DEVELOPMENT PATTERNS AND FACTORS INFLUENCING THE GROWTH OF INDUSTRIAL SYMBIOSIS

Case Study of Tata Steel IJmuiden and the Surrounding Industrial Region to Achieve Reduction in Water Consumption Using Industrial Symbiosis Approach

Satish Deshpande

Master of Science Thesis

TU Delft
Delft University of Technology

Faculty of Technology, Policy and Management
Note:

This is the public version of the report.

Due to the confidentiality agreements, this report does not contain all the information in the appendix. For full version contact Tata Steel IJmuiden or the supervisors of this thesis.
Development Patterns and Factors Influencing the Growth of Industrial Symbiosis

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Master of Science Thesis

For the Degree of Master of Science in Management of Technology at Delft University of Technology

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DELFT UNIVERSITY OF TECHNOLOGY

The undersigned hereby certify that they have read and recommend to the Faculty of Technology, Policy and Management (TPM) for acceptance of the thesis entitled DEVELOPMENT PATTERNS AND FACTORS INFLUENCING THE GROWTH OF INDUSTRIAL SYMBIOSIS

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Dedicated to my lovely parents....

“Success of our life should be seen in our children’s education, knowledge and their contribution to the society”

- Aai & Baba
EXECUTIVE SUMMARY

In today’s competitive and environmentally conscious industrial society, companies thrive to perform their production activities in the most environmentally friendly way. Companies are moving from individual resource efficiency approaches to broader community approaches. They are now looking for opportunities to broaden the scope and go beyond their fence to share and cooperate. In essence, they are looking for ecological aspects in an industrial site. Waste of one industry could become resource to another industry. Webs of exchanges of by-products, wastes and residues are seen to reduce the overall environmental impact of the industries. These webs are called as Industrial symbiotic links. A classic example is Kalundborg industrial site where several industries share wastes and resources with each other to add benefit to the environment in an economic way.

Several attempts have been put to replicate Kalundborg example of industrial exchange but less success has been achieved. Many sites who claim to have a symbiotic development approach are either in planning stage or have failed. According to academic scholars, there is a gap in what industrial symbiosis is in theory and what is being implemented. Therefore, it is important to understand the development patterns of Industrial Symbiosis and find out what factors influence the development of Industrial Symbiosis.

This thesis investigates the factors influencing the development of Industrial Symbiosis (IS) in a well-established industrial site which shares a long history of colocation with other firms. The Aim of this thesis is to understand development pattern of IS and find (factors in terms of) drivers and barriers which foster or impede the growth of IS links among the firms. To serve this purpose a literature review and interview based analysis approach has been used. This thesis was conducted on the region of IJmuiden/Velsen Noord/Beverwijk/Hemskerk (For simplification it is called as IJmuiden region).

This research uses case study approach. At IJmuiden several resources and residues are produced. Tracking each resource is very difficult and does not fit in the scope of the study. Therefore a practical case is defined. This study investigates only water and water related by-product sharing links. The case study approach is chosen considering the stage of the research. Currently IS study at IJmuiden is very new and in the exploratory stage. There has been no prior study at IJmuiden with regard to IS. In this thesis totally 14 companies are involved; Namely, Tata Steel IJmuiden (TSIJ), Vattenfall – NUON, Crown van Gelder papier, Linde gas, Harsco, Aroc/Indaver, Floricultura, Nalco, Anteagroup, Tebodin, ENCI, Hoogheemraadschap Hollands Noorderkwartier (HHNK), Schiphol, Waternet and Grontmij. Out of these 14 companies Nalco, Anteagroup, Tebodin and Grontmij are consultancies which provide engineering and policy consultation to the companies situated at IJmuiden mainly
related to water and Waternet is the main water producing company of the region. Apart from these 5 companies remaining companies are users of water for various purposes like cooling, scrubbing, washing, rinsing, pickling and for the steam generation. Data required for this thesis is collected in three ways; observation, document review and unstructured interviews. Documented data is used to understand the water qualities and quantities and, interview transcripts are used to extract new ideas for symbiotic links and factors influencing the growth of identified links. In this thesis interview data is analysed using Atlas.ti software. This study is conducted mainly in three steps – Literature review, data analysis and results and, discussion and conclusion.

In the first step, literature review is conducted. Firstly, characteristics of IS are explained followed by the key development steps of IS present in the existing literature. This comprises of explanation on Self-Organizing nature of IS, Planning approach to IS, Facilitated Evolution approach and other important aspects such as Uncovering, Precursors and Kernels, Spatial scale of IS – Internal Efficiency, Regional Learning and Sustainable District Development and, development stages of IS – Predevelopment, Early development and Complex network development. Combining these concepts of IS resulted into a double S-Curve for the development of IS which is an outcome of this thesis as the part of literature review.

Secondly, the literature review investigates several examples of IS development around the world and extracts the factors influencing the development of IS. They are mainly categorised into Technical and Chemical, Management and Behavioural, Financial and Economic and, Regulatory and Administrative. Second framework is developed based on this list which will be used as the analytical framework to process the interview data in the later stages of analysis using Atlas.ti.
Second step deals with data analysis and result section. This has two main parts. Firstly, results from document review and new ideas gathered from interviews are analysed. Upon collecting the ideas and documents of consumption and usage, manual input output matching is conducted. The result of this analysis is presented as a block diagram of symbiotic links among the companies situated at IJmuiden. These block diagrams represent the future and current exchanges depicting the industrial symbiosis. They are represented in two diagrams. One shows the existing symbiosis between the companies and other shows new ideas of symbiotic links in the IJmuiden region mainly focusing on water. Only the diagram of new ideas of symbiotic links is shown below.

Secondly, results from the Atlas.ti analysis are presented. These factors are presented in terms of Technical and Chemical, Economic and Financial, Management and Behavioural and, Regulatory and Administrative. Additionally these factors are divided in terms of drivers and barriers of their respective category. These drivers and barriers are also listed with respect to their importance. This is the second main output of this thesis work.
As a result of this thesis it was found out that IJmuiden industrial site is at early development stage of IS. This is evident by the presence of a lot of precursors and kernels for IS development. Additionally, it was found out that investment costs, cost of resource (water), financial viability, technical and chemical compatibility etc. were the main barriers of IS whereas information flow and communication, trust and assurance, existing interactions, willingness to participate were found to be drivers. A list of drivers and barriers based on the results obtained from the Atlas.ti analysis are given below.

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In the third step outcomes of this thesis work have been discussed. Result obtained from the data analysis and the frameworks proposed at the end of the literature review are compared. Reflections on the robustness of S-Curve that resulted from the literature is discussed followed by a discussion on factors resulted from the unstructured interviews and their similarities and differences with the literature. To conclude this chapter different aspects of rigor, validity and generalizability of this research are discussed.
In the final chapter main conclusions and findings of this thesis are presented in terms of academic findings and practical findings. This is followed by recommendations and future scope.

As the outcome of this thesis following conclusions are made: 1) Development of IS is a double S-curve like trend involving both Self-Organizing and Planning approach for all sites around the world. 2) These approaches act strongly at different stages of development of IS. In the pre-development stage, Self-Organizing plays a crucial role whereas in the complex network development stage, Planning approach plays a crucial role. In the early development stage, combination of both approaches are required. 3) A push is required to go from predevelopment stage to early development stage and it involves a lot of drivers and barriers. In this thesis those drivers and barriers are categorised into four categories and it was found that Managerial and Behavioural factors play a crucial role to push an IS site take the shift from pre-development stage to early development stage. Technical and Chemical and Financial and Economic factors are seen to act as barriers. 4) In terms of practical outcomes current and future IS links at IJmuiden to share water and other resources are shown. They are initial ideas extracted from the data collection and unstructured interviews and require further in depth analysis. 5) Water from Crown van Gelder and ENCI has a very good quality of water and could be used at Tata Steel. 6) Water from HHNK's Beverwijk treatment plant could be reused at Tata Steel which could replace up to 60% of fresh water use of Tata Steel.
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The purpose of this chapter is to introduce the reader with the topic under study. In light of this introduction chapter begins with an explanation on how industries are now looking for the energy and resource efficiency opportunities in a community perspective in contrast to individual efforts. In the next paragraphs a brief description of Kalundborg symbiosis is given followed by a small introduction to practical case of IJmuiden industrial site.

In the first subchapter of this chapter, theoretical background of IS is explained in three parts namely; Industrial Ecology, Eco-Industrial Parks and Industrial Symbiosis. The second subsection of this chapter the knowledge gap in implementation of IS is briefly explained.

“In a free enterprise, the community is not just a stakeholder in business but is in fact the very purpose of its existence”

– Jamshedji Tata

1 INTRODUCTION

Industrial development in an environmentally friendly way is a modern day challenge. There are several means to reach this goal. The Classical Approach makes government authorities to put certain limits on companies with the help of regulations and laws. The companies stay in compliance with these rules and regulations to claim that their business operations are environment friendly (Vermeulen, et al., 1995; Vermeulen, 2002). In the past decades there have been changes in this Classical Approach. Now companies are willing to go one step further than just complying with the government rules and regulations. They put efforts to do their tasks efficiently so that they reduce the total burden of environmental impact and while doing so, gain economic benefits (Glasbergen, 2000). They are now looking for opportunities to broaden the scope and go beyond their fence to share and cooperate (Ayres, 1995).

This deviation from the classical approach has made Industrial Symbiosis (IS) a popular topic of discussion which has gained attention of research community and industries in recent years; especially in past two decades (Ayres, 1995). In the Danish city of Kalundborg, various industries share resources, energy flows and, material flows with each other which would otherwise remain wastes. For example, wastes such as waste heat and cooling water and/or by-products such as sludge. 9 such sharing activities evolved as a result of mutual collaboration for pure economic gains which later turned out to be also environmentally beneficial (Ehrenfeld & Gertler, 1997). In 1989, a local high school students’ group making a scale model of pipelines and connection of their community found these unique links at Kalundborg. Though accidental, this led to the realization of true potential of such exchanges and made Kalundborg a classic example of IS (Chertow, 2007). Currently, after 25 years of its continuous development, 20 exchanges are occurring among the participants involving water, energy and wide variety of waste and residue materials. 2.9 million tons of waste
products are shared, water consumption was collectively reduced to net 25% from the total initial consumption of each company and 4500 homes receive district heating through waste heat (Chertow, 2004).

Many researchers and industries started to search ways to replicate such waste, resource and residue sharing networks in other industrial regions in order to achieve economic and environmental gains (Sterr & Ott, 2004). Despite of the promising aspects of IS, many empirical studies show that establishing symbiotic links is a difficult process. Interchange and networking like Kalundborg is not only difficult to replicate but also difficult to develop from beginning. In both scenarios, i.e. while developing an industrial region from scratch or in an already established industrial site, implementing IS is a challenge. These challenges may be technological, regulatory, behavioural or economic etc. (Gibbs & Deutz, 2005).

This thesis investigates IJmuiden/Velsen Noord/Beverwijk industrial region, simply called as IJmuiden industrial site hereafter for the reader’s convenience. This site is situated in the North Holland province of the Netherlands. This site is known for Tata Steel IJmuiden (TSIJ) plant spread across 750 hectares of land and produces 7.5 million tons of crude steel and strip products every year popularly known as De Koninklijke Hoogovens. This steel production site was established in 1918 and shares a long history of transition from Hoogovens to Corus and now to Tata Steel IJmuiden. Presence of TSIJ and its long history, proximity to capital region and IJmuiden port has influenced several other industries to establish their production facilities in and around this region. Cement, chemical, paper, gas and power companies are situated around IJmuiden (EE Archive, 2015).

1.1 Theoretical Background

Theoretical concepts related to IS mainly come under the broad umbrella of Industrial Ecology (IE). Based on IE concepts, worldwide Eco – Industrial Parks (EIPs) are being proposed, developed and maintained. The essential condition to call an industrial region an EIP is that there should be some amount of symbiotic links to share material, resources, by-products and residues (Gibbs & Deutz, 2005). Therefore, in this sub section, these three core theories are shortly introduced with appropriate definitions.

1.1.1 Industrial Ecology (IE)

The term, ‘Industrial Ecology’ was widely discussed and popularized by Frosh and Gallopoulos (1989) in an attempt of mimicking the natural systems in the industrial environment. In nature there are almost no wastes. One organism produces waste which becomes a resource to the next organism in a biological chain. This consumption system runs utilizing every type of resource, waste, residue and even toxic materials to its full extent. In such a system, organisms, plants, and natural phenomena (weather changes, light etc.) co-operate and coexist in support of the ecosystems in which they reside (Hawken, et al., 1999).

Based on these natural systems, industrial production systems could also work in such a way that energy and material resources are utilized to the full extent with almost no waste exiting the system. Improving the use of raw materials, the re-use and the recovery of industrial and
consumer wastes are essential steps towards this approach to provide a more sustainable and eco-friendly industrial development (Roberts, 2004). Therefore, IE is defined as –

“The study of the flows of materials and energy in industrial and consumer activities, of the effects of those flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use and transformation of resources” (Chertow, 2004: p01).

Figure 1: Basic concepts of Industrial Ecology (Graedel & Allenby, 1995: p95)

1.1.2 Eco – Industrial Parks (EIPs)

Much attention has been paid to economic aspects of sustainability and environment but less attention has been paid to the society and community aspects until 1987, when IE concepts were proposed. Humans who establish industries are basically social animals which creates a need for an approach bringing industry and environment together with a society or community perspective. What IE concepts emphasize on is interaction and interdependence among the various business operations bringing stability to the system in which they exist (Cote & Cohen-Rosenthal, 1998).

In contrast, until past 2 decades industries tend to be independent and competitive with each other. Despite of this desire to be self-sufficient, there have been always interrelations, webs of suppliers or distributors serving common interests of customers. In a system perspective, these companies are still competitive but now they are looking for opportunities to cooperate
as an individual company as a part of a large system comprising of natural resources to achieve resource efficiency (Cote & Cohen-Rosenthal, 1998).

Therefore, one of the most popular definitions of EIP is given by United States Presidents Council for Sustainable Development (USPCSD). It is defined as –

“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” (PCSD, 1996: p17-18)

1.1.3 Industrial Symbiosis (IS)

The term symbiosis builds upon the notion of biological symbiotic relationships in nature. The term ‘mutualism’ means that at least two or more species in nature exchange materials, energy, food and sometimes information in a beneficial manner. So is the concept of IS wherein the collective benefits are greater than the sum of individual benefits that could be achieved from acting together. Therefore, IS is more focused on internetwork sharing of by-products, resource synergies and collective waste reduction (Chertow, 2004).

Symbiotic relationships are presumed to provide environmental benefits in an economic way. Apart from this noble motive behind adopting IS some obvious motivations are conventional; resource sharing can reduce costs and/or increase revenues, it can enhance resource security through long term contracts (water, energy, raw materials) and create good corporate relationships between companies. Therefore, IS is a part of IE focusing on the interrelations among different types of companies and it is defined as -

Traditionally separate industries engage in a collective approach to achieve collective advantage involving physical exchange of materials, energy, water and by – products. The keys to symbiosis are collaboration and the possibilities offered by the geographical proximity (Chertow, 2007: p03)

1.2 The knowledge Gap

In the beginning, Kalundborg Industrial Park was not explicitly designed to display IS. Each link was a systematic negotiation over a period of 25 years to establish final link (Ehrenfeld & Gertler, 1997). Studies conducted on the development of Kalundborg have also shown that before this site was uncovered as a good example of IS, autonomous economy driven utility sharing exchanges existed. When it got attention after the uncovering, the approach broadened and new links were slowly established by creating awareness (Chertow, 2007).

In IS, after the initial symbiotic development, there exists a long period of slow development in terms of inter-firm relations. This period includes events like entry of new players, die off of some companies and continuous negotiations on the possible links that could be established (Chertow, 2007). This period is rather long and the potential synergies only remain in the very early stages of planning (Gibbs & Deutz, 2005).
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Many IS projects do not even come to existence. They remain in the planning stage for a long time for up to 25 to 30 years and eventually fail. In a study on the proposed sites for IS in the Netherlands, out of over 200 sites only 85 could be seen as completed projects and out of those 85, only 8 were seen to use the concepts of utility sharing and symbiosis as mentioned in theory (Eilering & Vereulen, 2004). Therefore, there exists a gulf between what IS and EIP concepts can deliver and what is being used in practice (O'Rourke, et al., 1996).

Two types of developments of IS are widely discussed in academic literature: Planned approach (goal oriented) and evolutionary (self-organizing) approach. They are many times addressed as exclusive of each other (Desrochers, 2004). Self-organizing is considered as a successful model and central planning of waste networks by government authorities or third party agents is considered as a failed approach (Desrochers, 2004). Sometimes self-organizing is considered as the prerequisite to develop EIPs using synergies. Interestingly, both concepts occur and have been fruitful while implementing IS. It could be argued that self-organizing lays the groundwork of an industrial ecosystem whereas planning approach fosters the already existing interaction leading to the continuous growth of IS relations among the companies situated in and around a particular industrial site (Raymond & Howard-Grenville, 2012).

Hence, the knowledge gap that is addressed in this thesis is to identify the pattern that industrial sites follow to become a well-developed IS site and what factors influence the growth of IS where already some sort of interaction occur but systematic industrial synergies are missing. This knowledge gap is not directly coined by any author but it is a resultant of the literature review. Nevertheless, various authors have dully discussed this issue in their articles. Chertow (2007) states that early stages of IS links called ‘precursors’ or ‘kernels’ need to be nurtured and need extra efforts to develop them further. Ehrenfeld & Gertler (1997) call for the need of middle ground approach between heavy policy intervention and pure laissez-faire. Gibbs & Deutz (2007) call it as an implementation gap between what theory is and what is being implemented. O'Rourke, et al., (1996) call it a large gulf that exists between the theory of IS and the strategies used to implement IS. Furthermore, Eilering & Vereulen’s (2004) study on Dutch EIPs also indicated towards a similar gap. They argue that out of 200 sites, only 8 were able to foster utility sharing and symbiosis characteristics. Therefore, it is apparent that there exists a knowledge gap in implementation of IS that needs to be addressed in terms of - how an industrial site develops into a well-established IS site and what factors influence this growth. This knowledge gap in implementation is further elaborated in terms of nature of implementation and methods used in implementation in the literature review.
The purpose of this chapter is to make the reader familiar with the research method and structure. Therefore, first subchapter of this chapter explains the practical case that has been defined to conduct this thesis. In the second subchapter research objectives and research questions are formulated.

Third subchapter explains the complete methodology of this research. This subchapter has three main parts. The first part explains purpose and structure of research work. Second part gives a brief reasoning on why case study approach was chosen to achieve the objectives and, third part gives detailed explanation on interview methods, Atlas.ti analysis, advantages of this data collection method and, disadvantages of interview based data collection.

Fourth subchapter explains the scope of the thesis by clearly defining the boundaries of this research and limitations of the research. Finally fifth subchapter explains the structure of the report. In this subchapter, schematically main objective of each chapter and its role to reach the final objectives of this thesis is shown.

"I don’t believe in right decisions. I take decisions and then make them right"

– Ratan Tata

2 OBJECTIVES, METHODOLOGY & STRUCTURE

Once the knowledge gap has been identified, the next step is to understand methodology used to address this knowledge gap. As mentioned in the first part of the introduction section, this thesis investigates IJmuiden region of the Netherlands. Due to the constraints such as time frame of this thesis and first ever attempt to explore this site with IS approach, complete IS investigation of this site is very difficult to achieve in the given time of 5 months. Therefore, a practical case has to be defined.

2.1 Practical case

Industries situated at IJmuiden use several resources to produce their end products. They range from iron ore to water and produce by – products that range from iron slag to cock oven gas. The resources are used directly or indirectly to produce the end product and while doing so, by-products are produced. Water is one among such resources widely used on this site. It is used as a coolant, source of steam production or dust cleaning, carrier of waste heat etc. The amount of water used in the production directly influences the unit production cost. For instance, TSIJ spends approximately 20 – 30 m³ of water per ton of steel produced. This constitutes to an annual cost of 40 million euros per year (Groeneveld, et al., 2005). In
addition to the buying costs, money is spent on taxes on discharge also. Recent change in the 
EU legislation (European Commission, 2001) brings strict rules on industrial water discharge 
and high taxation. This urges industrial decision makers to reduce the water usage and adapt 
sustainable water management practices.

It is interesting to note that in other parts of the world, this issue becomes more complex if 
the industries are situated in the countries with limited water resource. In this case, the 
Netherlands and overall Europe has abundant water resource. Despite of abundance, recent 
figures on industrial water consumption in Europe have alarmed the policy makers. For 
instance, industrial sector uses approximately 40% of the total water abstractions. 
Furthermore, industrial sector is the main pollutant of the water resource and only 60% of 
the total water discharge receives adequate treatment (Eurostat, 2014).

TSIJ considers this issue very important and investigates all possible opportunities to 
achieve reduction in water resource demand and reduction in its environmental impact. IS 
approach may help to serve this purpose which has not been studied before on this site and 
could lead to some savings on water and its usage (Jägers & Bol, 2015). A correlation of this 
investigation conducted and the evolution of Kalundborg IS is that the establishment of 
symbiotic links at Kalundborg also began with an intention to tackle the low availability of 
ground water and to use minimum surface water (Chertow, 2007).

After regular consultation with supervisors from Delft University of Technology and 
Managers of Energy Efficiency team of TSIJ, it was finally decided to track only water and 
water related by-products and residues to fulfil the purpose of this study (Stikkelman & 
Jägers, 2015; Jägers & Bol, 2015). This is due to 2 main reasons; one, the limited time frame 
of this thesis, i.e., 5 to 6 months which makes it impossible to track every flow; and second, 
internal studies have found out that the water consumption at TSIJ is more than the other 
steel industries (Groeneveld, et al., 2005; World Steel, 2011). Moreover, even if one resource 
is tracked, a convincing reflection on mind-set of firms at an industrial region regarding IS 
could be sufficiently understood (Stikkelman & Jägers, 2015). Therefore, these two practical 
reasons accounted to the selection of water as a resource for investigation.

Additionally, in another interaction at the faculty of Technology Policy and Management of 
Delft University of Technology same suggestion was given by an expert professor of Energy 
& Industry department. According to the professor, there are two ways to approach IS studies 
in initial stages. Either 3 or 4 most important companies situated closely could be selected 
and all the material flows should be tracked or all the possible companies could be selected 
and one material flow could be tracked (Korevaar, 2015). In this thesis the later approach is 
chosen.

2.2 Research Objectives and Research Questions

Once the knowledge gap has been identified and practical case has been defined, the next 
logical step is to propose research objectives and research questions. Water is relatively a 
cheap product in the Netherlands and it has been put off the priority list of TSIJ since past 
one decade. This is mainly due to internal financial reasons and high priority issues that 
were important to be handled first (UIIC16, 2015). Though TSIJ maintains discharge water
quality under the government limits and an overall trend of reduction in effluents per year has been achieved, the total usage of water is relatively higher than the other Steel companies (Groeneveld, et al., 2005, World Steel, 2011). Reducing the water use will not only bring economic gains to TSIJ but in general reduces the total discharge water creating benefits to the environment. Therefore research objective of this thesis is:

**RO: To investigate what is the pattern of development of Industrial Symbiosis observed in the academic literature. To identify factors that influence growth of Industrial Symbiosis in an already established industrial site like IJmuiden Industrial region. This thesis uses Industrial Symbiosis approach to achieve reduction in water, water related by-products and wastes and to achieve higher environmental and costs efficiencies for companies situated in and around Tata Steel IJmuiden.**

Therefore, academically this thesis contributes on insights on development pattern of IS and factors that influence the growth of symbiotic links at an already established industrial region like IJmuiden where some links already exist. While doing so, the purpose of this thesis is also to investigate the reduction in water usage at TSIJ using IS approach. This thesis work looks into the evolution of current symbiotic links already existing on IJmuiden site and try to locate the potential links that could be realized in future mainly focused on water. To achieve this objective, the research questions are proposed below:

**Main RQ: What is the pattern of development of Industrial Symbiosis that is observed in the existing examples and what are the factors that influence the growth of Industrial Symbiosis in an already established industrial site like IJmuiden to achieve reduction in water usage?**

To support the main research question, following sub questions are also taken into account:

I. **What are the factors that are important for the Tata steel and what are the factors that are important to other surrounding firms involved?**

II. **Which of those factors act as drivers and barriers for the growth of Industrial Symbiosis in this region?**

III. **What are the potential water and related by-products and waste sharing opportunities in Tata steel and IJmuiden region?**

**2.3 Research Methodology**

This part explains research methodology used to conduct this thesis. This part includes the purpose of the thesis research methods used and data collection techniques. This section elaborates on the advantages and disadvantages of each option used.

**2.3.1 Purpose & Structure**

The purpose of this thesis is to understand the development of IS at industrial sites and understand the factors influencing the growth of IS as explained in the objectives section. This purpose is fulfilled in a three step structure as shown in the figure 2: Literature review, Data Analysis and Results and, Discussion and Reflection. This study uses a combination of literature and case study approach.
From the literature various theories like Self organization theory of IS (Chertow, 2007; Lowe, 1997; Gibbs D, 2003), Planning approach for IS (Gibbs & Deutz, 2005; Baas L, 2011), Facilitated evolution approach of IS (Raymond & Howard-Grenville, 2012) etc. are investigated. Based on these theories a S-Curve of IS development is proposed as an addition to the existing literature through an conceptual framework. Further, past experiences and the lessons learnt will also be analysed. These include experiences in Chinese scenario, South Korean scenario, British IS programmes and also Dutch and Danish IS projects. Through these experiences, a list of factors is extracted and another conceptual framework is proposed.

Further, the case study approach is applied to the practical case of IJmuiden industrial site. All the companies involved were visited and unstructured interviews were conducted to collect the data. Additionally, each company was asked to share all the possible data regarding water consumption and its chemical composition. Through this, already existing material exchanges identified during the analysis are shown and potential links that could be realised are proposed. After this, qualitative data collected through interviews is analysed using Atlas.ti software to understand the factors influencing the growth of IS. These factors are divided into drivers and barriers and into four main categories; namely, Technical and Chemical, Financial and Economic, Regulatory and Administrative and Management and Behavioural. Moreover, the IJmuiden industrial site is positioned on the S-Curve of IS development resulted from the literature review. Appropriate reasoning is given for that particular position of IJmuiden IS based on the key objective indicators shown on the curve.

Finally, the similarities and the differences, new observations and old trends seen through the literature review and case study are discussed to reflect upon the insights gained during this research; especially in terms of factors seen to act as drivers and barriers. The generalizability and the robustness of S-Curve of IS development is also discussed and the shortcomings are indicated. At the end, recommendations in terms of practical solutions to
the development of IJmuiden site to various Energy and Environmental Managers and recommendations to the academic enthusiasts of IS are given.

2.3.2 Case Study approach

Among the five type of study approaches (Yin, 2003) namely, Narrative, Phenomenology, Grounded theory, and Ethnography, the case study approach is the most suitable approach for solving the above discussed problem. The nature of the study depends on the stage to which the knowledge about the research topic has advanced (Uma Sekaran, 2010). A case study is used when an exploration of the situation with a holistic approach is required. Case studies are most useful methods when sampling is not possible due to the law number of samples or other constraints (Yin, 2003).

Case studies are well suited when how and why questions have to be answered or a very relevant contextual condition has to be covered in the study and the boundaries are not yet very clear (Yin, 2003). IS development study on IJmuiden creates such a contextual situation. IJmuiden site has to be solved understanding the factors of companies situated on site and its surroundings, the number of companies that will participate, and the boundaries of the material exchange are not yet known. Further, other studies conducted in Australia, Denmark, China etc. are similar but can significantly vary with Dutch situation due to local conditions, availability of resource (water), cost of resource etc.

Before conducting the case study, four basic questions have to be answered. 1) What is the case? 2) What is the research question? 3) Single or multi case approach? And 4) how the data will be collected and analysed. First two questions have already been addressed, third and fourth questions will be answered in the following sections (Yin, 2003).

The possibilities of Industrial Symbiosis and the influencing factors for the growth of IS in IJmuiden region to reduce water use is studied based on the inductive research studies. The case at hand is basically compared to other similar studies conducted in different industrial sites with similar basic circumstances. For example, in IS study, all sites around the world share some basic circumstances without which IS links cannot be established. For instance, co-location. Hence, in the literature and the experience learnt from the previous experiences is compared to the case study conducted and the conclusions are drawn. This is called embedded case study with a multi-case approach (Yin, 2003).

2.3.3 Data collection and interviewing methods

The last question while conducting case studies is how the data and information will be collected. Data collection in case studies can be done using three methods. Documents review, observation and interviews (Yin, 2003). All the three methods will be used in this case. Document review and interviews will be in central focus whereas, observational study is limited.

Data collection from the documents will be mainly focused on water consumption patterns of the company, type of water they use and the chemical composition of the water flows. This data is shared by the participating companies through reports or electronic sources according to their convenience. The purpose to collect this data is to create the initial data inventory of
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Each company’s water consumption and chemical composition. According to Roberts’ (2004) approach on guidelines to develop IS/EIPs in the industrial sites, the data is collected to fulfil the following purpose. Further data intensive study has been done after this initial exploratory study where the essential data inventory and initial potential links are analysed further. Therefore, in this thesis the documented data collection is done with intentions to (Roberts, 2004):

- Assessment of total and segmented waste (water).
- Volumes/flows and chemical compositions of each waste (water) source.
- Identification of actual and potential commercial waste (water) sources.
- Initial list of potential links (water links) between the participants.

Observation and interviews are done through visits to the plants and unstructured interviews. Plant visits helped to understand the production processes and use of water in those processes. Interviews have been kept unstructured due to the early stage of the study and many leads were expected to be received during the interviews. Though it is unstructured, basic set of questions were asked to every interviewee. For example one of the basic question that was asked to everyone is; what is your opinion on water saving efforts in IJmuiden region using IS like methods which require collaboration between two or more players. Unstructured interviews are so labelled because the interviewer do not enter the interview setting with a planned sequence of questions. The objective is to bring some preliminary issues to the surface. This helps to find focus in a broad research area. These broad question could be later funnelled to some specific category if a lead is found (Uma Sekaran, 2010). Open ended questions are more suitable at this stage. Some sample questions that will be asked at this stage of interviews would be:

_Tell me something about the water use in your company in terms of where it is used, what is the purpose, what methods are used?_

This open ended question could be then narrowed down based on the answer received. For example:

_Keeping other industries at the site in mind, which type of water do you think is reusable again and where?_

Interviews are electronically recorded wherever possible or thorough transcripts are made to not to miss any information as this thesis focuses on the qualitative data analysis. If the interviews are electronically recorded, the interviews were later made into transcripts extracting all the relevant information.

Once, all the transcripts are made, qualitative analysis is conducted in Atlas.ti (Muhr, 2004). It is a computer based qualitative data analysis software especially used to extract factors from the interviews. This software helps researchers to code, segregate, categorise and analyse highly unstructured sources of data such as all types of interviews, videos, symposiums and even random text documents. Using this software qualitative data could be coded, codes could be unified wherever necessary and, codes could be consolidated into common categories if they cause same kind of consequences. This software is equipped with
various analytical tools with visualization effects which helps researchers to open new interpretative views on the data collected. This is a biggest advantage of using Atlas.ti over manual coding methods wherein, crucial insights could be missed (Muhr, 2004).

Some useful tools given in this software such as drag and drop linking, coding and merging, code families, code network view, primary document view, visual model building using network editor, categorization of codes based on their groundedness etc. helps the researcher to convert any kind of unstructured data into meaningful insights (Muhr, 2004).

In this thesis, the following procedure is used in Atlas.ti to analyse data collected through unstructured interviews and some company documents such as environmental reports and vision documents shared during the visits.

I. A general coding list of various factors is prepared based on the list extracted from the literature review. Content is coded according to the list from the literature but initial grouping is avoided.

II. Two types of coding method is used. Single sentence coding and paraphrase coding.

III. Several codes which later found similar were unified

IV. Once a part of the transcript was coded, the new code’s influence on other codes was checked. If there is a relation such as associated with or cause of, etc., that connection is established in the network view

V. Final set of codes are categorised into families, in terms of four main categories; Technical and Chemical, Managerial and Behavioural, Regulatory and Administrative and, Financial and Economic

VI. Network view of each code family is closely examined to analyse new insights.

VII. Codes are also analysed based on their groundedness (importance) and on their repetitiveness in the transcripts.

VIII. Graphs and network diagrams are extracted.

Care is taken to not to bias the interview process by asking loaded questions. For example, questions such as – water use reduction is important, let me know what do you think? Should be avoided. Rather, questions such as – why water usage reduction is important? Should be asked. Personal likes and dislikes should not be portrayed and should not influence the interview. Clarity and complete understanding of questions and answers is important. If there is some confusion, questions could be repeated or simplified. In fact, questions should be formulated an easy and understandable way (Uma Sekaran, 2010). Not only while interviewing, coding process is also done with clear understanding of the point of view mentioned by the interviewer to avoid coder’s bias. Each code is reviewed repeatedly to make sure that the code is not affected by the personal perspective.

Main advantages and disadvantages of interview based data collection over survey methods are (Uma Sekaran, 2010) –

Advantages

- Researcher can modify, clarify, and simplify questions wherever necessary.
- Interviewer can collect some non-verbal clues of the respondent such as his body language, discomfort etc.
Disadvantages

- Geographical limitations is a key disadvantage. This does not affect the survey method which can be sent electronically anywhere.
- Minimizing interviewer bias is very important and crucial. This is not the case in surveys. The involvement of researcher during the answering process in very less or none.
- Sometimes, interviews may make the interviewee uncomfortable due to revealing of their identity to the interviewer. In case of surveys anonymity is totally assured.

These disadvantages can be overcome in case of IJmuiden industrial region. The geographical disadvantage is significantly ruled out as the purpose of this study is to investigate IS of closely located industries on IJmuiden. Anonymity is not a significant issue as most of the interviewees are already in contact with Energy Mangers of TSIJ and nevertheless, their identity was assured to be kept confidential. Codes have been assigned with UIC numbering which stands for Unstructured Interview Candidate. Moreover, interviews are conducted with managers who are already concerned about the efficiency issues in their industries and hence, their resistance was minimal (Jägers & Bol, 2015).

Over all, case study method is good method for in-depth, realistic analysis of a practical case which is in its early stages of research. It has a high internal validity of results and wide overview of the total scenario. This method however has some limitations. Main issue related to case study is bias; it could be observational, interpretation and researchers own bias or favouritism. To deal with this, care is taken to include all possible aspects of causality (Yin, 2003). Based on above description a schematic representation of methodology is shown below.

![Figure 3: Research Methodology](image-url)
2.4 Scope and limitations of this research

IS study could be as broad as it can be. It ranges from internal plant studies to national and international level synergies. The scope ranges from upstream activities like synergies among suppliers to downstream activities such as synergy in customer delivery. Moreover, hundreds of resources, by – products and wastes are used, discharged and reused in an industrial region (Sterr & Ott, 2004). All these aspects cannot be studied in the given time. Therefore, this thesis only focuses at a regional level study including close located companies and the main focus will only be on water and water related by-products such as sludge as explained in the practical case subchapter.

This thesis does not involve in depth technical analysis of water resources and wastes among the companies. Techniques such as pinch technology and water pinch have not been included in this thesis. As defined in the knowledge gap, the purpose of this thesis is to identify the development patterns of IS and factors influencing the growth of IS. Therefore, pinch analysis and water pinch fall outside the scope of this thesis. The water links shown in the results chapter are result of ideas suggested during the interviews and a quick input output matching using the data collected. The question of whether to do in depth pinch analysis was discussed during the pre-kick off meeting and it was decided that it will not be included in the thesis (Stikkelman & Jägers, 2015).

Study of water has a lot of chemical and technical aspects. For example, even if a reuse option is located, different aspects such as effects of waste water on the pipeline, effects of reusable waste water on the equipment and effects on the final product play a big role. They have not taken into account. The financial feasibility of the proposed options is also mainly based on the expert’s opinions from the energy efficiency department of Tata Steel.

There are some limitations too to this thesis work. Though the water consumption data was received and there were very less instances of reluctance, the data cannot be considered up to the mark as it is not consistent. Moreover, the unit of analysis of data shared also varies. Some companies shared monthly data and others weekly. Therefore the main focus of the analysis is only put on the idea generation rather than implementing symbiotic links per se. Economic and financial feasibility study of each link including the cost of infrastructure, pipelines and etc have not been included in this study. Another limitation is that all participants were not involved. One of the key participants in the study, the regional water board was not interviewed due to time constraints. Hence their perspective is unknown.

To attain a wide scope and higher validity, it is recommended to conduct interviews in at different hierarchical level (Uma Sekaran, 2010). Unfortunately this cannot be done due to the strict time frame of the thesis and difficulty to match the schedules of the interview candidates. Nevertheless, candidates that were interviewed represented mainly Environmental or Energy departments of their respective companies who were highly concerned about the sustainability issues of their company and the region. Therefore, it could be presumed that these managers represented the company perspective on issues such as IS.

Finally, the rigor of this thesis is convincing but cannot be generalised. Internal validity is high due to the fact that apart from the regional water board, all the participants responded
and gave the required data and interviews. However, this study only studies IJmuiden and therefore external validity is not very strong. Nevertheless, care has been taken to compare all the findings of this thesis with the cases described in the literature and the factors that have been derived from past experiences to attain generalizability as much as possible.

2.5 Report Structure

The structure of this report is schematically presented in the figure 4. Note that each chapter is indicated with the colour and its legend is given in the diagram. Chapter represent investigation phase, development phase and, validation. Scientific additions made to the existing literature are also shown with a different colour indicating the main findings of the thesis.

Figure 4: Research methodology and report structure for the thesis

So far, in the first section, theoretical background of IS and the knowledge gap has been introduced. In the second chapter, research objectives and questions, structure, methodology, and data collection methods have been explained. In the third chapter an extensive literature
OBJECTIVES, METHODOLOGY & STRUCTURE

review is conducted on IS covering important aspects and theories. On the basis of this literature review, a S-Curve of IS development is proposed. Also, in the same chapter, various IS sites around the world are analysed and factors influencing the growth of IS are extracted and a framework is proposed.

In the fourth chapter, a brief explanation is given on data analysis conducted. In the same chapter, results from the data collected are presented; current water flows of each companies involved, already existing material exchange and new potential links related to water are presented. After this, a sub section will present the result of interviews conducted and factors that resulted from the Atlas.ti analysis are presented. They are listed in terms of four categories; namely, Technical and Chemical, Managerial and Behavioural, Financial and Economic and, Regulatory and Administrative. They are further categorised into drivers and barriers of IS development to reduce water consumption and encourage reuse of water related residues at IJmuiden.

In the fifth chapter, findings of this thesis are compared to the previous experiences from the literature. Seminaries, differences, new observations related to the factors and, academic addition of this thesis - the S-Curve of IS development are reflected and discussed. In the sixth chapter, conclusions of this research are presented and suitable recommendations are given to the academic enthusiasts of IS and managers of various industries around IJmuiden. Finally, seventh chapter gives an account of author’s reflection on this research thesis which includes personal insight gained during this thesis, difficulties faced and, experiences during the thesis.
In this chapter, an extensive literature review is presented. The purpose of this chapter is to make the reader familiar with the existing knowledge about IS and its various aspects. Before beginning the first subchapter, a clear step by step procedure has been explained to choose the relevant articles. Based on these articles 5 subchapters explain the existing research on IS.

First subchapter explains the characteristics of IS which distinguishes IS from other green park initiatives. In the second subchapter, three parts thoroughly explain the planning approach, self-organizing approach and the facilitated evolution approach respectively. Each approach is explained with relevant concepts observed in literature. After this, third subchapter explains different examples observed around the world where IS approach was used to reduce total water consumption. In the fourth subchapter different examples of IS projects are shortly investigated and in the following fifth subchapter, relevant factors that were observed to influence the growth of IS in those examples are listed.

As a result of this literature review, 2 conceptual frameworks are presented in the sixth subchapter. First framework summarises the main IS concepts and development patterns observed in the literature. It is represented in a double S shaped curve to explain the development of IS. On that S-curve Key Objective Indicator events that take place during the development of IS are shown. In the second framework, factors influencing the growth of industrial symbiosis are presented in four categories; namely, Technical and Chemical, Managerial and Behavioural, Financial and Economic and, Regulatory and Administrative which will be used as an analytical framework to process the interview data in Atlas.

“To aim at the perfection has its own drawbacks. It makes you go into details that you can avoid. It can take a lot of time and energy, but it is the only way you can achieve excellence”

– JRD Tata.

3 LITERATURE REVIEW

In this section detailed literature review will be presented in connection to the knowledge gap that has been introduced in the first chapter. Various characteristics of IS will be studied to understand the underlying theories and what has been done in academia so far related to this topic. Data for the literature review is extracted mainly using online tool Scopus. This topic has been discussed many times in the literature and a large amount of articles related to IS are available. The main journals which were seen to publish articles on IS are Journal of Business Strategy and Environment, Journal of Cleaner Production, Journal of Environment Technology and Management, Journal of Industrial Ecology and Progress in Industrial Ecology etc. A general search for IS articles published till now gives a result of 713 articles on Scopus with search word Industrial Symbiosis. This shows that there has been plenty of research already conducted on this topic. Therefore, to limit the number of articles
and to seek appropriate information, different combination of key words, year of publishing, number of citations and popular Authors’ names were used.

To begin the literature review, an initial search with key word Industrial Symbiosis two articles out of 713 articles were selected. These articles were selected based on the number of citations. It is good to select highly cited articles at the beginning of the literature research to get a quick understanding of the subject (Bouwman, 2014). These two articles were: Industrial symbiosis (Chertow, 2004) with 344 citations, and Industrial ecology in practice: The evolution of interdependence at Kalundborg (Ehrenfeld & Gertler, 1997) with 294 citations. These articles were very well written and clearly represented the topic giving useful initial insights. One of the main insights was that Eco Industrial Parks and Industrial Symbiosis concepts are most of the time used in synonymy and these topics come under the field of Industrial Ecology (Chertow, 2004).

Therefore the Scopus search was revised with key word Industrial Symbiosis, Eco-Industrial Parks and restricting the research to the field of Industrial Ecology. The resulting articles were 358 out of which 5 articles were selected. This selection was made based on two criteria: content and number of citations. Two articles initially chosen to understand the IS indicated that planning and self-organizing are two main approaches to implement IS. Therefore articles were chosen to understand these theories. Additionally, number of citations was still considered an important criteria, so as to get well established articles used to represent those theories. These articles were “Uncovering” Industrial symbiosis by (Chertow, 2007) with 202 citations, eco-industrial parks initiatives in USA and the Netherlands: first lessons learnt (Heeres, et.al., 2004) with 199 citations, Designing eco-industrial parks: a synthesis of some experiences (Cote & Cohen-Rosenthal, 1998) with 169 citations, creating by-product resource exchanges: strategies for Eco-Industrial Parks (Lowe, 1997) with 118 citations and, the application of industrial ecology principles and planning guidelines for the development of eco-industrial parks: an Australian case study (Roberts, 2004) with 89 citations.

From these 7 articles various aspects of implementing IS were understood. As expected, there are mainly two theories widely discussed in the literature; self-organizing and planning approach for IS. Moreover, all 7 articles indicated towards a slow or difficult phase of development that exists after the stage of initial development of IS until the stage at which a site becomes well-established IS site. This led to the identification of the initial knowledge gap. This gap also created a curiosity to understand the development pattern of industrial symbiosis and understand what factors influence this development.

Therefore, based on the initial knowledge gap identified, the literature was further funnelled to extract the articles explaining the development patterns of IS. Scopus search was further subjected to the key words such as planning of IS, Self-Organizing of IS, Development of IS, Implementation of IS in different combinations. This search resulted to 142 articles. The Scopus code for advance search of these 142 articles has been given below. Different combinations of ‘AND’ and ‘OR’ and ‘AND NOT’ give different results.

(TITLE-ABS-KEY(industrial symbiosis) OR TITLE-ABS-KEY(Eco Industrial Parks) AND TITLE-ABS-KEY(industrial ecology) AND TITLE-ABS-KEY(Planning) OR TITLE-ABS-KEY(Self organizing) OR TITLE-ABS-KEY(Implementation) OR TITLE-ABS-KEY(Development)) AND SUBJAREA(MULT OR CENG OR CHEM OR COMP OR EART OR ENER OR ENGI OR ENVI OR MATE OR MATH OR PHYS OR MULT OR ARTS OR BUSI OR DECI OR ECON OR PSYC OR SOCI) AND (LIMIT-TO(SUBJAREA,"ENVI") OR LIMIT-TO(SUBJAREA,"SOCI") OR LIMIT-TO(SUBJAREA,"ENGI") OR LIMIT-TO(SUBJAREA,"ENGI") OR LIMIT-
To further increase the robustness of the literature research articles with less than 5 citations were excluded (Bouwman, 2014). Moreover, a 15 year time frame was considered to be good enough to extract all relevant information on a topic from the literature review. Therefore, apart from the preliminary literature review articles, articles older than 2000 were excluded (Bouwman, 2014). The Scopus search also excluded optimization, Computer programming and biotechnological, finance and political studies coming under this research topic. This resulted in 76 articles on the Scopus. These selection steps have been shown in the figure 5 below.

Reading through the abstracts of each article from the above 76 articles, a set of 39 articles were downloaded. This created a complete data set for the literature review. This is not a onetime selection process. New articles and supporting articles were downloaded step by step to make the final set of 39. While downloading the articles a main criteria and the selection process has been shown in the figure 6 below schematically.

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**Figure 5:** Selection criteria to select articles for literature review
After the identification of the initial knowledge gap, the articles were chosen based on the content of the articles by carefully reading the abstracts of all 76 articles on the Scopus. The 7 articles chosen for preliminary literature review were supported by 2 more articles to further understand self-organizing and planning approaches of IS. In addition to these 9 articles two more articles were added to compare and understand advantages and disadvantages of both approaches. Further, to those 11 articles 4 more articles were added to understand European style of development versus US style and development and other comparative aspects. This is shown in the figure 6. These 8 articles were chosen due to their clarity, high citations and, content in the articles explaining the development of IS with relevant examples. Those 8 articles are: implementing industrial ecology? planning for eco-industrial parks in the USA (Gibbs & Deutz, 2005), the evolution of facilitated industrial symbiosis (Raymond & Howard-Grenville, 2012), an industrial ecological project in practice: exploring the boundaries of decision making levels in regional industrial systems (Baas & Boons, 2004), reflections on implementing industrial ecology through eco-industrial park development (Gibbs & Deutz, 2007), strategies for sustainable development of industrial park in Ulsan, South Korea – from spontaneous evolution to systematic expansion of industrial symbiosis (Hung-Suck, et al., 2008), industrial symbiosis: the case for market coordination.
(Desrochers, 2004), reflections on implementing industrial ecology through eco-industrial park development (Gibbs & Deutz, 2007) and, the industrial region as a promising unit for eco-industrial development - Reflections, practical experience and establishment of innovative instruments to support industrial ecology (Sterr & Ott, 2004). The information extracted from these articles will be presented in the following sections of this chapter and the resultant of these 15 articles is a S – curve depicting the development of all IS sites around the world.

Moreover, to understand various factors that influence the development of IS sites, 24 articles explaining different case studies conducted around the world have been included in this literature review. These case studies mainly include studies conducted in USA under the United States Presidents Council for Sustainable Development (USPCSD), in the Netherlands, in Australia, in UK under the National Industrial Symbiosis Programme (NISP), in South Korea, in China and last but not the least, in Denmark. From those case studies presented in the articles various factors are listed and categorised in Technical and Chemical, Financial and Economic, Management and Behavioural and, Regulatory and Administrative. Based on this list a conceptual framework for factors influencing the IS is presented.

In the following subsections of this chapter, first, characteristics of IS are explained, followed by development patterns of IS. After that, a section will present examples from the literature were significant amount of water has been saved using IS concepts. In the later section, past experiences and various IS programmes undertaken around the world are shortly explained followed by a list of factors influencing IS extracted from those experiences. Finally, based on the above listed information from the literature, a S-Curve representing the development of IS is shown and also, a conceptual framework representing the factors influencing the formation of IS is presented.

3.1 Characteristics of IS

Interestingly, in the academic literature and among the industries IE, EIPs and IS concepts are always used as equivalent terms. Hence it is important to understand and differentiate these concepts. They come under the broader idea of Eco-Industrial Development but the scale and features of interactions of these three concepts varies creating not a very clear, but a hazy distinction between them.

IE approach is broad and addresses the issue at national and global levels to track the flow of materials whereas, EIPs and IS focus on a regional level. In the scientific literature, EIPs and IS may confuse the reader as it becomes really hard at some points to differentiate whether it is IS or EIP. The main difference between the EIPs and IS is that EIPs focus more on location factor. EIPs are usually community of businesses that are co-located on a common property whereas, IS focuses on the flow of materials, energy and resources at different scales. IS takes into account different networks of businesses locally as well as regionally to achieve exchanges that are economically and ecologically sustainable for industrial development (Chertow, 2004).
It is also important to differentiate these three concepts from Green Industrial Park development. Four important points that are used to distinguish (Gertler, 1995):

i. Reduction in use of virgin materials as resource inputs
ii. Increased energy efficiency leading to reduction in total energy use
iii. Reduction in waste products
iv. Increasing the amount of process outputs that have market value

IE, EIPs and IS offer unique opportunities to add value to the manufacturing firms located closely with the above 4 possibilities. Whereas, Green Industrial Parks do not fit the above 4 criteria to be considered under the umbrella of IE because most of the Green Industrial Parks around the world are just co-locating environmentally conscious companies. They hardly have any synergies or symbiosis to improve environmental performance. Therefore, for this research only IE, EIP and IS concepts will be considered useful (Roberts, 2004).

Lot of interactions happen within an industry and interaction with other industries. Some industries produce intermediate products using raw materials and finally supply it to the final producer to make the final product; for instance car manufacturing. Sometimes interactions are based on recycling the product for example, scrap steal to the steel plant. Etc. These are mainly business interactions and cannot be taken under the IE umbrella. Key to IS, EIP and IE concepts are collaborations and the synergistic possibilities offered by geographic proximity (Chertow, 2007).

Cote & Cohen-Rosenthal (1998) in their articles on designing EIPs provide 11 characteristics based on the experiences collected from various proposed IS sites in United States and Canada. They define the characteristics of EIPs as –

i. It should define the community of interest and it should involve their interests
ii. They should reduce environmental impacts or ecological footprint by substitution, absorption, materials exchange and integrated treatment of waste.
iii. Maximise energy efficiency by cogeneration and cascading
iv. Conserve materials by reuse, recovery and recycling
v. Link or network companies with suppliers and customers to widen the reach of community involvement
vi. Continuously improve the environmental performance in individual businesses as well as community as whole
vii. Have a regulatory group which permits some flexibility but drives companies to meet environmental goals
viii. It should discourage waste and pollution using economic instruments
ix. Should have an information management system for all flows
x. A central system that teaches and educates workers regarding the new tools and instruments to be developed to improve the system
xi. Orient its marketing to attract companies which fill niches and compliment other businesses

In addition to these characteristics, Cote & Cohen-Rosenthal (1998) argue that EIPs need a system approach involving understanding of qualities and quantities of material that flow in
the processes, regulatory and managerial aspects. They are explained in the following sub-sections.

3.1.1 Geographical Proximity and Spatial Scale

EIPs and IS work the best when there is a strong agglomeration or clustering of firms that have the capacity to utilize waste as a resource in production. Proximity generates savings from many options such as economies of scale, sharing common suppliers and sharing common facilities (Roberts, 2004).

Roberts & Greenhalgh (2000) in their article on application of industrial ecology principles, define different scales of IS. They basically divide them into following three levels –

i. Micro level: firm level symbiosis among different work units
ii. Meso level: industrial site level and its surroundings
iii. Macro level: regional or national level. Sometimes international level symbiotic links.

They specify further that these levels are not exclusive, sufficient or absolute. They could further be defined as an area, district level or as an industrial cluster. Meso level, could be further divided into different scales. It would be an Eco – Industrial Park where companies are situated on a common site can involve in all sorts of material sharing or it could be an integrated Eco Industrial park where firms in a particular surrounding region share materials. There could also be the synergies between two EIPs.

Chertow (2004) observes numerous instances of IS occurring around the world and gives 5 types of exchanges in line with Roberts & Greenhalgh (2000). They include:

i. Through waste exchanges (type 1);
ii. Within a facility or a firm or an organization (type 2);
iii. Among the firms co-located on a common property/EIP (type 3);
iv. Among the local firms in a region that are not co-located (type 4);
v. Among the firms virtually organised across the border (type 5);

Type 1 cannot be looked upon as a IS link as it is more about scrap exchange than exchange of residues. They are called as end of life exchanges. Type 2 is the basic form of symbiosis that takes place in large firms. In modern times within a firm, different work units act as separate entities and they take fairly autonomous decisions. Significant gains can be made if the entire life cycle of a materials is tracked and the opportunities are tapped wherever synergistic possibilities exist. This could be called as internal synergies within the firm. This will help to reduce internal cost of buying virgin materials and reduction in total energy usage. Type 3 represents what is known as EIP. In this approach companies are located on a common facility and look for opportunities to share water, energy and materials. A well-developed EIP can go further to share information, training facilities and services. Exchange occur within an area and it could be called as partners within the fence. Type 4, the firms need not necessarily be co-located on a common site/area or be a part of EIP. The exchanges occur within a small geographic area roughly 2 miles radius of each other. Finally type 5 focuses on virtual linkages than co-locations. It defines regional economic community in which all potential for product exchanges in a large region are explored. For example, in this
type outlying business such as agriculture, and supply chain collaborations could be considered (Chertow, 2004).

### 3.1.2 Selection Criteria and Spatial Scale

A way to distinguish a well-developed IS link with other conventional exchanges is 3-2 heuristic. Chertow (2007) emphasises on ‘3-2 heuristic’ as a minimum criterion. At least 3 different entities which are not related to recycling oriented business should exchange at least 2 different resources. A simple example would be an industry receiving waste water from an urban treatment plant for cooling purposes after the treatment. Households, industry and waste treatment plant are 3 business entities and drinking water and effluent water are two resources that are being shared. This does not mean that bilateral reuse option or waste sharing option cannot be deemed as IS, but a standard symbiotic link at its maturity shall meet this criterion.

In the figure below, 3-2 heuristic is represented. 2 different types of aero signify sharing of two different resources or wastes or residues whereas triangle, Square and circle signify 3 different kinds of companies sharing those products.

![3-2 Heuristic](image)

**Figure 7: 3 – 2 Heuristic**

3 – 2 heuristic is a good way to characterize symbiotic links but it cannot be made as a yardstick to categorize IS from other interactions. Chertow (2007) mentions that many streams are bilateral or multilateral have the potential but may not have yet meet the criterion of 3 – 2 heuristic. Terms used to describe such links were ‘kernel’ and ‘precursor’. Therefore at the exploratory stage of IS, all such links are important. Basically, all possibilities fulfilling:

i. *By – product reuse* – the exchange of firm specific materials between two or more parties for use as substitutes for commercial products or raw materials,

ii. *Utility/infrastructure sharing* – pooled use and management of commonly used resource such as energy, water and waste water,

iii. *Joint provision of services* – meeting common needs across firms for ancillary activities such as fire suppression, transportation and food provision.

Moreover, Sterr & Ott (2004) in their article on industrial region as a promising unit of EIPs reflected on the selection criterion with spatial scale of industrial symbiosis. What size is regarded as right size? Industrial synergies should reach much greater boundaries than the
fence of industrial estate. Greater the number of variety of actors, higher the probability of finding an appropriate partner and it may consequently lead to reduction in use of virgin material. Therefore, why not proceed to include the national or even international scale? To answer these question they propose four parameters which reduce the process distance between the input and the output processes:

i. Minimum distance on the material level → minimum down cycling
ii. Minimum distance on the territorial level → minimum kms per ton
iii. Minimum distance on the system level → minimum transaction costs
iv. Minimum distance on the temporal level → minimum time for the development of waste related secondary effects and uncertainties.

This multifaceted minimization approach yields to answer the question – what is the right size. A right size is the minimal size in which outputs can be retransformed into desired inputs. Thereby adequately closing material loops. Sterr & Ott (2004) propose in their article that an industrial region which is not really confined as an EIP but covers firms nearly by which are also not co-located on the site. In the study conducted on an industrial region in their article they argue that going beyond industrial region scale does not lead to any additional possibilities. In the Rhine – Neckar region it is revealed during the analysis that only one inter regional round-put system was found out; the metal scrap recycling. Apart from that there were not interaction that existed and it is also mentioned that there is most likely no possibility such link also. Therefore a right size could possibly be considered while selecting a potential possibility be industrial region (type 4) or Meso scale but of course the higher level possibilities cannot be overruled.

While selecting an industrial site for IS, what is not an IS link should also be clearly defined. Certainly a site where the following type of interaction occur cannot be considered as IS. Research Triangle Institute and Indigo Development International (1994) suggested that IS or EIP term is applied to those sites which are more than:

i. A single by – product exchange pattern or network of exchanges is observed
ii. A recycling business cluster (example recycling companies or resource recovery)
iii. A collection of environmental technology companies
iv. A collection of green product producing companies
v. A group of companies situated around a single theme
vi. A park that is environmentally constructed and friendly
vii. Or a mixed use development (industrial, commercial and residential)

Additionally, it is also important to note that there should be at least one major firm exporting raw or processed materials, connected to one of more firms capable of utilizing significant portions of the major waste streams of the ‘anchor’ (central player) Industry (Ayres, 1995).

3.2 Patterns of Development of IS

Most of the academic literature is often divided into two theoretical concepts on development of IS. One group advocates for planning of IS whereas the other for creating room for self-
organizing. Through many of the successful or working examples of IS till date have never been really planned but have developed as result of pure business interests, there are still people in academia who believe that planning for IS may also work. Desrochers (2004) in the article on IS take a historical perspective and compare two different examples of IS. One in the free market of England and the other in the Socialist Hungary. Using the results from ‘Austrian’ critique for central planning, they prove that IS can only be successful in a spontaneous manner rather than planning. But authors for example Gibbs & Deutz (2005), have provided various planning guidelines to promote IS. Therefore, it is important to understand these two theories and what are their pros and cons.

3.2.1 Planning Model of IS – Goal Directed Approach

To apply IE principles, EIPs and IS are two major approaches. In the academic literature, Lowe (1997) Roberts (2004), Gibbs & Deutz (2005) and many other authors provide different methods to plan an EIP and synergies between companies.

To develop communities of IE in State of Queensland, Australia, Roberts (2004) gives a set of principles and planning guidelines for use by government and third parties to build a symbiotic industrial park in his article. The underlying principle to plan an IS as proposed in this article is to create situation where application of IE principles should improve total environmental quality while satisfying the economic demands of industry in a win-win situation. Based on this principle following strategies are proposed:

i. Promote opportunities to establish genuine partnerships and engagement with communities and government in developing a more responsive attitude towards sustainable practices

ii. Locate industries strategically to optimize the material flow and capture of by – products and wastes

iii. Co-locate industries that will benefit economically from the exchange

iv. Capture and create possibilities to promote waste recoveries in the industrial system

v. Provide a catalyst to create synergies and an environment for fostering technical production in a cleaner way.

vi. Provide an appropriate ‘Smart infrastructure’, to insure the growth of eco-industrial parks and to maintain high level of innovation as the basis of their competitive edge.

vii. Support industry policies and incentives to encourage innovation, collaboration and commercialization of new improved product developments using materials, water and energy surplus to production and;

viii. Demonstrate commitment to the benefit of industries that have strong, sustainable development.

Using these strategies it is argued that planning of EIPs is possible. At a system level, planning of EIPs should include detailed plan on how the projects will be conducted. Following list represents the points that have to be taken into consideration while doing a system level planning (Roberts, 2004):

i. Organizational arrangement for developing EIP

ii. A local champion or a catalyst industry around which other can congregate
iii. A core project team to work with the champion to develop other potential partners
iv. Design guidelines should include objectives of communities involved
v. A detailed development plan
vi. Financing and risk management strategies for development and management of ongoing IS
vii. An effective marketing plan
viii. Economic analysis of the potential for product exchange
ix. Determination of the potential for using membership in any EIP and marketing strategy
x. Examination of potential to reduce any regulatory costs
xi. Site planning, location factors, waste storage facilities, transportation, and future utility infrastructure
xii. Landscaping and building design to facilitate resource recovery
xiii. Flexible tenancy agreements
xiv. And finally a framework for community relations services to respond to concerns and gain support for eco-industrial development activities

These planning methods will help to develop an EIP and create IS links among the companies when carefully implemented. Lowe (1997) also gives similar guidelines to create by-product resource exchanges. They give five preconditions to facilitate cooperation while planning an industrial site:

i. A clear statement of the park’s vision and performance objectives
ii. Screening of candidates to attract high quality companies
iii. Methods and information to support companies in seeking by – product sales
iv. Flexibility in recruitment strategy for the candidate firms to be situated on the site
v. And assurance of continued support for the exchange network.

Additionally, Lowe (1997) propose that an Anchor Tenant can also play an important role while planning IS. Its prestige and large scale resource and material exchange can provide stability to the exchange networks. Role of Organizing Team is also one more option to plan EIPs. Organizing team can educate potential participants to the opportunities and in creating the conditions that support the development. Developing a resource exchange in an industrial region may require creation of this organizing entity if there is no industrial development authority. It is interesting to see that so far this work has been mainly done by research institutes, environmental agencies and universities.

In the same article how to recruit tenants while planning EIPs is also explained. Initial surveys should be taken regarding ‘what each player can offer’. Once this data is available, missing components could be realized which can lead to targeted prospects (Lowe, 1997).

Overall, this model includes a conscious efforts to identify companies, locate them together so that they can share resources across and among each other. It could be said that typical planning of US EIPs has followed this trend involving the formation of stakeholder group of diverse actors and participation of at least one government or semi-government agency such as United State President’s Council for Sustainable Development. This party has some power.
to encourage development of IS such as zoning, grant giving or long term financing (Chertow, 2007).

### 3.2.2 Self-Organizing model of IS – Evolutionary Approach

Currently observed successful examples of IS have not really evolved out of a grand plan. The most colourful example of IS, Kalundborg had never had a planning authority or government involvement. Industrial synergies took place to achieve economic goals of the participant companies with bilateral negotiations (Chertow, 2004).

Industrial synergies develop based on the win-win situations in three steps. The first stage is regional efficiency. It mainly involves autonomous decision making by firms. At this stage companies coordinate with each other to tackle their inefficiencies. The second step is regional learning. By gaining mutual trust and partnerships they share knowledge, they try to broaden the definition of sustainability. The third step is development as a sustainable industrial district where many resource, waste and energy exchanges occur (Boons & Berends, 2001, Baas & Boons, 2004).

In the empirical findings of Chertow (2007) on the progression of IS in an article propose a concept called Uncovering. This article suggests that links between the companies exist from a long time and they are most of the time driven by economic interests of individual companies. It is after their discovery that the potential of these synergies is unveiled. Therefore, the article clearly makes distinction between two stages in Self – organizing model; one, before the discovery and two, after the discovery. The point at which the discovery takes place is called as Uncovering of IS.

Looking at the figure below, we can see that IS develops gradually rather than rapidly with a grand plan of strategies and planning guidelines as mentioned in the planned approach. it begins with collaborations intended to tackle with inefficiency and to stay below the government regulations. Once this kind of link is established it is followed by a period where new entrants enter and some firms die off due to several changes in the process as industrial development is highly dynamic and new technologies and methods may affect the participation of companies involved. After this step comes the stage of uncovering when usually a third party, most of the time an academic team or a consultancy finds out these connections. Following this discovery, the long period of continuous development comes where new symbiotic links flourish (Chertow, 2007).

Over all, in this model an industrial ecosystem emerges from decisions by private actors motivated to exchange resources to meet goals such as cost reduction, revenue enhancement or business expansion. This individual exchanges later face the market test where their success or failure is observed by many. This leads to withdrawal and entry of some participants. Then the uncovering takes pace. From this moment on, slowly new links start developing and industrial synergies take shape. The peculiar characteristic of this model is that at the early stage there is no awareness in the participants about the bigger picture. This characteristic is also the reason for higher success of such examples. This is because these exchanges purely due to economic interest create a base work for future fostering. Nevertheless, still this fostering take time (Chertow, 2007).
3.2.3 Combination of Self–Organizing and Planning – Facilitated Evolution Approach

Though there is no good set of sample to empirically establish the fact that self-organizing approach leads to higher rate of success in using IS rather than the planning approach. Gibbs and his colleagues studied several sites from Europe and United states to examine the IS development. According to their findings they reflected that it is very difficult to implement interaction between the companies based on waste and cascading. They studied 63 sites out of which 33 were from Europe and 30 from United States. They observe that sites from Europe had somewhat greater success than sites in United States. One of the major reasoning for this difference in success rate is the initiator of the projects. Almost all the projects in United States were planned under the United States Presidents Council for Sustainable Development (USPCSD) in 1996. Whereas, initiatives taken in Europe were mainly internal. i.e., by the participating companies (Gibbs, 2003, Gibbs, et al., 2005).

The sample of planned IS sites succeed less than the self-organizing ones mentioned in various articles could easily make the readers believe that the success of IS could only happen with accidental findings or mere serendipity; but that is not the case (Raymond & Howard-Grenville, 2012). A nationwide central body in UK called National Industrial Symbiosis Programme (NISP) is seen as a successful body to strategically implement IS in different industrial regions of UK. It is considered as the first successful IS programme at the national level (Domenech & Davies, 2010).
Chertow (2007) argues that the distinction between planning and self-organizing is not exclusive. In the article, while explaining uncovering, Chertow emphasises on planning the self-organizing, i.e. self-organizing could be choreographed. This mainly involves Precursors and Kernels. In this article it is suggested to plan a self-organizing of an industrial site basically in two ways; Assisting Kernels beginning to take place and identify and access precursors to symbiosis. Kernels are those links which are already being thought of and emerging from the idea phase. They are excellent candidate for IS. Otherwise, efforts to be put to identify precursors of symbiosis. Precursors could be interactions and involvement of companies for bilateral efficiency gains or economic gains. For example land fill or reuse of waste water. In general following three steps are key to plan the self-organizing of IS:

i. Bring to light Kernels of cooperative activities that are not yet uncovered

ii. Assess the Kernels that are taking shape &

iii. Identify precursors to symbiosis and catalyse them by providing incentives.

In the article of Lowe (1997) on strategies to create by-product exchange, the role of organizing team has been explained. The self-organization could be organized with the help of an organizing team. This argument also comes in line with Chertow (2007). The self-organizing team should select the participant companies based on some parameters such as areas existing industrial mix, work force, markets and resources. It is emphasised that early targets might be those companies that would benefit particularly from having their unmarketed energy and materials consumed as by-products. Anchor tenant can also play an important role in organizing the self-organization by giving stability to the collaboration due to its large operational reach and high number of resources.

From the two paragraphs above it could be seen that, many times, there have been discussion on using both approaches; goal directed (planning) and serendipitous (self-organizing) together (Kilduff & Tsai, 2003). Close examination of patterns of development of many sites conducted by Raymond & Howard-Grenville (2012) also propose that they are not exclusive of each other. In fact, both type of patterns could be seen in various IS examples. Therefore they propose a theory what they call facilitated IS. It is a middle out approach which argues that both type of theories act at different point in time.

In this article the action of a facilitator is divided into Conversation, Connection and Co-creation. These three actions occur in different points of the development of IS. Conversation comes in the early stages wherein companies try to build the contact and create relations. This is named as Pre-network development stage. At this stage companies capture interest, broader institutional awareness and potential exchanges found during the conversations. Almost in all cases this stage is line with self-organizing nature of IS. Connection occurs mainly during the early network development stage. At this stage low handing fruit type of networks are strategically pushed up the ladder. Upon their success, deeper trust and relationships prosper among the firms. At this stage self-organizing and planning, both approach work. Serendipitously, the potential low fruit networks are located but they are strategically pushed up the priority list using tricks from planning approach. Co-creation comes in the later part. Co-creation marks the later network development. This involves replicating IS in difficult network option, developing high value networks and creating further intercompany interactions. At this stage the prevailing strategy is planning approach.
rather than self-organizing. Specific projects are pushed with a well-planned goal (Raymond & Howard-Grenville, 2012).

3.3 IS concepts and Water

One of the key aspects of industrial symbiosis is to change the material flow from linear to circular. Water is a key element to implement this feature. Issues related to water are increasing in all parts of the world. At some places due to scarcity and in all places due to the release of effluents. In the conventional system companies pump the water, use it and release it in the environment. This may not be the complete cycle of water use, many times the water after treatment will be good enough to use in many industrial purposes. Scarcity also creates need for long distance transport and pumping costs. Therefore, keeping the water in the system as long as possible is the key to reduce water consumption. Therefore priority should be given to reduction in water resource use, and reuse of waste water (Barton & Tsourou, 2000).

As explained in the introduction, water scarcity and restriction to use surface water at Kalundborg initiated the process of pooling among the close located companies in that region what we call today is the best example of Industrial symbiosis. One of the primary patterns of synergic network at Kalundborg is oil refinery, a power station, a gypsum board facility, and a pharmaceutical company, share ground water, surface water, wastewater and steam. An aggregate consumption water has been reduced to 25% for the whole industrial region from its initial consumption before the links were established. Moreover, one of the companies could achieve 50% reduction in water usage after the implementation of IS (Chertow, 2000).

In the beginning due to the lack of water for cooling, Statoil refinery pumped in cooling water in 1973. In 1987, this cooling water after the cooling of refinery was found suitable for the cooling of power plant. Therefore Statoil started sending water to the Asnaes power plant. Additionally in 1991 Statoil also started sending treated waste water for utility use. In total, Statoil supplies 700,000 cubic meters per year of cooling water to Asnaes, where it is purified and used as boiler feed-water. Statoil supplies treated waste water available to Asnaes, which uses about 200,000 cubic meters a year for cleaning purposes. Regarding the investment, Statoil's investment in the biological treatment plant has made it possible to create a water good enough to use it in the power plant. Later in this network, power plant started supplying its cooling water to Fish farm to keep the fish form warm as the output cooling water from the power plant is higher in temperature. Though these water links were not created based on the grand plan the scarcity and restrictions on water availability made these links come to existence (Ehrenfeld & Gertler, 1997).

Therefore, a simple example of water related IS network could be that a waste treatment plant receiving water from the town and cleaning it and sending it to the power plant for the cooling purposes. In turn the power plant supplies steam to another industrial user. Apart from the Kalundborg, many plants in US associated with USPCSD programme also showed concern about the water and they solved this issue with the IS approach to the water. Power plants at Hawaii, Puerto Rico, and New Hampshire use millions of cubic meters of sewage
water for cooling every day. Currently, Chinese and Korean policies are focusing on retrofit of existing parks to increase symbiotic exchanges as a means of conserving water and other resources and simultaneously increasing competitiveness (Chertow, 2007). At Londonderry Eco Park, wastewater is being planned to use for cooling at the power plant which will lead to the savings of about 4 million gallons of water extraction from the nearby Merrimack River (Gibbs & Deutz, 2007).

In relation to this thesis research, in a study conducted by Heeres, et al., (2004) reflected on projects related to infrastructure building. For example projects like water sharing links. They observed that infrastructure building projects related water were given less importance in Dutch EIPs. Water and other wastes which need physical infrastructure to be built can only be shared at the close distances for instance, inside the firm, or on the industrial site. Larger distances makes it economically difficult (Roberts, 2004).

Therefore water makes a good case to investigate IS and it relates to the research gap explained in the chapter 2.

### 3.4 Learning from the past experiences

From the literature review so far, it could be seen that IS provides a promising opportunity to reduce environmental impact with better management of relationships between the companies closely located. We could also see that EIPs provide a chance to demonstrate IE concepts on those industrial sites mainly by the use of IS links (Zhang, et al., 2009). Therefore, IS is essential for the development of EIPs. Hence, after understanding the theoretical point of view established in the scientific articles, the next step is to look into specific EIPs to understand their development and what were the lessons learnt.

Researchers like Ehrenfeld & Gertler (1997) & Chertow (2007) have studied development of Kalundborg industrial symbiosis in detail. Gibbs & Deutz (2005) (2007) have studied several EIPs from USA and Europe. Heeres, et al., (2004) have looked into the development of USA and Dutch EIPs and have established first lessons about their growth. Baas (2008) (2011) studied development of Rotterdam Harbour in the Netherlands. Roberts (2004) reflected upon the first Australian eco – industrial park. Sterr & Ott (2004) studied a large industrial region in Germany whereas, Deog-Seong, et al., (2005) and Hung-Suck, et al., (2008) studied the first Korean attempt to adapt IS concepts. Moreover, new increase in IS application has been observed in Chinese industrial locations which are studied by Qinghua, et al., (2007) and Zhang, et al., (2009). One of the successful planned IS implementation attempt in UK was conducted by NISP. This programme was widely discussed in the articles of Raymond & Howard-Grenville (2012). Therefore, there is plenty of literature available that has investigated EIP and IS sites all around the world.
Figure 9: Kalundborg Industrial Symbiosis, Denmark (Chertow, 2007: p19)

In this report, development of Kalundborg has been already covered largely. In the figure above, an overview of all the exchanges and symbiotic links developed over the years has been shown. Kalundborg town has four main industries; Asnaes 1500 megawatt coal fired power plant, Statoil refinery, NovaNordisk a pharmaceutical company and Gyproc a plasterboard manufacturing company. Mainly because of the links between these companies 3500 oil fired heating furnaces have been replaced though pipe networks. Power plant also supplies heat to the fish farm and sludge from the ponds is sold as fertilizer. NovaNordisk and Statoil receive process steam from the power plant. To achieve this 2 long steam pipes had to be build but the investment costs were recovered in two years. Power plant also provides gypsum containing feed stock to Gyproc. This is a result of installation of sulphur dioxide scrubber. This resulted in the production of Gypsum of about 80 – 85000 tons per year. Fly ash from the power plant is sold to cement companies and road building companies. Pipelines of gas are shared between Statoil and Gyproc. These were waste gases before. Fresh water sharing is huge in this region. 700,000 m3 per year cooling water is supplied by Statoil to the power plant. In process it is purified as used as boiler feed water. Waste water od Statoil is also used at the power plant for cleaning purposes. Statoil has invested in biological treatment plant which produces effluent sufficient clean water for power plant leading to the reduction of its total water use by 25% (Ehrenfeld & Gertler, 1997).

Apart from Kalundborg there have been several attempts to replicate such an example around the world. It is a matter of discussion to say whether other attempts have been successful or not, but investigating their pattern of development is a good way to understand them (Gibbs & Deutz, 2005). In the following paragraphs initiatives for IS taken in other parts of the world will be shortly investigated to understand their patterns of development.
3.4.1 USPCSD – United States President’s Council for Sustainable Development

Out of 30 industrial sites investigated by Gibbs and colleagues in their paper on implementation of IS, half of the sites were proposed under USPCSD programme during the time of Clinton administration under the programme Sustainable America. This programme recommended that (USPCSD, 1996) federal and state communities should assist communities to establish EIPs to create new models of industrial efficiency, cooperation, and environmental responsibility. These projects were highly funded by U.S Environmental protection agencies of various states. In the analysis of these 15 sites it was found out that five where somewhat acting as EIPs, 3 failed, and seven were still in the planning stage (Gibbs & Deutz, 2005).

Upon further analysis of US projects, Gibbs & Deutz (2005) found out that though these sites represent the features to be the candidates for EIPs, the sense of ecological exchange was missing. People saw them as green parks. Only true ecological sense of interaction occurred in the Londennery Eco – Park were treated waste water for the cooling of power plant. One of the candidates they interviewed stated that they were mainly focused on green architecture rather than the ecological principles of IS. They also reiterate the question whether the word ‘Eco’ is simply used as a marketing tool by the industrial sites rather than practicing IE principles. For example projects such as Cape Charles Park and Devens were able to extend the luxury of having subsidies and grants for the government for a longer time to attract appropriate tenants. Unfortunately, after 4 years the site is now for sale. Therefore they conclude that so far USPCSD attempts to increase environmental gains through waste reduction, material interchange, cascading are not being achieved are not being achieved by the deliberate attempts to establish EIPs. Additionally they mention that collaborative behaviour is a central theme to EIP development.

Overall, the conclusion of this study is that the classic example of Kalundborg should be seen as the essential structure of IS networks what they quote as ‘sine qua non’. Rather, a gradual approach is the need of the hour. Networks should be established phase by phase and every phase should go through the test of market (Gibbs & Deutz, 2005).

3.4.2 Heidelberg’s industrial Estate of Pfaffengrund and Rhine-Neckar Region

IUWA (Institute of Eco-Industrial Analysis) following the Rio conference of 1992 decided to try to implement Kalundborg like interaction elsewhere on the globe. By examining some sites, they selected a site which is developed over the decades and has middle sized industries which represent wide range of industrial sectors. Due to the high rate of close down of companies in 1990s, this site was looking for opportunities to attract investors which created a required atmosphere for IS research. Though there was no support from the government, the non-monetary community support was always there (Sterr & Ott, 2004).

This site had metal, chemical, electronic as well as paper industries. Totally 14 industries participated in this research and upon application of IS in four main aspects – 1) Direct
output-input relations 2) tender solutions 3) joint transportation and 4) information coordination, links could be successfully established. For example, Tender solution with used paper has flourished and being expanded. Untreated wood from one of the industries was successfully transported to a neighbouring towns company where they use to heat the shop floor. The only failed links were those which were cancelled due to the lack of proper policy. For example, granulated plastic was a idea input for plastic industry in the reason but DSD (Dual System of Germany) guarantees a free of charge disposal of packaging materials (Sterr & Ott, 2004).

Although such waste sharing does not fit into the definition of IS but the point to learn here is that a large amount of material was being wasted and now being used as a resource on the same site serving the ecological purpose of the IS and EIPs. (Sterr & Ott, 2004).

Expanding the boundaries, Sterr & Ott (2004) look into the Rhine-Neckar region. This region includes the Heidelberg and spreads across 3 provinces of Germany. They investigate if such a large area could be a home to IS ideas. In such a large area plenty of possibilities were found out but very small amount of them were seen to be implemented. According to this article, expanding the area leads to greater number of variety of actors, greater economies of scale. Nevertheless, it increases the distance between the industries, communication complexity and sophisticated data management and transport costs.

3.4.3 Sustainable Industrial Development in Queensland, Australia

It took approximately more 5 years to develop the park and a long history of planning the site and the location of the park. This concept was called as Synergy Park. This area has a history of food processing industry surrounded by most fertile cropping areas in Australia. Additionally it has water and sewage facilities already established. Moreover, this region had high unemployment rates and food and beverage industry is a labour intensive industry. Number of beverages and food processing industries were invited to be a part of this EIP planning process and a trust called Synergy Trust was established to oversee the construction and marketing of the project. One of the key take homes of this EIP planning was to plan common storage, warehouse and cold storage facilities. Another important feature of this planning was that they had a control on the occupancy. Only food, pharmaceutical and service industries were allowed to be located on the site making the match making easy. The overall planning is guided by a master plan of the project. This master plan was prepared with consulting the key players their requirements such as features like Cafeteria, medical facilities, training facilities etc. the key idea behind this planning was to utilize economies of scale. For example common logistical movements and common warehouses. To store at the warehouse, the space was rented not based on room size but on the bases of per kilo or per carton size. Just – in – time delivery methods were used with the help of bar code to understand whose item has been used in the supermarkets so that they can produce more and who shouldn’t. Effluent disposal was also one of the important aspects of this park. Segregation at source was a new idea. Effluents and wastes will be segregated at the source site and then the domestic waste will be treated council sewage treatment plant and industrially important waste will be treated and recirculated to the industries. In general,
the learning from this Synergy Park were; 1) Synergy trust a local cooperative body acted as a catalyst. 2) Strategic planning by making a master plan lead to success of the project and 3) government support is essential. There were several problems which could have been remained unsolved if government didn’t support. Therefore partnership between government and developer companies is important.

### 3.4.4 IS attempts in South Korea in Daedok Technovalley (DTV project) and Industrial Park in Ulsan

Daedok technovalley project is one of its kind in Korea as it was the first attempt to implement IS. This area has an old history of science and innovation due to the largest science park of Korea situated here. The development of IS in this region was mainly undertaken by Daejeon Metropolitan City under the High Tech Industrial Estate Development Plan. This provides a platform for regional development. It was first considered to be developed as a conventional industrial park but later decided to be developed as an EIP. According to the old plan 80% of industries were electronics industries, additionally many other basic support facilities were planned separately on the western side of the site. In this plan however there was very less environmental consideration. Later when environmental concerns were raised, this site was re-planned based on three principles; 1) develop a multi-functional mixed-use industrial park as an regional development centre, 2) instead one time development, phase wise development to secure economic efficiency; 3) promote environmentally friendly site planning and layout and 4) cultural sustainability; to develop this plan a consortium of government, private companies, and financial companies was formed. This lead to a very sustainable and environmentally friendly site development. Main advantages of opting for EIP plan were – (1) transport oriented energy consumption was reduced and air sustainability was achieved. (2) In addition to basic support industries various other facilities such as training and education. (3) Adopting a 5 stage phase plan helped to keep up with the economic viability and difficulty in finding initial investments (4) and finally, it lead to cultural sustainability creating awareness among the companies and surrounding localities to adapt sustainable practices (Deog-Seong, et al., 2005).

In terms of practicality, one of the main IS implementation was the grey water recycling system, and rain water reuse system to reduce water consumption. In addition penetration of extra 30% in to the ground water. Additionally, waste treatment plants were situated on the site which treated industrial and domestic bio wastes which later could be used as fertilizers and several such material flow management ideas were applied. Moreover, the companies were advised to develop green designs of the buildings with green space ratio of 17%. Over all, whether this site fits into the definitions of IS and EIPs yet to be seen as it is in very early stages but one important learning from this project was that including EIP aspects in an industrial site development plans helps to bring chance in people culturally regarding the environmental responsibility (Deog-Seong, et al., 2005).

Ulsan project is more advanced project compared to Daedok technovalley. This site comes under the 6 projects undertaken by Ministry of Commerce, Industry and Energy (MOCIE). A body named Korea National Cleaner Production Centre (KNCPC) affiliated to the Korea Institute of Industrial Technology (KITECH) managed all 6 projects including the Ulsan
project. This city has a long history of being an industrial park, and before converting it to EIP, this city was considered as the ‘pollutants department store’ or ‘country’s most polluted city’. The key success factor of this site was the high influence of government. To tackle the serious issue of pollution, government came up with 5 principles which they called Environmental Vision. These 5 principles were 1) principle of prevention 2) principle of harmony and integrity 3) principle of utilizing economic incentives 4) principle of charging the polluter and 5) principle of opening information and getting the community involved. This pro-activeness of government acted as a catalyst. Using these policy changes, industries put themselves to a rapid shift towards innovativeness to tackle environmental pollution. One of these solutions was to opt for EIPs. Currently, this EIP includes mainly 7 industrial players. An environmental management company – Koentec Ltd which incinerates industrial wastes and cleans the industrial waste water (445 m3/day), an oil company SK corp, SK chemicals a life science petrochemical company, LS-Nikko Corp, which produces pure copper anode and cathode, Koreazink Corp, a major precious metal and chemical producing company, The Ulsan metropolitan city, and KOWACO, a Korean water resource cooperation concentrated on water resource management and flood control activities. Currently in the first phase of the project, waste water, waste plastics, steam and sludge are being shared and these interactions are considered successful. In the next two 5-year segments, in total 56 such projects will be undertaken (Hung-Suck, et al., 2008).

### 3.4.5 Guitang Group – Industrial symbiosis in China

Guitang group is basically the largest sugar refinery of China situated in southern China. Uniquely, this example of IS demonstrates IS strategies at two stages. First, internally looking on option to reuse all its wastes and externally, by improving supply base. This site produces approximately 50% of total sugar output of China (Wei, 2004). Initially a standalone company, now it has developed as an EIP. This happened due to the concerns about environmental pollution due to sugar production. Since 2000, State Environmental Protection Administration of China (SEPA) has promoted this site as a strong environmental and economic performer. This group committed itself to promote as an IS example (Qinghua, et al., 2007).

Internal symbiosis include first use of by-product such as molasses by-product to produce alcohol. Later it added 3 paper plants to utilize sugar fibre (bagasse), a waste after the sugar processing and developed additional business lines. Additionally, the sugar chain, external rough fibre also results in production of fertilizer (sulfitation process) which helps to close the loop and utilize a waste. Hence, fertilizer goes back to the sugar field as a fertilizer closing the loop. The other fibre is which is soft and internal part of the sugar cane is separated and used in the paper mill. Remaining amounts of fibre (pith) is used to produce power in the cogeneration power plant. Guitang group has constructed an Alkali recovery plant situated at the site produces black liquor resulting in white sludge. White sludge is used in cement production, additionally the pulping process at three paper mills lead to a major waste (white liquor) which is again treated and water and fibre are recovered and recycled to paper mill. Additionally, energy recovery is done at the Guitang group boiler house. Air pollution control equipment at the boiler house is installed which consists of Scrubber
utilizing alkaline water, neutralize sulphur dioxide and electrostatic precipitator for small particles (Qinghua, et al., 2007).

Nevertheless, externally Guitang group maintains good symbiosis with government and even customers. It is known for its high quality sugar which contains very low levels of sulphur dioxide and colour. This helps to maintain significant contracts with giant companies like Coca-Cola. Another interesting example is the long border supply chain symbiosis to collect wood for the expanded capacity of its paper mill from countries like Canada, Russia, Indonesia and Chile. They also maintain close relationship with farmers to consult them on fertilizer quality and sugar cane production demands (Qinghua, et al., 2007).

Overall, Gruitang group is one of the unique examples of internal symbiosis and how a company can internally apply symbiosis strategies to reduce impact on environment and benefit economically at the same time.

### 3.4.6 First national level IS programme in UK – NISP

National Industrial Symbiosis programme (NISP) is the largest IS implementation programme undertaken by any institutional body around the world. The programme has four regional divisions – East midlands, West midlands, North East, and North West. As the initial IS programmes grew in UK, NISP’s West midlands projects is considered to be the most mature and developed region. The study conducted by Raymond & Howard-Grenville (2012), show that the actions taken by NISP are mainly related to three aspects – Conversation, Connection and Co-creation. Conversation action lead to create interest among the people and informal interactions. This is achieved by workshops and informal meetings. The main advantage of this step is in the predevelopment stage of IS development where a broad array of discussion can take place between the firms. Connection action helped to achieve IS exchanges which were low lying fruits, easily doable and serendipitous interactions. This is at the stage of early network development and finally, Co-creation wherein, deliberate attempts were made to develop difficult IS connections building upon the already established links and interactions.

### 3.4.7 IS projects in the Netherlands – Rotterdam harbour area, RiVu project, and Moerdijk projects

Heeres, et al., (2004) looked into 3 dutch EIPs and compared them with 3 EIPs of USPCSD projects. The Dutch EIPs chosen where INES (INdustrial Eco System) project of Rotterdam Harbour area, RiVu (Rietvelden/vutter sustainable revitalization project) and Moerdijk EIP project. All three projects are revitalization of old brownfield sites into Eco Industrial sites. Compared to USPCSD, the Dutch EIPs are seen to be more successful.

In general there were 6 fundamental differences were seen in the approach of Dutch EIPs and US EIPs which lead to their success; 1) Objectives: most of the initiatives in Dutch EIPs were taken to tackle with environmental obligations and economic efficiencies of the participating industries whereas as in US EIPs, Job creation and economic revival of the region was the objective beyond only environmental objectives; 2) Initiators: In Netherlands, local associations initiated the project whereas in US the government agencies initiated the
project; 3) Public participation: In the Netherlands, communities role is confined and only direct stakeholders are involved in the planning stages whereas, in US projects communities are encouraged to get involved in the project planning and share their views creating another heavy stakeholder from the beginning of the process; 4) Financing: by and large Dutch EIP planning and implementation was a 50 – 50% involvement of government on one hand and the companies involved on the other hand. Whereas in US, government took the initiatives and created extra motives and incentives to undertake such projects. However, the cost of building infrastructure was either gained by companies involved or the external companies who will gain money from it; 5) Local champions: Dutch and US EIPs both don’t have a particular local champion or anchor tenant, but this role is mainly played by local community. INES project anchor tenant role was not specified to any company to avoid favouritism. In other two cases most of the companies involved could play the role and hence no single company was given this role; and 6) Material exchanges: Rather than taking ambitious projects Dutch EIPs undertook economically and environmentally beneficial exchanges first. The best example is INES Rotterdam harbour project supplies waste heat to the neighbouring houses. However, the projects in US immediately focused on building physical infrastructures for water and waste exchange (Heeres, et al., 2004).

Over all, from all the cases explained above, most of the initiates were taken to develop the already established industrial sites into IS sites. Moreover, attempts to plan industrial sites from scratch have been limitedly successful. Role of external institution is seen crucial. Involvement of government and government’s success in planning is limited. In UK it has been very successful whereas, in US it has not been very successful. Almost all sites already had some sort of interaction before IS concept was introduced and policy intervention has been seen very impactful in Korea and China.

3.5 Drivers and Barriers of IS

From the past experiences it is evident that success and failures had different types of reasons. Those reasons have to be established to understand those factors. From the above mentioned cases, while reading trough the literature several points could be extracted which lead to success and failure.

From the literature, in the following paragraphs main factors that play a crucial role in implementation of IS are extracted. They are mainly divided into 4 types, namely – Technological and chemical, Behavioural and Managerial, Economic and Financial, and Regulatory and Administrative.

3.5.1 Technical and chemical factors

*Technological innovations*

Many times, for waste to be used as a resource, it must be adjusted to the requirements of the receiving industry. To do this, innovative technologies are needed. Therefore, technical innovations is a key pillar for reuse and waste sharing (Sterr & Ott, 2004).
**Interdependency**

Concerns such as closure of a particular company or relocation or end of a particular waste stream are considered as major problems in adopting IS (Lowe, 1997, Gibbs & Deutz, 2007). There is a two way problem while connecting waste streams. Any upset at the seller industry might interrupt the production process of the buyer. Whereas, a problem at the buyers side will lead to the disruption in outflow of waste material at the sellers side. Nevertheless, this is typically same as normal supply demand of materials. The only difference is the reliability and continuity of the flow (Ehrenfeld & Gertler, 1997).

**Technological lock-in**

Exchange of by-products will lead to long term reliance on outside company leading to a lock-in situation (Lowe, 1997). Due to the prior commitments it will confine the companies involved in the link and restrict new technological changes. This discourages upgrading the equipment and old systems (Chertow, 2004).

**Chemical and technical compatibility**

Basic chemical and technical compatibility is essential to achieve cost savings. Biodegradable waste is easy and need not need a lot of matching in terms of chemical compatibility. But non organic resources such as wastewater need higher chemical compatibility (Chertow, 2004). There are two types of by-products and wastes. Direct and mixed. Direct wastes/by-products, for instance, sludge could be used somewhere else easily without doing much with its current state. Whereas, mixed wastes are not up to the mark for a receiver. Many times other unwanted materials have to be removed from the waste before turning it into reusable. For instance wastewater for cooling purposes. Hence, dealing with mix waste is a real challenge (Ehrenfeld & Gertler, 1997). Uneven quality and inconsistency in the waste composition might damage the equipment in the company. Therefore, pre-treatment and monitoring becomes necessary (Lowe, 1997).

**Upgrading and pre-treatment**

If the product is not compatible, pre-treatment is required which is at times adds to the costs making the whole deal unattractive. Interestingly, initial symbiosis in Kalundborg didn't involve any pre-treatment. It was only rerouting of used resources what was formerly a waste. New links have been established after the application of pollution control technologies. These technologies play an important role in upgrading the quality of the product to the desired quality by the consumer party (Ehrenfeld & Gertler, 1997).

**Distance**

Apart from this, there is always a question of distance to avoid large transportation costs and energy degradation in some waste transports. Distance also adds to the infrastructure costs (Ehrenfeld & Gertler, 1997). Relatively large distance between the companies was seen as one of the major impediments in the Dutch EIPs (Heeres, et al., 2004).
Size of the plant

Symbiosis seems to work best when the size of the waste produced by plants is large. Small plants target to achieve reduction in environmental emissions internally (Ehrenfeld & Gertler, 1997). However, large plants surrounded by small plants dominate the material flow. Small companies finds it difficult to match the size of the requirement by large plants (Heeres, et al., 2004).

Supply scarcity

Limited or scarce supply of resource is important to establish symbiotic links. This leads to higher responsibility in use of virgin feed supply. Recovery activity or reuse activity can only look attractive if the recovery/reuse of material is cheaper than the virgin material purchase (Ehrenfeld & Gertler, 1997). Lack or redundancy on the demand side leads to the collapse of the proposed waste sharing link, as the waste is no longer valuable (Sterr & Ott, 2004).

3.5.2 Behavioural and Managerial Factors

Attitude towards Waste

Social attitude towards waste and by-products have to be changed. They no longer have to be seen as a burden but rather a business opportunity. Moreover, each saving on waste, water and energy has to be seen as a potential resource for future generation. It has to be understood that waste is not a problem in itself but the necessary initiatives and infrastructure is the problem. And this is due to the value being attached to the waste. Attitudinal changes will lead to higher pro-activeness (Roberts, 2004).

Awareness

The study of EIPs conducted by Gibbs & Deutz (2005) indicates that most of their respondents had just an idea about industrial synergies. Moreover, everyone believed that correct promotion of these ideas is a key to success. Respondents to Gibbs & Deutz (2005) said that even if we want to start a new industrial park, we would call it ‘eco’. It gives sense of environmental friendliness and cost savings at the same time.

Culturally also, the awareness of environmental improvements is also essential. In the Scandinavian society, back drop of environmental concerns is always given importance (Ehrenfeld & Gertler, 1997).

Negligence

Waste has a long history of being neglected and its impact being ignored. This made it difficult to integrate these issues into company’s strategic processes. Therefore there is a need to change the mind-set if the entire value chain of the production of a company has to be optimized. It is necessary to realize that there is a world beyond the fence-lines apart from just only customers (Ehrenfeld & Gertler, 1997).
**Long term vision**

A long term vision for the development of EIP is the must. Every participant involved should have a clear reflection on EIP concepts and their vision should focus on networking and collaboration and that an EIP/IS should be a community of co-located companies (Gibbs & Deutz, 2005). Industrial Symbiosis takes years to grow therefore, a long term approach is necessary to nurture and develop key elements of infrastructure. To do this a long term vision is necessary (Roberts, 2004). Therefore, clear statement of vision and performance objectives of a proposed EIP is essential (Lowe, 1997).

**Trust and Cooperation**

Issues related to trust and cooperation between the companies have also been widely discussed in the literature. It is observed by Gibbs & Deutz (2007) that these two factors help to reduce the mental distance between the companies. Issues of trust were found critical while raising funds for IS projects. Pre-existing links were crucial during these fund raisings as already some type of interaction existed. Trust and co-operation need to be developed between firms before they are prepared to link their processes and involve in a IS network. Inter-firm trust is essential to establish alliances or contract among participants (Ehrenfeld & Gertler, 1997). Mutual trust among the companies was seen to be a guarantee for a continued input output relationship between the companies at Heidelberg industrial site (Sterr & Ott, 2004).

On the negative side, companies always worry about the proprietary information being exposed to other companies which may harm their business due to the lack of trust. One of the solutions could be that source of the waste could be kept secret until the buyer agrees to receive the waste (Lowe, 1997).

**Willingness to participate**

Greater willingness to participate makes it very easy to start the interaction between the companies. This interaction may not be about the waste exchanges but openness and willingness set the stage for such talks (Sterr & Ott, 2004).

**Information flow and Communication among the firms**

There must be sufficient information flow to develop waste exchanges to enable companies to involve in community business interactions (Gibbs & Deutz, 2005). Unfortunately it is difficult to obtain. Data about inputs and outputs of surrounding companies is costly to obtain. Countries such US where there is a strong sense of privacy, data sharing is difficult (Ehrenfeld & Gertler, 1997). Information sharing on the industrial wastes, products among the industries and development of industrial database will help to discover benefits of co-location (Lowe, 1997).

The significance of communication could be seen in Kalundborg where a small number of industrial decision makers were already in contact well before the first ever discussion on waste sharing network was observed. This was missing in the Heidelberg industrial site which could have played a crucial role in the faster development of industrial site (Sterr & Ott, 2004).
**Existing interaction**

Some sort of interaction, especially between at least two different industries on an industrial site is essential before the actual symbiotic links are discussed. A gradual intensification would help to implement such a change (Sterr & Ott, 2004).

**Transparency**

A key to the success of IS is transparency. A full degree of transparency in terms of material flows, discharges and discharge related issues should be shared with neighbours. This can take the industrial site on the path of cooperation to achieve environmental goals (Sterr & Ott, 2004).

**Marketing of the projects**

These projects need to be put on the table in a good manner. The advantages such as environmental benefits and economic benefits have to demonstrate to the community. This will help to gain financial aid and attract companies. This role has to be played by the coordinating community or organizing team (Lowe, 1997).

**3.5.3 Economic and Financial**

**Financial Awareness**

Corporate managers neither have time nor the ability to appreciate the commercial opportunities that IS can offer (Esty & Porter, 1998). Still a lot of people in the industry look for more traditional option compared to community kind of approach. The main reason is the nature of these solutions. They provide independence and control over the process. For instance, circular cooling systems instead of cascading (Chertow, 2004).

**Financial viability**

Each phase of the project should go through the test of economic success. A failed link will contribute nothing to the environment and society and rather end up damaging the EIP/IS concept (Gibbs & Deutz, 2005). Every link that was observed in Kalundborg IS was a result of a pure economic business deal. Adding to this, people from Kalundborg believe that business leaders of this industrial site have made ‘right thing’ for the environment in the pursuit of rational business interests (Ehrenfeld & Gertler, 1997). Therefore environmental impacts could be seen as a welcome side-effects for economic efficiency (Sterr & Ott, 2004). Therefore every link should be financially viable before it is undertaken. Each option should be analysed and examined before signing the deal (Lowe, 1997). Therefore, it could be stated that at the initial stages of any industrial symbiosis companies will do what serves their economic interests (Chertow, 2004).

**Cost savings and Market test**

Besides the larger picture of financial viability of the whole project, each link should provide cost savings. Either the cost of by product reuse should save a good amount of money rather than buying the virgin materials or the waste treatment costs should be high. Another unrecognized cost saving that can result from IS is the costs saved from avoiding the efforts
put to stay under the regulation, reduction in monitoring costs and future liability costs (Ehrenfeld & Gertler, 1997).

Since the Kalundborg was never really subsidized or financially added, there was no symbiotic link or output-input combination implemented that was not economically sound (Roberts B. H., 2004). Additionally each link requires substantial amount of investment. This investment should stand the market test, if it fails it jeopardises the future investments in IS (Chertow, 2004).

Ownership of infrastructure

Equal ownership of parties involved is the pattern seen in Kalundborg where there was no institutional intervention. In the planning method, the risks and costs could be divided into all potential participants in the exchange. Other possibility is to have a central institution with substantial equity, for example a bank or consultancy may play a role of developing the infrastructure and earning from the lavage created by such links (Ehrenfeld & Gertler, 1997).

Value of the waste

High value products such as sulphur, gases are much more easily tradable than the low value products such as water and waste water (Ehrenfeld & Gertler, 1997). Most of the times businesses want lowest cost and method to use lowest amount of resource. Therefore, sometimes, recirculating the low cost items and wastes is not economically beneficial. Though it has clear environmental benefits, due to the cheap value, it may not end up in the objectives of the company (Chertow, 2004)

3.5.4 Regulatory and Administrative

Policy intervention

Policy intervention may work as an enabling support in helping to identify IS opportunities and creating the appropriate conditions for inter-firm networking to take place (Pellenbarg, 2002). Environmental solutions in terms of IS are absolutely viable options but economically unattractive. Therefore, policy decision maker should ways push on emission reduction incentives or adjusting the prices of resources to make them economically viable (Ehrenfeld & Gertler, 1997). For example pollution control measures by Danish government changed the price system of several resources creating a need to implement different technical and management solutions (Sterr & Ott, 2004). Moreover, lack of appropriate policy might act as disincentive. For example in US, on one hand USPCSD was promoting waste exchange but on the other hand, RCRA (Resource conservation and recovery act) was stating that reuse, storage and disposal of hazardous waste. Low required the companies to match a particular predefined protocol and very strict rule on the waste composition making the companies disinterested in reusing the waste (Chertow, 2004).

Government's involvement

Kalundborg came to existence without having any help or intervention from the government. The failure of many sites planned under USPCSD to implement IS concepts could be seen as ‘no’ to government intervention. US government’s intervention in IS development has rather
hindered the process by over burdening it through high expectations like job creation and economic regeneration which go beyond environmental goals than benefitting the development (Gibbs & Deutz, 2007). Danish regularity body compared to US were seen to be more consulting, open and flexible. Instead of using command and control type of approach, they asked companies to propose their ideas to create waste sharing networks and helped them to reduce environmental impacts without harming their economic interests (Ehrenfeld & Gertler, 1997). Additionally, Lowe (1997) found out in his study that early involvement of government often slows down the process. Nevertheless, sometimes the appropriate legislation encouraged the symbiosis. For example, ban on use of organic waste for land filling in the Netherlands and Denmark. Now, sludge is used in power generation (Chertow, 2004).

In United States, standards were set in terms of pollution control technologies used by the companies. This hindered the innovativeness and cooperativeness of companies. Whereas, in Europe, the government was more inclusive and asked companies to come up with ideas to achieve a particular reduction goal (Ehrenfeld & Gertler, 1997).

**Presence of coordinating body and Recruiting for tenancy**

To solve coordination problems some form of common ownership or institutional management whose power is spread across the industrial region could help to bring the involved parties closer and enhance the chances of emergence of symbiotic links (Ehrenfeld & Gertler, 1997). Having a right institutional body in a region is among the most important elements of IS and this gap has to be filled by coordination bodies or consultancies (Marita, 2004). One of these examples was seen in Wales in Eco Dyfi project where local institution named Centre for Alternative Technology has led community controlled development of Eco projects (Gibbs & Deutz, 2007). In Kalundborg the Centre for Industrial Symbiosis was established to play this role. This created room for face to face contacts to achieve common interests (Sterr & Ott, 2004).

It is observed that tenant recruitment for a particular activity is difficult. Finding a suitable match is fairly a difficult challenge to accomplish. There must be a degree of flexibility to be given to the coordinating body to recruit appropriate tenants. Another idea is to recruit Scavengers and decomposers in the system who can act as cleaners of the resource and recirculate the waste (Lowe, 1997). In two UK projects, a coordinating body has been successful to find a suitable tenant to catalyse a particular recycling process. Therefore, over all, role of coordinating body seems important (Gibbs & Deutz, 2007).

**Role of key anchor tenant**

Absence of corporate culture to share and presence of strong culture of privacy could be mitigated by Anchor tenant who can lead the symbiosis initiative (Lowe, 1997). In Dutch EIPs role of anchor tenant was seen insignificant as all companies could play that role (Heeres, et al., 2004). Commitment by an anchor tenant to IS will determine the future needs of the project. Anchor tenant should take the initiative to undertake survey on what by – products and inputs other companies need (Lowe, 1997).
Presence of project champions

Each company should have key actors representing the symbiotic interests of the site. Their openness will lead to innovative spirit and create faster intercompany cooperation (Sterr & Ott, 2004). In Dutch EIPs local champion’s role was mainly played by coordinating body or local association rather than a particular champion (Heeres, et al., 2004).

3.6 Conceptual Framework

This section summarizes the whole literature review and based on this literature review two frameworks are built. Conceptual framework is way to represent concepts that have been extracted from the literature directly or indirectly and presented in a meaningful way. It is a method to put various concepts and factors in a sequential and logical way (Maxwell, 2009; Ravitch & Riggan, 2012). As a result of literature review of this study, one framework summarises various concepts explained in the literature and already existing studies related to the development of IS; and second framework represents the factors influencing the formation of industrial symbiosis.

It is evident from the literature that development of IS can happen in many ways. One theory argues that IS links form due to the economic interests and no external stimulus is required in the beginning (Ehrenfeld & Gertler, 1997; Desrochers, 2004) whereas, other theories argue that appropriate policy and institutional guidance will lead to the success of IS (Gibbs, et al., 2005; Gibbs & Deutz, 2005). A combination of both is also possible where EIP concepts are applied on an already well-established site containing some kind of bilateral interaction (Lowe, 1997; Marita, 2004; Chertow, 2007; Raymond & Howard-Grenville, 2012). Over all, all approaches mentioned in the literature have its own features, advantages and disadvantages.

The knowledge gap explained in the introduction section could be now further expanded in detail. From various articles in the literature we see that IS develops in a particular trend. Therefore combining the theories with their underlying features, a general development curve could be made. Each IS site could be situated on this curve based on its stage of development. This curve is shown in the figure 10. This figure is a resultant of all the planning and self-organizing examples and also from the examples of facilitated self-organizing. Basically the 15 articles investigated in the literature lead to this curve. Though useful information from each article has been used to visualise this figure, the main features are explained in the following paragraphs.

On the y-axis, development stages have been shown as a result from the study of Raymond & Howard-Grenville (2012). In their paper they clearly distinguish the development of IS in three stages; pre development, early development, and complex network development. On the other side, the use of main theories has been explained. According to Ehrenfeld & Gertler (1997), Gibbs & Deutz, (2005), Chertow (2007) and almost all the literature on IS states that the first stages of IS development are spontaneous or serendipitous or self-organizing and does not need any push. Whereas, in the complex network development stage of IS most of the time, planned approach or goal oriented approach is suitable as there is a requirement of investment, large scale projects and new infrastructure development. Interestingly, in the
middle of these two stages a combination of both planning and organizing is required (Raymond & Howard-Grenville, 2012). Therefore, on one side of the y-axis it is the stage of development and on the other side of the y-axis it is the use of two approaches and their combination is shown.

On the x-axis, the time is shown in the bottom. Time is a very relative aspect. In the literature, Gibbs, et.al. (2005) explain sometimes it takes several years to develop an IS link and it is very site specific. It can differ highly based on the local scenario. Therefore, a specific time in terms of years or decades cannot be given. On the top of the x-axis, expansion of boundaries of an IS site has been shown. i.e., spatial scale of the IS increases as the age of the IS in terms of time increases. This is extracted from the Baas & Boons (2004) article. They propose that first internal efficiencies are attained, followed by a regional learning and finally attaining a district or area wide IS development which can further expand to nationwide and global level.

The development of IS could be depicted by a double S-Curve as shown in the figure. At early stages serendipitous or spontaneous exchanges occur. These exchanges are mainly win-win situations economically for all participating companies and environmental benefits are later realised (Gibbs & Deutz, 2007). This growth takes off on its own and there is no extra efforts to be put (Chertow, 2007; Ehrenfeld & Gertler, 1997). After this there comes a long and slow process of development which lasts for a long time before the IS again takes off and new links are proposed replicating the old links or complex networks are planned with deliberate attempts (Raymond & Howard-Grenville, 2012). The time in between these two stages is important. It is called as early development phase (Raymond & Howard-Grenville, 2012). Few major Key Objective Indicators at each stage of development are shown in the figure. Pre-development stage is signified by the presence of kernels and precursors of industrial symbiosis. They are promising links which could be easily realised. Moreover, there could be some easily doable links which companies happen to quickly materialise which are called as low laying fruits (Chertow, 2007). After this, there is a stage at which uncovering of these interactions takes place. At which point the uncovering takes place is very case specific matter and debatable. In most cases in the literature the uncovering takes place after the low laying fruits have been picked up and the effects of these links are seen by industrial decision makers (Raymond & Howard-Grenville, 2012). The next stage is a tricky one where there is a long gap and a significant push is required by either IS enthusiasts, project champions or coordinating bodies within the industrial sites to promote various drivers and by supressing various barriers (Gibbs, 2003; Gibbs & Deutz, 2005; (Gibbs & Deutz, 2007). Therefore it becomes really important to understand the drivers and barriers at this stage and foster the IS development. Once IS is pushed to the next stage, for instance with the help of policy intervention (Lowe, 1997) or participation of a third party (Heeres, et al., 2004) or by marketing successful IS links (Lowe, 1997), it kick starts the next stage of development. In this stage, there will be periods of new entrants and die outs of industries followed by efforts to replicate the old exchanges and expand them to new boundaries (Baas & Boons, 2004). Later deliberate planning efforts are made to undertake challenging and complex projects to attain well-developed network of IS links (Raymond & Howard-Grenville, 2012).
It should be noted that quantifying or measuring the symbiotic development in terms of number of exchanges, or total amount of waste shared, or total amount of financial and environmental benefits gained is very difficult (Raymond & Howard-Grenville, 2012). The above diagram is a representation of different concepts highly discussed in the literature to understand the development of IS. The measurement cannot be done as IS development depends on each individual case. For example, if a site is as large as Rotterdam harbour area, more than 50 companies are involved (Heeres, et.al., 2004), whereas, the site such as Kalundborg only have 8 companies (Ehrenfeld & Gertler, 1997). They cannot be compared. Moreover, the ratio of number of companies to the amount of waste shared also differs greatly. Quality of the waste also differs based on the type of industries involved (Zhang, et al., 2009). For example, the presence of a pharmaceutical company can affect the type of wastes differently than presence of a steel company in the network.

At each point in time of the development of IS, various factors influence its growth. These factors have been addressed in the literature but not considering the stage of the development of IS. Factors act differently in different stages of development. Moreover, the spatial scale of IS also affects the factors and their influence (Roberts, 2004). These factor vary based on whether they are internal, internetwork or regional (Roberts & Greenhalgh, 2000). Finally these factors also vary in terms of the categories divided in the literature review; namely – Technical and Chemical, Management and Behavioural, Financial and Economic and Regulatory and Administrative. All these aspects on factors influencing the growth of IS have
never studied before. Therefore, the framework proposed below will be used to analyse these factors. This conceptual framework will be compared to the actual findings in the IJmuiden case and the stage of development of IJmuiden region. Based on its stage, these factors will play a significant role in future development of IS in this region. Many of these factors act as drivers and some as barriers. Therefore, understanding them is important and the framework as shown in the figure 11 provides a list of factors found in the literature. This framework will be used as an analytical framework to assess the factors extracted from the interview data from Atlas.ti. This is a unique method for analysing the factors and it has not been studied before in the literature.

Figure 11: Conceptual Framework for factors influencing development of IS
In this chapter, the main results obtained from the investigation of various companies located at IJmuiden conducted via document review and interviews are presented. This chapter begins with a description on how the data is collected from each company and what is the purpose of the data collection. Followed by this subchapter, a brief description of each participating company is given in the second subchapter including their production processes mainly focusing on water.

Third subchapter gives description of IJmuiden industrial symbiosis in four parts. This subchapter begins with data collection and analysis method used to come up with symbiotic links with schematic diagram. After this, in the first part all water flows at IJmuiden are presented. In the second part new ideas generated as a result of this thesis are shown. In the third part existing symbiosis are presented and, in the fourth part overall symbiotic view of IJmuiden combining existing and potential symbiotic links are given in a table.

The result from Atlas.ti analysis are presented in fourth subchapter in 3 parts. In the first part a list of factors irrespective of any category are presented based on the groundedness (importance). In the second part factors are presented in four subsections dedicating one section to each category namely; Technical and Chemical, Managerial and Behavioural, Financial and Economic and, Regulatory and Administrative. Finally in the third part all these factors are divided into drivers and barriers based on interviewee responses with respect to their categories.

“If you want to walk fast, you walk alone; if you want to walk far, you walk together”

– Ratan Tata

4 DATA ANALYSIS AND RESULTS

IJmuiden industrial site is situated in the Velsen Noord region of the North Holland province of the Netherlands. It is a small industrial site mainly located around 3 large companies – Tata Steel IJmuiden, Crown van Gelder Paper mill and Vattenfall-Nuon power plant. Additionally, there are several companies that are located in this region due to the presence of these three companies and to either act as complimentary businesses to these companies or use their by-products and recycle them. The IS study conducted on this site in terms of reduction in water consumption fetched usual results. These results are presented in this chapter.

4.1 Setting up the stage – Data Collection

After the brainstorming sessions with energy efficiency and environment specialists from the Energy department of Tata steel, a list of potential participant companies was made. This list is mainly based on the past experiences and the contacts already established with the surrounding companies by the managers of Energy department. As we have seen in the
literature, existing contacts play a crucial role in success of IS (Sterr & Ott, 2004). As the focus of this thesis is on water, the participant companies are selected based on the understanding and prior knowledge of each company’s production processes by the energy managers of Energy department. The members of the Energy department could suggest the names of the companies that could be involved in IS like study by their understanding of the water system in the surroundings. First contacts were made via emails (Jägers & Bol, 2015).

Table 1: List of Participant companies and the codes.

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Industry / Stakeholders</th>
<th>Candidate Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Linde</td>
<td>(UIC1)</td>
</tr>
<tr>
<td>2</td>
<td>Harsco</td>
<td>(UIC2)</td>
</tr>
<tr>
<td>3</td>
<td>Grontmij</td>
<td>(UIC3)</td>
</tr>
<tr>
<td>4</td>
<td>Aroc</td>
<td>(UIC4)</td>
</tr>
<tr>
<td>5</td>
<td>ENCI</td>
<td>(UIC5)</td>
</tr>
<tr>
<td>6</td>
<td>CVG papier</td>
<td>(UIC6)</td>
</tr>
<tr>
<td>7</td>
<td>Vattenfall – Nuon</td>
<td>(UIC7)</td>
</tr>
<tr>
<td>8</td>
<td>Flora Cultura</td>
<td>(UIC8)</td>
</tr>
<tr>
<td>9</td>
<td>WRK</td>
<td>(UIC9)</td>
</tr>
<tr>
<td>10</td>
<td>HHNK</td>
<td>(UIC10)</td>
</tr>
<tr>
<td>11</td>
<td>Schiphol</td>
<td>(UIC11)</td>
</tr>
<tr>
<td>12</td>
<td>Symposium</td>
<td>(UIC12)</td>
</tr>
<tr>
<td>13</td>
<td>Nalco</td>
<td>(UIC13)</td>
</tr>
<tr>
<td>14</td>
<td>Tebodin</td>
<td>(UIC14)</td>
</tr>
<tr>
<td>15</td>
<td>Tata Steel Procurement</td>
<td>(UIC15)</td>
</tr>
<tr>
<td>16</td>
<td>Tata Steel Environmental department</td>
<td>(UIC16)</td>
</tr>
</tbody>
</table>

Every company was made aware that to participate in this study, they have to share data regarding their water consumption, chemical composition of the required water, chemical composition of the discharged water and types of water they use. Each company was assured to keep the data confidential and without the permission and consent of each company data will not be disclosed. Invitations were sent to 17 companies in the beginning of February 2015. The invitation email has been given in the appendix. 16 companies responded and were looking forward to participate. A contact list was made based on interviewee assigned by each company. Interviews were scheduled in the month of March, April and first 15 days of May. As a result of this data collection, details of water quality, quantity of each company was received and approximately 40 pages of interview transcripts were made. Additionally, about 500 pages of different documents such as environmental reports, sustainability reports, water quality reports etc. were also analysed to extract relevant information. List of companies with codes of each contact person has been given in the table 1. The names of the candidates have been given with the transcripts in the appendix. For privacy purpose, the names have not been disclosed in the report.
4.2 Participating companies

In the following paragraphs, companies selected for this thesis are introduced in short. Note that the production process of each company and process details have not been included in this report. During the visits, a quick tour of each candidate industry was made. Based on this, their production process is explained very shortly. The focus is mainly on the water use and the process in which they use water and hence, in the following description, the production process is explained with water perspective.

Due to the length of the report, the diagrams and schematic representations of company’s production process have been given in the appendix.

Tata Steel is an iron and steel production company and the largest company in the region. It is an integrated steel production site. It has 10 work units spread across 750 hectares of land. It produces 7.5 million tons of steel every year mainly in strip products. All ten work units use water. The production process starts from Raw Materials Agglomeration plant. Iron ore, limestone, olivine and dolomite are heated and converted into sinters and pallets. At the Coke Plant, coal is converted coke. These three materials, coke, sinter and pellets are charged into the blast furnaces. In the blast furnace iron ore is reduced to liquid iron and slag. The liquid iron is transported to the Basic Oxygen Steel plant (BOS). BOS is charged with molten iron and steel scrap. Using the oxygen jet blown on the liquid iron, the carbon content of the liquid iron is reduced and molten steel is produced. This liquid steel is either transported to Direct Sheet Plant (DSP) or the Continuous Casting Plant. In the DSP, hot rolled steel coils are produced from liquid steel, whereas in the continuous casting plant, steel slabs are produced by casting process. The steel slabs from casting plant are transported to the Hot Strip Mill (HSM) where steel coils are produced from steel slabs by rolling process. The coils from the HSM and the DSP, can either be sent to Tata Steel Packaging (TSP) or they are sent to cold strip mill. In the cold strip mill the thickness of the steel is further reduced through annealing. The final treatment is coating during which steel is coated with tin, zinc, or organic coating (Walker, 2012; Tata Steel IJmuiden, 2015).

TSIJ mainly uses 6 types of water namely Sea water, brackish water, salt ground water, Wrk/Lek water, A Water and M water. Sea water is the biggest source of water at TSIJ. It does not cost anything. The costs involved for sea water are only pumping, cleaning and distribution costs. Major use of sea water is in once through cooling (UIC16, 2015). Brackish Water is the cheapest water type that is bought by TSIJ and most of it is used in slag granulation. The source of brackish water is staal haven. Lek/Wrk Water is the most widely used water type at TSIJ. It is used by almost all the work units. It is bought from Water transport masstschappij rijn – kennemerland (wrk), hence the name wrk water. It is also called Lek water as it is taken from Lek from Nieuwegein from south of the Netherlands (UIC09, 2015). Lek/wrk water is used in almost all the activities like circulation cooling, gas cleaning, quenching etc (UIC15, 2015). Salt ground water is another cheap source of water at TSIJ and the specialty of this water is, it is available at 14°C throughout the year. It is mostly used in hot strip mill and cold mill. A water is special water which is produced from Lek water after passing through the ion exchanger. M water is the best quality water...
available on TSIJ which results from the A water after going under mixed bed filter treatment process. Before these two types of water are produced, G water is made from Lek water which is the result of softening of Lek water commonly known as demi water. A water and M water are the costliest type of water used in IJmuiden and M water costs highest. A water is mostly used to produce M water, apart from that A water is used in circulation cooling of blast furnace. M water is mainly used to produce steam (Groeneveld, et al., 2005).

This is a paper company situated in the Velsen Noord. It has a production capacity of 225,000 tons of paper per year. The paper production process starts with pre-treatment of the chemical pulp fibres suspended in water. To maximise the strength of the final product, the pulp fibres are cut and fibrillated. The refined product is blended to a homogeneous stock and diluted. Additives and fillers are added to the stock. The stock passes through the cleaners and pressure screens for thorough cleaning. The clean stock is pumped into the wet end of the paper machine where the paper web is formed. The stock is evenly distributed by the head box on a fast moving, endless wire. In this section, most of the water is removed from the paper web by gravity and vacuum forces. The paper web with a moisture content of about 80% then enters the press section. As the web passes through press section, the rolls and felts apply considerable pressure to it, reducing its moisture content to 55% before it enters the dryer section. At dryer section remaining water is removed as the web passes over the steam heated cylinders. About two third of the way through the dryer section, the paper is almost completely dry and enters the film press. In the film press, diluted starch and other additives are applied to the paper to create the surface characteristics required. The paper is subsequently dried to the required moisture content. Finally, the paper passes between the rolls of the calendar to create the required thickness and the smoothness (Crown van Gelder, 2015). CVG Paper Company only uses two types of water. One is cooling water from the sea canal and wrk/Lek water. On the industrial region of IJmuiden under study, CVG paper mill uses the second highest amount of fresh water after Tata steel (UIC06, 2015).

There are two Nuon plants, one in Velsen Noord and the other on the Tata Steel site which is called as IJmond 01 plant. Both plants are combined cycle power plants. Basic working of a combined power plant is based on the principle that they use two power generating machines—a combustion turbine and a steam turbine. The cycle begins with supplying cool air into the compressor. Hot compressed air then enter the combustion chamber. Here this hot air is mixed with combustibles for example natural gas or other rich gases. The reaction between hot air and combustibles gases are created. These gases are directed towards turbines which spin and drives the generator creating electricity. The electricity generated is transformed to the grid by means of a transformer. Here a conventional simple cycle electricity generation ends. But in combined cycle, the hot gases generated in the combustion chamber are captured in a recovery unit. Here, inside the boiler, gases heat up water. Water turns into steam and this steam is then sent into the steam turbine which sets the steam turbine into motion. The turbine is coupled with a generator which creates electricity and it is added to the grid. The steam is then recovered in a condenser and the cycle repeats (Wartsila, 2015). At Nuon, mainly, sea water for once through cooling and demi water for steam generation is used. This
dem water is created by Lek/Wrk Water. Nuon has its own demi plant in Velsen and creates its own M quality water for steam generation (UIC07, 2015).

ENCI is a conventional cement production company which uses slag produced from Tata steel, a major by-product of a steel industry to produce cement. The raw materials, clinker, gypsum and additives are charged into a dump hopper. A conveyer belt carries this material into the crusher and after crushing, the material is stored into the silos. The crushed material is then extracted from feeders in desired quantities and fed into the ball mill hopper. Cement milling process takes place inside the ball mill hopper. Feed rate of the mill could be controlled so that the fineness of the cement is controlled. Then this cement carried out and stored into silos and blended through the aeration assemblies to ensure consistent and high quality Blended Cement. This cement is ready for packaging and transport (Chanderpur Works, 2015). Most of the water is used for cooling purposes for the bearings and Lek water is used for this purpose. ENCI does not have any treatment plant and they discharge the water directly. According ENCI, they discharge almost same quality of water as they received (UIC05, 2015).

Linde is a gas company situated on site and mainly provides oxygen gas to Tata steel. The production of oxygen is based on the separation of air into its components. This cryogenic separation technique was developed more than a century ago by Carl von Linde. In an air separation plant compressed air is cleaned and then compressed again. Thereafter, the compressed air is cooled down to very low temperatures. It will be then compressed again in order to make the air and liquid separation and distillation into oxygen gas, among others (Linde gas, 2015). Major usage of water is for cooling purposes with no contact with actual processes. Lek water is used for this purpose and Linde uses circulation cooling system. The discharge water is added to Tata Steel waste plant (UIC01, 2015).

Harsco is a metal recovery unit situated at Tata Steel site. It has an old history of partnership with Tata steel. They recover metal for Tata steel from past 30 years almost. The process is relatively simple. After screening of slag materials a magnetic separation process ensures the highest level of metal recovery. Through further crushing and screening, the scrap can be upgraded to high-Fe material for use as coolant scrap in the mill. The residual slag is sold as an aggregate for cement factory, road building, fertilizer etc. (Harsco, 2015). They mainly use Lek water to cool the pits when the molten slag is poured. They have circulation cooling but 1/3 of the water is evaporated and for every cycle additional quantities are added (UIC02, 2015).

Indaver, popularly known as Aroc on the IJmuiden site, is a company that makes and cleans pickling acid for the Cold Strip Mill of Tata steel. It’s a hydrochloric regeneration plant with an annual capacity of 163,500 tons of hydrochloric acid (about 500 tons per day), processed for Tata Steel in a continuous process. From pipelines and trucks, over contaminated hydrochloric acid is brought to Aroc and in return the clean regenerated version is sent back to Tata steel. It’s a complete loop closing. Hydrochloric acid is used to remove rust from steel plates at cold rolling (Labvision, 2015).
The process is as follows. The contaminated hydrochloric acid is oxidized in the roasting furnace. This generates regenerated iron oxide and hydrochloric acid, which can be reused at Tata Steel. A small portion is also sent to pigment industry (Fe2O3, hematite is very fine powder that is suitable as a dye). AROC built the roasting oven in 2001, when an agreement was signed with the former Corus to process the hydrochloric acid for 15 years. Because, acid loss occurs both in the pickling as well as in the regeneration process, Aroc also mix it to the desired spec of 18%. Equally important is the process control. After all, it is important to regenerate as efficiently and cheaply as possible. A close eye is kept using the chemical analyse process on how the process works in almost all areas of the plant (Labvision, 2015). Indaver uses only Lek water in their process and interestingly they already reuse A water from Tata steel in suppression processes. Therefore there is already a symbiotic link (UIC04, 2015).

Hoogheemraadschap Hollands Noorderkwartier (HHNK) is a waste water treatment plant for the Berverwijk region. They treat domestic as well as industrial water if the industries release it in sewer. They discharge approximately 17.5 million m3 of effluent water per year. Visit to this treatment plant was not made, the officials from HHNK visited Tata steel and the discussion took place at Tata Steel Energy Department (UIC10, 2015).

Waternet supplies more than 90 million cubic meters of water annually to the households and business facilities in and around Amsterdam. Water is produced at two sites. One in Leiduin (70%) and Weesperkarspel (30%). The main source for water produced in Leiduin with river water from the Lek Canal, and this is supplemented by natural dune water. The pre-treatment of the river water takes place in Nieuwegein, after which it is transported to the Amsterdam water supply dunes (AWD). There, the post treatment takes place. The post treatment takes place in 14 steps: After intake from Lek water, coagulation process is carried out (ferric chloride is added) where suspended particles settle down with flocculate and sink to the bottom of large basins. This followed by rapid sand filtration wherein, remaining suspended particles are removed. At this stage the water becomes good enough for industrial use. This water is sent to PWN which is a water body in the North Holland region and it in term supplies water to the industries. Remaining water, is subjected to further treatment in 12 steps and sent for domestic use. This process is not explained in detail as drinking water production is not the central focus of this study. The capacity of water supply is 150 million cubic meters of water. 70% of it is approximately used for supply to Amsterdam for domestic purpose and 30% to PWN for industrial customers (Waternet, 2015).

Tabodin is a multidisciplinary consultation and engineering firm. This firm is situated in the Velsen Noord region. They are not direct participants of the industrial network but it gives several engineering solutions related to water cooling towers and engineering solutions to Tata steel and other companies around (UIC14, 2015). Therefore, their perspective was found to be important to this study and it was included in the interviewee list (Korevaar, 2015).

Grontmij is another consultancy that was included in this study. They are engineering and design consultancy firm having expertise in oil and gas,
energy and water solutions for sustainability. They have been already consulted once by Tata steel for the appropriate policy solutions to tackle the water case with Tata (UIC03, 2015).

Nalco is major water consulting company in this region. It gives technical and chemical solutions to deal with industrial water (Nalco, 2015). They are involved in testing of water for various effluents of Tata and how the water could be reused at Tata. Though the technical in-depth knowledge is not the focus of this thesis. In future, when each link that is found out has to be evaluated in all technical and chemical aspects, they can play an important role (UIC13, 2015).

Anteagroup is also a water and environmental consultancy company. The consultant from this company Toon Boonekamp visited Energy department of Tata and was introduced to this project idea. He was not interviewed but he provided a lead to include Harsco in this study as they use water for the cooling of pits on the plant situated on site (Boonekamp, 2015).

Schiphol airport was initially not included in this study. After one of the interviews, it was found out there is also a possibility of connecting Schiphol to this network as Schiphol is planning to extract cold from the Lek/Wrk water that is being transported to PWN for cooling purposes of the building and then send it over to north Holland region (UIC09, 2015).

Floricultura is a horticultural company situated in Hemskerk region around IJmuiden and they breed tons of young Orchids. As a horticultural company they use a lot of water for trees and hot water to regulate the temperature inside the green houses (Floricultura, 2015).

Now that all these companies have been introduced, the location of these companies according to the spatial scale and relative distance from the Tata Steel has been shown in the figure 12 below. Note, that distance is not according to the scale. In general, the companies have been only divided into their respective spatial category and direction keeping Tata Steel at centre.

On IJmuiden site, Aroc, Nuon’s IJmond plant, Linde gas and Harsco are situated. Aroc is situated in the north part of the IJmuiden site where as Nuon’s IJmond plant, Linde gas and Harsco are situated in the southern part. In the surrounding region, ENCI, CVG papier, HHNK and Nuon’s second plant are located on the southern side of Tata Steel whereas, FloriCultura and other horticultural community has been situated on the north side of Tata Steel near the Hemskerk region. Further, Waternet and Schiphol are situated considerably far from the region in the Amsterdam province. Regarding the distances, from the google maps, it could be approximated that the plants on site are in the range of 0.5km to 1.5km distance from each other. Plants in the surrounding are from 1.5km to 2.5kms and Schiphol and Waternet are 35km to 40km distance.

Another point to note that according experts from environmental department (UIC16, 2015) the actual distance while installing the pipelines greatly differs from the direct distance. Houses, already existing underground infrastructure and other aspects increase the distance up to 30%.
Figure 12: System representation in terms of spatial scale

Figure 13: IJmuiden industrial region from Google maps
4.3 IJmuiden Industrial Symbiosis

So far in this chapter, an overview of companies and their activities is shortly presented. In this section results obtained from the investigation of IJmuiden site are presented. These insights are gained by all three means as explained in the methodology: observation, document review and interview data analysis (Yin, 2003). During the visits, candidate from each company was interviewed focusing on water consumption at their company. Interview involved both water usage related questions and IS related questions. At the end of the interview, the company was asked to share relevant data in terms of either reports or electronic sources. This step was a bit challenging as consistency in the data received was missing. Moreover, a reliable symbiotic link can only be proposed after the analysis of hourly data and hourly discharge quality of the water from each plant. To receive such detailed data at the beginning of this study is very difficult and it is not the main focus of this study. The given time frame of the thesis was also a concern. The main focus of the study is to locate the potential options and create a water data inventory for further analysis as specified in the methodology chapter with appropriate justification.

In the schematic diagram below the data collection and analysis method to come up with IS links is shown. First data was collected in terms of transcripts and interview recordings, followed by the documented data on water consumption and water qualities. Ideas generated during the interviews and the data collected were used to conduct a manual input output matching and the links are visualised in the upcoming sections.

![Data analysis steps to locate potential IS Links](image-url)

*Figure 14: Data analysis steps to locate potential IS Links*
Water, the focus of this thesis is a cheap resource in the Netherlands. The buying cost of industrial water is 0.11 euros per cubic meter. This water is produced by Waternet. They are the producer of drinking water and industrial water in Amsterdam and north Holland region. In the IJmuiden region, Waternet supplied water to PWN and distributes to various household and industrial customers (UIC09, 2015).

Figure: 15: WRK water supply (Waternet, 2015)

In 50’s there was only one drinking water company in Amsterdam. It use to take water from the duin area to supply to Amsterdam region. Later it was found out that taking ground water continuously without replenishing it back to the duins can create drought like
situation. Therefore, taking water from elsewhere in the Netherlands and adding back that water to the duin area was the main purpose why Waternet was established. Therefore an agreement was made between Amsterdam and province of North Holland to bring water from some place, treat it and add it to the duin area (UIC09, 2015).

In light of this, WRK thought, not only households but some other players in the region might also want water (pre-treated/half treated). Those were mainly two. Tata Steel (former Hoogovens) and CVG papier. Therefore, since then the main customers of Waternet/PWN are four: CVG, Tata Steel, North Holland and Amsterdam. The majority of the water was decided to be brought from Nieuwegein (90%) from the river Lek (hence the Lek water name). In 60’s second pipe system was made from WRK to bring some more water. Finally in 80’s third part was made from the north IJsselmeer Lake. In total, Waternet system is designed to produce 259 mil m3 per year. On an average annual production is approximately 150 mil m3. Out of this 150 million m3, Tata steel consumes approximately 32 million m3 water (Groeneveld, et al., 2005), CVG papier, 3.1 million m3 and remaining companies use relatively very law (UIC06, 2015). Each company’s consumption could be seen in the table 2. It represents annual consumption of each company situated at IJmuiden.

<table>
<thead>
<tr>
<th>Name</th>
<th>Types of Water</th>
<th>Amount (mil m3)</th>
<th>Discharge (mil m3)</th>
<th>Receiving Quality</th>
<th>Discharge Quality</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tata Steel</td>
<td>Sea Water</td>
<td>154</td>
<td>153</td>
<td>-</td>
<td>Not reusable economically</td>
<td>Once through cooling</td>
</tr>
<tr>
<td></td>
<td>Lek water</td>
<td>24</td>
<td>20</td>
<td>Lek water</td>
<td>Not reusable for process purposes</td>
<td>Cooling, quenching, scrubbing etc.</td>
</tr>
<tr>
<td></td>
<td>Brackish water</td>
<td>21</td>
<td>10</td>
<td>-</td>
<td>Internal reuses are possible</td>
<td>Slag granulation</td>
</tr>
<tr>
<td></td>
<td>Salt ground water</td>
<td>0.66</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>cooling</td>
</tr>
<tr>
<td></td>
<td>Demi water</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Scrubbing, pickling, steam production</td>
</tr>
<tr>
<td>CVG papier</td>
<td>Sea Water</td>
<td>10.7</td>
<td>10.7</td>
<td>-</td>
<td>Not reusable economically</td>
<td>Once through cooling</td>
</tr>
<tr>
<td></td>
<td>Lek water</td>
<td>3.2</td>
<td>2.9</td>
<td>Lek water</td>
<td>Reusable</td>
<td>Paper making</td>
</tr>
<tr>
<td>Nuon IJmond</td>
<td>Sea water</td>
<td>15.4</td>
<td>15.4</td>
<td>-</td>
<td>Not reusable economically</td>
<td>Once through cooling</td>
</tr>
<tr>
<td></td>
<td>demi water</td>
<td>0.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Steam production</td>
</tr>
<tr>
<td>Nuon Velsen N</td>
<td>Lek water</td>
<td>0.08</td>
<td>-</td>
<td>Lek water</td>
<td>-</td>
<td>Demi water production</td>
</tr>
</tbody>
</table>
DATA ANALYSIS AND RESULTS

<table>
<thead>
<tr>
<th>Company</th>
<th>Water Type</th>
<th>Demi water</th>
<th>Stream production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linde</td>
<td>Lek water</td>
<td>0.5</td>
<td>Discharged via Tata Steel, Cooling</td>
</tr>
<tr>
<td>Harsco</td>
<td>Lek water</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>Aroc</td>
<td>Contaminated acid water</td>
<td>0.3</td>
<td>Discharged via Tata Steel, Regeneration of pickling acid</td>
</tr>
<tr>
<td></td>
<td>Lek water</td>
<td>0.14</td>
<td>Discharged via Tata Steel, Incineration column</td>
</tr>
<tr>
<td></td>
<td>A water</td>
<td>0.09</td>
<td>Discharged via Tata Steel, For washing the pickling acid</td>
</tr>
<tr>
<td>HHNK</td>
<td>Waste water</td>
<td>-</td>
<td>Reusable</td>
</tr>
<tr>
<td>ENCI</td>
<td>Lek water</td>
<td>0.2</td>
<td>Reusable, Cooling</td>
</tr>
</tbody>
</table>

Additionally, in the table above, the quality of water is also shown indicatively. Due to the data privacy, only indicative figures of each company’s discharge water quality is given. Exact content of discharge water could be found in appendix.

In the table if the field is empty, the water is lost in evaporation losses and make up water is added to the remaining water. Demi water is usually produced from Lek water at Tata Steel and Nuon Velsen Noord plant. The amount of demi water has been shown separately in the above table whereas the actual Lek water received is the sum total of Demi water and Lek water. For example, total Lek water used at Tata Steel is 32 mil m³, i.e., 24 mil m³ in Lek water form and 8 mil m³ in Demi water form. To get into further detail, a diagram of exact M water and A water production has been shown in the appendix. Most of the time, the receiving quality of water is Lek water. One of the major issues that has been encountered during the data collection is the required quality of water. There are some indicative figures such as chloride content should be less than at least 200mg/l and the scale index should be less than 2.5. But exact quality requirements needed to reuse the water are not specified by the companies involved. During the interviews, each company was requested to share the required quality of water. Respondents answered this question saying, we need Lek water quality. i.e., Lek water composition. The composition of Lek water has been given in the appendix. Composition of each company’s discharge water qualities have also been given.

4.3.1 Water Flows and Reuse options based on the Data Collection and interviews

In the above table, we can see the consumption of each company and the quality of water they use for various production activities. In this section, based on the data collected, different flows are analysed and reuse options are evaluated; both, already studied reuse options and new reuse options.
It is important to note that Tata Steel is a huge consumer of water compared to any other industry in the surroundings. Just in terms of total amount of water, HHNK is a largest source of waste water that could be used at Tata Steel. It will make up to 60% of the total consumption of Tata Steel if reused. Currently no such infrastructure exists between these two companies. Waste water from CVG papier can also make up to 10% of the total Lek water consumption. This possibility also could be analysed further in detail. Discharge water from HHNK and wastewater from CVG papier have convincing qualities compared to the Lek water quality (UIC16, 2015). It could be said that there is approximately 20% higher content in these discharge waters compared to the Lek water quality. During the interviews, environmental managers at Tata advocated that it is reusable (UIC16, 2015). For example, water from HHNK has chloride content varying between 80mg/l to 150mg/l whereas, chloride content in Lek water varies between 50mg/l to 80mg/l. An in-depth analysis is required which involves collection of appropriate data hourly or daily to access reuse possibilities. Scaling factors, corrosion and effects on pipelines and infrastructure have to be studied in detail before drawing any conclusions.

Reuse of discharge water from Tata Steel elsewhere has been already studied in the Royal Haskoning report (Groeneveld, et.al., 2005). Though this study was targeted to reuse the water internally, it gives insights about discharge quality of water from the waste plants and their reusability. One of the major possibilities proposed in that report was to use discharge water of Tata Steel BIO2000 treatment plant for slag granulation. This could lead to the savings of about 2 mil m3 of Brackish and Lek water combined. This option was overruled as the requirement of ENCI is very high and chloride content of this water is not within the permissible limits to maintain the quality of cement. Moreover, the waste water has effluents which can affect the exhaust air quality. Though the exact study of this has not been conducted. Another possibility is to bring waste water from the Basic Oxygen Plant (BOS) which has relatively very low contents of chlorides compared to BIO2000 waste plant. Despite of this, distance was considered an impediment in this case. The water has to be brought from BOS plant to slag granulation plant, bringing extra costs of pipelines and pumping. Moreover, in environmental terms, the savings in water contradict with the use of electricity for pumping. Therefore, this option was also ruled out.

4.3.2 Visualization of water symbiotic links at IJmuiden

While conducting the interviews, one of the main purposes to keep them unstructured was to keep room for all kinds of inputs. Based on this, the few minutes of each interview was spend on discussing the possible links and ideas. Candidates came up with several new ideas and ideas that are being already discussed between the companies. The combination of the ideas suggested in the interviews and the data collected from the participating companies, manual input output matching study was conducted and the following links are visualised. These ideas are represented in the diagram below (fig 16). As in this thesis water usage reduction is in the focus, water related links are mainly explored. Nevertheless, during the investigation and interview stages, other ideas were also considered. Overall, a bird’s eye view on how a symbiotic network of IJmuiden to deal with water, other water related resources and residues has been shown in the figure 16.
The grey dull lines show the current flow of water around the industrial area of IJmuiden and Velsen Noord. Each flow has been labelled with the type of water being supplied and the amount that is being used (K = thousands, M = million cubic meters). As explained in beginning of this section, WaterNet takes water from the Nieuwegien from the Lek River and transported Amsterdam region for treatment. After initial treatment, 4 pipelines carry this water to PWN in the north Holland province. PWN distributes this water to various industrial customers and domestic customers (WaterNet, 2015). The consumption of each industrial customer of PWN has been shown in the figure in grey lines and it has already been given in table 2. For instance, Tata uses 32 mil m³ of water each year. Therefore in the diagram, the non-highlighted line pointing towards Tata steel is labelled as 32m. It is to be understood that since the line is directly off shooting from PWN line, its Lek water. Other specialty waters like demi water have been labelled so in the bracket. The lines labelled with blue colour and continuous black lines are the links that are already being thought of. There have been few meetings and feasibility studies on those links. Links that have been shown in broken lines with blue label were found during the investigation of this thesis.

Figure: 16: Ideas for Industrial symbiosis related to water and related residues

Over all, there have been meeting about district heating network using the waste heat from Tata and the initial talks require approximately 20MWt in terms of hot water. Tata Steel and Nuon Velsen power plant together can provide total requirement of CVG papier
company’s steam requirement. It is about 80tons/h. Nuon and Tata steel can contribute 40 each to the network. ENCI also requires steam of about 17MWt which could be provided by Tata Steel. There have also been talks about using waste water from the Beverwijk treatment plant of HHNK which fulfils 60% of the total requirement of Lek water of Tata steel. Also, there have been talks about bringing sludge produced at the treatment plant for drying at Tata Steel using Tata Steel’s waste heat (UIC10, 2015).

During this thesis it was found that approximately 500,000 of Lek water used by Harsco could also be replaced and interestingly, Tata steel is the provider of Lek water to Harsco. Therefore, from the Tata Steel, for instance, direct sheet plant or water which is used for cooling purposes could be reused. This possibility has to be investigated further (UIC02, 2015). One more possibility is to use CVG papier’s waste water at Tata. It is approximately 10% of the total consumption of Tata but this water is considered, quality wise to be very good (UIC09, 2015). Aroc is already looking for a replacement water at their last basin column (refer the diagram in appendix). They already did a study on using rinse A water in the basin column also but it was not successful as there was a lot of HCl in the exhaust which is not permissible. Tata can provide some quality of water which is less in chloride content to Aroc. This possibility also could be studied further (UIC04, 2015). ENCI discharges water approximately 200,000m3 per year without treatment assuring that the waste water quality of ENCI is good enough for reuse and it could be directly added back to the pipelines. This could also be considered as a potential water reuse opportunity.

Another interesting possibility that has been seen as a good potential example of water symbiosis is the link between Waternet and Schiphol. A business case has been already made to extract cold from the WRK water before it flows to the PWN. This cold is stored underground and used during the summers. The business case was negative due to two reasons. First, the main technical problem was that the average temperature that Schiphol requires is 8 °C whereas, the current average temperature of Lek water is 11 °C and there are already existing air-conditioning systems at Schiphol. Second, the quantity of cold extracted from WRK water is huge compared to Schiphol’s requirement. Therefore an additional proposal was made by few managers as Schiphol to involve data centres around Schiphol to use this cold to make the business case attractive. This new proposal is still in the idea phase.

In the figure above, an overall picture of what could be achieved on water and water related residues could be visualized. By representing these links doesn’t mean that these links are either economically beneficial or win-win situation of IS can be realized. Financial calculations including the cost of pipelines and other infrastructure has not been included in this study. Nevertheless, these links could very well be the prospectus of what could be achieved with IS mind-set. A thorough economic analysis, technical and financial feasibility analysis must be done before coming to any conclusions about these links. Considering the fact that this thesis is the first ever attempt to implement IS concepts at this industrial region, this could be considered as starting point. As Gibbs & Deutz (2007), in their article on reflecting on implementation of IE techniques said, each link takes almost 25 years to get developed, one should consider the above representation as only a starting point.
4.3.3 Existing material exchanges at IJmuiden

There exists already a good amount of waste sharing among the companies situated at IJmuiden. Though there have been no studies so far to look into this region in IS perspective, this site has a very good structure of IS. Though the focus this thesis was to track the water flow and collect data regarding water, during the data review and interviews, these links were identified which exist from a long time.

Steel company produces slag as a major by – product. A company like Tata steel produces huge amount of slag every year. Most of it is bought by ENCI which has the capacity to process 1.4 million tons of slag per year. This is the oldest bilateral interaction among the two companies since 1931 (ENCi, 2015). Same holds correct for Harsco as well. The relation between Harsco and Tata steel is 15 years old and Harsco helps to recover metal from blast furnace slag. The metal recovered goes back as feedstock whereas slag is used in asphalt and cement factories. Tata steel provides approximately, about 65 pots per day with approximately 50 tons of slag. This makes it almost one million tons of slag per year (UIC02, 2015).

Aroc (Indaver) produces mainly 2 products. Fe2O3 and HCl from the contaminated pickling acid of cold strip mill from Tata steel. They both are sent back to Tata steel for pickling the slabs at cold strip mill and Fe2O3 at steel making. Additionally there is already A water (rinse water of Cold strip mill) is used by Aroc. It has a higher chloride content which is good for acid making process. They use in total 1/3 of the total A water from the pickling line. It is approximately 90,000 m3 per year (Tata Steel IJmuiden, 2015). This is because Aroc uses HCl 30% as a concentrate to make pickling acid which is made for the pickling line. It has to be reduced to HCl 18%, for which Aroc needs makeup water. The water from pickling line serves the purpose (UIC04, 2015).

Finally, The IJMOND 01 plant of Nuon, which is situated at Tata Steel site is completely fired by work arising gases of blast furnace and coke oven. It is approximately 676,692GJ per month. Additionally axillary steam is supplied by Tata steel to start up IJMOND 01. Moreover, M water is shared by Tata steel to produce steel at this plant. This is approximately 165,000 m3 per year. Additionally common facilities are shared. Nuon uses pumping station 3 of Tata steel to pump sea water for cooling purposes. They pump approximately 15.4 mil m3 of sea water per year. Very limited amount of Lek water is also used at IJMOND 01 plant which is sent to treatment plant of Tata steel (UIC07, 2015). Finally, Linde produces Oxygen, Argon and Nitrogen for basic oxygen plant of Tata steel. In term Tata Steel provides steam to Linde. The total steam send to Linde is approximately 20,000 tons per annum (UIC01, 2015).

Therefore we can see there are already several interactions that exist already at IJmuiden. All these interactions are mainly due to economic interests and high value wastes such as work arising gases, A water which is high quality water, steam and slag. The supporting documents are all given in the appendix.
Overall, the new links are early indications of moving towards a circular economy from linear economy from all these companies and companies are opening up to look for opportunities to utilize their waste in an eco-friendly way making IS one of the important approaches.

### 4.3.4 Complete representation of existing and new links at IJmuiden

In the table below, all types of interactions present at IJmuiden have been listed with relevant materials and quantities. Already existing links are given in black whereas, new potential links are given in green.

<table>
<thead>
<tr>
<th>Name of the companies</th>
<th>Name of the resource/residue/waste</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Exchanges</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tata Steel – Aroc</td>
<td>Rise A water</td>
<td>90,000 m3/year</td>
</tr>
<tr>
<td>Tata Steel – Aroc</td>
<td>Rinse pickling acid</td>
<td>163,000 tons/year</td>
</tr>
<tr>
<td>Tata Steel – IJmond Nuon</td>
<td>M Water</td>
<td>160,000 m3/year</td>
</tr>
<tr>
<td>HHNK – Tata Steel</td>
<td>Waste Water</td>
<td>17.3 mil m3/year</td>
</tr>
<tr>
<td>CVG Papier – Tata Steel</td>
<td>Waste Water</td>
<td>2.9 mil m3/year</td>
</tr>
<tr>
<td>ENCI – Tata Steel</td>
<td>Waste Water</td>
<td>200,000 m3/year</td>
</tr>
<tr>
<td>Tata Steel – Harsco</td>
<td>Waste water from DSP plant</td>
<td>500,000 m3/year</td>
</tr>
<tr>
<td>Tata Steel – Aroc</td>
<td>Waste water of column incineration</td>
<td>140,000 m3/year</td>
</tr>
</tbody>
</table>
### DATA ANALYSIS AND RESULTS

| **WRK – Schiphol – Data Centres** | **Cold storage facility at Schiphol** | 275TJ |
| **Waste Heat** | | |
| **Tata Steel - District heating** | **Hot water** | 24MWt |
| **Steam** | | |
| **Tata Steel - Linde** | **Excess Steam** | 20,000 tons/year |
| **Tata – Nuon – CVG Papier** | **Steam network** | 80tons/hour |
| **Tata Steel - ENCI** | **Steam** | 17MWt |
| **Work Arising Gases** | | |
| **Tata Steel – Nuon IJmond** | **Coke oven and Blast furnace gas** | 676,692GJ/month |
| **Shared Facilities** | | |
| **Tata BIO2000 treatment plant** | **Linde** | 500,000m³/year |
| **Tata AZI treatment plant** | **Aroc** | 317,900m³/year |
| **Tata Steel Pumping Station 3** | **Nuon IJmond – Sea water** | 15.7 mil m³/year |
| **By-products** | | |
| **Tata Steel – ENCI** | **Slag** | 1.4 mil tons/year |
| **Tata Steel – Harsco – Tata Steel** | **Slag metal recovery** | 1.2 mil tons/year |

Please note that the links shown in green are not yet existing and they are being discussed. Some of the links have been through the stage of business case development but have been not yet materialised. This typically indicates towards the gap that has been found in the literature review. It is the early development phase. At IJmuiden already few links are established. These links are not deliberate steps taken under the IS study. These links are result of mutual benefits and financial attractiveness of these links. New links proposed above, and the links already being discussed are yet to be implemented. Therefore, as explained in the knowledge gap, it is important to understand factors that influence the implementation of IS at this stage of development. In the following section, results obtained from interview analysis are given.

### 4.4 Interviews analysis and results

This analysis elucidates how firms participated in this thesis think about implementing IS at IJmuiden to tackle the issue of usage of water. Participants are mostly designated as Environmental and Energy managers/consultants of their companies, and most of the time expect one or two exceptions are water specialists of their respective industries.

#### 4.4.1 Interview protocol and Atlas.ti

Out of 16 interviews, 12 were electronically recorded and 3 were not recording due to noise and walk and talk situations. Symposium, its proceedings and summary of each presentation and workshop is available online. Interview with Toon Boonekamp from Anteagroup is not included due to, firstly, the lack of complete information and total time of the interaction, second, the discussion was mainly about Harsco and reuse of water at Harsco. Later in the data collection period, Harsco was separately visited and Environmental manager from Harsco was interviewed. Interview procedure of each candidate was simple. In most cases interactions were informal and unstructured. Nevertheless, basic structure of the interviews was as follows –
First, an introduction to the thesis was given. This made the interviewees familiar with the study that is being conducted. Note that prior to the visit, during the invitations, a short description of the thesis and a detailed thesis proposals were sent to each company. Most of the candidates didn’t read it due to their busy schedule making it necessary to explain the thesis in the beginning of the interview. After the introduction, basic set of questions were asked to start the conversation. These questions were mainly related to qualities, quantities and temperature of the water their company uses. Additionally they were asked to share their views on water reuse and sharing water with other surrounding companies. After this, the conversations were unstructured and participants were encouraged to bring as many factors as possible to the surface which they think are important to establish IS links.

Once the interviews were done, the recordings were heard carefully and transcripts were made extracting useful information from them. These transcripts were then uploaded on Atlas.ti software for analysis. Steps in Atlas.ti have been explained in the methodology chapter. Once the transcripts were uploaded, each transcript was coded to extract factors. For instance, if a candidate says that, “here in Netherlands, we stand one fit inside the water. Therefore, water is not scarce resource” (UIC14, 2015). This is coded as scarcity of resource or value of resource. This way all transcripts were coded. After each coding, interrelation between each code was also coded. It was important to see if interviewees think that some factors influence the other factors and therefore, interrelation between these codes were also coded. These interrelations are labelled as associated with, cause of or a part of.

Unification and grouping is applied wherever necessary. Initially the total number of codes extracted from the interview transcripts were 96. Creating a network diagram out of these elements and analysing so many factors is very complex and does not fetch any meaningful results. Therefore, unification strategy was used. Factors with same meanings and factors with synonymy were unified and made into a single category. For example, timely supply, risk of availability of resource, and interdependency were clubbed into one single category; interdependency. High chloride content, high scaling factor etc. were put into chemical compatibility. 

Coding interviews is a tricky process and it could create bias of interpretation. Therefore, wherever possible, complete sentences or quotes have been coded rather than coding a single word. For instance, “Change in their process upstream - If their process changes and it affects the output of water, we still have to match it up with additional new water” (UIC04, 2015) is coded as interdependency. Multiple coding is also used wherever necessary. For instance, “Costs of having a pipeline is important. Compared to the cost of water, pipeline costs are too costly” (UIC04, 2015) is coded for cost of pipeline, cost of water and investment costs.

Additionally, these factors are represented in a network diagram. Once each factor was found out, those factors were somehow interrelated and shared. Therefore, these factors were linked with relations namely; is cause of, is a part of and is associated with. For instance, marketing projects is a part of long term vision. Cost of water and cost of pipeline is a cause of financial viability and when the factors are influencing each other in both ways, bidirectional, then they are linked with is associated with. For instance, information flow and communication is associated with trust and assurance.
After, taking the overall picture of the factors and their importance, Atlas.ti also offers a feature called code family which helps to group the factors into a particular category and major their groundedness. Moreover, it creates a network among the factors based on the links defined in the overall picture. This helps to understand, how factors influence other factors in a particular category.

4.4.2 List of factors influencing IS based on interview results

The factors resulting from the interview analysis in Atlas.ti are shown in the figure 18. In total they are 40. They range from investment cost to upgrading and pre-treatment. Clearly investment costs has been discussed by every participant and some participants have discussed it more than once. This shows that this is a very important factor in this region. Second most important factor is Cost of water. Due to the cheap cost, participants found it difficult to make a good business case. Third factors which was found to be very relevant was awareness about IS. Most of the participants didn’t know about the IS concepts and had never looked upon this industrial area in terms of IS. Value of the resource is also an important factor that has been observed to be very important. High value items such as work arising gases and steam are easy to create interest among the participants but water, which is abundantly available in the Netherlands is a low value item.

Financial viability is another important factor that has been considered very important by the participants. This is very evident by the existing infrastructure also. Every company advocates for economically attractive opportunities. Willingness to participate is most important attitudinal factor. Many participants in the study found IS as an interesting
approach and were willing to participate. Other factors and their importance is explained in the upcoming sections in their respective categories.

On the other hand, attitude towards change, tenant recruitment, upgrading and pre-treatment have been discussed less. As we see in the network diagram attitude towards change is associated with negligence. Negligence is in term associated with the value of the resource. In the following section, each category of factors are analysed based on groundedness and network diagrams and results are presented.

Figure 19: Overall interrelation between factors

4.4.3 Technical and chemical factors influencing the IS based on interview results

As we can see in the figure below, there are in totally 9 factors in this category. The most important technical and chemical factor is interdependency with more than 15 times of occurrence during the interviews. As could be seen by the comment of one of the interviewees, “Continuous flow of materials is also important. Without synchronizing the flow or making sure that the continuous flow exists we cannot completely depend on other industrial suppliers” (UIC06, 2015). Chemical compatibility and technical compatibility are associated with safety of equipment and pipelines from the problems like salinity, conductivity of water, and compatible machinery. Quality of water and dissolved effluents are associated with composition of water. Few interviewees spoke about technical lock in stating “They first want to optimise everything internally.
Though reliability is interlinked with interdependency, it has been spoken about by very few participants. One of the interesting point that came to surface is knowledge about required quality of water. According to few interviewees, “many companies, especially work units of Tata steel inside doesn’t really know what kind of quality is required. If companies don’t know what they want, how can you expect that they will use waste water? Lek water has been used traditionally from long time and nobody wants to see if some water from other part of the site could be used” (UIC16, 2015). Upgrading and pre-treatment before reuse has been least discussed in technical and chemical factors. This could be due to the fact that companies don’t know what quality they desire.

Below, the network diagram of technical and chemical factors has been shown. Based on the interview respondents and their quotations the links were made between the factors. Then factors are restricted to technical and chemical category, the resulting network is shown below (fig 21). Interestingly, even if the knowledge about required quality was discussed by only few interviewees many factors such as chemical compatibility, technical lock in and upgrading and pre-treatment were seen to be highly linked to it. One more interesting relation that could be seen from the network diagram is the loop between the technical compatibility, reliability and size of the plant. It could be seen from the quote, “Additionally, the companies you have taken into account, only big companies are suitable and I have doubts about how small companies can be incorporated as they have very small flows” and “already recirculating the water internally” (UIC16, 2015). There is also a loop between composition of water, chemical compatibility and upgrading and pre-treatment of water. This is due to the fact that upgrading and composition of water directly relate to the chemical compatibility. It could be seen from the quote “water can cause salinity and scaling due to some chemicals. Therefore it has to be upgraded before it is reused” (UIC13, 2015)

Figure 20: Technical and chemical factors based on groundedness
4.4.4 Management and behavioural factors influencing the IS based on interview results

The next category in which the codes were put into one family was management and behavioural factors. Considering the number of factors per category this category has the highest number of factors. There are in total 14 factors in this category. One of the major findings in this category is that managers at IJmuiden, despite of being involved in various types of interactions were not aware of the IS concept. Another important factor that seems very important in this category is value of the resource which is grounded 17 times. As quoted by an interviewee, “we here in the Netherlands stand with one feet always in the water. This makes water very cheap” (UIC14, 2015). Willingness to participate is one of the key factors in this category and most of the interviewers were positive about it. As quoted by an interviewee, “we are always looking for such possibilities internally. Not even once like this. Unknowing we do some kind of sharing already but with planning sounds interesting. Therefore I think it’s a good approach. We hardly ever think going over the border” (UIC07, 2015). Environmental awareness was seen dominant in all interviewee’s responses. They always showed high interests in this kind of approaches. Information flow & communication and transparency and data sharing are seen very often in the region overall. The respondents were ready to share data and the communication and information flow was smooth. This could be seen by several quotes such as “of course we will give you the data” and “let me know
if you need any more information, I will respond as soon as I can. Or visit our office” (UIC10, 2015) in several email conversations and interviews. Trust and assurance, attitude towards waste, negligence and existing interaction were also mentioned by almost quarter of the interviewees. One of the interesting factors that came up while having conversation with Grontmij is the establishment of long term vision. Though it was discussed by only two interviewees, long term vision can help to grow the industrial symbiosis. Supply scarcity is found really unimportant as water is abundantly available.

Also, in the next page network diagram of managerial and behavioural factors is presented. An interesting observation is that willingness to participate is caused by existing interaction between the companies and the environmental awareness of the participant. As it could be seen in the symbiosis diagram (fig 16), there exists already some interactions but the willingness to participate is mainly caused by environmental awareness. As stated by one of the interviewee “As from the procurement perspective (buying costs are low) I don’t really get the point of saving water. But yes, there are environmental responsibilities and this could be a good approach to tackle it” (UIC15, 2015).

![Management and behavioural factors based on groundedness](image)

Figure 22: Management and behavioural factors based on groundedness

Another interesting observation from the network diagram is the loop between the trust and assurance, existing interaction and willingness to participate. This shows that the participants build trust and assurance based on existing interaction. Therefore, despite of the low groundedness, the already existing interactions still acts as a cause of willingness to participate. Another aspect is the value of the resource. Due to the abundance water in the Netherlands, the value of the resource is spoken a lot of time. Cost of water may sound synonym to value of the resource but, for the analysis sake, those two aspects are kept different to tap the financial side and behavioural side of the value of resource.
4.4.5 Financial and economic factors influencing the IS based on interview results

In the analysis, these factors were seen to be most important and companies focused more on these aspects compared to other aspects discussed in the interviews. As discussed in the previous part, the value of the resource is discussed several times so as the cost of water. In this case, the cost of water is discussed not in terms of behaviour but in terms of creating financial value. The reason to keep cost of water separate from value of resource is; high cost materials such as work arising gases are reused and dealt faster than the other low priced materials such as water. Another reason is, high cost water, for instance A water and M water are dealt with high care as they are costly. Lek water is cheap and hence cannot be dealt easily as it directly relates to the financial feasibility of the project. As one of the interviewee stated, “Especially Lek water is ok. It’s cheap but M water costs a lot. Therefore it can form a good business case may be” (UIC07, 2015). Therefore, to support the financial visibility in financial terms cost of water and value of the resource are kept different. Most of the time they are coded in co-occurrence. That’s the reason why, both have groundedness of 18.

Another important aspect and the most grounded one is investment costs. To save a cheap resource, a huge amount of money has to be invested to build pipelines, pumps and etc. As an interviewee states, “The pipeline costs a lot and distance between our company and Tata is approximately 2kms. Until it is something really promising, it is difficult to make such decisions” (UIC16, 2015). In the network diagram these same interrelations could be easily
DATA ANALYSIS AND RESULTS

seen. Distance and cost of water affect the investment cost and financial viability. Existing investments is also sometimes discussed as there are already circulation systems placed and separate treatment plants are available. This also make the financial viability difficult.

Ownership of infrastructure is also a reason; especially inside Tata. As they mention, “these infrastructures do not deal with our core business and therefore we will not investment in infrastructure. This has been the policy of Tata steel always” (UIC15, 2015). They state that third parties can get involved and benefit from it. As there taxes on discharge, few interviewees mentioned this point. It is important and it can lead to a lot of cost savings to the companies but, considering the cost of water, these are very small amounts and do not motivate the companies to take water seriously.

![Financial and economic factors based on groundedness](image)

**Figure 24: Financial and economic factors based on groundedness**

Since there have been very rare examples of water sharing apart from Nuon IJmond and Tata Steel A water link, market test and cost savings have not been discussed a lot. The projects should pass the stage of financial viability stage to face the market test. Market test and cost savings are dealt then. Therefore financial viability is pre-requisite for market test. In fact, the only difference between market test and financial viability is that market test is faced by a symbiotic link once it is implemented and the financial viability test is done before implementation. Nevertheless, in the later stages of the symbiosis, market test becomes important. Another interesting but obvious causal relation is the relation between transportation cost and distance. Due to the low cost of water and high investment costs for transportation, the distance acts as a decisive factor. As one of the interviewee quoted, “distance is not that far. Just 1.5km. Still, it couldn’t be a business case” (UIC16, 2015)
4.4.6 Regulatory and administrative factors influencing the IS based on interview results

At this initial stage, most of the participants rule out any intervention of regulations apart from regulatory compliance. All companies are well within the compliance and hence, they think that government should not be involved in these projects. They believe that until and unless the practicalities of these projects are not tested, they don’t want to put new ideas in government’s mind (UIC16, 2015). Also, supply companies like water net are not willing to put any sort of pressure on companies as they expect them to increase the efficiency on their own with their own solutions (UIC09, 2015). Therefore, government’s involvement, policy intervention are not given much importance. Taxes on discharge is also not motivating enough to take water case seriously. That could be seen in the diagram below.

Coming to the administrative factors, absence of a coordinating body is seen important. There is no central body yet which will look into all aspects of IS on the site. There are some community group which deal with the issues of the region but not an institute like Industrial Symbiosis Institute at Kalundborg. Third party involvement such as university or consultancy to deal with IS aspects is also not spoken much. This could be attributed to the stage of the study as it is the early stage.
Role of project champion or key anchor tenant were not considered important and were only mentioned by consultancies (UIC14, 2015). Though role of Tata steel is important as many flows pass through or created by Tata steel, providing stability to the network. Tenant recruitment is too early to be discussed and that is reflected by the low groundedness. Finally in the network diagram below, government’s involvement directly affects the regulatory compliance. This means if government intervenes and urges companies to take action, perception of the companies may change.
4.4.7 Factors influencing the IS as drivers and barriers based on interview results

So far, the factors have been divided according to technical and chemical, management and behavioural, finance and economic and, regulatory and administrative categories. Now in this section, these factors are divided into two categories to further analyse them: drivers and barriers. Each factor acts as a driver or as a barrier for the implementation of industrial symbiosis. Based on the interview transcripts and the quotes, these factors were divided into drivers and barriers. It should be noted that this list is very case specific and in other industrial sites they might act in a different way. In figure 24 and figure 25, the drivers and the barriers are shown irrespective of their category. Afterwards, in table 2, drivers and barriers are listed according their categories and importance. The factors are arranged in the table in a descending order.

Irrespective of categories, the most important factor in terms of groundedness is investment costs. While implementing IS network with a cheap resource like water investment costs act as a biggest barrier. These investment do not fetch returns very quick and existing investment acts as an addition to this by not letting the change to take place. Nevertheless, biggest driver of IS is willingness of firms to participate. At IJmuiden, companies are interested in concepts like IS and willing to be involved in it. This created a positive atmosphere for new ideas.
Interestingly barriers are concentrated more in the technical and chemical factors and financial and economic factors. Whereas, drivers are more concentrated in the management and behavioural factors. Regulatory and administrate factors are have same number of drivers and barriers.

![Barriers based on groundedness](image)

**Figure 29: Barriers of IS based on interview results**

Despite the results show a high groundedness for lack of awareness for IS, the companies are open to IS type of concepts. This could be seen in the list of drivers with factors like information flow and communication and transparency and data sharing are highly grounded.

In terms of costs, only treatment costs and taxes on discharge act as drivers. Remaining all kinds of costs act as barriers. Cost of water is major barrier. It is very cheap and end up last in the priority list of every company to increase its efficiency. Therefore, the value of the resource is very important factor directly relating to cost of the resource (water). The same water with added value say M water, becomes important to companies. Financial viability another huge impediment. Due to the low cost of water and high pipeline costs, shortest distances also become unviable financially. Therefore, no company wants to voluntarily invest in such a project until a detailed feasibility study does not show a positive result. Cost savings and market test might act as drivers but firstly, some of the successful symbiosis must be established. Currently, market test and display of cost savings is far from reality.
Table 4: Drivers and barriers based on their category ranked according to their groundedness

<table>
<thead>
<tr>
<th>Category</th>
<th>Drivers</th>
<th>Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical and Chemical</td>
<td>Size of plant</td>
<td>Interdependency</td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
<td>Chemical compatibility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technical compatibility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Composition of water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technical lock – in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knowledge about req. quality</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upgrading and pre – treatment</td>
</tr>
<tr>
<td>Management and Behavioural</td>
<td>Willingness to participate</td>
<td>Lack of awareness</td>
</tr>
<tr>
<td></td>
<td>Environmental awareness</td>
<td>Value of resource (water)</td>
</tr>
<tr>
<td></td>
<td>Existing interaction</td>
<td>Negligence</td>
</tr>
<tr>
<td></td>
<td>Information flow and communication</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transparency and data sharing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trust and assurance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Attitude towards waste</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Long term vision</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Attitude towards change</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Supply scarcity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marketing projects</td>
<td></td>
</tr>
<tr>
<td>Financial and Economic</td>
<td>Cost savings and market test</td>
<td>Investment cost</td>
</tr>
<tr>
<td></td>
<td>Treatment costs</td>
<td>Cost of water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Financial viability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distance (between companies)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Existing investments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ownership of infrastructure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transportation costs</td>
</tr>
<tr>
<td>Regulatory and Administrative</td>
<td>Taxes on discharge</td>
<td>Regulatory compliance</td>
</tr>
<tr>
<td></td>
<td>third party investment</td>
<td>Absence of coordinating body</td>
</tr>
<tr>
<td></td>
<td>project champion</td>
<td>Lack of policy intervention</td>
</tr>
<tr>
<td></td>
<td>tenant recruitment</td>
<td></td>
</tr>
</tbody>
</table>

Third party investments and project champion can act as drivers. For instance, regional water board can build a treatment plant near the industrial site to treat industrial water of all the companies (UIC16, 2015). This will create a close loop and zero discharge from the site. Tata steel can clearly play a role as project champion or key anchor tenant as most of the flows incoming or outgoing will flow through Tata. Moreover, size of Tata will gives stability to the network. New tenants involvement may change the scenario but no such examples have been observed.

Regulatory compliance also contradicts the environmental goals of policy makers. Current regulations on water use and discharge are not motivating enough to make companies act and reduce the water consumption. Policies are also not seen in action anywhere in IJmuiden.
Though this could be just because IS is a new topic to this site. Policies can act as big drivers if this site is considered in IS site by the government or policy makers.
In this chapter resulted obtained from data analysis are discussed and compared with the existing knowledge extracted from literature. Firstly, in this chapter, the S-Curve for development of IS has been discussed based on its features and what could be understood from the curve.

Followed by this, drivers and barriers influencing the development IS extracted from the interview analysis from Atlas.ti are discussed and compared with the observations from the literature. The similarities, dissimilarities, new observations and correlation to other industrial sites are discussed.

In the final section of this chapter, Three features of this research thesis are discussed. Rigor, Validity and Generalizability.

“We generate wealth from the people. What comes from the people must go to the extent possible back to them.”

– JRD Tata

5 DISCUSSION AND REFLECTION

Results presented in the previous chapter clearly show that IJmuiden has very good potential to be an Eco industrial site by establishing various IS links comprised of several types of materials, resource and residue exchanges. In contrast to the typical planning method to implement IS concepts used more often in USA, IJmuiden site correlates with European pattern of EIP development. At IJmuiden, like other European examples, already some kind interactions exist. These interactions are chosen purely based on economic interests. Existing interactions have already helped to gain a smooth information and communication flow among the companies and several new possibilities are already being discussed. The initiatives to use work arising gases, A water, use of common facilities, use of steam by Nuon from Tata Steel etc. are a result of mutual win-win situations. This indicates that IJmuiden site fits in the knowledge gap identified and comes under the category of early development phase of IS development. In the following paragraphs, each aspect of IS study investigated in the conceptual frameworks is compared to the practical findings of this thesis and in turn, it is compared to the existing literature.

5.1 Development pattern of IS

From the literature, we have observed the development of several IS sites around the world. Each site represented some sort of pattern of development. At some sites, government or institutional agencies took the initiatives. For instance in US under the USPCSD programme to plan and implement IS sites (Gibbs & Deutz, 2005) and in UK under the NISP programme to develop existing sites to IS sites and develop new sites (Raymond & Howard-Grenville, 2012). In China also, sites such as Guitang Group were mainly developed due to the
involvement of government to tackle the environmental impacts of IS (Qinghua, et al., 2007). Therefore, it could be said that these IS development programmes use planning approach, other sites such as Kalundborg (Ehrenfeld & Gertler, 1997), Rotterdam harbour area (Heeres, et al., 2004) and other European sites explained in the literature are result of spontaneous or serendipitous development without a push by an external institution. Nevertheless, all these sites share some common features. Despite of the fact that many sites in NISP programmes and USPCSD programmes were planned, there existed already some sort of industrial region in that area where cluster of companies were already established. Those projects which were undertaken as the industrial district development in the name of EIPs hardly ever succeed or came into existence (Gibbs & Deutz, 2005). Therefore, planning an EIP for the implementation IS from the scratch is a very difficult process and hardly sees any success. Further, when there is already an existing industrial site, implementation of IS using deliberate attempts is possible. That is, when there is already a well-established industrial site, the implementation of IS could be done with the combination of both planned and self-organizing nature of IS depending upon the stage of the IS development.

Through the investigation, it could be observed that IJmuiden has a long history of industrial clustering where companies have been situated closely for decades. When companies are closely located, there ought to happen some interaction. This could be seen in the case of IJmuiden. Despite of the fact that so far there have been no studies related to IS at IJmuiden, some sort of interaction, material exchange, facility sharing took shape. Not surprisingly, it was serendipitous and only materialised for the sake of tapping the economic benefits. Therefore, the success of IS mainly depends on the type of IS project undertaken. Just for the sake of eco image or based on the promises to create jobs, establishment of IS or EIPs is not possible. At IJmuiden the chances of development of IS is higher as the companies on their own are taking initiates to develop waste or material sharing links without any external stimulus. This approach in the literature has been advocated to see higher success than the centrally planned IS development (Desrochers, 2004). If the conceptual framework for the development of IS is used to represent this observation, it could be done as shown in the figure 30.

What we can discuss from the 2 diagrams below is the shortcomings of both approaches. In figure a, we can clearly see that due to the high planning, initial stages such as precursors, kernels and low hanging fruits for the IS development does not exist. Therefore, this makes the development of IS slow. Hence there is a huge time consumed to convince the potential tenant companies to situate their companies on the planned site without showing any evidence of success and without having any prior interaction between them. Even if some interaction takes place, in the pre-development phase, highly planned links lead to failure due to the factors such as lack of interaction, privacy, trust and reliability, information sharing etc. Therefore, pure planning approaches either stay in the planning phase or soon reach the saturation level without actually attaining the status of EIP. This relates to the knowledge gap explained by Gibbs & Deutz (2007) stating that there is a big gulf between what IS in theory is and the methods that are being used to implement it.
DISCUSSION AND REFLECTION

Figure 30: Separate Development Curves for Planning (a) and Self Organizing (b)

From the literature, success rate is comparatively higher due to the fact that already some sort of interaction exists. This is shown in the figure b above. This makes barriers like communication, trust and information sharing easy to breach and establish good contact among the participants. Kernels and precursors are quickly materialised and low laying fruits are picked up. Due to this initial success, several external and internal organizations get attracted and somewhere in this period, typically uncovering takes place (Chertow, 2007). After the uncovering, suddenly attempts are put to establish complex networks by replicating the old networks. This step is difficult due to the fact that the new links may not be as attractive as the old ones. This slows down the IS development.

It is important to understand that what is needed is a combination of both methods to foster the development of IS in an already existing industrial symbiosis after the initial development. The conceptual framework proposed during the literature indicates the appropriate representation of how IS development should occur.

As we see from the examples from the literature, industrial sites which are currently considered to be in the initial stages of the development (Gibbs & Deutz, 2007) are basically at the beginning of the early development stage. These sites have successfully undertook the easily doable links as we see in the Queensland synergy park, Australia (Roberts, 2004) and Guitang IS site in China (Qinghua, et.al., 2007). The development after this stage is tricky. There is a need of extra push from some stimulus that will keep the participating companies interested in developing new networks. This is where the need of finding the drivers and barriers of IS development plays a crucial role.

In successful IS examples such as Kalundborg (Ehrenfeld & Gertler, 1997), Rotterdam harbour area (Heeres, et.al., 2004) and some examples from NISP program in UK (Raymond & Howard-Grenville, 2012), the drivers have been exploited to foster further development of IS and barriers have been overcome by either third party involvement or regulatory stimulus. This helped these sites to take a jump to the second curve shown in the figure which leads to the events like new entrants and die outs of firms followed by replicating the old links or expanding the boundaries of the links. Finally, they gain maturity by implementing complex links which include high infrastructure and rigorous coordination and planning (Chertow, 2007).
Reflecting upon the practical case, IJmuiden is also at the early development phase. It is a well-established site with 3 large companies and several small companies situated in a cluster and already some sort of interchange of resources, materials and residues takes place. The exchanges between Aroc and Tata Steel are considered to 90% symbiotic and most of the material is reused and the loop is closed. Links established to use M water at Nuon and shared treatment facilities of Tata Steel BIO 2000 plant and AZI plant are other examples of already existing interactions.

Moreover, there are 2 major kernels of IS being discussed currently. One, steam network between Tata Steel, Nuon and CVG papier, and district heating network for surrounding residential region. In terms of water, the resource under study, it is still a challenging issue as water is not a scarce resource in the Netherlands. Nevertheless, HHNK waste water link and CVG waste water and ENCI waste water together can replace up to 70% of the total water consumption of Tata Steel. This possibility must be studied in further detail. These water links can be considered as precursor of IS.

What is yet to be achieved is the step forward to take these projects and implement them. To do this, several drivers and barriers have to be overcome like other sites around the world. Therefore, in the following parts of this chapter, drivers and barriers influencing the growth of IS are discussed.
5.2 Drivers and Barriers influencing the development of Industrial Symbiosis

So far, from the discussion it is clear that the knowledge gap located in the beginning of the thesis fits the IJmuiden case. It is a well-established site with an old history of industrial colocations but IS studies have never been conducted. Moreover, this site already has some kind of interrelations in terms of material and waste exchange links that are realized without knowing about the IS concepts (not yet uncovered). Those links were low hanging fruits and easily created win-win situations for parties involved. Therefore, this stage of IJmuiden is a unique point in development where companies are opening up to external inputs. At this stage it is very interesting to discuss the factors that interviewees found very important compared to the literature.

5.2.1 Technical and Chemical Factors

Based on the results from the interview analysis, technical factors are key to overcome the challenges for the development of IS. They are not only challenging but difficult to tackle as there are a lot of complex situations involved. In the following subsection some of the main factors that came to the surface during this thesis will be discussed and compared with the literature.

Interdependency

Interdependency is one of the major factors that was mentioned during this research. In the literature also, similar observations were made. Concerns about closure of an upstream company activities or disruptions in their production process were considered as main barriers in the literature (Lowe, 1997). In case of IJmuiden, Interdepenacy also acts as barrier for the development of IS. Participants do not want to have any interruptions in their processes and dependence on a crucial source like water. It is used in almost all the companies for various cooling purposes and is a major reason that holds back the companies to involve in the kind of approach to deal with water is being proposed. Ehrenfeld & Gertler (1997) in their article also mentioned the same point. Problems at the buyer’s side will lead to the disruption of production process at the seller’s side as they will have excessive water and vice versa.

Chemical compatibility, Technical compatibility, Composition of water, Knowledge about required quality, and Upgrading and pre – treatment

Chemical and technical compatibility is also seen as a very dominant factor that impedes the development of industrial symbiosis. In the literature, this point has been widely discussed and similar observations have been made. Chertow (2004) states that basic chemical and technical compatibility is the key to cost savings. Among the two types of wastes and by-products; direct and indirect, direct wastes are already being used; for example, slag and work arising gases. They need little adjustment. Whereas, indirect wastes such as water which needs adjustments such as upgrading and pre-treatment are difficult to implement. This point has been discussed in the literature in similar ways by Ehrenfeld & Gertler (1997).
Moreover, knowledge about the required quality of water is also lacking. Though it has been discussed less during the interviews, one personal observation is, whenever a question was asked about the quality requirement of the company, most of the respondents responded with the answer - standard Lek water. Therefore, knowledge about required quality also plays an important role.

**Size of plant & Reliability**

Despite of the several challenges in technical and chemical factors, size of plant is seen as a driver. If large firms are involved in a particular symbiotic link, it bring stability due to the large amount of flows. This creates reliability in the symbiotic link. Same observation was done in the literature by Ehrenfeld & Gertler (1997). In contrast, Heeres, et al., (2004) state that small companies might find it difficult to match the large company requirements making the network less attractive. This has not been observed in the interviews. Rather involvement of Tata Steel is considered important in establishing IS links.

Overall, technical and chemical factors correlate with the factors extracted from the past experiences except the factor of size of the plant. Presence of a large dominating firm in the network is considered beneficial rather than a problem as observed in the literature. Nevertheless, still technical factors are seen to continue to challenge the IS concepts.

### 5.2.2 Management and behavioural factors

Based on the results it could be seen that at this stage of IS development (in between predevelopment stage and early development), managerial and behavioural aspects play a very important role in overcoming the challenges. Most of the drivers belong to this category and this indicates that these factors should be promoted more to walk the path of IS development and implementation of EIPs.

**Willingness to participate & Environmental awareness**

Willingness to participate and environmental awareness were seen to be crucial for the development of IS in the literature (Sterr & Ott, 2004). Interestingly, they act positively in case of IJmuiden. Each participant was happy to be involved in this research and the response rate was very high. Out all 17 invitees 16 agreed to participate. This could be attributed to the existing interaction among the managers with Tata Steel managers. Environmental awareness also plays a crucial role and unlike in the literature (Gibbs & Deutz, 2005), at IJmuiden, managers were seen to be concerned already about the environmental effects of their production systems making them interested in IS.

**Existing interaction, Information flow and communication, Transparency and data sharing, and, Trust and assurance**

Above concepts are intertwined with each other and act as a great force behind implementing IS. Existing interactions create an easy path for information flow (Sterr & Ott, 2004). As it was evident by the openness of participants to share their consumption and chemical composition data at IJmuiden, this observation contradicts the literature. In the countries like US and Asia privacy is a strong factor. Nevertheless, IJmuiden site follows Scandinavian
trend where anything with the backdrop of sustainability pulls companies to share data (Gibbs & Deutz, 2005). There is a high degree of transparency contradicting the US trend where companies have corporate privacy culture. Due to these factors it is very obvious that trust and assurance factor is easy to bring among the industries and fostering these factors will help to bring companies close and their mental distance closer (Sterr & Ott, 2004).

**Attitude towards waste**

Attitude towards waste act as drivers. Unfortunately, when a resource like water in the Netherlands is abundantly available, the attitudes are not positive (Heeres, et al., 2004). Due to the abundance, saving the water is put very low in the priority lists of the companies at IJmuiden.

**Long term vision & Marketing projects**

Long term vision and publicizing the IS concepts may help to bring the companies closer (Lowe, 1997). As we see in the case of IJmuiden, the IS concepts are not known to many. Therefore, such an approach needs a certain amount of marketing.

**Lack of Awareness of IS**

Despite of several drivers, lack of IS awareness acts as a barrier for the development of IS. Companies hardly spend any time or efforts to think beyond the fence of their own company (Ehrenfeld & Gertler, 1997). This is the case in IJmuiden. Many companies until recently worked in isolation. Therefore, this concept is relatively new to them.

**Value of resource (water) & Negligence**

Value of water is a major impediment and it causes a lot of negligence (Ehrenfeld & Gertler, 1997). It could be reflected from the fact that last study done at Tata Steel related to water to reduce water consumption was in 2005. Since that time, the consumption has remained almost the same. This negligence is caused by the low value of water.

### 5.2.3 Financial and economic aspects

Financial aspects are the second most important barriers in the development of IS. This relation is stronger if the cost of the resource to be dealt with is cheap and abundantly available. The observation made during the study of IJmuiden are discussed below.

**Cost of water, financial viability, existing investments**

In literature it is stated in several occasions that IS links can only see success if financially and economically rational decisions are made (Ehrenfeld & Gertler, 1997). In Denmark, Kalundborg, managers in pursuit of financial interests did the right thing environmentally (Chertow, 2007). Unlike places such as Australia, China and also in European countries like Denmark, the Netherlands has almost free industrial water. It costs just 0.11 euros per cubic meter. This makes every possible link between the companies difficult. Due to the low costs financial viability of the whole project in most of the cases is negative and hence, these projects are discarded. The only solution to these issues is the policy intervention or changes in the cost structure of water. Otherwise, water in the Netherlands will always have this
issue if dealt using IS concepts. To put it in simple words, in IS, environmental benefits are seen to be welcome side effects of the economically feasible resource and waste sharing links (Sterr & Ott, 2004)

**Investment cost, Distance (between companies), Transportation costs & Supply Scarcity**

Large transportation costs, energy degradation, need for infrastructure all make distance a very crucial factor; same observation was done in literature by Ehrenfeld & Gertler (1997). Heeres, et.al., (2004) stated correctly that large distances are major impediments in Dutch EIPs. Same observation is made in case of IJmuiden.

The resource under investigation of this thesis was water which is abundantly available in the Netherlands. Therefore, supply scarcity was not considered a major issue. Nevertheless, in other parts of the world, especially in USA and Australia, water is not so abundantly available and hence this observation differs from the literature.

**Cost savings & Treatment costs**

Cost savings could be achieved from either avoiding to buy virgin materials or by supplying the by-products or wastes to the other companies (Ehrenfeld & Gertler, 1997). In case of IJmuiden, it is very difficult to achieve this purpose as the cost of water is very cheap. The only strong driver is cost savings in terms of reduced treatment costs or savings on taxes on discharge as water need not to be treated anymore but redirect to another firm.

**5.2.4 Regulatory and administrative factors**

At this stage of IS development, regulatory and government interventions are mainly seen as barriers by the participants. As one of the respondent stated, “we don’t want to implant a new idea in the government’s mind until all aspects of that idea are judged” (UIC16, 2015). Though it is apparent that until a decisive policy change does not occur, costs of water or legislation on discharge of water does not become stringent, putting water under the umbrella of IS is very difficult and challenging in the Netherlands. Policy changes in United States (Gibbs & Deutz, 2005), Denmark (Chertow, 2007) and other countries have triggered water symbiosis, but currently, the cost of Lek water is not going to support most of the business cases. That is, creating win-win situations environmentally and economically is not possible in the current scenario.

In terms of administrative factors, absence of coordinating body is seen very crucial. Success of NISP programme in UK, the first successful nationwide programme to promote IS has proved the need of coordinating body (Raymond & Howard-Grenville, 2012). Coordinating body can act as a knowledge centre where ideas could be created (Gibbs, 2003). In light of this, on 6th of July, a meeting with a local community representative has been conducted to discuss this issue and to propose that an industrial symbiosis group to be created for IJmuiden mimicking the Symbiosis Institute of Kalundborg (Robert, 2004). Nevertheless, Tata Steel can always act as a key anchor tenant as it provides stability to the current network due to its large operations and size.
Therefore, finally arriving at the framework proposed in the literature, the factors listed in the framework are arranged according to drivers and barriers of each category and their importance. Though it has to be mentioned that factors that have been extracted from the literature have a high correlation with factors explored during this study, the observations are different. For instance, the data sharing and transparency is seen as a challenge in literature (Gibbs & Deutz, 2005), whereas in IJmuiden case, it acts as a driver. Communication and flow of information is again considered to be hard to achieve (Lowe, 1997). Looking at the response rate of the participants, communication and information also acts as a very strong driver. Cost of water in other parts of the world is seen as a major driver due to the scarcity (Roberts, 2004; Gibbs & Deutz, 2005; Chertow, 2007; Zhang, et al., 2009), but here in the Netherlands it’s a major barrier. Governments and institutional involvement is seen to be important in the early stages any EIP/IS development in UK, US, and Australia. In fact in countries like China, Government themselves initiate the process, but in IJmuiden, it follows the northern European trend like Kalundborg. Government intervention is considered important in the later parts of the project and during the idea phase it is considered irrelevant.

### 5.3 Discussion on outcome of this thesis

There are mainly two outcomes of this thesis; academic and practical. In this section quality of each outcome is discussed to reflect upon the validity, rigor and generalizability of the outcomes.

Validity is defined as the quality of a research to be factually and logical sound (Uma Sekaran, 2010). The study conducted in this thesis research is a literature based case study wherein, information was first extracted from the literature and then a conceptual framework was proposed. Followed by this, based on the methods presented in the literature, secondary data such as documents and reports were collected from the participating companies. The data was analysed using Atlas.ti software and the results were presented. These results were compared to the data extracted from the literature and the observation were discussed in the previous sections. This procedure is fairly sound. Though the observations of some factors differed from the observations in the literature, factors resulting from the case study are almost similar to those extracted from the literature review. Therefore, there is no requirement to have a validation workshop or validation step as the factors from the literature and factors from the interviews are compared; making the research process considerably sound.

Rigor is defined as the quality of the research process (Uma Sekaran, 2010). In this part this research has some short comings. Though the interview analysis was done in depth, the secondary data analysis from the reports and documents is subjected to limitations. Firstly, links visualised in the results chapters are not tested with all the aspects including financial analysis and technical analysis. The financial and economic feasibility is required to propose a link. In this research only basic input output matching was done to check whether the qualities of the water sources match. This was done mainly due to two main reasons. The data collection lasted for 3 months including interviews. This made it difficult to analyse the financial and technical aspects of each link in depth and made it very difficult to fit into the
DISCUSSION AND REFLECTION

Time frame of this thesis. Moreover, IS study is a continuous process and each day new inputs were received from the participant making it difficult to do a quantitative analysis. Second, only one interviewee from each company was interviewed. To achieve higher rigor, it is suggested to do the interviews though the hierarchy (Uma Sekaran, 2010). Nevertheless, the resultant S-Curve of development of IS is a result from extensive and systematic literature review creating a unique value addition to the existing literature. Having said that, this framework also has some limitations. For example: quantification of IS development. The question, how to access/measure the development stage of IS in the S-Curve is not included in this thesis. This information was not easily available in the literature and present information in terms of quantities of exchange were case specific. The only way to access the stage of IJmuiden was to see which key objective indicators were fulfilled. It was seen that low laying fruits were picked up (A water, work arising gases etc), many kernels and precursors exist (waste heat network, water from Beverwijk treatment plant etc) and the ‘Uncovering’ of these interaction has not yet been taken place.

Lastly, generalizability of the results of this thesis is fairly good. The S-Curve of IS development defines the development of any IS site around the world and the current status of the IS site could be determined using conceptual framework. Though the measurement of IS is not explained in this thesis, quantitatively, Key Objective Indicator events such as existing interlinks, presence of kernels and precursors, process of uncovering etc. can determine the current status of any IS site around the world. Regarding the second result of this thesis, the list of drivers and barriers in the early development stage of a well-established IS site, the internally, for IJmuiden the results are very generalizable for each participating company are generalizable. They match highly with the literature. But the factors may differ a bit in other cases as this thesis only focused on water. When a holistic approach is chosen listing all types of wastes and by-products, the factors might act in a different way. Therefore, it could be said that the list of factors has a very good generalizability but the observation will differ based on chosen case study.
In this chapter main conclusions of the thesis are presented in the first subchapter. Followed by this recommendations are given to the academic readers and IS enthusiasts on how to deal with IS at the industrial sites in the second subchapter and finally scope for the future research is given in the third subchapter.

“No success or achievement in material terms is worthwhile unless it serves the need of the people and it is achieved by fair and honest means”

— JRD Tata.

6 CONCLUSIONS, RECOMMENDATIONS AND SCOPE FOR FUTURE RESEARCH

6.1 Conclusions

In this master thesis research, patterns of development of Industrial Symbiosis and factors influencing the development of Industrial Symbiosis are investigated at an already well-established industrial site. The concepts of industrial symbiosis which claim to create circular flow of materials instead of linear flow of materials that could benefit industrial users to reduce the consumption of virgin resources are applied to an industrial site. In light of this, a befitting case of IJmuiden industrial region is chosen. This site is situated in the North Holland province of the Netherlands. This site shares a long history of colocation with other firms and therefore has been chosen as the candidate to investigate possibilities of implementing synergies of material, resource and residue exchange (focused on water). The aim of the study was to understand the development of industrial symbiotic sites and to reflect upon various factors that influence the development of industrial symbiosis.

The first goal of this thesis was to understand the development pattern of the IS sites around the world. In this regard, as a result of a thorough literature review, main approaches towards Industrial symbiosis were extracted. This includes Self-organizing approach, Planning approach and combination of both approaches known as Facilitated evolution approach. Moreover, from the literature, different stages of development of IS were understood and three stages were distinguished. These stages were predevelopment stage, early development stage and complex network development stage. Development of IS was also studied in terms of spatial expansion and three distinctive stages of IS development were identified. They are internal efficacy, regional learning and sustainable district development.

Additionally, at each development stage, key features were identified which were considered to be Key Objective Indicator events in IS development and could help to determine the stage at which a particular IS site is. Those features are presence of Kernels and Precursors of IS, Uncovering of IS, materialization of low laying fruits (easily doable IS links), new entrants
and die outs of companies, replicating the old links to new links and finally implementing complex symbiotic links.

As a result of all these aspects of IS development, a unique conceptual framework was build explaining the development of Industrial Symbiosis. It is a double S-curve which helps to identify in which stage an industrial site is. This literature review also resulted in the identification of knowledge gap. This knowledge gap is the switch from predevelopment stage to early development stage which takes a long period of time at many IS sites. Some IS site never even make this switch and remain in the planning or predevelopment stage. This is often referred as implementation gap or gulf between what IS is in theory and what is being implemented in the academic literature. Another important insight from the first framework is that it is not necessary to separate self-organizing and planning approach. They both appear in the development at different points in time. In fact in the predevelopment stage, combination of both approaches is required.

To do the switch between the predevelopment stages to early development stage, the second task of the literature review was to extract a list of factors that are found to be important and influence IS development. The result of this part of the literature review was a framework categorising the factors in 4 categories: Technical and Chemical, Managerial and Behavioural, Financial and Economic and, Regulatory and Administrative.

Practical side of this thesis research, the IJmuiden site is investigated and a practical case was defined. The task was to identify water and water related by product synergies to reduce water consumption at IJmuiden. While identifying these links, factors influencing the development of Industrial Symbiosis should also be extracted. As a result of this analysis following links were determined (in the table). These links were only in the idea phase and could be considered as the Kernels of IS. Links shown in green are in idea phase and their environmental and economic benefits are yet to be determined. Links in black are the existing links between the companies. Following table shows not only water links but also overall picture of all symbiotic links that are either existing or potential.

<table>
<thead>
<tr>
<th>Name of the companies</th>
<th>Name of the resource/residue/waste</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Exchanges</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tata Steel – Aroc</td>
<td>Rinse A water</td>
<td>90,000 m³/year</td>
</tr>
<tr>
<td>Tata Steel – Aroc</td>
<td>Pickling acid</td>
<td>163,000 tons/year</td>
</tr>
<tr>
<td>Tata Steel – IJmond Nuon</td>
<td>M Water</td>
<td>160,000m³/year</td>
</tr>
<tr>
<td>HHNK – Tata Steel</td>
<td>Waste Water</td>
<td>17.3 mil m³/year</td>
</tr>
<tr>
<td>CVG Papier – Tata Steel</td>
<td>Waste Water</td>
<td>2.9 mil m³/year</td>
</tr>
<tr>
<td>ENCI – Tata Steel</td>
<td>Waste Water</td>
<td>200,000 m³/year</td>
</tr>
<tr>
<td>Tata Steel – Harsco</td>
<td>Waste water from DSP plant</td>
<td>500,000 m³/year</td>
</tr>
<tr>
<td>Tata Steel – Aroc</td>
<td>Waste water of column incineration</td>
<td>140,000 m³/year</td>
</tr>
<tr>
<td>WRK – Schiphol – Data Centres</td>
<td>Cold storage facility at Schiphol</td>
<td>275 TJ</td>
</tr>
<tr>
<td><strong>Waste Heat</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tata Steel - District heating</td>
<td>Hot water</td>
<td>24MWt</td>
</tr>
<tr>
<td><strong>Steam</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tata Steel - Linde</td>
<td>Excess Steam</td>
<td>20,000 tons/year</td>
</tr>
<tr>
<td>Tata – Nuon – CVG Papier</td>
<td>Steam network</td>
<td>80 tons/hour</td>
</tr>
<tr>
<td>Tata Steel - ENCI</td>
<td>Steam</td>
<td>17MWt</td>
</tr>
<tr>
<td><strong>Work Arising Gases</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CONCLUSIONS, RECOMMENDATIONS AND SCOPE FOR FUTURE RESEARCH

<table>
<thead>
<tr>
<th>Shared Facilities</th>
<th>Coke oven and Blast furnace gas</th>
<th>676,692GJ/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tata BIO2000 treatment plant</td>
<td>Linde</td>
<td>500,000m³/year</td>
</tr>
<tr>
<td>Tata AZI treatment plant</td>
<td>Aroc</td>
<td>317,900m³/year</td>
</tr>
<tr>
<td>Tata Steel Pumping Station 3</td>
<td>Nuon IJmond – Sea water</td>
<td>15.7 mil m³/year</td>
</tr>
</tbody>
</table>

| By-products                     |                                 |                 |
|--------------------------------|                                 |                 |
| Tata Steel – ENCI               | Slag                            | 1.4 mil tons/year|
| Tata Steel – Harsco – Tata Steel| Slag metal recovery             | 1.2 mil tons/year|

Based on these links the current status of IS in IJmuiden was determined and placed on the S-Curve. IJmuiden is in between the predevelopment phase and the early development phase where a lot of precursors and kernels to IS exists. The links proposed are considered as kernels and precursors. IJmuiden is just in between internal efficiency phase to regional learning phase. That is, firms in this site are slowly opening up for external focus and broader perspective. At this stage the combination of self-organizing and planning strategies has to be applied. Moreover, at this stage, management and behavioural factors are seen to be very important drivers to promote IS.

Second sub-objective of thesis was to investigate various factors that are important for the formation of industrial symbiosis.

In the technical and chemical category, factors such as chemical compatibility, technical compatibility, composition of water, interdependency were found to be very important and all of them acted as barriers for the development of IS links between the companies. Drivers in this category were size of the plant and reliability. Large companies could be influencing the other companies to participate in the IS as they give stability to the network and hence create reliability.

In the management and behavioural part, most important factors were willingness to participate, information flow and communication, transparency and data sharing, trust and assurance. Interestingly these factors were acting as drivers for the development of symbiosis. One of the major barrier found in this category was lack of awareness about IS. Most of the managers didn’t know what IS is. Therefore, at the stage of pre-development where there exists a lot of kernels and precursors these factors play an important role and help to bring participating companies close.

In the category of financial and economic factors, a list of major barriers were found, for instance, cost of water, investment costs, distance between the firms. All these factors impede the development of IS for water as water is a cheap resource. Therefore, implementing IS with a cheap natural resource with only ecological objectives is very difficult.

Finally, a set of drivers and barriers were found related to regulatory and administrative aspects. Interestingly, all the companies involved found government intervention unnecessary in this stage of IS as they wish to involve government only when all the aspects of proposed links are majored. Role of coordinating body was found missing and it could act as a major driver at this stage of IS if established.
Overall, the drivers and barriers were mostly followed the European pattern of characteristics rather than Asian and American. Role of central body, institutional involvement etc. were found irrelevant as in the case of Kalundborg. At this stage of development, managerial aspects are really important. Companies should try to reduce their mental distance and greater data sharing and communication should foster. A role of coordinating body is crucial and it can create a playground for these drivers. Regarding the barriers, major barrier is cost of water, finance related aspects and technical aspects. These aspects should be tackled either by policy intervention or third party involvements.

In general, the finding of this thesis research could be summarised in the following points:

Academic conclusions -

- IS and EIP approaches are neither strictly planning approaches nor self-organizing approaches. They both work at different stages of the development of IS and at some point, both approaches work together.
- Pattern of IS and EIP site development is same irrespective the initiatives taken. Each site has to go through initial phases of self-organization, then a combination self-organization supported by some planning and in the later stages, highly planned sites when the trust and sound communication between the participants has been established. Therefore, the S-Curve, result of this thesis is common development pattern for all sites.
- Highly planned EIPs and IS tend to fail due to the forceful implementation of IS concepts at the early stages or due to the pursuit of Eco – image of the industrial development or in pursuit of job creation.
- Kernels and Precursors of IS are very crucial. Links that are purely a result of planning in the predevelopment stage are difficult to implement due to barriers such as trust, communication and etc.
- After one point in the development of IS, self-organizing also slows down. It will require a boost from some institute or external party to further develop the IS. Best example is the role of Kalundborg Symbiosis institute.
- A switch between predevelopment phase and early development phase is very crucial. This could only be made if the drivers and barriers of local scenario are determined.
- Factors influencing the growth of IS vary at different stages of development. The most crucial stage is the switch between the predevelopment stage and the early development stage. These factors are fairly generalizable but are still confined to the local scenario and value of resources, presence of resources and influence of external institutions and culture of the country or region. Therefore, analysis of each site has to be conducted with certain expectation of surprising results.
- Overall, a middle out approach or a combination of all aspects of IS is required to understand the development of an industrial site.
- Uncovering is not a very specific act that has to occur during the EIP/IS development. But whenever it occurs, it grabs a lot of attention due to the market success of the links.
- At the stage of switch between the predevelopment and early development, managerial and behavioural aspects are major drivers whereas financial, chemical
and technical factors act as barriers. In the regulatory and administrative factors, government or institutional involvement is seen as a major barrier at early stage but a third party involvement such as consultancy or other mediating firms is seen useful.

Practical conclusions -

- IJmuiden, like many other industrial sites, is in middle of the switch between predevelopment and early development phase. Therefore, the factors that have been found out play very important role. Barriers have to be overcome to materialise the potential links and drivers need to be fostered.
- A bit of marketing of IS is required around the IJmuiden site. It has to be told to the companies and put into the minds of the managers so that managers can look into holistic approach considering their company as a part of community of businesses not an isolated business unit.
- A local coordinating body is a must. This creates room for discussion and helps to reduce mental gap between the companies.
- Currently, among the companies close located at IJmuiden maintain good bilateral contact. This smooth contact should be fostered to multilateral contacts so that it creates channels for sharing data and possibilities of new idea generation.
- Water is a very cheap resource to reuse. This makes it difficult to transport it in large distances and upgrade it a desired quality of another recipient. In the beginning it is wise to find out sources which do not need high treatment and are at minimum distance. Such links will probably make a good business case.
- Overall, water is difficult resource to tackle at IJmuiden due to its abundance.

6.2 Recommendations

The results of thesis are useful to mainly two interest groups. Academic scholars and Managers of various industries inside IJmuiden and managers in general looking for opportunities to reduce the resource (water) utilization in their industrial region.

Research community-

- IS and EIP issues which come under the broad area of IE should not be distinguished differently in literature while conducting a literature research. The underlying purpose of these three concepts is same. They only differ in terms of spatial scale.
- Though the literature is slightly biased towards the self-organizing nature, it is not a good idea to conclude that IS can only develop serendipitously. Planning approach is also important. Both concepts have to be given equal importance.
- The S curve uniquely mentions the key objective indicators of IS development. This resulted from the combination of various studies already existed in the literature. Though qualitative, these indicators can help researchers easily to determine the stage of IS development of any IS site.
- Drivers and barriers are very case specific. Therefore researching each IS site for important drivers and barriers is necessary. Moreover, before extracting the drivers and barriers it is also important to determine the stage of development.
Managers at IJmuiden –

- Now is the time to expand the bilateral communication to multilateral communication among the companies. This could be done by promoting the third party involvement that is ready to tap the opportunity or invest to create IS network.
- A coordinating body is very important. Around the site of IJmuiden many organization exist but a body dedicated to IS is still missing. Therefore, it is recommended to form such body.
- Create awareness about IS. This requires a little bit of marketing of such concepts in various events and corporate gatherings. Therefore treat IS as one of the future visions of IJmuiden and present it in front of public.
- Water is a challenging subject to make a good business case. IS concepts should be first applied to easily doable projects with high value resources. Therefore, it is a good idea to bring all the wastes and resources under the IS and conduct further studies.

6.3 Future Scope

There is a lot of future scope for this study. Both academically and practically, this thesis represents new ideas of looking at IS development. In the following two paragraphs, first, future scope for academic research is given followed by practical scope

- **Academic:** Two conceptual framework discussed in this thesis have several limitations as explained in the discussion section. To overcome those limitations, this study could be explained to quantitative analysis of IS development. It is yet to be determined how to measure the development of IS from predevelopment to the next two stages in terms of quantities. Therefore, a method could be developed to determine the development of IS quantitatively. Regarding the drivers and barriers proposed by this study, they match with the literature but are very resource (water) specific. Their importance may change as new resources are added to the topic and a holistic approach is used to determine all the drivers and barriers. External generalizability can be improved.

- **Practical:** In terms of practical scope, there are two major opportunities to implement IS concepts. Water has been studied in this thesis. It is clearly evident that water is currently not a promising resource that can create win-win stations. IS should be expanded to the current hot topics of waste heat recovery and steam networks. They are costly materials and they can very well make a good business case. In terms of future candidates studying the water topic, it is a good idea to evaluate each idea generated during this thesis with more in-depth chemical and technical analysis using Water Pinch and Pinch Analysis techniques. Financial analysis of each link is also a good opportunity for future candidates who will take up water as research topic at Tata steel.
As a student of the faculty of Technology, Policy and Management doing master studies in Management of Technology track, this topic was an interesting topic to research for the fulfilment of master thesis research. Main advantage of choosing IS as a topic is that there existed plenty of research already in the academic literature. This made the task easy to extract information required to build a suitable academic case. The gap in implementation found in this research was dully discussed in the literature but was never approached in the way this thesis treated the topic. This created uniqueness to this research.

On the practical side, I was sceptical about the possibilities to interview 17 candidates to participate in this research in the given time. To my surprise, one of the main reasons to complete this thesis in time was the response rate of the candidates for the interview.

On the academic side, in the initial stages of the literature research itself I was able to locate the gap in implementation and the divide between the self-organizing and planning approaches. This made it easier for me to collect relevant literature and conduct an extensive literature review.

Despite of the above positive points, there are some short comings also that I had to face during this research. I couldn’t synchronize the timing of data collection and the literature review. An honest confession is that few early interviews took place in the middle of the literature review process which restricted to me from discussing some questions which I later found important. For example, third party involvement related questions.

Since there was limited time to complete this research and the master course I study is oriented more towards the management studies, I couldn’t conduct an in-depth analysis of water case at IJmuiden in terms of technical and chemical aspects. This would have deviated my focus from the main purpose of this study.

In the beginning I was planning to conduct in-depth input output matching, then a financial analysis of each link followed by another round of structured interviews. This was over enthusiastic and I realised later that it cannot be done in the given time. If given a chance and the time frame wasn’t strict, it would be great to do both technical and management studies in a single thesis. This would greatly increase the value of this thesis.

Finally, quantitative data could have been collected in a better way with same unit of analysis (weekly or monthly consumption) with a predesigned survey to include all the effluents of each company. This survey could have been circulated among the participants which could have helped to create a better data inventory than the present data inventory.
ACKNOWLEDGEMENTS

As a master student of Management of Technology I would like to first start by thanking Delft University of Technology and the faculty of Technology, Policy and Management for providing the opportunity to pursue my master studies in a very open and friendly Dutch society. It was truly a unique and lifetime experience to study in the Netherlands.

To conduct this thesis in the given time and successfully graduate from the university, I would like to thank for all the help and value adding suggestions given by my first supervisor Rob Stikkelman. Every discussion that took place with Rob on the research topic helped me to rethink and think differently to come up with the unique approaches. I would also like to heartily thank my chair Margot Weijnen for being critical and challenging which helped me to improve the scientific and academic quality of this research. I would also like to thank Margot for taking out time from her busy schedule and read the second draft of my thesis just in time before her holidays. I would like to thank Udo Pesch, my second supervisor, for giving useful suggestions to improve the thesis work.

As a thesis intern, working with TATA Steel, a company of high stature is always a value adding experience in student’s academic life. This value adding experience would not have been possible without Gerard Jägers. Not only he accepted to be my company supervisor and the committee member of my thesis, but also he helped me a lot to bring in contact with right people. Much of the credit for the practical success of this thesis goes to Gerard Jägers.

Besides, I would like to specially thank all the candidates who agreed to be interviewed from the participant companies. I would like to thank Frans bol for providing contacts of some crucial participant companies and Miklos Szabo for helping me with the practicalities of this project. Furthermore, I thank Hans Kiesewetter, Andre Oudhuis, Tamara Rozendaal, Ron Weltevrede, Nando Leentveld and Barbra Eilers for their support and suggestions throughout the research process.

I would like to heartily thank Arzu Feta for being such a great colleague and office mate who made the office experience unique and interesting. I also thank Arzu for being my proof reader of the report. I would like to thank my best friends Nitish Shah and Apurv Nigam for all those fun full weekends during this hectic and stressful period of master thesis.

Last but not the least, I would also like to thank three most important people in my life for standing with me in all ups and downs of my career; My father, Mother and my lovely little sister. I am greatly thankful to have such great parents who sacrificed many luxuries of their life to make their son a master of science.
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APPENDIX 1: MEETINGS

1.1) Pre-kick off meeting: Rob Stikkelman and Gerard Jägers

Friday, 16th January

Meeting began @ 13.00h

- First draft of the thesis proposal was presented.
- Discussion on how to approach the research was discussed and after a long discussion on what could be done in 6 months, a possible approach was decided.
- The focus of the thesis will be about tracking the water as a resource. While conducting the exploratory study, I might come across many other possibilities. Those will also be presented as the result of the thesis but in a very indicative way.
- Two main reasons to select water and water related products and all the companies is because, tata steel the company where the internship will be conducted as found out from its internal studies that they use a lot of industrial water when compared to other steel works. Therefore, we are looking for reduction opportunities in water. Second reason was the time frame of the thesis. Tracking all the resources was impossible.
- The main focus of the thesis will be on investigating the factors that influence the growth of industrial symbiosis on the selected case (Tata steel Ijmuiden, the Netherlands and its surrounding companies)
- Framework was discussed and suggested that the factors should also be divided into 4 main categories (technical, behavioral, regulatory and economic).

Outcome: 1) Water as a resource under study and 2) framework in terms of technical, behavioral, economic and regulatory.

Meeting ended @ 14.00h

1.2) Meeting on Candidate Company Selection – Gerard Jägers & Frans Bol

Tuesday, 10th February

Meeting began @ 13.30h

- Initial introduction of the project. Planning of the project. I explained what kind of data I am looking for.
- Clear distinction between a core technical assignment and the assignment I have undertaken which is more towards the management and behavioral side of the technical problem (Thesis in Management of technology requirement).
- Discussion with Micheal Spits (energy department Colleague) on my approach was summarized and his suggestions were told to Gerard and Frans
- Brain storming sessions began. All the possible companies where listed first based on the experience and knowledge of Gerard and Frans.
- The result of this brain storming session was a list of companies with suitable contacts persons listed the second chapter of this report.
- Discussion on the type of approach to be used was decided. via email and sometimes phone calls to schedule an visit to the plant to understand the production activities and conduct unstructured interviews regarding the possibilities of symbiosis mainly focused on water and related wastes.

Outcome: 1) As a result of this meeting a list of participant companies the contact details of the contact person were made. 2) I was asked to make a draft invitation letter which will be first reviewed by Gerard and Frans and it will be sent to the companies we are planning to involve in this study. The resulting invitation letter is given below.

Meeting ends @ 14.30h

1.2.1) Invitation to participate in the IS study

Short Description:

We are trying to reduce water consumption by forming shared networks of water, water related resources, infrastructure and to achieve reduction in water related costs and environmental effects.

In this regard we are taking an initiative through a master thesis assignment to understand the potential of such synergies or collaborations and find out what are the factors that are important for each participant company involved.

What are we doing?

This will be an empirical research through structured and unstructured interviews to understand the factors that influence the nature of synergies between the companies to achieve water usage reduction.

Will you be interested to participate in this research?

What is the gain if you participate?

First, this research will mainly help to reduce water costs, which is the main take home of this research. Secondly, this will not only help to reduce costs but also will bring more interaction within the companies situated in North Holland. Third, this will help to gain some quick points in our efforts to reduce the environmental burden of water consumption.

What do we need from you?

Before we start our empirical research (interviews), we need some basic information. Considering the fact that most of the companies are not competitors and address very different market segments, we can complement each other’s business activities by bringing the resource cost down without causing any impact on our respective target markets and sales.
Therefore, we seek information from you mainly on the following points -

- Water and water related material flow of your company (input, output and waste)
- What are the energy expenses do you incur
- Required quality of input water
- Quality of discharging water (quality of output water)
- By product wastes (quality and quantity)

Basically, we are creating is a “water data bank” which will bring all water related activities under a single umbrella and then, we could map the possibilities and ask Decision makers/Energy and Resource managers of each company some set of questions during the interviews based on the resulting network of Industrial symbiosis.

*Your participation will be really helpful. Trust is the first key factor for this kind of synergies and therefore, the confidentiality and anonymity of the candidates and/or data provided for this project will not be shared with anyone without your consent.*

*Thank you all!*

**1.3) Discussion on literature and research approach - with Gijsbert Korevaar, TPM faculty, TU Delft**

**Tuesday, 10th March**

*Meeting began @ 10.30h*

- Initial introduction to my research approach was given
- Issues related to literature: what type of literature is best suitable were suggested. Chertow’s and Gibbs recent articles. Chinese EIP studies are very suitable as they have been published very recently. Etc
- What are the new trends in the industrial ecology and the difference between EIPs, IS and IE was explained by Gijsbert.
- Book of Industrial Ecology was recommended to read. Especially the chapter on Industrial Symbiosis.
- Suggestion was given regarding the research approach: two options are best suitable during the exploratory study of IS. Either choose 3 companies and map all the possible links and study them. Or use only one resource and all the key players present on the site.
- In my case the second one was more suitable to deal with water which is a new found problem at Tata steel and it is looking forward to solve it
- Framework should be divided based on spatial scale also if possible was told my Gijsbert. It could be very well the case that companies nearby might have a different set of issues and companies on the site might have different issues as well.
Outcome: Research approach: 1) one resource (water) with all possible companies. 2) Addition to the framework – the spatial scale of symbiotic links.

Meeting ends @ 11.00h

APPENDIX 2:

Information on technical and chemical factors to be considered during the water reuse

- Water’s Impact on Profit Drivers
- Water basics – Terms & Definitions
- Cooling Water Triangle – Scale – Corrosion – Fouling – Microbial Fouling

Why Use Water for Cooling?

Advantages
- Plentiful, Readily Available & Cheap
- Easily Handled: Pumpable
- Can carry large amounts of heat
- Does not expand/contract much at normally encountered temperatures
- Does not decompose

Disadvantages
- Dissolves everything it touches: – Metals – Earth – Stone
- Unique dissolving ability has earned water the title of the Universal Solvent

Sources of Water

Surface Water
- Low in dissolved solids
- High in suspended solids
- Quality changes quickly with seasons & weather

Ground Water
- High in dissolved solids
- Low in suspended solids
- High in iron & manganese
- Low in oxygen, may contain sulfide gas
- Relatively constant quality & temperature

Important Properties of Water
Conductivity

An Approximate Measure of the Total Dissolved Solids (TDS) in the Water, Read in Micromhos (mhos)

- Measure of water’s ability to conduct electricity
- Pure water will not conduct an electrical current
- As minerals accumulate, conductivity increases
- Proportional to amount of dissolved solids in the water
- Used to measure TDS
- Micromhos (umhos)
- Calcium, magnesium, alkalinity, silica, sodium
- Higher Conductivity = higher Corrosion/Scale Potential

Rule of Thumb: 0.65*mhos = TDS (mg/L)

Hardness

- Affected by the amount of Calcium & Magnesium present in the water
- Ca/Mg Carbonates are inversely soluble with temperature
- Hardness reacts with other minerals such as carbonate alkalinity, phosphate, & sulfate
- Tendency to come out of solution & form hard deposits in heat exchangers
- Ca/Mg inversely soluble with temperature

pH

7.0 = ‘Neutral’ not ‘pure’ water

- Balance between hydrogen & hydroxyl ions in the water
- Maintaining good pH control critical to cooling system operation
- Short pH excursions can be detrimental
- Low pH: Corrosive Conditions
- High pH: Scaling Conditions
Alkalinity

- Carbonate Ions (CO₃)
- Bicarbonate Ions (HCO₃)
- Hydroxide Ions (OH)
- React with hardness to form scale
- Higher pH/Alkalinity: Scale/deposition
- Lower pH/Alkalinity: Corrosion

Total Dissolved Solids (TDS)

- Mineral salts that have not met their saturation level in the cooling water therefore they are dissolved and appear as ions or molecules
- Mineral scale will form if the dissolved solids concentration in the cooling water becomes too high

Conductivity is a Proportional Measurement of TDS

Total Suspended Solids (TSS)

Substances dispersed in water that are not completely dissolved (insoluble or nearly insoluble) and can be removed with conventional filtration. They are: Coal, Dust, Clay, Silt, Iron etc.

Turbidity is a Proportional Measurement of TSS

Mineral Scale

Definition: Precipitation of dissolved salts. Scale occurs when their saturation limit is exceeded due to concentration effects or changes in water characteristics

- Water Chemistry, pH, and Temperature all affect the $K_{sp}$ for given molecules
- $K_{sp} = \text{Solubility Product Constant} = [Ca^{2+}] [CO_3^{2-}] / [CaCO_3]$

If $K_{sp} > 1.0$, scaling will occur without treatment
Commonly encountered cooling water scales:

- Calcium Carbonate
- Calcium Phosphate
- Iron Phosphate
- Iron Oxides
- Magnesium Silicate
- Calcium Sulfate
- Zinc Phosphate
- Aluminum Phosphate
- Calcium Fluoride
- Calcium Carbonate
- Calcium Phosphate
- Iron Phosphate
- Iron Oxides
- Magnesium Silicate
- Calcium Sulfate
- Zinc Phosphate
- Aluminum Phosphate
- Calcium Fluoride

As water utilization increases through recycle & reuse, the potential for mineral scale rise exponentially.

Four Requirements for Scale Formation are, Ion super saturation (Ksp > 1.0), Nucleation site, Adequate contact time, Dissolution & precipitation.

Factors Affecting Scale Formation

- Mineral Concentration
- Water Temperature
- Water pH
- Suspended Solids
- Water Flow Velocity

Contributing Factors to Scale Formation • Hydraulics and flow velocities • Surface characteristics • Corrosion • Fouling • Microbial activity • System design and operation.

Effects of Poor Scale Control • Reduces heat transfer efficiency • Decreases unit or production capacity • Can promote corrosion & microbial growth • Increases pump pressure requirements • Higher operating costs/decreased profits • Spray nozzle pluggage.

Corrosion

Corrosion is an electrochemical process by which metals are reverted back to their natural “oxidized” state.
Types of Corrosion

**General Corrosion** • Metal loss in which a given area is alternately a cathode and an anode. • Metal loss occurs uniformly over the entire surface. • This is the preferred type of corrosion.

**Localized Pitting Corrosion** • A localized attack caused by a chemical anomaly. – Crevice Corrosion – Under Deposit Corrosion – Tuberculation – Biologically Induced Corrosion – Acid or Alkaline Corrosion

**Galvanic Corrosion** – Corrosion associated with the current of a galvanic cell consisting of two dissimilar metals that are significantly different in nobility connected to each other and exposed to a common water system. (I.e. copper and mild steel)

**Mechanically Induced Corrosion** – Abrasion / Erosion – Cavitation
A 10°C increase in water temperature, doubles the corrosion rate.

**Effects of Poor Corrosion Control**
- Corrosion destroys system metal – Water leaks in equipment develop – Process side and water side contamination occurs – Corrosion product deposits on heat exchanger surfaces – Heat transfer efficiency is reduced by deposits – Maintenance and cleaning frequency increases – Equipment must be repaired and/or replaced – Unscheduled shutdown of plant.

**Fouling**

Fouling is the accumulation of solid material, other than mineral scale, in a way that hampers the operation of equipment or contributes to its deterioration. Such as: Silt, Sand, Mud and Iron, Dirt and Dust, Process contaminants – Oils – Greases – Mill Scale – Corrosion Products

**Factors which influence fouling**
- Process Contamination
- Water Flow Velocity – Design vs. Existing
- Water Characteristics – Seasonal Variations
- Water Temperature
- Microbiological Growth
- Corrosion

**Effects of Poor Fouling Control**
- Spray Nozzle Pluggage
- Reduced Heat Transfer
- Restriction of Flow
- Decreased plant efficiency
- Reduction in productivity
- Increased downtime for maintenance
- Cost of equipment repair or replacement
- Reduced effectiveness of chemical inhibitors

Fouling can be removed through properly operated mechanical methods.

**Microbiological Growth**

There are three Kinds of Microorganisms: Bacteria, Algae & Fungi

- Diversity refers to the various kinds of microbes
- highly diverse microbial populations are “healthy microbe communities” and are typically indicative of a system under poor control

**Algae**
- Common in both soil and water
- Use sunlight for Energy
- Causes green slime in cooling towers and open air tanks
- Grows on periodically wetted areas
- Profuse growth can restrict water flow
- Living or dead algae can feed bacteria in the system
- requires different controls than bacteria.

**Fungi**
- Yeast and mold
- Produce hard and rubbery slime
- Grow in water-wetted, rather than submerged areas
- Degrade wood
- May appear in closed loop as fluffy flock

**Effects of Poor Microbiological Control**
- Forms sticky slime masses that foul nozzles and cause reduced heat transfer
- Produces acidic waste that lowers pH and causes corrosion
- Produces large volumes of iron deposits that foul heat exchanger surfaces and spray nozzles
- Form biomasses that lead to fouling of piping and cooling towers
A 1 mm layer of sessile bacteria reduces heat transfer by 50%, similar to a 4 mm layer of calcium carbonate scale.

**Bacteria: Aerobic vs. Anaerobic**

**Aerobic Bacteria**
- Requires Oxygen for Growth
- Produces Slimy Biofilms
  - Reduces flow and Heat Transfer
  - Increases Corrosion
- Are Metabolically Diverse
- Populations Adapt Readily and Can Grow Anywhere

**Anaerobic Bacteria**
- No Oxygen Required for Growth
- Indicates Deposits/Stagnation in System
- Some Produce Hydrogen Sulfide
- Some Produce Organic Acids
- Metabolically Diverse
2.14) Industrial symbiosis Symposium: Zanstaad

Symposium proceeding: Wednesday, 22nd April

Symposium begins at 9.00h

In this symposium, I got the opportunity to interact with managers from all around the Europe looking for opportunities to implement industrial symbiosis. The event was titled as “Conference of E-Harbours Movement in Amsterdam Metropolitan Area: Port & City: Connected Energy”. There were several workshops followed by the initial presentations. During the presentation, various companies Zaanstad municipality, Director of tata steel etc presented their ideas about industrial symbiosis. This was a nice opportunity to interact with other industry specialists.

In this symposium, the initial presentation were mainly concentrated on waste heat networks and zaanstad, the overall impression about adopting industrial symbiotic outlook on industrial development could be seen. The chairman of the symposium was Mecha Hes from port of Amsterdam whom I had met previously also and we had discussed industrial symbiosis and my thesis. His comments were very general and the interview couldn’t be recorded. Additionally, port of Amsterdam’s perspective in IJmuiden case is not very relevant.

Coming back to the symposium, the symposium began with a presentation from Hans Grunfeld (chairman of the Dutch union of industrial end users). Followed by a showcase of Kalundborg industrial symbiosis by Michel van der liden (director of the technical,
environmental and development depart in municipality of Kalundborg). After this presentation, I got the opportunity to discuss with Michel. As I explained by thesis to him, one of his important suggestions was that combine water. Water in itself won’t make a convincing deal. In Kalundborg, water is enriched in every process and turns into steam which is used at the power plant. And in term the water is sent by power plant to the statoil refinery. Therefore, as it is, using water is difficult. Additionally he said that in Kalundborg, the lake tesso water has strict legislation. Moreover, for cooling purposes, despite of being next to the sea, we don’t use sea water. Instead we use lake water and we use it very less. This urged us to share water and save on the water as that lake is crucial for that community leaving nearly.

He also added that community involvement and strict stoppage on ground water extraction was a driver. That made water a precious element. Otherwise if the costs and legislation both are not pressing. It makes it difficult. Therefore there is a role of government in supporting such initiatives.

More than the technical feasibility, the cooperation and interaction play a great role. It helps to create ideas. Marketing of these links is also important as it has to be told to people around regarding what is happening so that community support could be gained.

After this conversation, I got the opportunity attend a workshop on drivers and barriers of industrial symbiosis conducted by Melmo Port & city, Sweden. There were almost 14 seminars and I found this one very suitable to my study.

In this seminar, the following drivers and barriers were brainstormed with sharing personal experiences from various participants mainly from the Netherlands, Germany and Sweden. All these representatives were either consultants at some Industrial symbiosis site, or company champions, representatives from the society and students who have done thesis on industrial symbiosis and phd on this topic. Therefore the result of this brain storming session for one and a half hour is very helpful and could be used as a point of validation of my thesis and the points I extracted. I also took active participation in the workshop.

These were the factors that were extracted from the brainstorming session.

- Knowledge (awareness) about industrial symbiosis
- Project champion – different roles, positions and organisations in the area;
- Traditional planning of new and existing areas;
- Strategic marketing in favour for both new establishments and to fit the “existing” industrial symbiosis;
- Business confidentiality – not an open attitude to others
- Actors may find it difficult to see their new role;
- Matureness of catching new opportunities within business development differs;
- Low knowledge of neighbours businesses;
• Limited resources to go beyond business as usual;
• Difficult to estimate the results and effects of industrial symbiosis (with that; difficult to attract actors to engage)

Symposium ends @ 12.00 h

2.15) Tata Steel water vision, IJmuiden, the Netherlands

Tata Steel plant of IJmuiden (TSIJ) is known for its efforts for energy efficiency improvements and high steel production standards. Every year TSIJ thrives to achieve 2% of reduction in energy consumptions. Recent days efforts have been put to investigate sustainable projects like waste heat recovery and district heating, hydrogen gas utilization from coke oven plant, steam network etc. This commitment and enthusiasm is missing while dealing with water resource. It is one of the major virgin resources that flows into the steel making processes. Though the discharge quality is continuously improved and has always stayed below the effluent limits, amount of water that has been used for various processes has not changed significantly. Due to many reasons, such as financial slowdown of past decade and abundance of water in the region, water efficiency projects have been pushed down the priority lists of TSIJ. This is evident by the fact that last thorough companywide water management study was done in 2004-05.

Despite of abundance, recent figures by Eurostat on industrial water consumption in Europe have alarmed the policy makers. For instance, industrial sector uses approximately 40% of the total water abstractions. Furthermore, industrial sector is the main pollutant of the water resource as only 60% of the total water discharge receives adequate treatment. This indicates that in coming years the legislation and rules are going to be stricter and more demanding. Sensing this future scenario, to cope up with future demands on water consumption of TSIJ a road map has to be established. Moreover, recent efforts of Tata steel Jamshedpur to install the state of art water treatment plant provides further interest in this subject. In last 18 months initial steps have been taken at TSIJ by including water in the energy efficiency investigations and 3 research projects by university students have been conducted. Taking this kick start to next level, in following parts a water vision is proposed to funnel down on the potential water reduction possibilities.

To achieve this goal to reduce water usage in TSIJ, a lean thinking is essential to eliminate excess consumption. Based on the concepts of lean, the following steps are proposed and then a framework is established.

“Tata Steel IJmuiden, our quest is to achieve reduction in water usage in compliance with the legislation in an economically feasible way to contribute to the goal of green and clean planet. We will achieve this target by emphasis on lean thinking and openness to external cooperation in the region for sustainability”

To achieve the above vision, we will take systematic steps mentioned below -

Identify Value
• Plant has a whole, what do we want to achieve is the first question. Sustainable water management practices to achieve a yearly target or Zero discharge policy, radical infrastructure changes or small economically viable options first?
• What are the customer requirements that are related to the type of water we use? For example the water type used in slag granulation directly influences ENCIIs requirements.
• What is the basic requirement to maintain the water quality in case of direct contact which influences the product (steel) quality?

Determine Essential Flows

• At many works water usage pattern has been the same from decades. Revisiting these processes, Understanding the usage of water in the production process and mapping the production requirements is the initial step.
• Once the requirement is known, it is essential check which level of quality and quantity contribute to the customer value and product demand?
• Is the current quality being used be reduced to other water types or could a water type be reused?
• Comparative case studies should be conducted to determine what are the consumption patterns of plants with same geographical situation is and what are their benchmarked activities. Example, water cascading example of Kalundborg, Denmark or Posco steel, South Korea for very little quantity of water for once through cooling.
• Necessary qualities and quantities are marked as essential prerequisites. All the other qualities and quantities are subjected to study.

Possible Improvements

• If the quality and quantity is found out to be suitable, the next logical step would be to check if the current technologies, equipment and methods used are the best suitable ones. If no, what are the new available options in the market?
• If the quality and quantities are found out to be more than necessary, develop usage reduction strategies. Check if the reduction is possible through traditional methods like recirculation or cascading or life cycle analysis? Or check if the non-technical options such as ‘cooperation among the regional companies to create a regional symbiosis for water consumption’ is possible?

Examine and prioritize

• Check whether the proposed new solutions, both technical and non-technical help to achieve the goal. Options such as impute output matching to high end options such as modelling could be used to determine which solutions are best.
• As a company, financial targets has to be achieved, therefore, the first criteria is costs against benefits. Return on investment and water foot print are most important criteria. Choosing easy and achievable solutions is the best approach. Projects with high impact on environmental performance, easily implementable, involving less
stakeholders, with minor changes in process and with very little new investments should be chosen first.

- This doesn’t mean that other options or large projects are not important. They are equally important but just to get the new change entrenched in the company, favorite projects shall be implemented first.

**Implement**

- Time scales have to be proposed to each possibility.
- While time scaling, it should be checked whether there are additional windows of opportunities that are arriving to implement such changes? For example, shut down of blast furnace no.6 for maintenance in 2017 or replacement age of a cooling tower.
- Last but not the least, industry wide water usage reduction has to be promoted and advantages of this projects in terms of monitory and environments have to be conveyed to the employees. It has been widely observed that many people still consider water as a very cheap resource despite of the fact that the recent studies by university students state the otherwise (30 mil/year).

**Feedback**

- These changes and their impact should be monitored real time and measuring equipment should be put up in all the consumption points.
- Based on the feedback, if necessary small incremental changes could be made.
- If the new solution is working as expected it should be benchmarked and efforts should be put to achieve perfection in that method.
APPENDIX 3: ATLAS.TI ANALYSIS

Codes-quotations list according to the companies

Code-Filter: All

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Code: absence of coordinating body {6-4}


Code: attitude towards waste {3-1}

P 1: Aroc.rtf


Code: attitude towards change {1-1}

P13: symposium.rtf (18:18)

Code: chemical compatibility {13-4}


(21:21)

Code: composition of water {10-4}


Code: cost of water {19-5}


Code: cost savings and market test {3-1}

Bibliography

Code: distance \{10-3\}

P 1: Aroc.rtf


(20:20) P 7: hhnk.rtf


Code: environmental awareness \{11-1\}

P 3: ENCi.rtf


(11:11) P15: Tata steel procurement.rtf (9:9) P16: tebodin.rtf

(7:7) P17: Waternet.rtf

(24:24), (27:27)

Code: existing investments \{6-2\}


Code: existing interaction \{10-2\}

P 1: Aroc.rtf

(8:8) P 2: Crown van gelder.rtf (10:10) P 4: Floricultura.rtf


Code: financial viability \{16-6\}


Code: governments involvement \{3-3\}

P14: Tata Steel Environmental department.rtf (34:34) P16: tebodin.rtf

(7:7) P17: Waternet.rtf

(29:29)
Code: information flow & communication {9-3}

P 3: ENCi.rtf

(31:31)

Code: interdependency {14-3}

(13:13) P14: Tata Steel Environmental department.rtf (15:15) P16: tebodin.rtf

Code: investment cost {23-8}

(14:14), (14:14) P 5: Grontmij.rtf (8:8) P 6: Harsco.rtf

(11:11) P11: Nuon.rtf


Code: knowledge about required quality {1-3}

P14: Tata Steel Environmental department.rtf (23:23)

Code: lack of awareness about IS {19-2}


(4:4), (11:11) P17: Waternet.rtf
(32:32)

Code: lack policy intervention {2-5}

P 7: hhnk.rtf (17:17) P13: symposium.rtf (7:7)

Code: long term vision {1-1}

P 5: Grontmij.rtf (13:13)

Code: marketing of projects {1-2}

P13: symposium.rtf (16:16)
Code: negligence {3-4}
P 3: ENCi.rtf


(22:22)

Code: ownership of infrastructure {5-1}


Code: project champion {1-2}
P13: symposium.rtf (14:14)

Code: regulatory compliance {8-4}

(29:29)

Code: reliability {2-4}

Code: size of the plant {3-2}
P14: Tata Steel Environmental department.rtf (32:32), (33:33) P16: tebodin.rtf

(7:7)

Code: supply scarcity {1-2}
P 2: Crown van gelder.rtf (21:21)

Code: tenant recruitment {1-2}
P 2: Crown van gelder.rtf (18:18)

Code: taxes on discharge {3-2}
P 3: ENCi.rtf (10:10) P15: Tata steel procurement.rtf (9:9), (14:14)

Code: Technical compatibility {12-3}
P 3: ENCi.rtf


(8:8) P10: nalco.rtf
Bibliography


Code: Technical lock in {4-2}


(13:13) P16: tebodin.rtf (10:10)

Code: third party investment {3-2}

P 4: Floricultura.rtf

(20:20) P 7: hhnk.rtf (21:21), (22:22)

Code: transparency and data sharing {8-1}

P 2: Crown van gelder.rtf (7:7) P 3: ENCi.rtf

(25:25) P 6: Harsco.rtf


Code: transportation costs of water {3-3}


Code: treatment costs {4-3}


Code: trust and assurance {4-3}

P 5: Grontmij.rtf (10:10) P 9: Linde.rtf (12:12)


Code: upgrading and pretreatment {1-4}

P 1: Aroc.rtf (15:15)

Code: value of resource {18-3}


(25:25)

Code: willingness to participate {16-7}

P 1: Aroc.rtf
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