facilities in the case study site to participate. There is an undertone of mistrust within the case study site between neighbouring facilities that needs to be rectified if such a project were to be undertaken successfully. Better communication and collaborative trust could perhaps be initiated through a committee/town hall meeting of the stakeholders in the case study site.

9.2.5 Implications for the Municipality

The municipality has the opportunity, through, for example, the implementation of an energy collaborative to further distinguish itself as an environmental stewardship leader among municipalities. The municipality already has a reasonably good working relationship with the local utility, and has an opportunity through a committee/town hall discussion to improve the working relationship with the industrial firms that employ many of the municipality's residents. The opportunity for collaboration is not limited to the case study site, and the municipality is encouraged to foster a project with any industrial clients that are willing to participate, it is definitely recommended that such a project be implemented through the utility provider.

9.3. Directions for Future Research

This thesis aimed to compare IHPC and EIP options for a focus company within a pre-existing industrial cluster, and to determine the drivers, barriers, and opportunities to implementing such improvements. This type of focus company oriented approach should be repeated using, for example, a potential anchor tenant to an EIP, such as a thermal power plant, waste treatment facility, or an industrial cluster with inherently compatible facilities and processes. This study highlights the need for more projects examining the implementation of industrial ecology in the industrial landscape, especially given the numerous EIPs that are planned in the North American market. Further studies that compare the returns on investment achieved in EIPs and IHPCs of different kinds and in different circumstances would improve understanding of these two efficiency improvement options. As well, further studies should look at the potential for combined EIP and IHPC initiatives and the nature of needed education, facilitation, and incentives for encouraging these efforts. Further collaboration by industrial companies with academic institutions and their local community and industry will hopefully foster an environment of learning, and efficiency improvements that deliver real change in the industrial ecosystem.

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