EFFECTIVE FACTORS ON APPLICATION OF INDUSTRIAL SYMBIOSIS : CASE STUDY OF MAB-TA-PHUT INDUSTRIAL ESTATE

Mr. Paitoon Termsinvanich

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ปัจจัยที่มีผลต่อการประยุกต์ใช้ Industrial Symbiosis
: กรณีศึกษา นิคมอุตสาหกรรมมาบตาพุด

นายไพฑูรย์ เติมสินวาณิช

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาศิลปศาสตรดุษฎีบัณฑิต
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By	Mr. Paitoon Termsinvanich
Field of Study	Environment, Development and Sustainability
Thesis Advisor	Associate Professor Dawan Wiwattanadate, Ph.D.
Thesis Co-advisor	Associate Professor Suwattana Thadaniti, Ph.D.

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Doctoral Degree

…………………………………………**Dean of the Graduate School**
(Associate Professor Amorn Petsom, Ph.D.)

THESIS COMMITTEE

…………………………………………**Chairman**
(Sangchan Limjirakan, D.Tech.Sc.)

…………………………………………**Thesis Advisor**
(Associate Professor Dawan Wiwattanadate,Ph.D)

…………………………………………**Thesis Co-advisor**
(Associate Professor Suwattana Thadaniti, Ph.D.)

…………………………………………**Examiner**
(Professor Supang Chantavanich, Ph.D.)

…………………………………………**Examiner**
(Assistant Professor Chantra Tongcumpou, Ph.D.)

…………………………………………**External Examiner**
(Assistant Professor Suphang Chulalaksananukul, Ph.D.)

ไพฑูรย์ เติมสินวาณิช: ปัจจัยที่มีผลต่อการประยุกต์ใช้ Industrial Symbiosis กรณีศึกษา นิคมอุตสาหกรรมมาบตาพุด จังหวัดระยอง (Effective Factors on Application of Industrial Symbiosis in : Case study of Mab-Ta-Phut Industrial estate)อ. ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร. ดาวัลย์ วิวรรธนะเดช, อ. ที่ปรึกษาวิทยานิพนธ์ร่วม: รศ. ดร. สุวัฒนา ธาดานิติ, 70 หน้า.

นิคมอุตสาหกรรมมาบตาพุด เป็นหนึ่งในนิคมอุตสาหกรรมที่มีชื่อเสียงของประเทศไทย ตั้งอยู่ที่จังหวัดระยองทางภาคตะวันออกของประเทศ แม้โรงงานอุตสาหกรรมส่วนใหญ่ได้พัฒนาและดำเนินการตามระบบการจัดการของเสียและสิ่งแวดล้อมตามกฎหมายมาอย่างต่อเนื่อง แต่ยังคงมีของเสียที่ต้องจัดการปริมาณมากกว่า 700,000 ตันต่อปี แนวคิดการจัดการของเสียด้วยการสร้างเครือข่ายแลกเปลี่ยนวัสดุ และ/หรือ พลังงาน ระหว่างโรงงานอุตสาหกรรม (Industrial Symbiosis) จึงเป็นอีกหนึ่งทางเลือกที่ก่อให้เกิดผลประโยชน์ทั้งด้านสังคม เศรษฐกิจ และสิ่งแวดล้อม ตลอดจนเป็นการบริโภคทรัพยากรอย่างมีประสิทธิภาพ (Resource Efficiency) เนื่องจากมีการนำของเสียจากโรงงานหนึ่งไปใช้ประโยชน์ในอีกโรงงานหนึ่ง เป็นการเปลี่ยนรูปแบบการไหลของวัตถุดิบจากระบบเชิงเส้น (บริโภควัตถุดิบ และปล่อยของเสียที่ต้องกำจัด) เป็นระบบป้อนกลับของเสียไปเป็นวัตถุดิบของอีกโรงงานหนึ่ง ซึ่งนอกจากช่วยลดปริมาณของเสียที่ต้องจัดการแล้ว ยังลดการบริโภควัตถุดิบอีกด้วย จึงเป็นการเพิ่มความสามารถในการแข่งขันของโรงงานอุตสาหกรรม ควบคู่กับการอนุรักษ์ทรัพยากรธรรมชาติและสิ่งแวดล้อม

การแลกเปลี่ยนวัสดุอุตสาหกรรม (Industrial Symbiosis) มีการดำเนินการในต่างประเทศหลายแห่ง ตัวอย่างที่ประสบความสำเร็จและเป็นที่รู้จักกันแพร่หลาย คือ สวนอุตสาหกรรม Kalundborg ประเทศเดนมาร์ค ขณะที่บางแห่งยังไม่สามารถดำเนินการได้อย่างมีประสิทธิผล การศึกษานี้จึงทำศึกษาปัจจัยที่ส่งให้การแลกเปลี่ยนวัสดุเป็นไปอย่างมีประสิทธิผล โดยใช้นิคมอุตสาหกรรมมาบตาพุดเป็นกรณีศึกษา

จากการศึกษาปัจจัยและรูปแบบการดำเนินการแลกเปลี่ยนวัสดุในกลุ่มอุตสาหกรรมอย่างมีประสิทธิผล โดยใช้แบบสอบถาม การสัมภาษณ์เชิงลึก และการสังเกตจากหน้างาน ทั้งโรงงานในนิคมอุตสาหกรรมมาบตาพุด และโรงงานจัดการของเสีย (Waste Processor Plants) ที่รับของเสียไปเป็นวัตถุดิบอุตสาหกรรมในจัดหวัดสระบุรี ผลการศึกษาพบว่า ปัจจัยที่มีผลต่อการดำเนินการแลกเปลี่ยนวัสดุอย่างมีประสิทธิผล ได้แก่ นโยบายการปลดปล่อยของเสียเป็นศูนย์ นโยบายการฝังกลบเป็นศูนย์ นโยบายการปรับปรุงกระบวนการ กลไกทางการเงิน และการมีผู้ริเริ่ม ขณะที่ปัจจัยด้านเทคโนโลยีและการมีส่วนร่วมของสาธารณะไม่มีอิทธิพลมากนักสำหรับกรณีของโรงงานในนิคมอุตสาหกรรม ดังนั้นผู้วิจัยจึงได้ยกร่างโมเดลการดำเนินการแลกเปลี่ยนวัสดุระหว่างโรงงานในนิคมอุตสาหกรรมอย่างมีประสิทธิผล แล้วนำไปสอบถามความคิดเห็นพร้อมรับฟังข้อเสนอแนะจากจากผู้เชี่ยวชาญโดยใช้เทคนิคเดลฟลาย เพื่อนำข้อเสนอแนะมาปรับปรุงโมเดลให้มีความสมบูรณ์มากยิ่งขึ้น

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PAITOON TERMSINVANICH: EFFECTIVE FACTORS ON APPLICATION OF INDUSTRIAL SYMBIOSIS : CASE STUDY OF MAB-YA-PHUT INDUSTRIAL ESTATE**.** ADVISOR: ASSOC. PROF. DAWAN WIWATTANADATE Ph.D., CO-ADVISOR: ASSOC. PROF. SUWATTANA THADANITI Ph.D., 70 PP.

Mab-Ta-Phut Industrial Estate (MTPIE) is a famous industrial estate located in Rayong province, eastern part of Thailand. Though most industries in the MTPIE have been continuously developing and implementing waste and environmental management system to comply with national regulation, more than 700,000 tons per year of waste are still emitted. Therefore, a new concept to manage waste by creating network for materials and/or energy exchange among industries, which is so-called 'Industrial Symbiosis', has been considered as an alternative system providing benefits for both social, economic, and environment. The industrial symbiosis also leads to resource efficiency improvement as well as competitive advantages because wastes or by-products from one firm can be transformed into valuable inputs of another; hence, material flow would be changed from a linear one (where raw material is consumed and waste is generated) into a circular one.

Industrial symbiosis has been implemented in various countries and one of successful and well-known case is Kalundborg's Industrial Park in Denmark, while many cases cannot be effectively implemented. Therefore, effective factors for implementation of industrial symbiosis in industrial estate were investigated in this study by using Mab-Ta-Phut Industrial Estate as a case study.

The study was carried out with questionnaires, in-depth interview, and site survey, both factories in MTPIE and waste processor plants in Saraburi Province. It's found that effective factors for industrial symbiosis implementation are policy on zero waste, zero landfill, and process adjustment willingness; financial mechanism and initiator available. Whereas, factors related to technology and public participation are not so effective for the case of industrial estate. Therefore, a model for effective implementation of Thailand's industrial estate has been formulated and modified upon experts' consideration by using a Delphi Technique.

Field of Study : Environment, Development and Sustainability	Student's Signature …………………..
Academic Year: 2012…………………………..	Advisor's Signature …………………..
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LIST OF ABBREVIATIONS

CH4	Substance formula of methane
CO2	Substance formula of carbon dioxide
DIW	Department of Industrial Work
EHWM	Center of excellence on Hazardous Substance management
EIE	Eco-Industrial Estate
EIN	Eco-Industrial Networks
EIP	Eco-Industrial Park
EMS	Environmental Management System
IE	Industrial Estate
IEAT	Industrial Estate authority of Thailand
IQR	Inter-quartile range
IS	Industrial Symbiosis
MTP	Mab-Ta-Phut
MTPIE	Mab-Ta-Phut Industrial Estate
ONEP	Office of Natural resources and Environmental Policy and Planning
P2	Pollution prevention
PCD	Pollution Control Department
WTE	waste-to-energy
US EPA	US Environmental Protection Agency

CHAPTER I
INTRODUCTION

1.1 Background and Importance of the Study

Impacts of industrialization and population growth on environment have been an issue of public concerns world-wide for several decades, especially in developed countries. In the past, industries could be located in any areas and individually emitted pollutants to environment causing difficulty in pollution control. Thus, an industrial park concept has been introduced to set up community of industries which are grouped to obtain advantages of arranging common services (Barrie, 1992) and controlling emissions in the standard level. However, many countries still confront the environmental problem due to accumulation of the impacts. Hence, a concept of Industrial Ecology as well as Eco-Industrial Park (EIP) that aim to create materials and energy interchanging networks among companies has been initiated to provide benefits for both environment and economy for the participating industries and societies (Graedel, and Allenby, 2003).

Eco-industrial Park (EIP) would bring to reducing virgin materials utilization, increasing energy efficiency, and reducing volume of wastes for disposal (Gertler, 1995). It can increase productivity of resource utilization, reduce by-products, wastes, and pollution, create employment opportunities, and also improve community's quality of life (Lilian, Elabras, and Alessandra, 2009).

Industrial symbiosis (IS), a sub-field of industrial ecology, is a famous tool often used to initiate ecosystem for industries to achieve an eco-industrial park (EIP) or eco-industrial estate (EIE). It focuses on transforming by-product and/or waste of one firm into a valuable input of another; hence, changing material flows from a traditional linear one into a circular flow. As the result, the industrial system can improve not only competitive advantages, but also environmental performance (Graedel, and Allenby, 2003; Zengwei, and Lei Shi, 2009).

Mab-Ta-Phut Industrial Estate (MTPIE)*, locating in Rayong province of Thailand, was developed in 1989 by Industrial Estate Authority of Thailand (state enterprise) to encourage investment of industries using natural gas as main inputs, where petrochemical industries are the most important ones. Although most industries in the MTPIE have been continuously developing and implementing environmental management system in accordance with ISO14001 and trying to control their emissions within emission standard, and also managing their wastes to comply with government's regulation, it's found that more than 700,000 tons per year of wastes are still emitted in the estate, and more than 500,000 tons of which emitted by petrochemical industries (Charmondusita, K. al. et. 2007). This have been affecting to communities for many years.

* Map-Ta-Phut can be expressed as Mab-Ta-Phut, which was used in this study.

In 2009, administrative court noticed that Mab-Ta-Phut was pollution controlled border and held over 76 projects. This means the current environmental management method is not sufficient to develop industries in a sustainable way. In addition, as industrial production is a dynamic system, wastes generated from the industries would be dynamic so that managing and addressing these wastes must be dynamic too. It was also expected that implementation of industrial symbiosis, focusing on waste utilization, would help to minimize these problems. Therefore, this study aimed to survey factors effective for implementation of industrial symbiosis and also to propose a model for effective implementation of the industrial symbiosis in Thailand's industrial estates.

1.2 Research Objective

Main objective of this study was to find out factors effective for implementation of industrial symbiosis (IS). Specific objectives of this study were as follows:

1.2.1. To search for any factories in the MTPIE having implemented or interested to implement the industrial symbiosis.

1.2.2. To identify factors effective for industrial symbiosis implementation.

1.2.3. To develop a model for effective implementation of industrial symbiosis in Thailand's industrial estates.

1.3 Scope of study

Target group of this study was petrochemical industries or 'waste generators' in MTPIE and 'waste processors' in Saraburi, which was referred by waste generators.

The study was divided into 3 stages, starting with questionnaire survey to search for factories willing to make an appointment for in-depth interview, either implemented or interested to implement the industrial symbiosis (IS). Next stage, the only respondent factories were then made appointment for site survey and key-informant interview to collect information about success factors and barriers on implementation, operation, and other opinion. Waste processors, waste management related government agencies, and experts or persons in charge with waste and/or environment in factories were also interviewed.

The third stage of the study was information analysis to identify factors effective for IS implementation, followed with formulation of a model for effective implementation. The identified factors as well as the preliminary model were then verified by experts from industries, government agencies, and academics, using Delphi technique.

1.4 Operational Definitions

Symbiosis Implementation refers to the plants or factories that transfer waste or by-product to be valuable material or energy in others.

Waste Generator refers to plants or factories that generate waste or by product.

Waste Processor refers to plants or factories that manage the wastes or by-products generated by waste generator.

1.5 Expected Outcomes

Expected outcomes of this study are:

- List of effective factors for IS implementation in MTPIE
- A model for effective implementation of industrial symbiosis

1.6 Limitation

The Mab-Ta-Phut area was declared to be pollution controlled area so waste; by-product and other data are sensitive data.

- The type of waste and by-product, if revealed, the rival can know their formulation and production process.
- The quantity of waste and by-product, if revealed, the rival can know their real production capacity.

Due to the waste and by-product information are sensitive data, it became limitation of gathering data from factories in the study. Therefore, only 7 of 32 factories of petrochemical industries in the MTPIE were willing to make appointment for in-depth interview

CHAPTER II
LITERATURE REVIEW

During the last few decades, most environmental policies have been focused on traditional “end-of-pipe” pollution controls. Although a concept of industrial park or industrial estate has been introduced to set up community of industries, to achieve advantages of arranging common services (Barrie, 1992) and controlling emissions to meet standard level, many countries still confront environment problems due to emissions accumulation.

Many approaches have been initiated to move from the traditional end-of-pipe control to a life-cycle approach which focuses on pollution prevention rather than control and treatment. The concept of ‘industrial ecosystem’, as a mirror of natural ecosystem, has been recommended as a goal for industrial estates in environmental management (UNEP 1996, cited in Suavanee, 2002). A tool of choice namely ‘industrial symbiosis’ which is a subfield of industrial ecology has been implementing in many countries to generate benefits for both environment and economic. This chapter therefore described terms of ‘environmental management and pollution prevention’, ‘waste management hierarchy’, ‘industrial symbiosis and industrial ecosystem’, and also case studies of industrial symbiosis implementation in some countries.

2.1 Pollution Prevention, Environmental Management Systems, and Sustainability

Pollution prevention (P2) has been defined by the Canadian Federal Government as "*The use of processes, practices, materials, products, substances or energy that avoids or minimizes creation of pollutants and waste, and reduces overall risk to human health or the environment*." The goal of P2 is to eliminate causes of pollution rather than manage the waste generated. Pollution prevention involves continuous improvement through design, technical, operational and behavioral changes. It also encourages transformations that frequently lead to lower production costs, increased efficiencies and more effective protection of the environment.

P2 practices and techniques focus on such areas as substances of concern, efficient use and conservation of natural resources, reuse and recycling on site, materials and feedstock substitution, operating efficiencies, training, procurement techniques, product design, process changes, product reformulation, equipment modifications and clean production.

P2 is the preferred environmental approach for attaining sustainability. It stands at the top of the environmental protection hierarchy (see also figure 2.1) as the environmental management tool of choice, so that, whenever feasible, pollution or waste should be prevented or reduced at the source. Reducing material, energy and water usage through improved efficiency is also considered as P2.

Figure 2.1: Environmental Protection Hierarchy

(Environment Canada, 2012: online)

An environmental management system (EMS) is a systematic way of applying the P2 approach. An EMS can be designed to address only environmental compliance and not P2. However, many leading organizations are building P2 goals into their EMSs, so that continuous environmental improvement becomes an organizational priority. Some organizations are even trying to build sustainability into their EMSs. Sustainability paradigms such as 'Natural Step' are used to evaluate impacts and action plans to determine if the organization is moving towards sustainability.

2.2 Waste Management Hierarchy

Waste management generally consists of collection, transport, processing or disposal, managing, and monitoring of the waste materials produced by human activity, whether the wastes are solid, liquid, gas or radioactive. The US EPA (US Environmental Protection Agency) has integrated and ranked solid waste management as shown in figure 2.2.

Figure 2.2: Waste Management Hierarchy

(U.S. Environment Protection Agency (EPA) 2012: online)

- **Source Reduction and Reuse**

According to the US EPA, '***source reduction***', also known as '***waste prevention***', means reducing waste at the source. It can take many different forms, including reusing or donating, buying in bulk, reducing packaging, redesigning products, and reducing toxicity. Source reduction is also important in manufacturing. Light weighting of packaging, reuse, and remanufacturing are all becoming more popular business trends. Purchasing products that incorporate these features supports source reduction.

- **Recycling/Composting**

The US EPA defines '**recycling**' as a series of activities that includes the collection of used, reused, or unused items that would otherwise be considered waste; sorting and processing the recyclable products into raw materials; and remanufacturing the recycled raw materials into new products. Consumers provide the last link in recycling by purchasing products made from recycled content. Recycling can also include composting of food scraps, yard trimmings, and other organic materials.

Recycling prevents the emission of many greenhouse gases and water pollutants, saves energy, supplies valuable raw materials to industry, creates jobs, stimulates the development of greener technologies, conserves resources for our children's future, and reduces the need for new landfills and combustors.

- **Energy Recovery**

Energy recovery from waste is the conversion of non-recyclable waste materials into useable heat, electricity, or fuel through a variety of processes, including combustion, gasification, pyrolysis, anaerobic digestion, and landfill gas recovery. This process is often called '***waste-to-energy***' (WTE).

- **Treatment & Disposal**

Landfills are the most common form of waste disposal and are an important component of an integrated waste management system. A landfill site is a site for the disposal of waste materials by burial. Well-designed and well-managed landfill can be a hygienic and relatively inexpensive method of disposing of waste materials, but poorly designed or poorly managed landfills can create a number of environmental impacts such as wind-blown litter, attraction of vermin, and generation of liquid leachate that affects to ground water.

Another product of landfill is '***landfill gases***' mainly composed of methane (CH_4) and carbon dioxide (CO_2). The methane gas, a by-product of decomposing waste, can be collected and used as fuel to generate electricity. After a landfill is capped, the land may be used for recreation sites such as parks, golf courses, and ski slopes.

Combustion or incineration is a disposal method which is defined as the controlled burning of solid, liquid, or gaseous wastes. Incineration of Solid waste is operated to reduce the amount of landfill space needed. Purposes of incineration waste treatment are:

- Reducing waste volume, with the ultimate result of extending the lifetime of a land disposal facility.
- Changing waste to energy.
- Detoxifying within the waste

Combustion in an incinerator is not always perfect and there have been concerns about pollutants in gaseous emissions from incinerator stacks such as acid gas, fly ash, etc. which may have serious environmental consequences.

Wastes or by-product exchange using industrial symbiosis concept is an option of choice for waste prevention which is ranked at the top of waste management hierarchy.

2.3 Definition of Industrial Symbiosis and Related Terms

According to the Encyclopedia of Earth, industrial symbiosis (IS) is part of a new field called industrial ecology, which is principally concerned with the flow of materials and energy through systems at different scales, *from products to factories* and *up to national and global levels*. Industrial symbiosis focuses on these flows through networks of businesses and other organizations in local and regional economies as a means of approaching ecologically sustainable industrial development. Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products. *The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity*.

The term 'symbiosis' builds on the notion of mutualism in biological communities where at least two otherwise unrelated species exchange materials, energy, or information in a mutually beneficial manner. Hence, an industrial symbiosis would consist of place-based exchanges among different entities that yield a collective benefit greater than the sum of individual benefits to be achieved by acting alone. Such collaboration can also increase social capital among the participants. The symbioses need not occur within the strict boundaries of an industrial park, despite the popular use of the term 'eco-industrial park' to describe organizations engaging in exchanges.

There are three primary opportunities for resource exchange:

1) ***By-product reuse***: the exchange of firm-specific materials between two or more parties for use as substitutes for commercial products or raw materials. The materials exchange component has also been referred to as a by-product exchange, by-product synergy, or waste exchange and may also be referred to as an industrial recycling network.

2) ***Utility/infrastructure sharing***: the pooled use and management of commonly used resources such as energy, water, and wastewater.

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

An ***eco-industrial park (EIP)*** may include many ecologically desirable goals, including mechanisms to reduce overall environmental impact, conserve materials and energy, and foster cooperative approaches to resource efficiency and environmental management. The terms ***'industrial estate'(IE)*** and ***'eco-industrial estate'(EIE)*** are more commonly used in Asia and can include communities of workers who live in or near the group of businesses constituting the industrial estate.

Some writers refer to ***eco-industrial networks (EIN)*** to capture a broad range of environmental and economic activities among businesses. Just as economic clusters have come to mean a group of businesses that are sectorally related by the products they make and use, such as the furniture cluster in central North Carolina in the USA, the term ***'eco-industrial clusters'*** is sometimes used to describe environmental interactions among firms in the same or related industries.

Spatial scale of industrial symbiosis

In general, industrial symbiosis occurs locally or regionally across participating companies. Increasing the distance among firms lessens the breadth of exchange opportunities because it is not cost-effective to transport water and steam beyond regional boundaries, whereas by-products can often travel much farther. Observing numerous instances of industrial symbiosis, Chertow (2000) devised taxonomy of materials exchange types to consider spatial and organizational elements as following.

Type 1: Through Waste Exchanges

This approach ***often focuses at the end-of-life stage*** of a product or process. The exchanges accomplish various input/output savings on a trade-by-trade basis rather than continuously. They feature exchange of materials rather than of water or energy.

Type 2: Within a Facility, Firm, or Organization

Some kinds of ***materials exchange can occur primarily inside the boundaries of one organization*** rather than with a collection of outside parties.

Type 3: Inter Firms Co-located in a Defined Eco-industrial Park

In this approach, businesses and other organizations that are continuously located can exchange energy, water, and materials and can go further to share information and services such as permitting, transportation, and marketing. Type 3 exchanges ***occur primarily within the defined area of an industrial park or industrial estate***, but it is also common to involve other partners "over the fence."

Type 4: Among Local Firms That Are Not Co-located

Participants in this type of exchange ***need not be sited adjacent to one another*** but rather are located within a small geographic area.

This approach draws together existing businesses that can take advantage of already generated material, water, and energy streams and also provide opportunity to fill in new businesses based on common service requirements and input/output matching.

Type 5: Among Firms Organized Virtually across a Broader Region

Given the high cost of moving and other critical variables that enter into decisions about corporate location, very few businesses will relocate solely to engage in industrial symbiosis. This type of exchanges depends on ***virtual linkages*** rather than co-location. Although still place-based enterprises, this approach encompass a regional economic community in which the potential for the identification of byproduct exchanges is greatly increased by the larger number of firms that can participate.

Industrial ecology is a new concept rising in the growth of environmental management paradigms (Ehrenfeld 1995). Industrial ecology is different from the end of pipe of waste management; it is view holistic industrial system (not isolated and focus only waste disposal). It seeks to optimize the total materials cycle, from virgin materials, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital (Graedel, and Allenby, 1995). Gertler (1995) defined Industrial ecosystem is mirror of natural ecosystem as '*a community or network of companies and other organizations in a region that choose to interact by exchanging and making use of by-products and/or energy in a way that provides one or more of the following benefits over traditional, non-linked operations*':

- Reduction in the use of virgin materials as resource inputs.
- Increased energy efficiency leading to reduced systemic energy.
- Reduction in the volume of waste requiring disposal

  (with added benefit of preventing disposal-related pollution).
- Increase in the amount and types of process outputs having market value.

There are various terms and definitions related to the industrial ecosystem such as industrial symbiosis (IS), eco-industrial park (EIP) or eco-industrial estate (EIE) and so on. Its relationship can be summarized and illustrated in figure 2.3. The difference between traditional industrial development model (linear flow) and eco-industrial development model (circular flow) can be summarized and illustrated in figure 2.4.

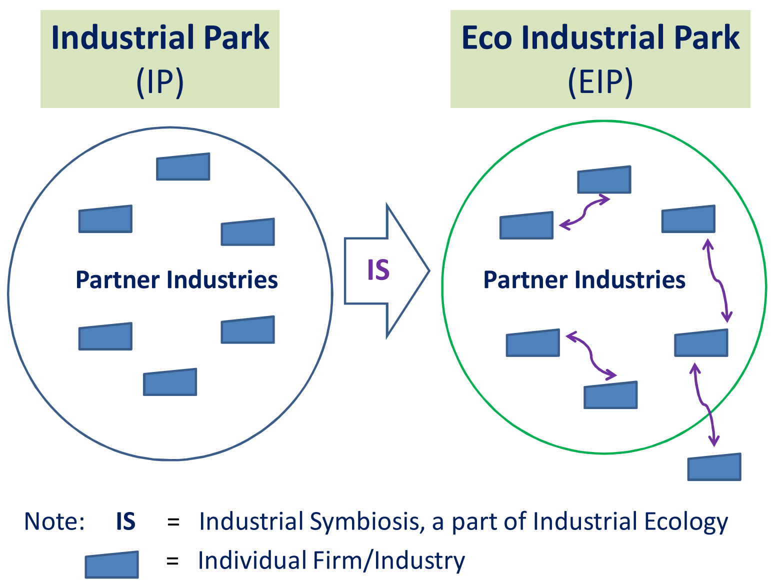

Figure 2.3: Industrial Symbiosis and Related Terms

(Stephens, 2012 : online)

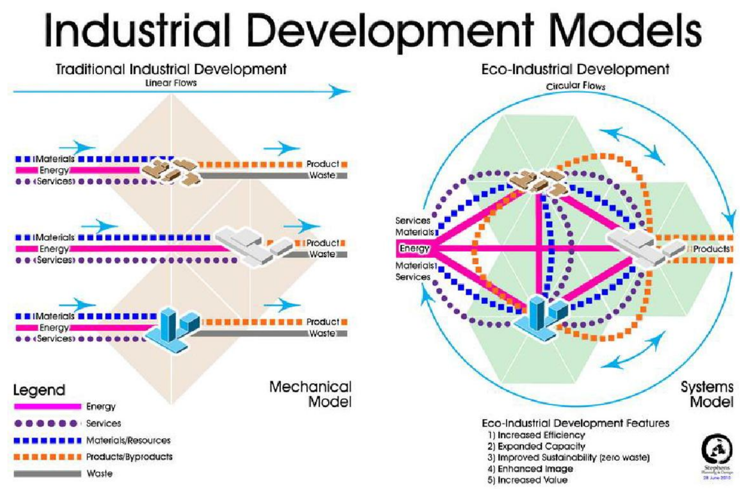

Figure 2.4: Traditional vs.Eco-Industrial Development Models
(Stephens, 2012 : online)

Chertow (2000) classified industrial ecology by implementation areas into 3 levels: facility or firm level, inter-firm level, and regional/global level as shown in figure 2.5. Various tools such as design for environment, pollution prevention, green accounting, etc. can be used for implementation at the firm level. However, implementation at the firm level is quite difficult to achieve zero waste. Hence, industrial symbiosis or waste/by-product exchange at the inter-firm level is recommended, especially those firms in industrial estate. Meanwhile, industrial metabolism is suggested for implementation at regional or global level.

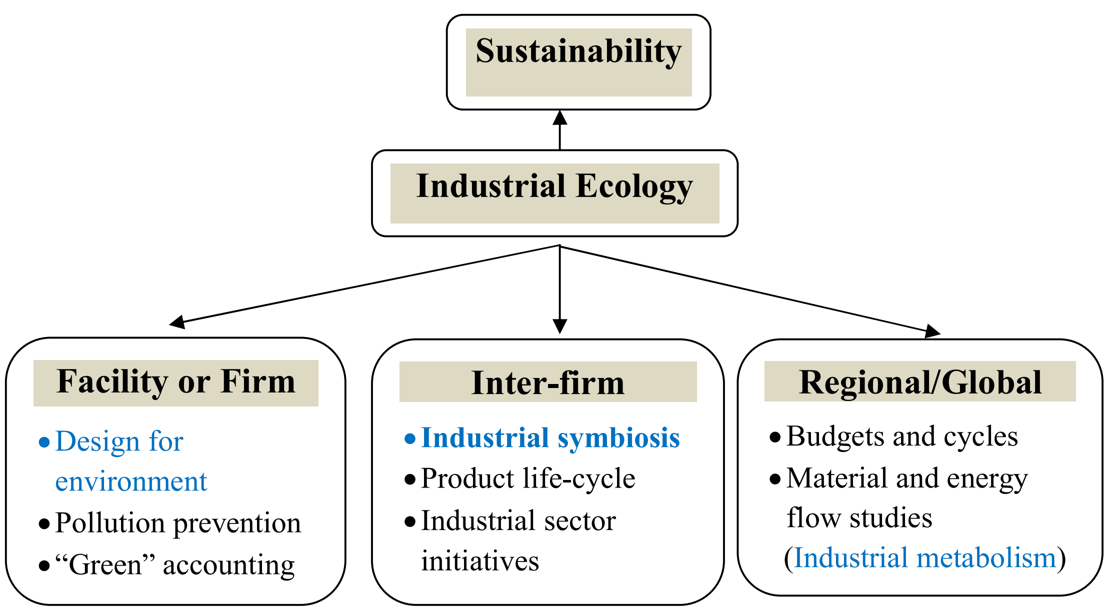

Figure 2.5: Industrial Ecology at three levels of implementation
Source: INDUSTRIAL SYMBIOSIS: Literature and Taxonomy Chertow (2000)

Implementation of appropriate tools mentioned above would help to develop a traditional industrial estate/park into an eco-industrial estate/park. Eco-industrial Park (EIP) is a local community of business and manufacturing that collaborate and seek for efficient sharing resources (information, materials, water, energy, infrastructure, natural habitat, etc) that lead to gain economic, environment, and social performance. This collaboration can get benefit greater than sum of the individual benefits of each business [(Lowe, Moran, Holmes, (1995); Lowe (2001)]. The key tool to develop EIP is industrial symbiosis that needs collaboration and synergistic materials, by-products and wastes exchange by geographic proximity.

2.4 Case Studies of Industrial Symbiosis Implementation

Industrial symbiosis is now well-known and worldwide. A key initiative has arisen from the hard work of a Belgian economist, Gunter Pauli. He recognizes the limits of a single firm to reduce wastes to zero, although substantially affording in pollution prevention (Chertow, 2000), it is need to addressing waste as defined industrial symbiosis.

A number of regions around the world have been implementing the industrial symbiosis. The well-known examples can be shown for case studies as follows.

2.4.1 Kalundborg's Industrial Symbiosis, Denmark

Kalundborg's industrial symbiosis implementation is the world's best known example of built network cooperation between five industries and municipality for both economic and environmental benefit (Suavanee, 2002; Ayres, RU. and Ayres LW. 2002). The result of profit-motivated business deals between a power station and oil refinery, a plasterboard manufacturer, a pharmaceutical plant, a biotech plant, and the municipality as shown in figure 2.6

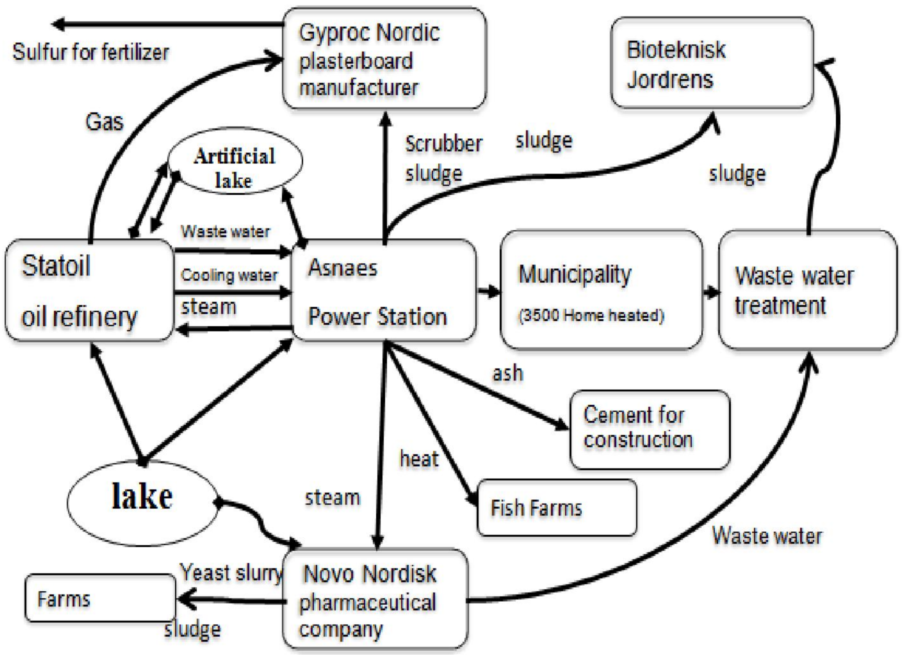

Figure 2.6 Industrial Symbiosis in Kalundborg's Industry.
(Ayres: 2002 - modified by Rick Proser: 2012 online)

Kalundborg's Industrial Estate, Denmark, began in 1961 with a project to use surface water from Lake Tisso for a new oil refinery in order to save the limited water. In this symbiosis, the five enterprises: Asnaes Power Station, Statoil oil refinery, Novo Nordisk, Gyproc Nordic East, Bioteknisk Jordrens, exchanged their by-product as a valuable raw material to one or more of the other. The symbioses were gradually developed (see also Table 2.1) without a grand design over the past few decades, as the firms sought to make economic use of their by-products and to minimize the overall cost.

Table 2.1 Chronology of Kalundborg Development

Year	Action
1959	Asnaes power station commissioned
1961	Statoil refinery commissioned; water piped from Lake Tissa
1972	Gyproc *A/S* built; gas piped from Statoil
1973	Asnaes expands; draws water from Pipeline
1976	Novo Nordisk begins shipping sludge to farmers
1979	Asnaes begins to sell fly ash to cement producers
1981	Asnaes produces heat for Kalundborg Kommune
1982	Asnaes delivers steam to Statoil and Novo Nordisk
1987	Statoil pipes cooling water to Asnaes
1989	Novo Nordisk switches from Lake Tissa to wells
1990	Statoil sells molten sulfur to Kemira in Jutland
1991	Statoil sends treated waste water to Asnaes for utility use
1992	Statoil sends desulfirized waste gas to Asnaes
1993	Asnaes supplies gypsum to Gyproc

(Source: Ehrenfeld, and Gertler 1997: online)

Asnaes Power Station, a coal-fired power plant, the park's heart, generates electricity, steam to pharmaceutical company, refinery plant, municipality, and heat to fish farms.

- Since 1979, fly ash and clinker of the power plant has been sold to cement plant.
- Since 1981, the power plant has supplied steam to resident in municipality of Kalundborg to replace oil fire furnaces through a network of underground pipes that paid by homeowner.
- Since 1982, the power plant starts selling steam to Nova Nordisk pharmaceutical because it seems to be cheaper than Nova's steam production. This symbiosis runs on *two-mile-long steam pipeline*. It reduces thermal pollution discharged by Asnaes.
- Since 1991, the power plant has received and treated waste water from refinery plant then sends its sludge to soil remediation plant. These reduce both resource consumption and environmental impact.
- Since 1993, the power plant starts sending scrubber sludge that invested $115 to plasterboard manufacturer. This produces industrial gypsum by-product 80-85,000 ton per year which is two-thirds of Gyproc's gypsum need, while much of the rest comes from a scrubber at a similar German power plant. In

the past before IS implementation, Gyproc obtained all its raw materials from Spanish open-pit mines which still supply a small portion of its need (Ehrenfeld, and Gertler 1997).

The Statoil refinery, across the road from Asnaes power plant, produces petroleum products ranging from light gas to heavy fuel oil. Before 1972, Statoil eliminated waste gases by flaring, which is common practice in industry. Now, this gas has been sending to Gyproc to fire wallboard drying oven. For continuity, Gyproc installed a butane backup system as if Statoil shuts down for maintenance (Ehrenfeld, and Gertler 1997).

In 1990, Statoil built desulphurization plant producing liquid sulphur, which is sold to a chemical company, Kemira in Jutland, *by trucked about 50 kilometer* to produce sulphuric acid and/or ammonia thiosulphate; the clean gas is then sent to Asnaes for combustion.

From freshwater scarcity in Kalundborg, Statoil has piped 700,000 cubic meters per year of cooling water to Asnaes since 1987, where it is purified and used as boiler feed-water. Statoil has also made treated waste water available to Asnaes, which uses about 200,000 cubic meters a year for cleaning purposes. Statoil's investment in a biological treatment facility produces an effluent sufficiently clean for Asnaes's use. These linkages have reduced the water demand around 25% (Ehrenfeld, and Gertler 1997).

Novo Nordisk, located a few miles from Asnaes and Statoil, is world leader in production of insulin, enzymes, and penicillin. The plant employs about 1,000 people, roughly 10% of Kalundborg's population. Novo Nordisk receives waste steam power from power plant to production line and sends yeast slurry and sludge to about thousand farms where it is spread on the land as fertilizer in 1976. This was the least-cost way to comply with regulations prohibition for Novo from discharging the sludge directly into the sea. Novo sends waste water to treatment plant. These also reduce both resource consumption and environmental impact.

Gyproc Nordic East, a plasterboard manufacturer receives scrubber sludge from power plant to production line and sends sulfur to fertilizer plant.

Bioteknisk Jordrens, a soil remediation plant, receives sludge for production line.

Benefits of the symbiosis on energy and resource conservation is shown in Table 2.2

Kalundborg case is one of the best practices for industrial symbiosis and has been gradually developing as shown in Table 2.2. There are other industrial symbioses developed in many countries.

Table 2.2 Waste and Resource Saving at Kalundborg

Annual Resource Savings Through Interchanges
Water savings Statoil-1.2 million cubic meters from Asnaes (Novo Nordisk is now producing 900,000 cubic meters of treated water that is available to replace Fresh supplies.)
Fuel savings Asnaes-30,000 tons of coal (about ***2%*** of throughput) by using Statoil fuel gas. about 19,000 tons of oil use by using fuel gas from Statoil in Novo Nordisk's boilers and Gyproc dryer fuel Community heating via steam from Asnaes
Input chemicals saving Fertilizer equivalent to Novo Nordisk sludge (about 800 tons nitrogen and 400 tons phosphorous) 2,800 tons sulfur 80,000 tons of gypsum
Wastes avoided through interchanges
200,000 tons fly ash and clinker from Asnaes (landfill) 80,000 tons scrubber sludge from Asnaes (landfill) 2,800 tons sulfur as hydrogen sulfide in flue gas from Statoil (air) 1 million cubic meters of water treatment sludge from Novo Nordisk (landfill or sea) 1,500-2,500 tons of sulfur dioxide avoided by substituting coal and oil (air) 130,000 tons carbon dioxide avoided by substituting coal and oil (air)

(Source: Ehrenfeld, and Gertler 1997: online)

2.4.2 Industrial Symbiosis in UK

UK initiated National Industrial Symbiosis Program and launched in 2003 to promote IS within UK to help industries look beyond their plant boundaries to find solution for improving resource efficiency. This is the first national scale in the world.

In Scotland, UK, the Forth Valley area, there are many companies in the petroleum and petrochemical industries, and also several industrial symbiosis initiatives. The most interesting exchanges are among Scottish Power, ScotAsh and Blue Circle, and among Exxon Chemical Olefins, Shell and BP Grangemouth. ScotAsh is a joint venture between Lafarge Cement UK and Scottish Power that manufactures construction products from wastes generated during coal combustion. In the Forth Valley, Scottish Power provides pulverized fuel ash (PFA in figure 2.7) and furnace bottom ash (FBA in figure 2.7) material to ScotAsh, who then turns it into a cement feedstock that is sold to Blue Circle, a cement manufacturer.

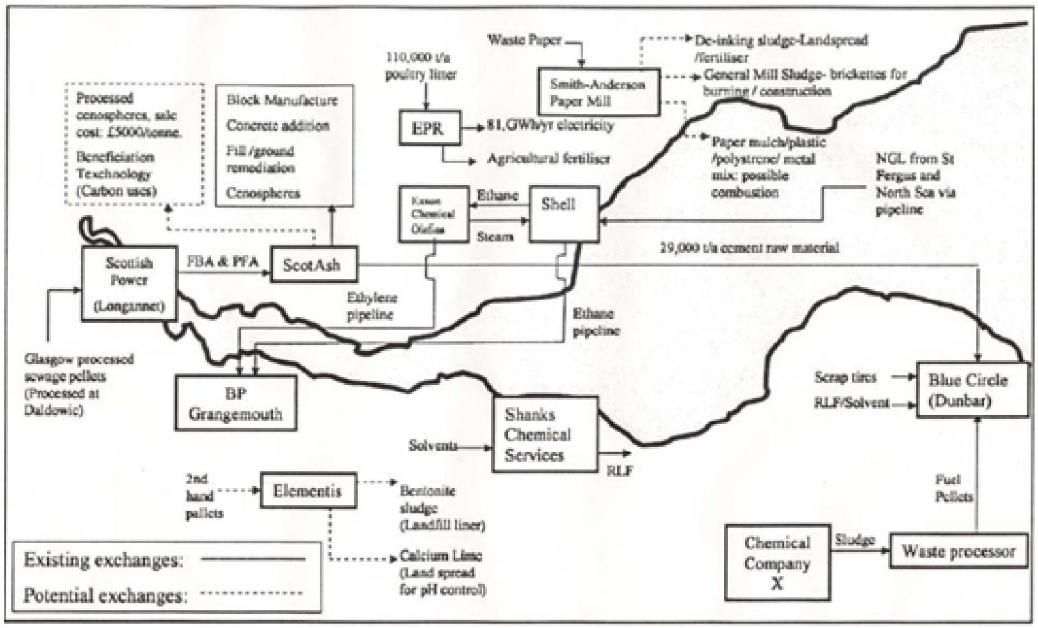

Figure 2.7 Industrial Symbiosis in Forth Valley, Scotland, UK (Harris, 2004 cited in Harris, Berkel, and Kurup, 2008)

ScotAsh reports that using its PFA products in cement production can result in a lower water demand and CO_2 reductions of around 30% per ton of cement produced via energy savings alone (www.scotash.com). The Exxon-Shell-BP exchange is typical for the petrochemical industry. Exxon provides steam to Shell and ethylene to the BP Grangemouth refinery; Shell in turn provides ethane to Exxon, as well as a limited amount to BP Grangemouth(Harris 2004).

Grangemouth Industrial Park, UK, also contains a number of symbioses, mostly centered on the BP refinery. In figure 2.8 are a number of potential synergies identified by Harris (2004). Grangemouth CHP supplies steam and electricity to BP, and could supply steam to GE plastics, and Rohm and Haas as well. Waste polymer generated by BP used to send to landfills, but now being used by Nychem, a plastics and rubber specialist.

BP is also looking for making use of its waste heat resource through a district heating system and/or by using it to heat its offices (Harris 2004). Harris (2004) studied in this area and identified many potential symbiosis as shown by dot line in figure 2.8.

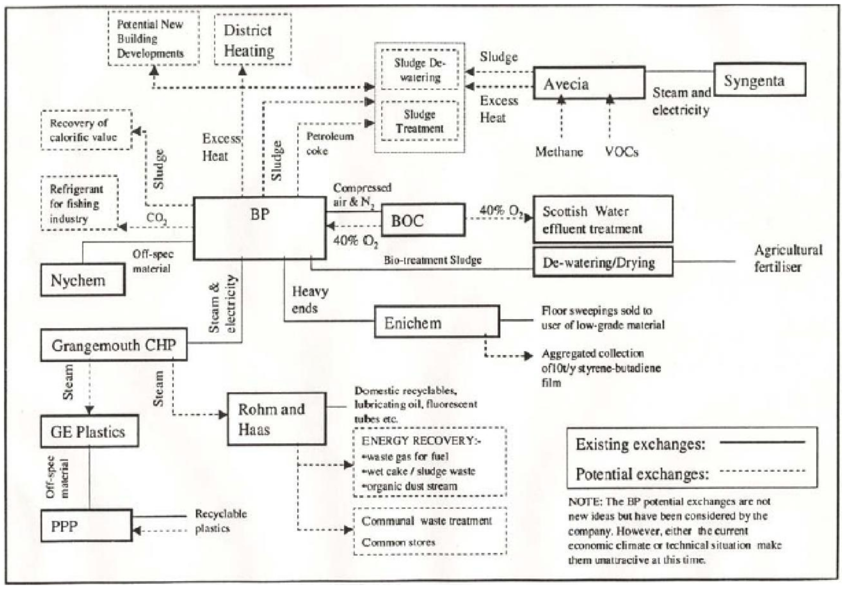

Figure 2.8 Industrial Symbiosis in Grangemouth Industrial Park (Harris 2004)

The UK industrial symbiosis benefits have been reported in the website (www.nisp.org.uk) since April 2005 as shown in Table 2.3.

Table 2.3 Benefit of Industrial Symbiosis in UK

Economic Perspective
Industry has saved an estimated £28,307,311 Investment for reprocesses and recycling business £7,246,000
Environmental perspective
Reducing 183,636 tons of waste to landfill. Reducing 273,350 tons of CO_2 emission
Social perspective
98 New jobs created 222 Jobs have been safeguarded

Source: Raymond and Ramsey (2006: online)

2.4.3 Kwinana Industrial Area Australia's West Coast

Kwinana Industrial Area was established in the 1950's. Its council, formed in 1991 by a core group of industries, was originally charged to monitor air and water emission, but now expanded to identify and promote industrial symbiosis (Bossilkov, Beers, and Berkel, 2005). The Kwinana Industries Council and Centre of Sustainable Resource Processing, Curtin University, developed Kwinana synergies project that many industries implemented synergies among companies in the area (Bossilkov and Berkel 2004, Bossilkov *et al.* 2005) as shown in figures 2.9 - 2.10. Some examples of resource symbiosis implemented in Kwinana Industrial Area can be shown as follows (Bossilkov *et al.* 2005) and its benefit shown in Table 2.4

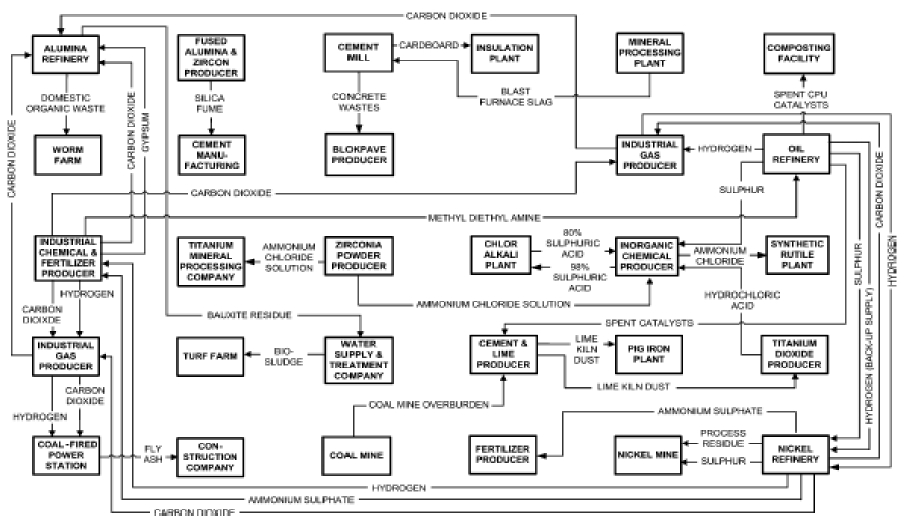

Figure 2.9 Resource Synergies (By product Synergy) in Kwinana Industrial Area.
(Source: Bossilkov *et al.* 2005)

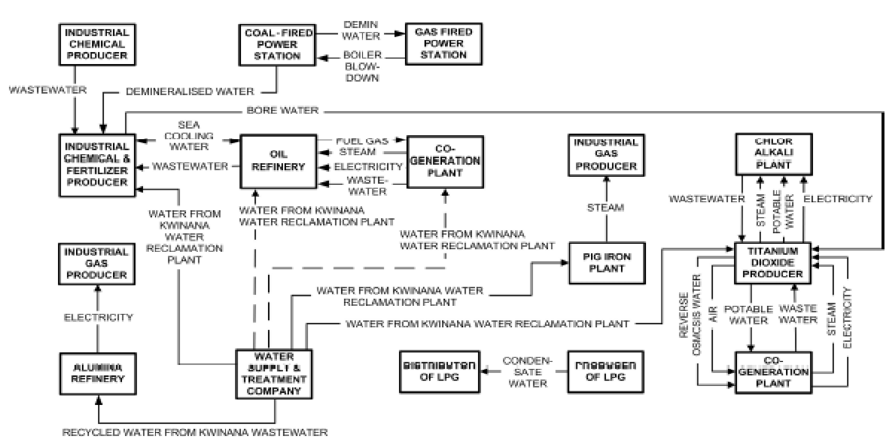

Figure 2.10 Resource Synergies (Utility Synergy) in Kwinana industrial Area.
(Source: Bossilkov *et al.* 2005)

Table 2.4 Benefit of Industrial Symbiosis in Kwinana and Gladstone (Beers et al., 2007)

Symbiosis	Commercial Benefits	Environmental and Social Benefits
CSBP gypsum reuse	Reduced cost to manage gypsum stockpile(long-term)	Reduction of stockpile gypsum onsite at chemical plant
	Lower cost gypsum source for alumina	Increased soil stability and plant growth at residue area of alumina refinery
Tiwest hydrochloric acid Reuse	Revenue from sale and conversion of recovered hydrochloric acid	Less waste from neutralization process at pigment plant
	Avoided treatment costs to neutralize dilute hydrochloric acid	
Gladstone power station	Revenue for power station	Reduced disposal of fly ash to local bunds
Fly ash reuse	Improvement of cement product quality	Reduced use of raw material by cement plant

Table 2.4 Benefit of Industrial Symbiosis in Kwinana and Gladstone (Beers et al., 2007) (Cont')

Symbiosis	Commercial Benefits	Environmental and Social Benefits
BP co-generation facility	Savings in capital and operational costs for oil refinery	Avoided impacts (energy efficiency with associated reduction of greenhouse gases)
	Reliable source of electricity and steam for oil refinery	Improved use of refinery gas
	Sales of electricity and steam from cogeneration plant	Employment
QAL effluent reuse	During drought alumina refinery was able to continue to operate at full production	No effluent discharge to local waterways
	No need for council to install tertiary treatment if or when required	Greater availability of water for region

From the case studies of industrial symbiosis above, there are many benefits to economic, environment and social. Many researchers suggest strategies to implement symbiosis and case studies related to factors and barrier influencing to implement industrial symbiosis.

2.5 Strategies and Factors Influencing on IS Implementation.

2.5.1 Strategies to implement

Many symbiosis projects have been implemented and most of which are likely to imitate the well-known Kalundborg model that focuses on heavy industrial sectors like petrochemical, chemical, cement, steel and metal processing or sugar industry; however, many areas do not have heavy industries. Various methodologies or strategies or steps to implement symbiosis in industrial park or regional scales can be suggested as following:

- Ernest (1997) suggested strategies for forming resources exchange
- Adoue (2004), cited in Guillaume and Erkman (2007), suggested methodology for detecting and implementing energy, waste or by-products synergies.
- Chertow (2000) suggested tool and approach to implement symbiosis

1) Strategies for forming resources exchange

Ernest (1997) suggested steps for forming resources exchange as follows:

- Analyze materials and energy inputs/outputs or materials budgeting of major industries in the area.
- Assess potential of materials collecting and pooling
- Disseminate information and check for possible matching or input-output matching
- Determine materials or energy required in processing of each industry
- Identify potential customer
- Define volume requirements of potential customer industries.
- Establish agreement for collaboration
- Implementation and monitoring

2) Methodology for detecting and implementing by-products and waste exchange

Guillaume and Erkman (2007) studies industrial symbiosis in Geneva, Switzerland. Switzer legislation stipulates and facilitates symbiosis to minimize environmental impacts. Adoue (2004) cited by Guillaume and Erkman (2007) developed methodology for detecting and implementing by-products and waste exchange as shown in figure 2.11.

Guillaume and Erkman (2007) commented that all data collected must be kept confidential and guaranteed not to be disclosed to any industrial competitors.

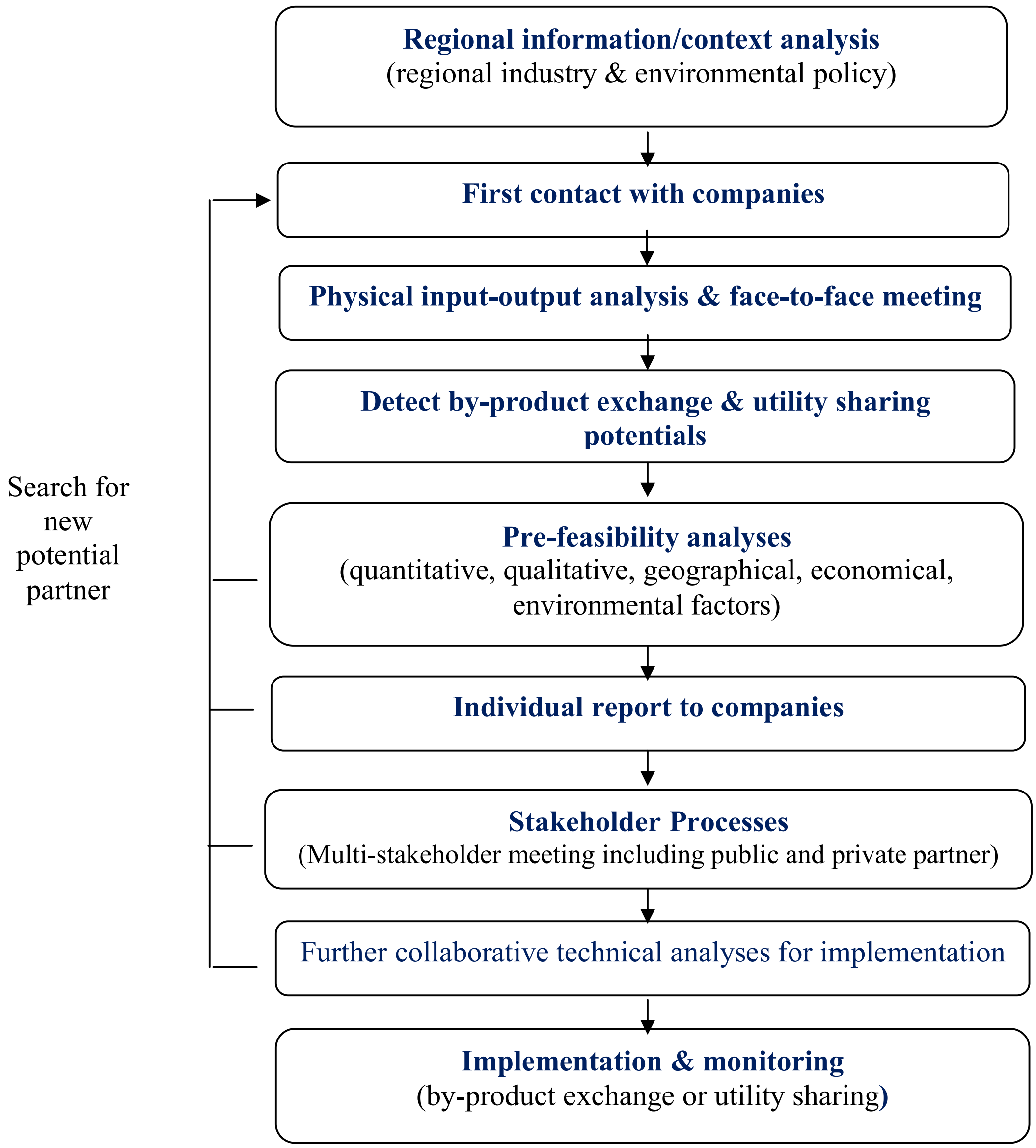

Figure 2.11 Methodology Flow for Detecting and Implementing Regional Synergies developed by Adoue (2004), cited by Guillaume and Erkman (2007).

3) Tool and Approach to implement symbiosis

Chertow (2000) suggested tool and approach to implement symbiosis. He examined 12 sample industrial symbiosis projects and recommended the following three tools for implementing symbiosis:

- Input-output matching
- Stakeholder processes
- Material budgeting

3.1 Input-Output Matching

The firm's input-output material, waste, and by-products are significant information that has to be gathered and analyzed. Result of this analysis may show possible linkage or symbiosis matching waste and by-product of one firm to be valuable feed stock of another.

There are many input-output matching soft-wares such as FaST (Facility Synergy Tool), DIET (Designing Industrial Ecosystems Tool), and REaLiTy (Regulatory, Economic, and Logistics Tool) used in USA. These soft-wares are planning tools that investigate potential symbiosis (Chertow, 2000).

a. Stakeholder Processes

The success eco-industrial park requires members' collaboration and open to each other (Research Triangle Inst. cited in Chertow, 2000). All stakeholders should understand symbiosis, EIP objective and involve in analyzing and design potential exchange and feel as owner of the symbiosis processes.

b. Material Budgeting

Material budgeting is quantity monitoring of raw material, waste, by-product, both entering and leaving per unit of time and amount of inventories keeping. For instance, study of computer flow at Yale industrial ecosystem, estimated 4,500 computers entered the university each year, yet only 250 of which were known to be the existing system through recycling and donation to other organizations (Chertow, 2000).

4) Integrated Strategy to Develop Industrial Symbiosis

According to the strategies, methodology, and tool to develop industrial symbiosis mentioned above, an integrated strategy and steps to develop waste and/or by-product exchange or to develop industrial symbiosis can be expressed as shown in Table 2.5

Although integrated step to develop and implement industrial symbiosis has been developed above, it needs collaboration and openness of input raw material, Energy and output of waste, by product information. According to Chertow (2000) states" The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity". Ernest (1997) also suggested that the information of material and energy input and output may be problem to implement symbiosis because it may come off to competitors. These are problem to develop symbiosis. Are there any questions to implement it?

Table 2.5 Integrated Steps to Develop by-product and waste exchange

No.	Activities	Ernest (1997)	Adoue (2004)	Chertow (2000)
1	Regional industry & environmental policy		/	
2	First contact with companies		/	
3	Analyze the materials and energy inputs and output	/	/ (adding face-to face meeting)	/
4	Assess the potential materials to create flows sufficient to market.	/		
5	Disseminate information matches with existing businesses	/		
6	Determine material processing required achieving quality requirements.	/		
7	Identify potential customer industries	/	/	/
8	Feasibility analyses (quantitative, qualitative, geographical, economic, environment factors)	/	/	
9	Individual report to companies		/	
10	Multi-stakeholder meeting, including public and private partners		/	/
11	further collaborative technical analysis for implementation		/	
12	Establish relative importance of by-product exchange in the overall recruiting strategy.	/		
13	Test recruitment of industries identified.	/	/	
14	Material budgeting			/

2.5.2 Factors and barrier influencing to implement industrial symbiosis

Industrial symbiosis provides benefit to economic, environment and social as shown above, one might ask why many companies are not engaged in these types of projects. The answer may be due to energy, water, and waste disposal cost are small percentage of operating costs and quantity of the waste or by-product is not much enough for new process investment (Chertow, 2000). This may be a key barrier for symbiosis implementation. Factors and barriers influencing on implementation of industrial symbiosis and EIP can be reviewed from the following case studies.

1) Success factors for implementation of EIP in Netherlands vs. USA

Heeres, Vermeulen and Walle (2004) compared and evaluated the success of EIP projects in the Netherlands and USA. They found that the Netherland's projects were more successful than the US's projects. The factors of success were described below.

- **Objective:** Heeres, et al. (2004) found EIP ***objective was a substantial factors*** and there was difference between the Dutch and American cases. The American objective mainly focused on economic, while ***the Dutch emphasized both environment and economic***, in accordance with the Kalundborg case that focused not only on economic but also environment (Chertow, 2000).
- **Initiator:** Dutch ***was more successful in EIP that was mainly driven by Entrepreneurs/employers' association,*** while the US case was driven by local community and NGO (Heeres, et al. (2004). Many country setup Business Council for Sustainable Development (BCSD) or analogy agency. This factor appears in both success and not success in implementing symbiosis. In Kalundborg, no deliberate institutional mechanism was needed to promote conversations among the potential partners. ***Inter-firm trust is important*** in establishing alliances or contracts among participants (Gulati 1995 cited in Ehrenfeld, and Gertler 1997). The initiator factor is important or not should be in-depth study.
- **Public participation:** Participation was a factor that Heeres, et al. (2004) studied. They found the local community and NGO (Non-government Organization) had very high participating in the US projects, while the Dutch case was limited only companies and direct stakeholders such as consulting agencies and/or educational institutions. Therefore, public participation may not be a key success factor; however, it should be confirmed during in-depth interview.
- **Financing:** Financial factor is a factor that Heeres, et al. (2004) studied. The more success Dutch case had local/regional governments' supports up to 50%; however, it should be confirmed during in-depth interview.

2) Factors Leading to Develop Industrial Symbiosis in Kalundborg

Ehrenfeld, and Gertler (1997) analyzed driver leading to industrial symbiosis evolution in Kalundborg. Each factor or driver can be concluded as following:

- **Economical factors**: both parties realized net cost saving related to their option. Hence, it should be considered as one of effective factors.
- **Organization interactive factors**: there are regular interactive among managers, employees of related firms to create trust among the firms.

Therefore, interaction or communication among organization should be considered as one of effective factors.

- **Technical factors**: waste and by-product pretreatment to meet the receiver requirement. This would be an effective factor or not should be checked during interview.
- **Regulatory factor**: Danish regulation focuses on supporting the evolution of industrial symbiosis, while the US's Resource Conservation and Recovery Act (RCRA) regulates treatment and disposal of industrial waste to prevent emission of toxic to environment and community. This would be an effective factor or not should be checked during interview.

3) Condition to implement EIP (suggested by Ernest, 1997)

Ernest (1997) suggested conditions facilitating cooperation in new eco-industrial park development. Removing screening and recruitment steps, the condition that Ernest suggested can be described as follows:

- **Clear statement of the estate's vision and performance objectives**. This is in line with the Heere's suggestion that EIP objective on symbiosis was substantial factor to implement symbiosis.
- **Methods and information** to support companies in seeking by-product trading. Ehrenfeld and Gertler (1997) also commented that symbiosis requires information exchange among nearby industries; however their inputs and outputs are often difficult or costly to obtain.
- **Assurance of continuing support** for the exchange network.

4) Obstacles or Problem to Implement Industrial Symbiosis

Although industrial symbiosis creates benefits to economic, environment and community, there are a lot of problem and risk to implement it. Ernest (1997) commented the problem and risks that made the industrial symbiosis failed can be described as follows:

- **The risk of losing a critical supply**: if a plant relies on by-product or waste from other firms, it may loss supply that may critically affect to plant production. Ernest (1997) suggested this risk would be addressed by keeping supplier and customer relationship.
- **Proprietary information** could become valuable to competitors: company's input-output data is a disclose information that most firms do not want to open it. This information can be mimic proprietary production processes. Ernest (1997) suggested that sources of by-product and waste exchanges usually do not reveal until a receiver agrees to join symbiosis.

- **Un-continuity quality of by-product and waste** could cause damage to equipment or quality of products: this is normally occurring in firms that do not control by-product and waste quality. Ernest (1997) suggested this issue could be solved by fairly contract.
- **Regulation/Act obstruction**: regulation may be suitable for some company, but may be obstructing to others; therefore, it needs to redesign selected regulation to encourage symbiosis in different groups.

5) Barriers and Strategies for Overcoming

Raymond and Ramsey (2006) reviewed literature of industrial symbiosis case studies such as Kalundborg (Denmark), Forth Calley (UK), Kwinana (Australia), Tampico (Maxico), Sarnia (Canada) and then identified barriers to industrial symbiosis. They categorized barriers and strategies to overcome as shown in Table 2.6

Table 2.6 Barrier to Symbiosis Implementation and Strategies to Overcome (Suggested by Raymond and Ramsey, 2006)

Barrier	Strategies
Technical	Technical personnel should be involved from the beginning. Process related issues must be given full consideration.
Economic	A project will not be sustained if economics are wrong; however opportunities should not be dismissed without considering the life cycle costs.
Geographic	Distance and transportation costs may be impediments
Regulatory	Flexibility on the part of regulatory agencies should be sought to allow managed symbioses. Legal Negotiations on quantity and quality of by-products should avoid liability risks in the same way as those with other suppliers.
Business	Issues associated with intellectual property and trade secrets should be addressed through contracts.
Social	Community leaders should be informed of environmental and social benefits.
Temporal	Contractual arrangements may have to recognize innovation in processes that may reduce or change by-products.
Informational	Managers and technical personnel have to comfortable enough to communicate regularly and exchange information.

Source: Raymond and Ramsey (2006: online)

2.5.3 Industrial Symbiosis Factors

Factors to support and obstruct implementation of EIE and symbiosis mentioned above can be grouping categorized as shown in Table 2.7

According to the categorized factors shown in Table 2.7, it's found that most factors were suggested by at least 2 researchers; especially the financial mechanism was suggested the most up to 4 researchers. While other factors like regulation, distance for transportation was suggested by only one researcher. Therefore, the factors with suggestion frequency at least 2 will be selected for questionnaire and interview in the present study.

According to Sauvanee's study (2002) in Mab-Ta-Phut Industrial Estate (MTPIE), it's found that most factories synergy their activities in the areas of environment health and safety (84%), and quality of life/community connection (83%), while only 52% for the most important material linkage. Hence, it's worth to investigate factors and/or barriers for IS implementation in the MTPIE.

Table 2.7 Preliminary Symbiosis Factors

No.	Suggested Factors	Details	Heeres, et al.(2004)	Ehrenfeld and Gertler (1997)	Ernest (1997)	Raymond and Ramsey (2006)	Suggestion Frequency
1	Estate policy and objective	Estate vision, policy, and objective to implement symbiosis	/		/		2
2	Initiator	Organization addressing symbiosis	/	/			2
3	Public participation:	Community and NGO participation (Inform environmental and social benefits)	/			/	2
4	Technical	Technology for waste and by product pretreatment		/		/	2
		Process flexibility		/	/		2
5	Information	Information need to analyze and possible symbiosis			/	/	2
6	Financial mechanism	Economic incentive and other financial mechanism to continue supporting the exchange	/ (50% support)	/	/	/	4
7	Others	Regulation: encourage industrial symbiosis		/	/	/	3
		Distance and Transportation				/	1
		Business issues associated with intellectual property and trade secrets should be addressed through contracts.				/	1
		Temporal: Contractual arrangements may have to recognize innovation in processes that may reduce or change by-products.				/	1

. 2.6 Study Area: Mab-Ta-Phut Industrial Estate (MTPIE)

MTPIE is the biggest and the most important in Mab-Ta-Phut area, consisting of five groups of industry as follows (Suavanee, 2002 and Charmondusita, et al., 2007).

- **Petroleum and Petrochemical Group**: there are 32 companies in this group
  a. Petroleum: 2 companies
  b. Upstream Petrochemical: 3* companies
  c. Intermediate stream Petrochemical: 5 companies
  d. Downstream Petrochemical: 22 companies
- **Chemical Industries Group**: there are 8 companies in this group
  a. Solvent and Catalyze Product: 5 companies
  b. Acid and Base Product: 3 companies
- **Iron Industries Group**: there are 7 companies in this group
  a. Billet iron: 5 companies
  b. Slab iron: 2 companies
- **Gas Industries Group**: there are 3 companies in this group
- **Utility Group**: there are 5 companies in this group

However, this study focused only on petrochemical industry because it's found to generate waste the most (As shown in 2.6.1 and table 2.8). Petrochemical industries are the most important in Mab-Ta-Phut area, both in economic perspective and environment perspective. There are a wide variety of products using natural gas and crude oil as raw materials in these industries. These produce basic materials like plastics, synthetic fibers, synthetic rubbers, and synthetic detergents, etc. Petrochemical industry is classified into 3 groups as follows

- Upstream Petrochemical Industry
- Intermediate Petrochemical Industry
- Downstream Petrochemical Industry

In MTPIE, there are many linkages of product between firms as shown in figure 2.12, this is called business-as-usual supply chain synergy (Desrochers, 2004 cited in Beers, Corder, Bossilkov, and Berkel, 2007), but not yet focusing on by-product, waste, and energy (Chertow, and Park, 2010 and see also appendix C).

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*note: Before 2007 there were 5 companies in up-steam petrochemical, then TOC and NPC were merged to PTTCH

ARC and ATC were merged to PTTAR, and in 2012 PTTCH and PTTAR were merged to PTTGC.

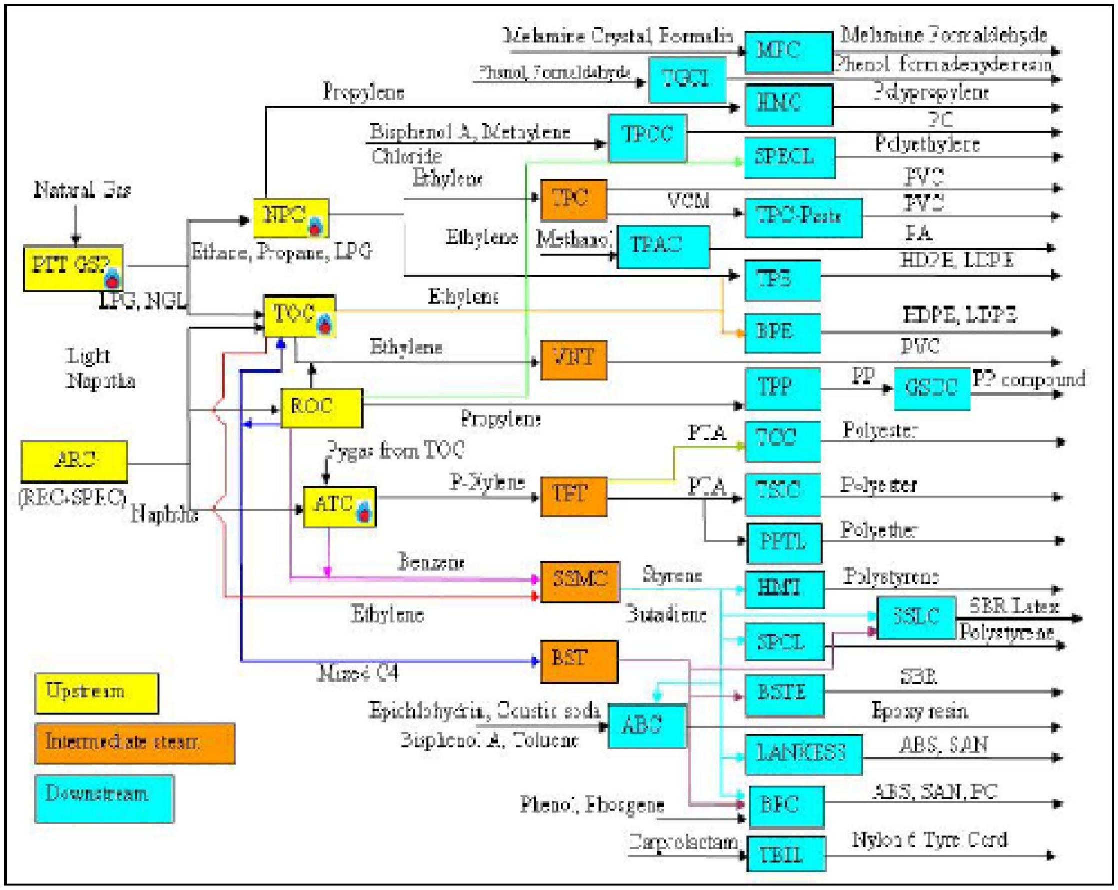

Figure 2.12 Materials and Product Flow in Petroleum and Petrochemical Group
(Charmondusita, et al. 2007)

2.6.1 Waste in Mab-Ta-Phut Industrial Estate

Charmondusita, et al. (2007) studied waste data in MTPIE during 2003-2005 and found that more than 700,000 tons of wastes are generated each year. This is generated by each group of industries that can be shown in Table 2.8 (Charmondusita, et al. 2007). It indicates that the petrochemical group generates wastes up to 70% or more than 500,000 tons a year.

Table 2.8 Waste Generated in MTPIE

Industry	No of total factories	No. of factories sent data	Waste (Ton/year)	Percentage of waste
Petroleum and Petrochemical group	33	28	541,348	70.4%
Chemical industries group	8	3	3,869	0.5%
Utility industries group	5	5	210,066	27.3%
Gas industries group	3	0	no data	0.0%
Iron and steel industries group	7	3	14,007	1.8%
Total	56	39	769,290.00	100%

Source: Charmondusita, et al. (2007)

2.7 Literature Review Conclusion

Industrial symbiosis is worldwide interest and benefit to environment, economic and social as shown in many case studies such as Kalundborg industrial area, Kwinana Industrial Area. However, there are some questions on implementing symbiosis and few eco-industrial parks have broken ground symbiosis project (Chertow, 2000). There are some case studies related to factors, condition to encourage and barrier to implement industrial symbiosis that can be summarized in Table 2.6

In MTPIE, Sauvanee (2002) studied the linkage of nine areas in Cohen Rosenthal Eco-industrial Estate and found that most factories synergy their activities in the areas of environment health and safety (84%), and quality of life/ community connection (83%), while the most important area of the Eco-industrial Park is material linkage or industrial symbiosis that Sauvanee’s study indicated that the factories have materials linkage only 52% and waste emitted in MTPIE especial in petrochemical is significant problem in area that is interesting to study.

From the factors and condition studied above(as shown in table 2.7 in 2.5.3), enhancing factors and obstructing factors selected for present study are as follows.

- Policy and objective factors
- Initiator factors
- Role of stakeholder and Public participation Factors
- information factor
- Technical and technology factors
- Financial mechanisms factor
- Others

CHAPTER III

RESEARCH METHODOLOGY

According to Ernest (1997), strategies to implement industrial symbiosis need collaboration and information openness. There are many factors establishing this need. This research therefore intended to gather information and identify effective factors for industrial symbiosis implementation. Then, the effective factors and relevant information were analyzed to formulate a model to implement industrial symbiosis effectively. A conceptual framework and methodology of this study can be shown in figure 3.1.

3.1 Research Conceptual Framework

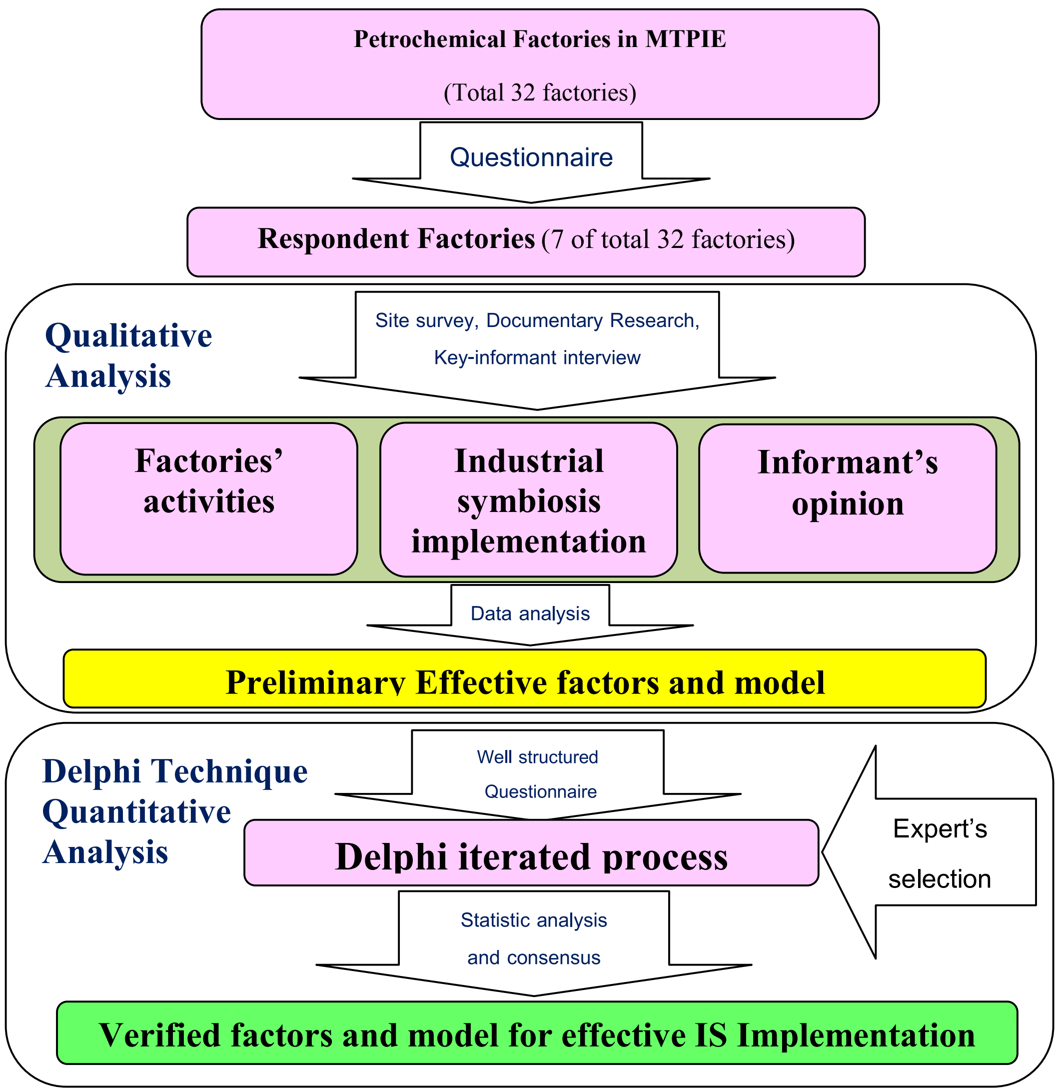

Figure 3.1 Conceptual Framework of the Study

From literature reviews mentioned above, seven factors were selected and supposed to be effective factors creating corporation / economic and technical feasible to implement industrial symbiosis. Information related to symbiosis and/or waste exchange as well as opinion on each factor was gathered from the waste generators (petrochemical industries) and the referred waste processor by questionnaire, site survey and/or key-informant interview(key informant is person/s who in charge in waste management department of waste generator and waste processor plant). The gathered information was analyzed to identify effective factors, and then a preliminary model for effective implementation of industrial symbiosis in the MTPIE was formulated. The identified factors and the model were then verified by using Delphi technique. After verification, the model was slightly modified and come to conclusion.

3.2 Research Method

3.2.1 Target group of the present study

Petrochemical industries in MTPIE were selected as target group (so-called ***waste generator***) of this study because they generate about 70% of total waste in the Mab-Ta-Phut area. However, only 7 waste generators (3 up-streams, 2 intermediates and 2 down-streams) participated in the study and informant of each factory is the one in charge with waste management in his or her factory.

Factories or plants that collect either hazardous or non-hazardous wastes and then transfer the wastes into secondary raw materials or energy (so-called ***waste processor***) selected for this study was those referred by waste generators in the MTPIE. The waste processors participated in this study are those in Saraburi province that collect wastes from various areas and convert to raw materials and/or energy in cement kiln process. Though both of them are professional, they still confront a lot of problems in waste conversion. Informants of the both plants are management level.

Some factories referred their symbiosis implementation were influenced by an industrial estate. The estate's activities to support implementation of factories implementing symbiosis were studied.

Government agencies in charge with waste management were also interviewed as a target group of this study.

3.2.2 Instruments used for information gathering

Various methods and instruments were used in this study as summarized in Table 3.1. The study was started with documentary reviews, followed with questionnaire formulated and pre-tested by experts in related industries. The questionnaire was then sent to all petrochemical industries in the MTPIE. Site survey and series of dialogues and/or in-depth interview were carried out with the questionnaire respondents as well as the related government agencies.

The collected information from factories consisted of 7 parts as follows (see also appendix A).

1) General information of each factory
2) General environmental data of each factory
3) General waste management and policy on symbiosis
4) Environmental management and/or symbiosis team
5) Information for environment and symbiosis implementation
6) Technical and technology
7) Financial mechanism

Table 3.1 Research method used to collect information

Selected Factors	In-depth interview	Field Survey	Documentary Reviews
Policy/objective	√	-	√
Initiator	√	-	√
Public participation /Stakeholders	√	-	√
Technology	√	√	-
Information	√	-	√
Financial mechanism	√	-	√
Others	√	-	√

3.2.3 Data Collection and Analysis

Data collection from each informant was conducted as follows:

- Questionnaires were sent out to 32 waste generators (PTTCH and PTTAR were merged to PTTGC in 2012) in up-stream, intermediate and down-stream petrochemical industries for gathering detailed information on their industrial symbiosis implementation, operation activities, and opinion on each selected factor. Only seven factories responded the questionnaires and provided relevant information (The limitation sensitive data as shown in 1.6, the participating factories are only seven plants. Although there are only seven plants, symbiosis and non-symbiosis plant are categorized and their activities were studied). Symbiosis implementation project of the respondent waste generators were studied by field survey, documentation, in-depth interview and series of dialogues to confirm their implementation, decision making, operation factors, opinion and others.

- Questionnaires were sent out to two waste processors (referred by waste generators) to investigate their problem to implement symbiosis, operation and other opinions by documentary research, interview, and field survey. A series of dialogues to confirm their problem, opinion and others were also carried out.
- Data of industrial estates operation to support symbiosis in waste generator was collected by in-depth interview to confirm and disclose their activities.
- Data of waste management related government agency was collected by interview, discussion on problem of symbiosis as well as opinion on factors influencing implementation of industrial symbiosis.

The collected data were then analyzed and interpreted. The symbiosis implementation of waste generators was indentified. Policy and objective, initiator, role of stakeholder and opinion of informant, information, technical and technology, and financial mechanism factors were indentified, categorized, described and considered in-depth. Effective factors were identified and a Preliminary Model for Effective Implementation of Industrial Symbiosis were formulated and verified by using Delphi technique.

3.2.4 Verification of identified factors and the preliminary model

Delphi technique is a research technique to hear expert opinion without facing each other to *reduce dominating and conflict between experts*. This can be described in this study as follow.

- **Well-structure questionnaire creation**

This study used a *modified Delphi technique* where well-structure questionnaire was created by the identified factors and preliminary model (in 3.2.3). The questionnaire with five levels of Likert-scale was used to evaluate significant of each sub-factor to implement symbiosis: *high important*, *important*, *non-important*, *obstruct*, and *high obstruct* (see also Appendix B).

In the first round, each factor was open for additional opinion and/or information. Results from the first round were analyzed and concluded. Then well-structure questionnaire was modified, and resent to achieve experts' rating until consensus. Each round experts' opinion will be coded to find out median and IQR to analyze consensus (see Appendix D).

- **Expert Selection**

Expert selection in Delphi technique is the most important step because it relates to the results (Judd, 1972; Taylor and Judd, 1989; Jacobs, 1996 cited by Hsu et al., 2007). In this study, experts consisted of waste generators, waste processors, and government agencies as follow:

- 2 Experts from waste generators having strong implementation on waste exchange. The selected experts are ***environmental specialist*** in charge with waste management at least 8 years.
- 2 Experts from professional waste processors. The selected experts are management level in charge with waste management at least 8 years.
- An expert from Industrial Estate Authority of Thailand (IEAT) who is a management level in charge with waste exchange for many years.
- An expert from Industrial Estate Authority of Thailand (IEAT) who is a scientist in Environmental Division in charge with waste exchange for many years.
- An expert from Office of Natural resources and Environmental Policy and Planning (ONEP) who is a division executive.
- An expert from Pollution Control Department (PCD) who is an executive of air quality division.
- An expert from Pollution Control Department (PCD) who is an executive of fresh water resources division (former director of industrial and hazardous waste management division)
- An expert from Department of Industrial Work (DIW) who is a division executive.
- An expert from Department of Industrial Work (DIW) who is an engineer in charge with waste exchange for many years.
- An expert from Center of excellence on Hazardous Substance Management (EHWM) who is a management level in charge with waste exchange for many years.
- An expert Center of excellence on Hazardous Substance management (EHWM) who is a researcher in charge with waste exchange for many years.

- **Delphi Iterate Processes**

Well-structure questionnaire was sent to all experts to rate important ranking of each sub-factor. For the first round, each factor was open for additional opinion and/or information. Results from the first round were analyzed and concluded. The well-structure questionnaire was modified, and concluded data were resent to experts. Each iterate step rating important ranking was code to find out median that resent to each expert in next step including each expert's old opinion to confirm his or she opinion and experts group's opinion.

- **Data Analysis**

Each iterated process experts' opinion, statistic technique (median and IQR) was used to analyze experts' opinion.

  - Median was used to represent experts' opinion on each industrial symbiosis factor because it reduces outliner effect (it is different from statistic mean). Median result can be interpreted as follows.

    Median value 1 = *high obstruct* 2 = *obstruct*
    3 = *non-important* 4 = *important*
    5 = *high important*

Inter Quartile Range (IQR) is a statistic deviation that also reduces outliner effect (it is different from statistic standard deviation). It can be calculated by equation below.

	IQR	=	Q1 – Q3
While	Q1	=	First quartile
	Q3	=	Third quartile

For the five level of Likert-scale, if the IQR is less than or equal 1, it means consensus achieved so that the iterate processes can be stopped (Sekaran, 2003 cited in Heiko, 2012).

Median information of each factor and sub-factor were analyzed and concluded for effective factors and model for effective implementation of industrial symbiosis.

CHAPTER IV
RESEARCH FINDINGS AND DISCUSSIONS

4.1 Symbiosis Status of the Studied Factories

Questionnaires were sent to all 32 up-stream, intermediate, and down-stream petrochemical industries in the MTPIE; however, only seven factories responded the questionnaires and provided relevant information. The respondents are all waste generators, of which symbiosis implementation status are summarized in Table 4.1 and Figure 4.1.

Table 4.1: Respondent factories and status of symbiosis implementation

Petrochemical Group	Symbol Used	Numbers of Factory	Products	symbiosis Implementation Status
Up-stream	U1, U2, U3	3	Olefin, Benzene	**U2** and **U3** send off gas to **U1** to be distilled and used. **U1** and **U2** send waste to **WP1**
Intermediate	I1, I2	2	PVC, Phenol	**I1** sends sludge waste to a footwear manufacturer and sends other wastes to WP1 using in cement kiln. **I2** sends salt waste water to Chlor-alkaline plant.
Down-stream	D1, D2	2	Polyethylene, Polypropylene	**D1** sends recycle vent gas to **U2** **D2** does not implement

Note: WP1 is a waste processor in Saraburi province.

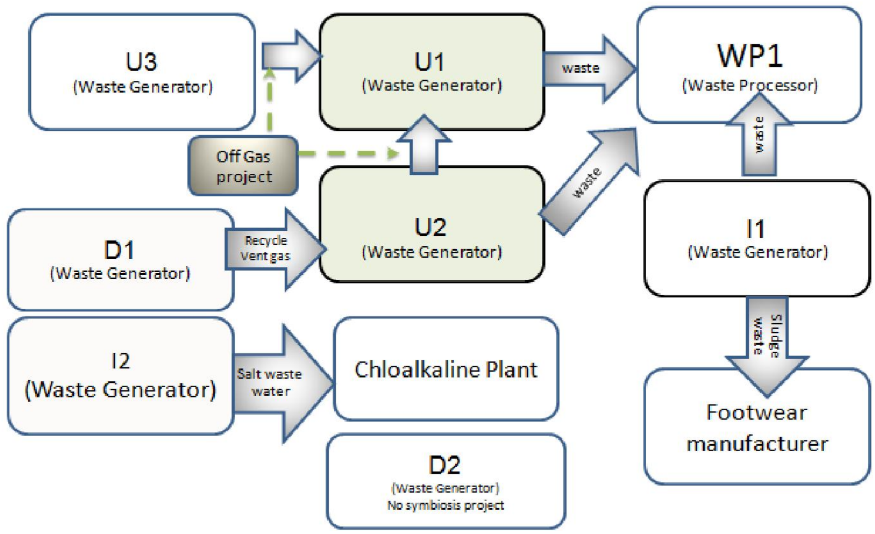

Figure 4.1: Symbiosis status of the studied factories

The symbiosis implementation projects and their decision making were studied by field survey and in-depth interview. Conclusion of the symbiosis implementation can be shown below.

1. **U1-U2 symbiosis:** off-gas from U2 is distilled to obtain valuable raw material for U1, while formerly burnt to get heat used in U2.

2. **U1-U3 symbiosis:** off-gas from U3 is distilled to obtain valuable raw material for U1. This project was suggested by a consultant after successful implementation of U1-U2.

3. **U1-WP1 symbiosis:** U1 sends solid wastes to WP1 to be converted to raw material and/or energy for cement kiln. Although U1 sends various solid wastes to WP1, only some wastes can be utilized, because the others contain heavy metals exceed cement kiln limitation. Therefore, U1 is searching for the way or process to improve waste qualification.

4. **I1-WP1 symbiosis:** I1 also sends solid wastes to WP1 to be converted to raw material and/or energy for cement kiln.

5. **I1-FW symbiosis:** I1 also sends sludge from waste water treatment plant by controlling its specification to match customer need for using as a mixture of raw material in footwear manufacturer (under contract).

6. **I1-CA symbiosis:** I2 will send salt waste water to extract chlor-alkaline to be used as a mixture of raw material in a down-stream plant (EIA approved and the plant is under construction).

7. **D1-U2 symbiosis:** D1 sends recycle vent gas to be used in U2.

8. **D2** is a down-stream plant that does not implement symbiosis because their wastes are addressed and complied to regulation.

4.2 Factors influencing symbiosis implementation

According to symbiosis situation, activities and operation information from each plant mentioned above, selected factors influencing symbiosis implementation can be evaluated and summarized in Table 4.2.

Table 4.2: Factors influencing on symbiosis implementation

Factors	U1	U2	U3	I1	I2	D1	D2 (no IS)
Policy on							
environmental management	√	√	√	√	√	√	√
zero discharge	√	-	-	√	√	-	-
zero landfill	√	√	-	√	√	√	-
process adjustment willingness	√	√	-	√	√	√	-
Initiator	Industrial Estate	Industrial Estate	Consultant	Industrial Estate	Manager	Environment officer	-
Information							
Confidential	√	√	√	√	√	√	√
reveal only distorted quantity	√	√	-	√	√	√	√
Financial mechanism							
incentives at initial project	BOI TAX	BOI TAX	Not expect	BOI TAX	BOI TAX	BOI TAX	50-50% support
continue subsidy	subsidy	subsidy	Not expect	subsidy	subsidy	Polluter pay discount	Polluter pay discount
Technology Assistant							
no technology problem	√	√	√	√	√	√	√
process flexibility	-	-	-	-	-	-	-
Stakeholder Participation							
government involve	√	√	-	√	-	√	-
communities involve	-	-	-	-	-	-	-
Other							
transportation loss	-	-	-	-	-	-	-
conflict of interest	-	√	√	-	-	-	-
Regulation	√	-	-	-	-	-	-

Note: √ represents answer yes

4.2.1 Factor 1: Policy

All factories in MTP have policy on environment according to ISO14001: Environmental Management System (see figure 4.2).

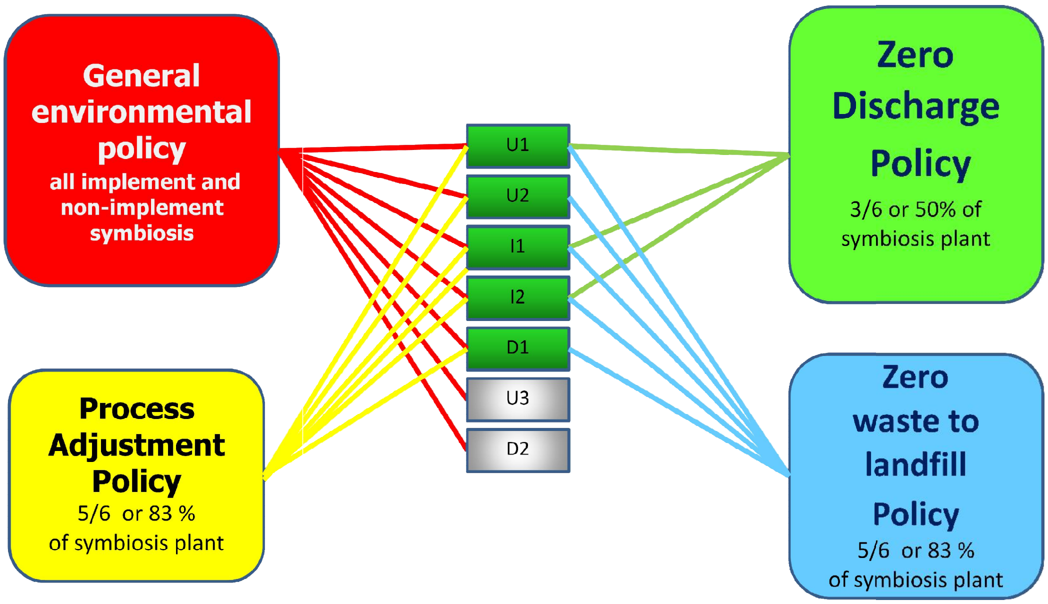

Figure 4.2: Relationship between policy and symbiosis implementation

According to the on-site survey and in-depth interview, it was found that all factories implementing symbiosis have policy on zero landfill and process adjustment willingness, except U3 and D2 (without symbiosis implementation). In case of U3, it implements symbiosis due to consultant initiator, even no policy on zero landfill and process adjustment willingness. Strongly implement symbiosis plant U1, I1, I2 have zero discharge policy.

The waste processors also have zero landfill and process adjustment willingness policy.

Therefore, **policy** on zero landfill and process adjustment willingness is considered as **an important factor** for symbiosis implementation. Policy on zero discharge is also important for IS implementation.

4.2.2 Factor 2: Initiator

According to the on-site survey and in-depth interview, it was found that all IS implementing factories (in the MTPIE) did not initiate the project by themselves, but having an initiator (see figure 4.3).

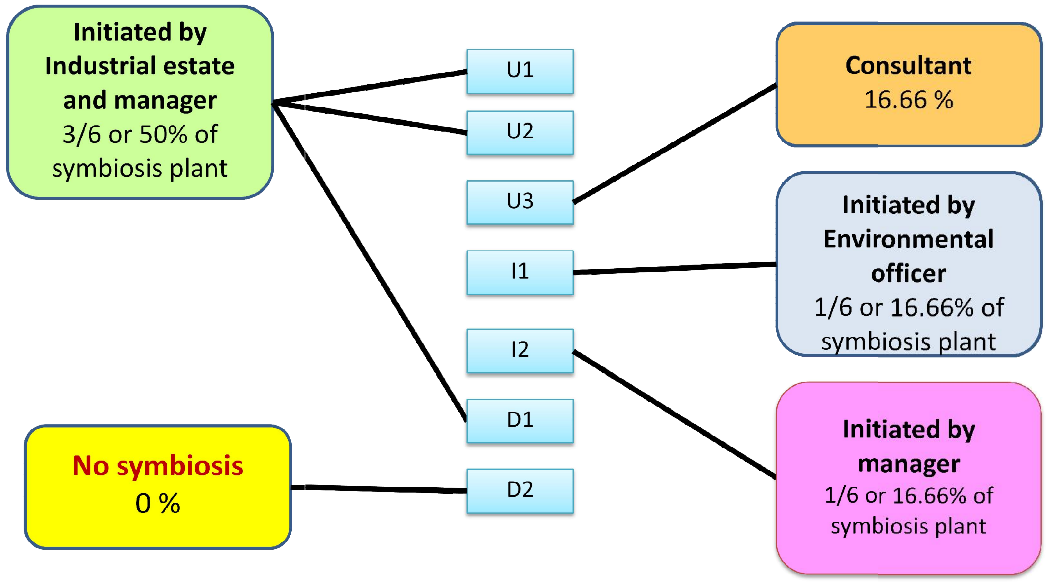

Figure 4.3: Relationship between initiator and symbiosis implementation

Three of symbiosis plant were initiated by industrial estates, one initiated by its manager, another initiated by consultant, and the other initiated by its environmental officer. Therefore, **initiator** is considered as **a more crucial factor** for symbiosis implementation.IE1 was a major initiator for symbiosis in the MTPIE, referred by symbiosis plants in the MTPIE. Therefore, industrial activities and operation of the IE1 was also studied and compared with another estate.

The IE1 has implemented symbiosis in the estate and become successful in its waste management due to its policy on zero waste to landfill. Its outstanding activities were environmental parameter monitoring and reporting to communities, and also having tri-parties meeting monthly. The monthly meeting was fruitful for symbiosis implementation so that managers can discuss and exchange information on various issues like economic, environment, and available waste or by-product. While another estate having discussion only on standard emissions.

4.2.3 Factor 3: Role of stakeholder and public participation

According to the on-site survey and in-depth interview, Government agency and community participation of informant can be shown in figure 4.4.

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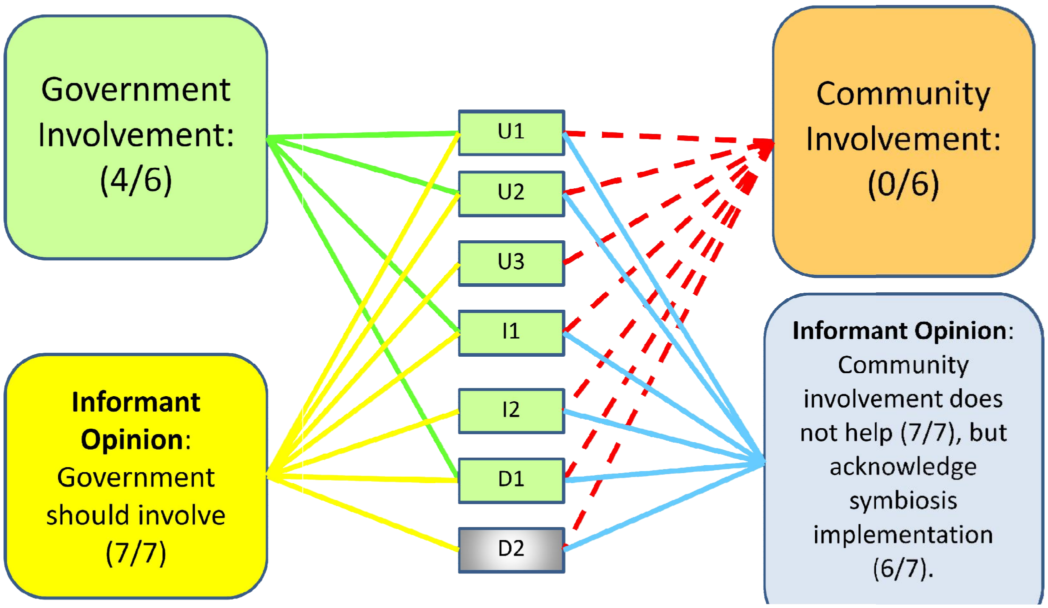

Figure 4.4: Involvement and Opinion on Role of Public Participation

Government agency has participated in some symbiosis plants (4 of 6 symbiosis plants), and all informants' opinion indicated that government agency should involve in the symbiosis implementation, while community involvement did not help implementation, but only acknowledge the IS activities.

However, the waste processors agreed that government agency involvement is very much important to motivate participating plant and help solving regulation obstructing the symbiosis implementation

4.2.4 Factor 4: Information on Waste Generation

The study found that all 7 factories agreed that information on waste generation in each factory was extremely important for symbiosis implementation, because it needed to know type, composition, and quantity of waste or by-product. However, they do not want to reveal such information. However, 6 of them were willing to reveal the distorted quantity information before signing contract. All informants said the data should be analyzed by expert.

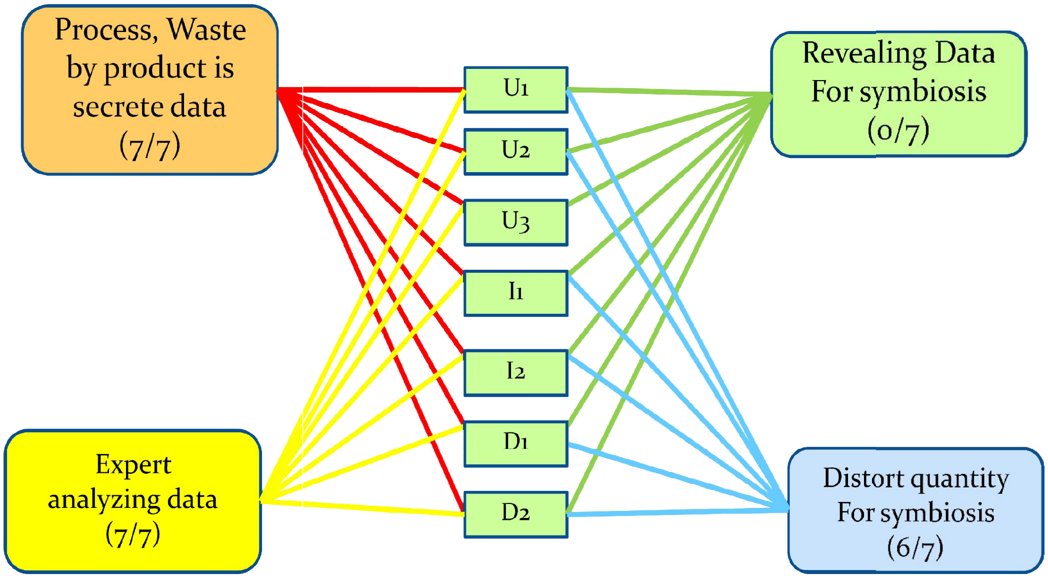

Figure 4.5: Informant's opinions on importance of information

All informants noticed that production process, waste and by-product quantity is secret data because it may affect their business. The rival may know its formula or production capacity (see also figure 4.5).

The study found that all 2 waste processors also agreed that information on waste generation in each factory was extremely important for symbiosis implementation but there were problem to reveal this information. They are willing to disclose the data just distorted quantity.

4.2.5 Factor 5: Technical and Technology Assistance

According to the on-site survey and in-depth interview, Technical and Technology Assistance factor in symbiosis plant can be shown in figure 4.6.

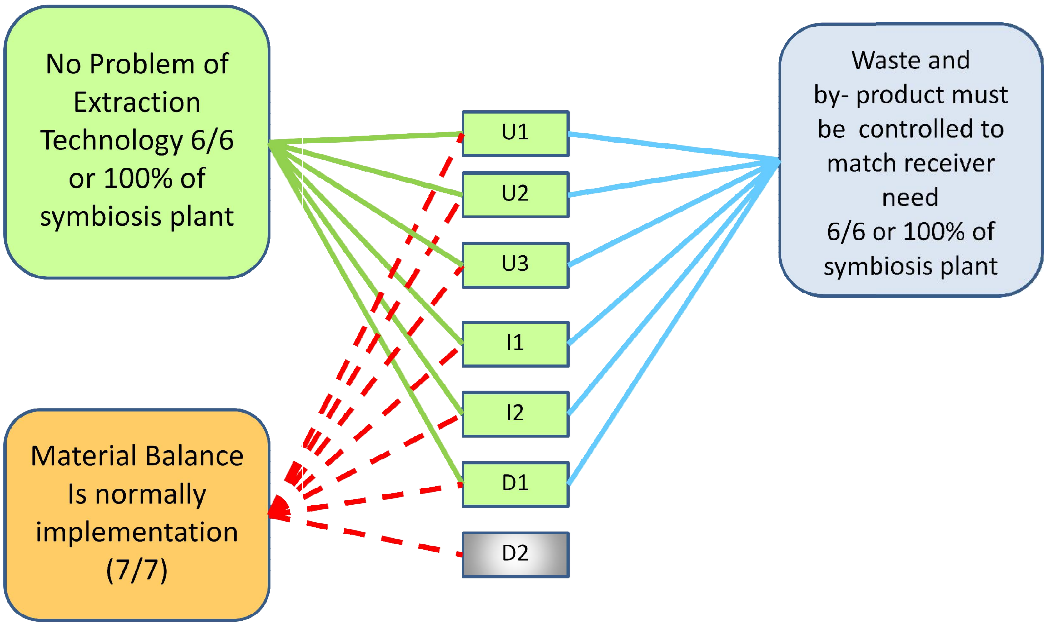

Figure 4.6 Informant result on technical and technology factor.

The study found that all of 6 symbiosis factories had no problem regarding to technology, in other words, technology is not a barrier for symbiosis implementation, because they can transfer or buy it. Therefore, technology assistant is not an important factor for symbiosis in the MTPIE. However, waste and by-product must be controlled to match receiver need because process adjustment when using variety quality of waste and by-product is quite difficult to control product quality.

In case of the IE1, though initiated many symbiosis projects in his industrial estate, its informant also informed that technology was not problem. For example, there is technology to change SO_X and NO_X to H_2SO_4 and HNO_3 acid and used to produce NPK fertilizer by the MIXED ACID ROUTE (EFMA, 2000), but no receiver for the products. In addition, the NPK fertilizer is not his core business so that it was difficult to implement this symbiosis. Therefore the estate should announce and cooperate with a preferable receiver plant.

4.2.6 Factor 6: Financial Mechanisms

Financial is an interesting factor. Informants' opinion on this factor can be shown in figure 4.7.

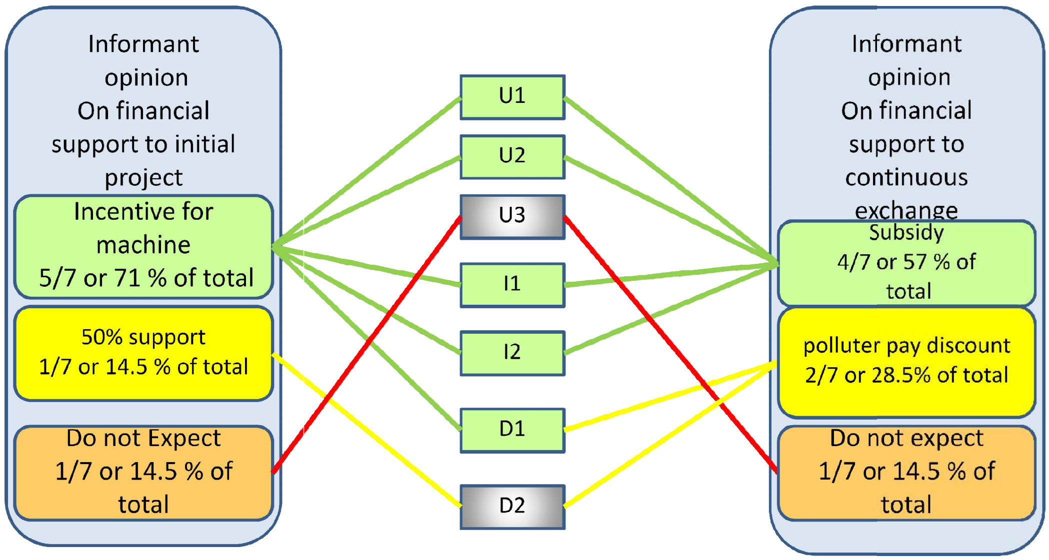

Figure 4.7: Informant opinions on financial mechanism factor.

Incentives or financial support can be implemented, either at the starting project or continuous supporting. The study found that 5 of 7 factories needed financial supports in term of BOI Exemption Tax at the initial project, and continue subsidy for the waste exchange. One of them suggested fifty-fifty percent government support; however, some informants said the fifty-fifty percent government support was impossible because the government had not enough funds, and one of which said he did not expect financial support from the government. Upon government agency interview, it was suggested that continuous subsidy is impossible, while 50% support for 5 years may be possible.

Polluter pay discounting based on quantity of waste/by-product exchange or ratio of recycled raw materials was also suggested by 2 informants. Informant from the government agency also agreed with this suggestion.

All informants agreed to set up funds to support waste exchange because implementing need financial support at the initial stage and some projects were not feasible itself, so it need financial subsidy. Therefore, **incentive or financial** mechanism is considered as **an important factor** for symbiosis implementation.

4.2.7 Factor 7: Others

According to the on-site survey and in-depth interview, transportation cost, regulation and conflict of interest barrier can be shown in figure 4.8

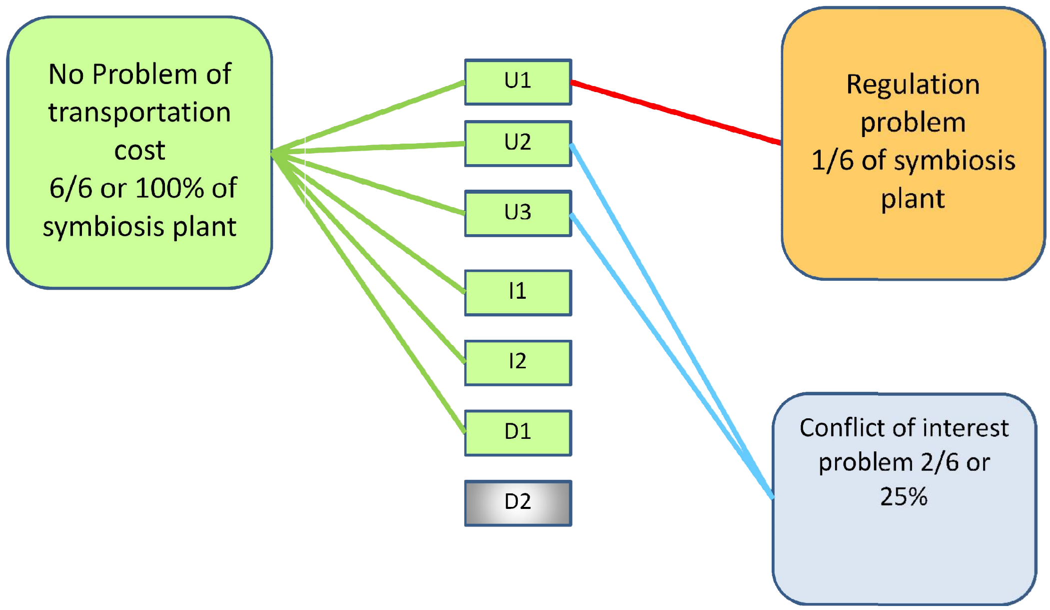

Figure 4.8: Informant results on transportation cost, conflict of interest, and regulation factor.

it was found that all of 6 implementing symbiosis factories agreed that ***transportation cost*** was not a barrier for symbiosis implementation. Although it takes about 295 km for sending waste from waste generator in Rayong to waste processor in Saraburi, the symbiosis can be implemented if economic feasible. Therefore, transportation cost is not an important factor for symbiosis implementation in MTPIE.

It was found that 1 of 6 implementing symbiosis factories had problem regarding to ***regulation***. They ever planned to send waste water to be treated in another plant, but it could not be done due to regulation.

It was also found that 2 of 6 implementing symbiosis factories had problem regarding to ***conflict of interest***. They produce the same product and do not want rival know their secret data (according to information factor).

4.3 Preliminary Model for Effective IS Implementation

According to the finding mentioned above, effective factors can be identified and a preliminary model for effective implementation of industrial symbiosis can be formulated as shown in figure 4.9.

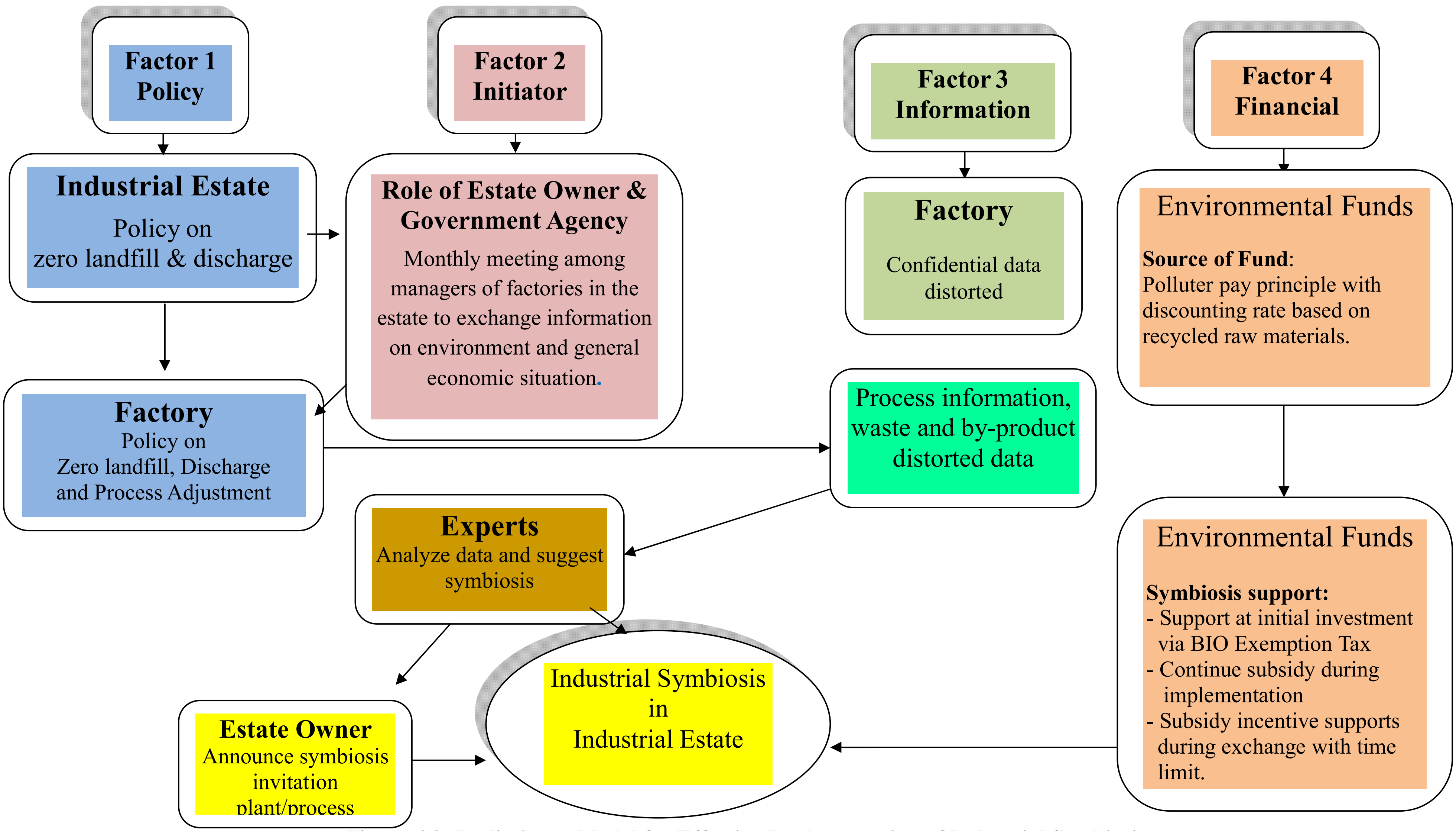

Figure 4.9: Preliminary Model for Effective Implementation of Industrial Symbiosis

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The only different between implementing and non-implementing factories is **policy** on zero discharge, zero landfill, and willingness to adjust process. This is the first effective factor for symbiosis implementation.

The symbiosis would not be implemented without **initiator**. Monthly meeting among executive and/or managers of all factories addressed by estate owners is extremely important for information exchange. Government agency should involve in the monthly meeting and participate as part of initiator to help solving regulation issues or obstruction of the symbiosis implementation.

Incentives or financial mechanism, either incentives at the initial project or continuous subsidy, is necessary for all factory informants. While, stakeholder participation and technology assistance are not effective factors for symbiosis implementation. Hence, a preliminary model for effective implementation of industrial symbiosis in industrial estate was proposed as shown in figure 4.8.

The identified effective factors and preliminary model was then verified by experts to ensure its effectiveness by using Delphi technique.

4.4 Verification of effective factors and preliminary model

Delphi technique is a research technique using group expert in finding their opinion on a study issue. The well-structure was sent to all selected expert and iterate processes conducted until achieving consensus at IQR of each sub-factor (less than or equal 1) that finished at the third rounds.

Finding and information can be concluded as follows.

- **Policy Factor**

The first round was opened for experts to suggest factors involving in policy factor, but only few suggestions were achieved.

The first expert (from waste generator) suggested that government should declare policy on IS implementation. There would be operation guideline for both government agency and private sector to implement symbiosis.

The second expert (from waste generator) suggested that key performance indicator (KPI) with target and objective to achieve zero landfill and discharge should be defined. This comment was then sent to other experts in the second round. Finding of sub-factors are shown in Table 4.3 and figure 4.10.

Opinion regarding to **government policy on supporting symbiosis** achieved 5 points of median and 0.25 of IQR. This indicates *consensus opinion (yes) and **high important** factor*.

Opinion regarding to **policy on zero landfill / zero discharge** at the estate level achieved 4 / 4 points of median and 0 / 0.25 of IQR for policy on zero landfill / zero discharge. This indicates *consensus opinion (yes) and important factor*.

Opinion regarding to **policy on zero landfill / zero discharge** at the factory level achieved 5 / 5 points of median and 0 / 0 of IQR for policy on zero landfill / zero discharge. This indicates *consensus opinion (yes) and* ***high important*** *factor*.

Opinion regarding to **process adjustment willingness** achieved 4 points of median and 0 of IQR. This indicates *consensus opinion (yes) and important factor*.

Opinion regarding to **KPI, Target and Objective** achieved 4.5 points of median and 1 of IQR. This indicates *consensus opinion (yes) and important factor*.

Table 4.3 Expert opinion on policy factors

Factor and sub-factors	Median	Q1	Q3	IQR	Consensus	Conclusion
1. Policy Factor						
1.1 Government policy on supporting IS	5	4.75	5	0.25	Yes	High important
Estate level						
1.2 Zero Landfill Policy	4	4	4	0	Yes	Important
1.3 Zero Discharge Policy	4	4	4.25	0.25	Yes	Important
Factory level						
1.4 Zero Landfill Policy	5	5	5	0	Yes	High important
1.5 Zero discharge Policy	5	5	5	0	Yes	High important
1.6 Process Adjustment Policy for IS	4	4	4	0	Yes	Important
1.7 KPI, Target and Objective	4.5	4	5	1	Yes	Important

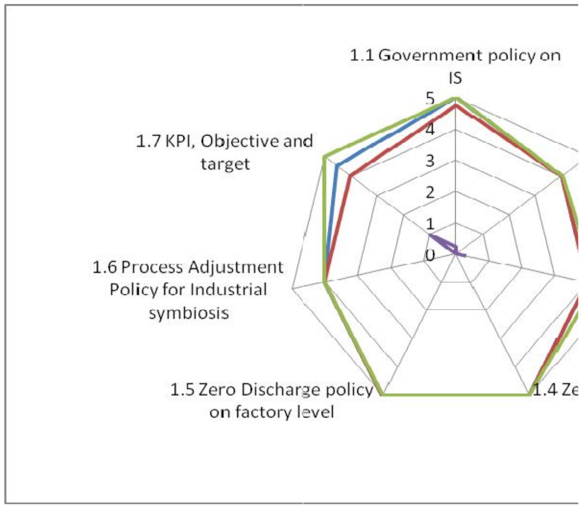

Figure 4.10 Radar-chart of policy factor.

Note: Q1 = first Quartile
Q3 = third Quartile
IQR = inter-Quartile Range

These finding on policy factor correspond with the findings of Heeres, et. al. (2004), Ernest (1997), and Kalundborg Policy (Chertow, 2000) in terms of "the estate's policy and vision should focus both economic and environment". Hence, this factor is substantial to implement symbiosis and corporation.

- **Initiator Factor**

The first round was opened for expert to suggest factors involving initiator factor. There are some suggestions as follow.

The first expert (from waste processor) suggested that meeting agenda should consist of issues on environmental impact to community. It can initiate awareness and commitment to improve environmental quality.

The second expert (from academic institute suggested that meeting agenda should consist of issues on problem and business opportunities or benefit to factory such as draught, ISO50001. It can pursuit factory owner interested in the meeting.

The third expert (from government agency) encourages IS and suggested it should have government agency committee to solve regulation problem. These comments were sent to other experts to get their opinion in second round by Delphi technique. Finding of sub-factors are shown in Table 4.4 and figure 4.11.

Opinion regarding the fact that **plant manager and owner meeting can create corporation in industrial symbiosis** achieved 4 points of median and 0.5 of IQR. This indicates *consensus opinion (yes) and* ***important*** *factor*.

Opinion regarding the fact that **meeting agenda should consists of** *overall estate emission report*, *overall estate emission and its impacts to communities*, and *problem and business opportunities* achieved 4, 4, 4 points of median and 0, 0, 0 of IQR. This indicates *consensus opinion (yes) and* ***important*** *factor*.

Opinion regarding the fact that **meeting agenda should consists of** *overall economic report* achieved 3 points of median and 1 of IQR. This indicates *consensus opinion (yes) but not* ***important*** *factor*.

Opinion regarding the fact that **meeting initiator should be** estate manager or owner achieved 5 points of median and 0.5 of IQR. This indicates *consensus opinion (yes) and* ***high important*** *factor*.

Opinion regarding the fact that **meeting initiator should be** government agency achieved 4 points of median and 0.5 of IQR. This indicates *consensus opinion (yes) and* ***important*** *factor*.

Opinion regarding the fact that **collaboration between government and private committee** can help to solve regulation and law problem to symbiosis achieved 5 points of median and 0.5 of IQR. This indicates *consensus opinion (yes) and* ***high important*** *factor*.

Table 4.4 Expert opinion on initiator factors

Factor and sub-factors	Median	Q1	Q3	IQR	Consensus	Conclusion
2. Initiator Factor						
2.1 Plant manager and owner meeting can create corporation in IS	4	4	4.5	0.5	Yes	Important
2.2 **Meeting Agenda** should consists of overall estate emission report	4	4	4	0	Yes	Important
2.3 **Meeting Agenda** consists of overall estate emission and its impact to communities	4	4	4	0	Yes	Important
2.4 **Meeting Agenda** consists of overall economic report	3	3	4	1	Yes	Not Important
2.5 **Meeting Agenda** consists of problem and business opportunities or benefit to factory such as Drought, ISO50001	4	4	4	0	Yes	Important
2.6 **Meeting initiator** should be managed by estate owner	5	4.5	5	0.5	Yes	High Important
2.7 **Meeting initiator** should be government agency	4	3.5	4	0.5	Yes	Important
2.8 **Collaboration between government and private committee** can help to solve regulation and law problem to symbiosis.	5	4.5	5	0.5	Yes	High Important

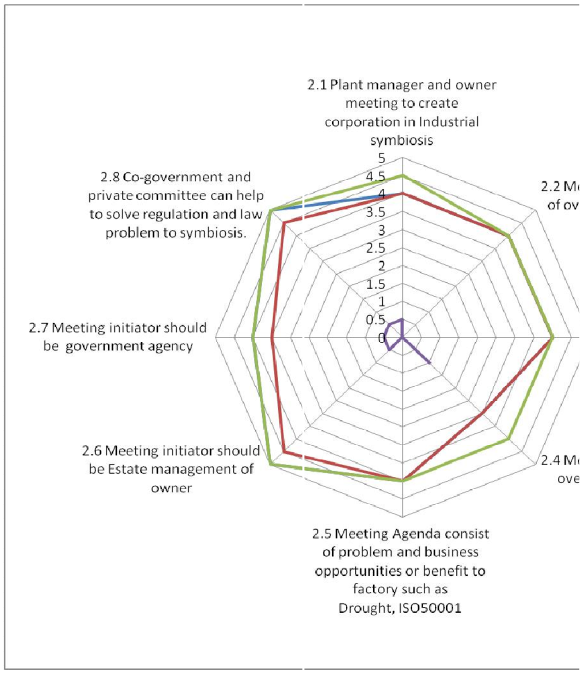

Figure 4.11 Radar-chart of Initiator factor.

It's realized that initiator is an important factor for IS implementation. Many foreign estates implementing symbiosis have initiated by Business Council for Sustainable Development (BCSD) or analogy agencies. For instance, Kwinana Industries setup Council in 1991 initiated by core group industries and succeed in implementing symbiosis project (Bossilkov *et al.* 2005); in Geneva Industry, Switzerland, Board for Industrial Ecology and Industrial Symbiosis implementation was established in 2002; Dutch success implementing symbiosis was initiated by Entrepreneurs'/ employers' association. Estate owners and their role to encourage meeting and agenda on economic situation, pollutant emission, and impact to community can make them aware and commit to improve environment quality. Complementary of policy, initiator and their role can support collaboration to implement symbiosis.

- **Information Factor**

The first round was opened for expert to suggest factors involving information factor. There are some suggestions as follow.

Encourage the factory to understand benefit of revealing waste information.

Information disclosure contract between specialist and factory would make factory ensure to reveal their information.

Specialists who act as initiator or data analyzer should be faithful and creditable. Their revenue should not come from factory or estate directly. These comments were sent to other experts to get their opinion in second round by Delphi technique. Finding of sub-factors are shown in Table 4.5 and figure 4.12.

Opinion regarding the fact that **creating factory's awareness of benefits of revealing waste information** achieved median at 5 points and IQR at 1. This indicates ***high important*** *factor, and consensus*.

Opinion regarding the fact that **At the beginning(first), factory revealed type of waste to pre-symbiosis** achieved median at 4 points and IQR at 1. This indicates ***important*** *factor, and consensus*.

Opinion regarding the fact that **secret data distorted** (distorted quantity of waste) achieved median at 3 points and IQR at 1. This indicates *consensus, but not* ***important*** *factor*.

Opinion regarding the fact that **specialists who analyze waste information should be faithful and creditable** achieved median at 5 points and IQR at 0.5. This indicates *consensus and high important factor*.

Opinion regarding the fact that **information reveal contract must be settled between specialist and participated factory** achieved median at 4 points and IQR at 0.75. This indicates *consensus and important factor*.

Opinion regarding the fact that **specialist's revenue should not come from the factory or estate** achieved median at 3 points and IQR at 0. This indicates *consensus, but not* ***important*** *factor*.

Opinion regarding the fact that **possible symbiosis plant information that links to existing plant in estate** achieved median at 4 points and IQR at 0. This indicates *consensus and important factor*.

Table 4.5 Expert opinion on information factors

Factor and sub-factors	Median	Q1	Q3	IQR	Consensus	Conclusion
3. Information Factor						
3.1 Creating Factory awareness of beneficial of revealing waste information	5	4	5	1	Yes	High Important
3.2 At the beginning (First), factory revealed type of waste to pre-symbiosis.	4	3	4	1	Yes	Important
3.3 Secret data distorted	3	2	3	1	Yes	Not Important
3.4 Specialist who analyzes the waste information should be faithful and Creditable.	5	4.5	5	0.5	Yes	High Important
3.5 Information reveal contract must be settled between specialist and factory	4	4	4.75	0.75	Yes	Important
3.6 Specialist's revenue should not come from factory directly	3	3	3	0	Yes	Not Important
3.7 Specialist's revenue should not come from estate.	3	3	3	0	Yes	Not Important
3.8 Possible symbiosis plant information that links to existing plant in estate	4	4	4	0	Yes	Important

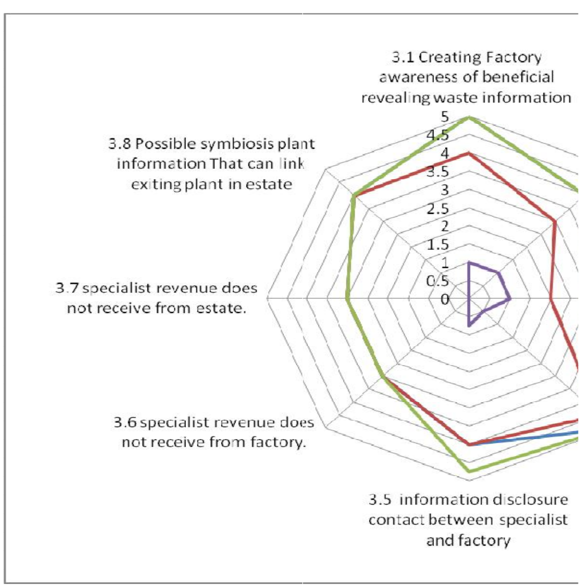

Figure 4.12 Radar-chart of Information factor.

These finding on information factor correspond with the findings of Chertow (2000), Guillaume , and Erkman (2007) who stated that information is a key factor to implement industrial symbiosis; Raymond, and Ramsey (2006) who commented that information exchange is a barrier to implement symbiosis, and Ernest (1997) who stated that it's difficult to obtain secret information. Therefore, information is a key success factor for implementation of industrial symbiosis.

- **Financial Mechanism Factor**

Financial mechanism is one of the most important factors. It may make un-feasible project to be feasible and implemented. Finding of sub-factors by Delphi technique are shown in Table 4.6 and figure 4.12.

Opinion regarding the fact that **financial support or fund is needed for symbiosis implementation** achieved median of 4 points and IQR of 0. This indicates *consensus and important factor*.

Opinion regarding the fact that **sources of fund should come from factories based on polluter pays principle** achieved median of 4 points and IQR of 1. This indicates *important factor*, *and consensus.*

Opinion regarding the fact that **polluters pay discount rate should base on in-house recycling** achieved median of 4 points and IQR of 1. This indicates *consensus and important factor*.

Opinion regarding the fact that **polluters pay discount rate should base on recycled waste from other factories** achieved median of 4 points and IQR of 0.5. This indicates *consensus and important factor*.

Opinion regarding the fact that **the fund should support at initial investment for symbiosis** achieved median of 4 points and IQR of 0.5. This indicates *consensus and important factor*.

Opinion regarding the fact that **the symbiosis fund should support during implementation** achieved median of 4 points and IQR of 0. This indicates *consensus and important factor*.

Opinion regarding the fact that **the fund during implementation should be continuously supported** achieved median of 3 points and IQR of 1. This indicates *consensus, but not important factor*.

Opinion regarding the fact that **the fund during implementation should support with limited time** achieved median of 4 points and IQR of 0. This indicates *consensus and important factor*.

Table 4.6 Experts' opinion on Financial Mechanism Factors

Factor and sub-factors	Median	Q1	Q3	IQR	Consensus	Conclusion

4. Financial Mechanism						
4.1 Symbiosis fund is needed to support implementation	4	4	4	0	Yes	Important
4.2 income to fund should come from factories based on polluters pay principle	4	3.5	4.5	1	Yes	Important
4.3 Polluters pay above there is discount, if factory recycle his waste to be raw material in his plant.	4	4	5	1	Yes	Important
4.4 Polluters pay above there is discount, if factory recycle waste from other plant to be raw material in his plant.	4	4	4.5	0.5	Yes	Important
4.5 The fund should support to initial investment for implement symbiosis	4	3.5	4	0.5	Yes	Important
4.6 The fund should support factory to exchange implementation.	4	4	4	0	Yes	Important
4.7 Fund support in 4.6 should continuous support.	3	2	3	1	Yes	Not Important
4.8 Fund support in 4.6 should limit in 3 or 5 years.	4	4	4	0	Yes	Important

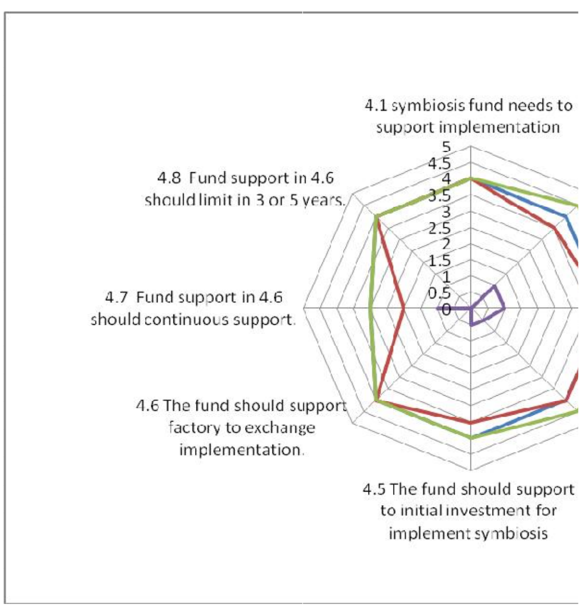

Figure 4.13 Radar-chart of Financial Mechanism factors

These finding on financial mechanism factor correspond with the findings of Heeres, et al. (2004), Gulati (1995), Ernest (1997), Raymond, and Ramsey (2006) that suggested financial mechanism makes more success symbiosis implementation. Hence, this factor is substantial to implement symbiosis.

CHAPTER V
CONCLUSION

This research was carried out with an objective to find out effective factors and a model for effective implementation of industrial symbiosis in an industrial estate. Selected factors considered to be effective for symbiosis implementation were confirmed and ranked by experts by using various tools like documentation, questionnaire, on-site survey, and in-depth interview. A preliminary model for effective implementation of industrial symbiosis was formulated from effective factors identified from the studies. The identified effective factors as well as the preliminary model were then verified by experts using a Delphi technique.

5.1 Conclusion of Research Findings

Factors selected for experts' confirmation and ranking are policy, initiator, stakeholder participation, information, technology, financial mechanism, and others. Finding from the studies indicates that the only 4 factors that are *policy*, *initiator*, *information*, and *financial mechanism* are effective for symbiosis implementation among petrochemical industries in MTPIE, and details of which can be summarized as follows.

- **Policy Factor**

The study found that key success policies for symbiosis implementation among petrochemical industries in MTPIE are on the following issues in each level:

1) **Estate level**: the estate should have policy on zero landfill, zero discharge, with KPI and target setting.
2) **Factory level**: all factories in the estate should have policy on zero landfill, zero discharge, with KPI and target setting, and also have policy on willingness to adjust process ready for symbiosis.
3) **Government level**: government should have policy to encourage and support industrial symbiosis, either financial support or regulation amendment.

- **Initiator Factor**

The study found that successful symbiosis implementation must be initiated either by personnel or activities. Therefore, monthly meeting among factories' executive or manager is strongly recommended, and the meeting agenda should consist of not only emission monitoring report, but also possible impacts to communities, general economic situation, success story of each other, and other general issues. The activities during such meeting would create trust, information exchange, and collaboration. In addition, an initiator or an arranger is very much important for the symbiosis initiating.

- **Information Factor**

Detail information of wastes and/or by-products generated by each factory is usually secret. Most factories are not happy to reveal such information. The study found that most of them prefer to reveal only distorted information, except having contract each other.

Specialists who analyze the waste information in each factory must be faithful and keep information confidentially. Therefore, it's quite difficult to know waste information of other factories, except having an initiator or invitation for collaboration.

- **Financial Mechanism Factor**

The study found that financial support, either BOI Tax Exemption at the initial investment or supporting during symbiosis implementation is an important factor for encouraging the symbiosis implementation. It's suggested that sources of the fund should come from factories based on polluters pay principle, and its discount rate should base on amount of raw materials from recycled wastes, either in-house or wastes from other factories.

Upon verification of the preliminary results with Delphi technique, the results can be categorized by sub-factors and level of implementation as shown in Table 5.1.

Table 5.1 finding effective factors by Delphi technique

Factors	Sub-factors	Level	Degree importance
Policy			
	Government policy on supporting and encouraging industrial symbiosis	Government	High important
	Zero landfill policy	Estate	Important
	Zero discharge policy		Important
	Zero landfill policy	Factory	High important
	Zero discharge policy		High important
	Process adjustment policy for industrial symbiosis		Important
	KPI, objective and target	Estate and factory	Important
Initiator			
	Plant manager and owner meeting can create collaboration in symbiosis	Estate and factory	Important
	Meeting agenda consist of overall estate emission report and its' impact to communities		Important
	Meeting Agenda consists of problem and business opportunities or benefit to factory		Important
	Meeting initiator should be managed by estate owner	Estate	Most Important
	Collaboration between government and private committee can help to solve regulation and law problem to symbiosis.	Estate and factory level	Most Important
Information			
	Creating Factory understanding benefit of revealing waste information	factory level	Most Important
	At the beginning (first), factory revealed type of waste to pre-symbiosis.		Important
	Specialist who analyzed the waste information should be fairness and creditable.		Most Important
	Information reveal contract must be settled between specialist and factory		Important
	Possible symbiosis plant information that links to existing plant in estate		Important
Financial mechanism			
	Symbiosis fund is needed.		Important
	Sources of fund should come from factories based on polluters pay principle.		Important
	Polluters pay discount rate should base on raw materials from recycled waste.		Important
	Financial support should be provided at initial investment for implement symbiosis		Important
	Financial support should be provided during symbiosis implementation with limited time.		Important

Hence, a model for effective implementation of industrial symbiosis in industrial estate was proposed as shown in figure 5.1.

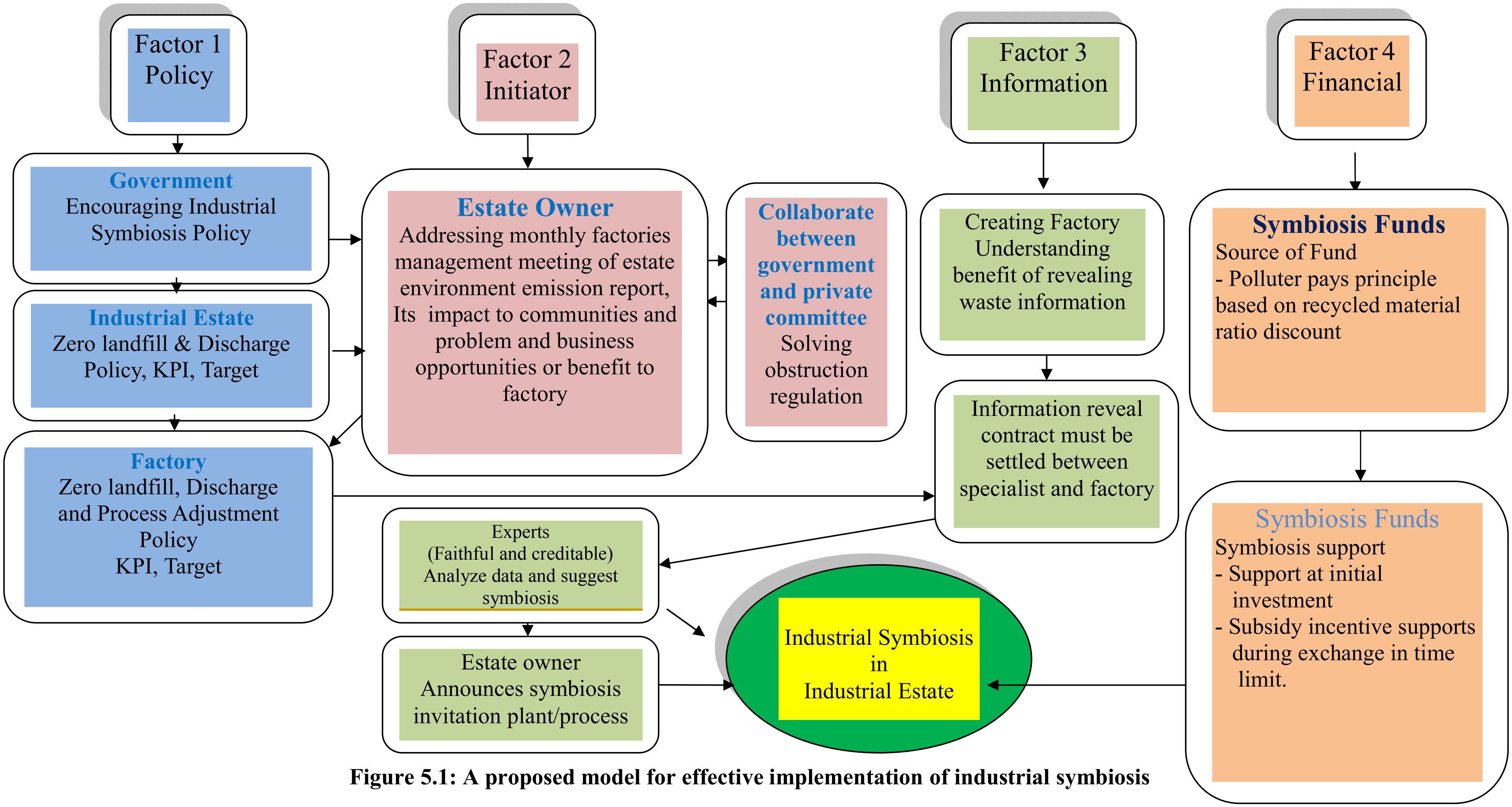

Figure 5.1: A proposed model for effective implementation of industrial symbiosis

5.2 Recommendations

Industrial Symbiosis is a tool to develop industry in sustainable way. It is benefit to economic like reducing waste disposal cost and get profit from sale waste or by-product; environment like reducing use of virgin resources; and social like reducing community health impact. To encourage industrial symbiosis, resource efficiency and reduction of wastes for disposal, stakeholders should encourage and support as best as possible.

1) Government Policy changing from waste disposal to waste exchange to achieve benefit to both waste generator and waste processor that can reduce breaking waste disposal regulation and encouraging knowledge IS principle and advantage to industrial estates entrepreneurs and factories owner and manage to participate to Industrial symbiosis.
2) A committee from government agency should be designated to solve any regulations obstructing the symbiosis implementation: it is need to declaration of new Act that declares committee responsibility and authorities.
3) Industrial estate entrepreneurs as initiator should set up policy on zero discharge and encourage factories in estate meeting to aware and reduce estate emission together.
4) Information is a crucial factor that factories owner should understand its importance to implement IS. Experts who analyze this data is not only specialist in waste management and matching in symbiosis but also keep factories information as secrete.
5) Financial mechanism and funding: it is need to declaration of new Act that involves source of fund mechanism as in the model (polluter pay principle based on recycling rate) institution addressing and inventive procedure to support symbiosis.

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APPENDICES

APPENDIX A

INDEPTH-INTERVIEW QUESTIONNAIRE
ข้อมูลผู้ตอบแบบสอบถาม และโรงงานอุตสาหกรรม

ชื่อ..นามสกุล..
ตำแหน่ง..
ชื่อ..นามสกุล..
ตำแหน่ง..
ชื่อ..นามสกุล..
ตำแหน่ง..
ชื่อ..นามสกุล..
ตำแหน่ง..
ชื่อ..นามสกุล..
ตำแหน่ง..

บริษัท/โรงงาน..
ที่อยู่
....
....
หมายเลขโทรศัพท์..
Email..

คำชี้แจง โปรดทำเครื่องหมาย ✓ ลงใน ☐ ให้ตรงกับความเป็นจริงของท่าน

1. ประเภทอุตสาหกรรม

- ☐ อุตสาหกรรมปิโตรเคมี **ขั้นต้น Upstream**
- ☐ อุตสาหกรรมปิโตรเคมี **ขั้นกลาง Intermediate stream**
- ☐ อุตสาหกรรมปิโตรเคมี **ขั้นปลาย Downstream**
- ☐ อื่นๆ โปรดระบุ ....

2. ปีที่ตั้ง โรงงาน อุตสาหกรรม พ.ศ...............................

3. ผลประกอบการด้าน การเพิ่มผลผลิต การใช้ทรัพยากร ของโรงงานในรอบปีที่ผ่านมา

หัวข้อ	ลักษณะข้อมูล			หมายเหตุ
	มีการดำเนินการ	ไม่มีการดำเนินการ		
การจัดการ ISO 9001				
หัวข้อ	ลักษณะ		ผลดำเนินการ	
	มี	ไม่มี	สำเร็จ	ไม่สำเร็จ
1. เป้าหมายการลดต้นทุน				
2. เป้าหมายการเพิ่มประสิทธิภาพการใช้วัตถุดิบ				
3. เป้าหมายการเพิ่มประสิทธิภาพการใช้พลังงาน				
4. เป้าหมายการเพิ่มประสิทธิภาพการใช้น้ำ				
5. การออกแบบผลิตภัณฑ์ใหม่เพื่อตอบสนองความต้องการลูกค้า				
6. การออกแบบผลิตภัณฑ์หรือ กระบวนการใหม่เพื่อลดต้นทุน				
7. การออกแบบผลิตภัณฑ์หรือ กระบวนการใหม่เพื่อ ลดปัญหาสิ่งแวดล้อม				

4. ผลประกอบการด้าน**สิ่งแวดล้อม** ของโรงงานในรอบปีที่ผ่านมา(สามารถตอบได้มากกว่า 1 ข้อ)

หัวข้อ	ลักษณะข้อมูล			หมายเหตุ
	มีการดำเนินการ	ไม่มีการดำเนินการ		
การจัดการสิ่งแวดล้อม 14001				
หัวข้อ	ผลดำเนินการ			
	ไม่ได้ตามเกณฑ์ตลอดเวลา	ไม่ได้ตามเกณฑ์2-3 ครั้งต่อปี	ได้ตามเกณฑ์ตลอดปี	ได้ดีกว่าเกณฑ์กำหนด
1. การปล่อย ก๊าซ เสีย ตามมาตรฐาน				
1.1 Sox				
1.2 NOx				
1.3 VOC				
1.4 อื่นๆ โปรดระบุ				
1.5 อื่นๆ โปรดระบุ				
2. การปล่อย น้ำเสีย				
1.1 COD				
1.2 BOD				
1.3 อื่นๆ โปรดระบุ..............................				
1.4 อื่นๆ โปรดระบุ................................				
1.5 อื่นๆ โปรดระบุ................................				

หัวข้อ	วิธีการจัดการ			
	โรงงานดำเนินการกำจัด	ส่งกลับคืนผู้ขาย	ส่งบริษัทรับกำจัด(กรุณาระบุ บริษัท ฯ)	อื่นๆ
1. การปล่อยของแข็ง ที่เป็นของเสีย				
1.1 ของแข็ง ที่เป็นของเสียทั่วไป				
1.2 ของแข็ง ที่เป็นของเสีย มีพิษ				
1.3 สารแผ่รังสี				
1.4 อื่นๆ โปรดระบุ				
1.5 อื่นๆ โปรดระบุ				

5. ผลประกอบการด้าน**<u>การเงิน</u>**ของโรงงาน ในรอบปีที่ผ่านมา

☐ ยังไม่สามารถให้ข้อมูลได้ ขอให้ในภายหลัง

☐ เป็นความลับไม่สามารถให้ข้อมูลได้

☐ ผลการดำเนินงาน ได้กำไรมากกว่า 10%

☐ ผลการดำเนินงาน ได้กำไรมากกว่า 5%

☐ ผลการดำเนินงาน ขาดทุนน้อยกว่า 5%

☐ ผลการดำเนินงาน ขาดทุนมากกว่า 5%

Management Policy

ชื่อโรงงาน.. โทรศัพท์...................

ผู้ให้ข้อมูล..ตำแหน่ง...................

โรงงานได้มีนโยบาย องค์กร ในด้านต่างๆ ที่ชัดเจนอย่างไร

1. องค์กรให้น้ำหนักความสำคัญในนโยบาย ด้านต่างๆ อย่างไร

นโยบาย	ระดับความสำคัญ						
	ไม่สำคัญมากที่สุด	ไม่สำคัญมาก	ไม่สำคัญ	ปานกลาง	สำคัญ	สำคัญมาก	สำคัญมากที่สุด
ด้านการเงิน, เศรษฐกิจ							
สิ่งแวดล้อม							
สังคม							
อื่นๆ							

2. โรงงานมีการกำหนด งบประมาณ ในการปรับปรุง เพิ่มประสิทธิภาพการผลิต พัฒนาคุณภาพสิ่งแวดล้อม และสังคม

นโยบาย	ระดับ(บาท)						
	0-500,000 บาท	500,000-1,000,000	1,000,000-2,000,000	2,000,000-4,000,000	4,000,000-6,000,000	6,000,000-8,000,000	มากกว่า 8,000,000
งบประมาณ ในการปรับปรุง ลดต้นทุนในการผลิต							
งบประมาณ ในการปรับปรุง คุณภาพสิ่งแวดล้อม							
งบประมาณ ในการปรับปรุง พัฒนาคุณภาพสินค้าเพื่อตอบสนองต่อความต้องการของลูกค้า							
งบประมาณ ในการปรับปรุง พัฒนาคุณภาพสินค้าเพื่อลดผลกระทบต่อสิ่งแวดล้อม							
งบประมาณ ในการช่วยเหลือสังคมภายนอก							
	ไม่มีการกำหนด	1-10 ชม. ต่อคน	10-20 ชม. ต่อคน	20-30 ชม. ต่อคน	30-40 ชม. ต่อคน	40-50 ชม. ต่อคน	มากกว่า 50 ชม. ต่อคน
การให้พนักงาน มีส่วนร่วมในการช่วยพัฒนาสังคม ภายนอก							

3. โรงงาน ท่านได้มีการกำหนด นโยบาย ในการทำกิจกรรมกลุ่มย่อยต่างๆ เช่น QCC, KAIZEN, 5ส, ข้อเสนอแนะ หรือไม่

กิจกรรม QCC

☐ มี ☐ ไม่มี

กิจกรรม KAIZEN

☐ มี ☐ ไม่มี

กิจกรรม 5ส

☐ มี ☐ ไม่มี

กิจกรรม ข้อเสนอแนะ

☐ มี ☐ ไม่มี

4. โรงงาน ท่านได้มีการทำกิจกรรมกลุ่มย่อยต่างๆ เช่น QCC, KAIZEN, 5ส, ข้อเสนอแนะ ในการดำเนินการ ปรับปรุง ในด้านใด บ้าง (ตอบได้มากกว่า 1 ข้อ)

☐ การลดต้นทุน

☐ การลดการใช้วัตถุดิบ เพิ่มประสิทธิภาพ การใช้วัตถุดิบ

☐ การเพิ่มประสิทธิภาพ การใช้พลังงาน

☐ การเพิ่มประสิทธิภาพ การใช้ทรัพยากรน้ำ

☐ การปรับปรุง คุณภาพ อากาศเสีย

☐ การปรับปรุง คุณภาพ น้ำทิ้ง

☐ การปรับปรุง ของแข็ง ของเสียทิ้ง

5. โรงงานมีนโยบาย ในการ ให้ความร่วมมือ(Collaboration) กับโรงงานอื่นๆ ในการ **สนับสนุนความร่วมมือกัน**(Synergy) **หรือ ดำเนินการ** Symbiosis หรือไม่

☐ ไม่ทราบความหมายของ Synergy **หรือ** Symbiosis

☐ มีนโยบาย ให้ความร่วมมือ Synergy **หรือ** Symbiosis กรุณา ยกตัวอย่าง

....

☐ ไม่ มีนโยบาย ให้ความร่วมมือ Synergy **หรือ** Symbiosis

6. โรงงานมีนโยบาย ในการ **<u>ปรับปรุงกระบวนการผลิต</u>**เพื่อ **สนับสนุนความร่วมมือกัน (Synergy) หรือ ดำเนินการ Symbiosis**

- ☐ ไม่ทราบความหมายของ Synergy **หรือ** Symbiosis
- ☐ มีนโยบาย ปรับปรุงกระบวนการผลิตเพื่อ Synergy **หรือ** Symbiosis
  กรุณา ยกตัวอย่าง ....
- ☐ ไม่มีนโยบาย ปรับปรุงกระบวนการผลิตเพื่อ Synergy **หรือ** Symbiosis

7. โรงงานมีการกำหนดเป้าหมาย ไม่ปลอดปล่อย ของเสียสู่สิ่งแวดล้อม (Zero Discharge) หรือไม่

- ☐ ไม่ทราบความหมายของ Zero Discharge
- ☐ มีนโยบาย Zero Discharge
  กรุณา ยกตัวอย่าง ....
- ☐ ไม่มีนโยบาย Zero Discharge

8. โรงงานมีการกำหนดเป้าหมาย Zero landfill หรือไม่

- ☐ ไม่ทราบความหมายของ Zero landfill
- ☐ มีนโยบาย Zero landfill
  กรุณา ยกตัวอย่าง ....
- ☐ ไม่มีนโยบาย Zero landfill

Environment and symbiosis Team

ชื่อโรงงาน.. โทรศัพท์...................

ผู้ให้ข้อมูล...ตำแหน่ง...................

1. ท่านคิดว่า ใครในทีมงานมีส่วนสำคัญที่ทำให้การดำเนินการปรับปรุงคุณภาพสิ่งแวดล้อม ของ โรงงานประสบความสำเร็จ เพราะอะไร(กรุณากรอกตำแหน่งสมาชิกทีมงานด้านสิ่งแวดล้อม ในช่อง สมาชิก และประเมิน ช่วยทำให้สำเร็จ หรือ ขัดขวาง และกรุณาระบุเหตุผล)

สมาชิกทีม	ช่วยทำให้สำเร็จ	ขัดขวาง	เหตุผล

2. ท่านคิดว่าผู้แทนชุมชน ภาครัฐ ควรมาอยู่ร่วมในทีมงานด้านสิ่งแวดล้อมหรือไม่ เพราะอะไร

ผู้แทนชุมชน

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ผู้แทน ภาครัฐ

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Information for Environment and Symbiosis

ชื่อโรงงาน.. โทรศัพท์...................

ผู้ให้ข้อมูล...ตำแหน่ง...................

1. ลักษณะข้อมูล และความลับ

ข้อมูล	การเก็บข้อมูล(มี-ไม่มี)	ความลับของข้อมูล (ลับ-ไม่เป็นความลับ)	การเปิดเผยต่อสาธารณะ (เปิดเผยได้ทั้งหมด-บางส่วน-ไม่เปิดเผย)	เหตุผล
1. ลักษณะคุณภาพวัตถุดิบที่ต้องการแต่ละกระบวนการ				
2.ปริมาณวัตถุดิบที่ต้องการแต่ละกระบวนการ				
3 ลักษณะคุณภาพสินค้าที่ต้องการแต่ละกระบวนการ				
4. ปริมาณสินค้าที่ได้ในแต่ละกระบวนการ				
5 ลักษณะคุณภาพพลังงานที่ต้องการแต่ละกระบวนการ				
6 ปริมาณพลังงานที่ต้องการแต่ละกระบวนการ				
7 ลักษณะคุณภาพน้ำที่ต้องการแต่ละกระบวนการ				
8 ปริมาณน้ำที่ต้องการแต่ละกระบวนการ				
9 ปริมาณ By Product ที่เกิดขึ้นแต่ละกระบวนการ				

ข้อมูล	การเก็บข้อมูล(มี-ไม่มี)	ความลับของข้อมูล (ลับ-ไม่เป็นความลับ)	การเปิดเผยต่อสาธารณะ (เปิดเผยได้ทั้งหมด-บางส่วน-ไม่เปิดเผย)	เหตุผล
10 ปริมาณ By Product ที่เกิดขึ้นแต่ละกระบวนการ				

2. ข้อมูลที่เปิดเผยไม่ได้ ถ้าทางภาครัฐกำหนดให้เปิดเผยเพื่อร่วมมือกัน เพื่อดำเนินการแลกเปลี่ยน ซื้อขาย **ของเสีย** (Waste) **ผลิตภัณฑ์ ส่วนเหลือ** (By Product) กันโรงงานของท่านยินดีเปิดเผยข้อมูลหรือไม่ เพราะอะไร

☐ ยินดีเปิดเผยข้อมูล

☐ ไม่ยินดีเปิดเผยข้อมูล

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3. ถ้ามีปัญหาในการเปิดเผยข้อมูล ถ้าภาครัฐกำหนด ช่วงค่าความถูกต้องของปริมาณ เพื่อให้โรงงานอื่น หรือผู้อื่นไม่ทราบปริมาณที่แท้จริงทางโรงงานท่านยินดีเปิดเผยข้อมูลหรือไม่

☐ ยินดีเปิดเผยข้อมูล

☐ ไม่ยินดีเปิดเผยข้อมูล

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Technical and Technology

ชื่อโรงงาน.. โทรศัพท์...................

ผู้ให้ข้อมูล...ตำแหน่ง...................

1. ข้อมูลปริมาณของเสีย และของเหลือทิ้งทั้งหมด ทุกกระบวนการ

กระบวนการ	ชื่อ/ชนิด ของเหลือ(By product)ของเสีย(waste)	ปริมาณ/ช่วงเวลา	คุณลักษณะ ของเหลือ(By product) ของเสีย(waste)	วิธีการการจัดการ หรือ โรงงาน/ หน่วยงานที่รับไปแปลงสภาพเป็นวัตถุดิบ หรือพลังงาน

2. โรงงานได้มีการหาสัดส่วน ปริมาณ ของเสีย(Waste) หรือของเหลือ(by product) ที่ได้ขายเป็นวัตถุดิบ หรือให้เป็นวัตถุดิบ โรงงานอื่น เทียบกับข้อมูลปริมาณของเสีย และของเหลือทิ้งทั้งหมดที่เกิดขึ้น

☐ ได้มีการดำเนินการหาสัดส่วน สัดส่วนที่ได้คือ ....

☐ ไม่มีการดำเนินการหาสัดส่วน

3. ถ้าโรงงานมีการดำเนินการ Industrial Symbiosis ในการรับวัตถุดิบจากโรงงานอื่น ทางโรงงานมีปัญหาในเรื่องความคงเส้น คงวาของคุณภาพ และปริมาณของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) หรือไม่ ถ้ามีทางโรงงานมีการดำเนินการแก้ไขอย่างไร

วัตถุดิบ	เป็นของเสีย หรือ By Product จากโรงงาน(ถ้าไม่ใช่ ใส่ " – ")	มีสัญญาในการซื้อ	สัดส่วนการใช้	มีปัญหาคุณภาพ	มีปัญหาปริมาณ	แนวทางในการดำเนินการแก้ไข

4. **ถ้าโรงงานมีการดำเนินการ** Industrial Symbiosis ในการส่ง หรือขาย ให้โรงงานอื่น ทางโรงงานมีข้อตกลงคุณภาพ และปริมาณ**ของเสีย** (Waste) หรือ**ผลิตภัณฑ์ ส่วนเหลือ** (By Product) ที่ต้องดูแล ควบคุมหรือไม่ อย่างไร

ของเสีย (Waste) หรือ **ผลิตภัณฑ์ ส่วนเหลือ** (By Product)	ของเสีย หรือ By Product จากกระบวนการ(ถ้าไม่ใช่ ใส่ " – ")	มีสัญญาในการขาย	มีข้อตกลงคุณภาพ	มีข้อตกลงปริมาณ	ลักษณะข้อตกลง

5. โรงงานได้มีการดำเนินการ สมดุลมวล(Mass balance)หรือไม่ ประสิทธิภาพการผลิตเป็นเท่าไร

กระบวนการ	มีการทำสมดุลมวล Mass Balance	ประสิทธิภาพการผลิต

6. โรงงานมีขั้นตอน(Procedure) วิธีการในการปรับเปลี่ยนกระบวนการในกรณีที่ รับ**ของเสีย** (Waste) หรือ**ผลิตภัณฑ์ ส่วนเหลือ** (By Product) หรือไม่

วัตถุดิบ	สัดส่วนการใช้	มีการปรับเปลี่ยนวิธีการในการผลิต	การปรับเปลี่ยนออกแบบไว้ตั้งแต่ตั้งโรงงาน หรือ ไม่ได้ออกแบบไว้และมาปรับปรุงภายหลัง	อธิบายโดยย่อ

7. โรงงานได้มีการหาเทคโนโลยี ในการ recycle **ของเสีย** (Waste) หรือ**ผลิตภัณฑ์ ส่วนเหลือ** (By Product) หรือไม่

☐ ไม่มีการดำเนินการ
☐ มีการดำเนินการ โปรดระบุ มาตรการ หรือโครงการ

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8. ท่านมีโรงงานอื่นที่สามารถดำเนินการ **<u>ซื้อ</u>** ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) จากโรงงานของท่าน แต่ไม่ได้ดำเนินการซื้อขายกัน หรือไม่เพราะอะไร

☐ ไม่ทราบว่ามีโรงงานอื่นที่สามารถ **<u>ซื้อ</u>** ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product)

☐ มีโรงงานอื่นที่สามารถ **<u>ซื้อ</u>** ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) **<u>และได้ซื้อขายกัน</u>**

- ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) คือ

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- โรงงานที่รับซื้อคือ

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☐ มีโรงงานอื่นที่สามารถ **<u>ซื้อ</u>** ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) **<u>แต่ไม่ได้ซื้อขายกัน</u>**

- ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) คือ

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- โรงงานที่รับซื้อได้คือ

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- ปัญหาที่ไม่มีการซื้อขายกัน

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9. ท่านมีโรงงานอื่นที่สามารถดำเนินการ **ขาย** ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) ให้โรงงานของท่าน แต่ไม่ได้ดำเนินการซื้อขายกัน หรือไม่เพราะอะไร

☐ ไม่ทราบว่ามีโรงงานอื่นที่สามารถ **ขาย** ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) ให้โรงงานของท่าน

☐ มีโรงงานอื่นที่สามารถ **ขาย**ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) **และได้ซื้อขายกัน**

- ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) คือ

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- โรงงานที่รับซื้อคือ

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☐ มีโรงงานอื่นที่สามารถ **ขาย** ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) **แต่ไม่ได้ซื้อขายกัน**

- ของเสีย (Waste) หรือผลิตภัณฑ์ ส่วนเหลือ (By Product) คือ

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- โรงงานที่รับซื้อได้คือ

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- ปัญหาที่ไม่มีการซื้อขายกัน

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10. ท่านคิดว่ากฎหมาย หรือกฎระเบียบต่างๆ ของภาครัฐมีผลต่อการดำเนินการ Symbiosis หรือไม่ อย่างไร

☐ **ไม่ทราบ**ว่ากฎหมายมีผล

☐ **คิดว่า**กฎหมาย**ไม่มีผล** เพราะว่า

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☐ **คิดว่า**กฎหมาย**มีผล** เพราะว่า

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Financial Mechanism

ชื่อโรงงาน... โทรศัพท์...................

ผู้ให้ข้อมูล...ตำแหน่ง...................

1. ในหลายปีที่ผ่านมาโรงงานดำเนินการโครงการ มาตรการปรับปรุงคุณภาพ สิ่งแวดล้อม หรือ Symbiosis อะไรบ้าง

มาตรการ	เงินลงทุน	ผลการประหยัดพลังงาน หรือทรัพยากร	ระยะเวลาคืนทุน	หมายเหตุ

2. การดำเนินการโครงการมีการพิจารณาผลการตอบแทนการคืนทุนอย่างไร

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3. โรงงานมีการดำเนินการในการวิจัยพัฒนาผลิตภัณฑ์ สิ่งแวดล้อม และ Recycle or reuse **ของเสีย** (Waste) หรือ**ผลิตภัณฑ์ ส่วนเหลือ** (By Product) หรือไม่

โครงการวิจัย	**วัตถุประสงค์การวิจัย** (พัฒนาผลิตภัณฑ์ ,กระบวนการ สิ่งแวดล้อม, Recycle, Reuse, อื่นๆ..)	งบประมาณในการวิจัย	หลักการและเหตุผลในการวิจัย

4. ให้ประเมิน และจัดลำดับการสนับสนุนทางการเงินจากภาครัฐในการดำเนินการ วิจัยเพื่อ Recycle or reuse ดังต่อไปนี้

โดยเรียงลำดับจากที่ให้ความสำคัญมากที่สุด เป็น ลำดับที่ 1

ลักษณะการให้การสนับสนุนการวิจัย	ระดับการให้ความสำคัญ	หมายเหตุ
a. การให้การสนับสนุน 50-50%		
b. การให้เงินกู้ดอกเบี้ยต่ำ		
c. การลดหย่อนภาษี		
d. อื่นๆ ระบุ............................		
e. อื่นๆ ระบุ............................		
f. อื่นๆ ระบุ............................		

5. ให้ประเมิน และจัดลำดับการสนับสนุนทางการเงินจากภาครัฐในการดำเนินการ ลงทุนให้เกิดการซื้อ-ขาย **ของเสีย** (Waste) หรือ**ผลิตภัณฑ์ ส่วนเหลือ** (By Product) ดังต่อไปนี้

ลักษณะการให้การสนับสนุน	ระดับการให้ความสำคัญ	หมายเหตุ
a. การให้การสนับสนุน 50-50%		
b. การให้เงินกู้ดอกเบี้ยต่ำ		
c. การลดหย่อนภาษี		
d. อื่นๆ ระบุ............................		
e. อื่นๆ ระบุ............................		

6. ท่านมีความคิดเห็นอย่างไรใน จัดตั้ง “กองทุนสินแร่ และสิ่งแวดล้อม เพื่อส่งเสริมการ Recycle และSymbiosis”

☐ เห็นด้วย

☐ ไม่เห็นด้วย

เหตุผล

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7. ท่านคิดว่าแหล่งรายได้ของเงินที่จัดเก็บเข้ากองทุนข้างต้นควรมาจากส่วนใด กรุณาเรียงลำดับ

ลักษณะการจัดเก็บ	ระดับการให้ความสำคัญ	หมายเหตุ
a. เก็บเพิ่มจากการใช้สินแร่		
b. เก็บจากปริมาณการใช้พลังงาน		
c. เก็บจากปริมาณการใช้น้ำ		
d. เก็บจากปริมาณการปล่อยมลพิษ		
e. อื่นๆ ระบุ............................		

Appendix B

Delphi Expert Questionnaire

ปัจจัย	ระดับความเห็นผู้เชี่ยวชาญ		ความเห็นเดิม		ระดับการสนับสนุน การดำเนินการ Industrial Symbiosis					หมายเหตุ/ความคิดเห็นเพิ่มเติม
	median	ระดับ	Code	ระดับ	ขัดขวางอย่างมาก	ขัดขวาง	ไม่สำคัญ	สำคัญ	สำคัญมาก	
1.ปัจจัยด้านนโยบาย										
1.1 นโยบายส่งเสริมการดำเนินการ Industrial symbiosis ของภาครัฐ										
1.2 นโยบาย Zero landfill ของนิคมอุตสาหกรรม										
1.3 นโยบาย Zero Discharge ของนิคมอุตสาหกรรม										
1.4 นโยบาย Zero landfill ของโรงงานอุตสาหกรรม										
1.5 นโยบาย Zero Discharge ของโรงงานอุตสาหกรรม										
1.6 นโยบาย การปรับเปลี่ยนกระบวนการเพื่อรองรับ Industrial symbiosis										
1.7 นโยบาย sustainability policy of factory										
1.8 การกำหนด วัตถุประสงค์ และเป้าหมาย เพื่อให้บรรลุนโยบาย (objective and target)										
2. ปัจจัยด้าน บทบาทหน้าที่ และกลุ่มผู้ริเริ่มดำเนินการ										
2.1 การจัดให้มีการประชุมผู้บริหารโรงงานอุตสาหกรรม เพื่อให้เกิดความร่วมมือ Industrial symbiosis										
2.2 หัวข้อการประชุม ควรมีการรายงานปริมาณการปลดปล่อยของเสียทั้งหมดของนิคมฯ										
2.3 หัวข้อการประชุม ควรมีการรายงานผลกระทบของการปลดปล่อยของเสียต่อชุมชน										
2.4 หัวข้อการประชุม ควรมีการรายงานสภาวะเศรษฐกิจโดยรวม										
2.5 หัวข้อประชุม ที่เป็นปัญหา หรือโอกาสในทางธุรกิจหรือที่เป็นประโยชน์ต่อโรงงานอุตสาหกรรม เช่น										

ปัจจัย	ระดับความเห็นผู้เชี่ยวชาญ		ความเห็นเดิม		ระดับการสนับสนุน การดำเนินการ Industrial Symbiosis					หมายเหตุ/ความคิดเห็นเพิ่มเติม
	median	ระดับ	Code	ระดับ	ขัดขวางอย่างมาก	ขัดขวาง	ไม่สำคัญ	สำคัญ	สำคัญมาก	
ปัญหาน้ำแล้ง ISO50001.										
2.6 ผู้ริเริ่มการประชุม ควรเป็นผู้บริหารหรือเจ้าของนิคมฯ										
2.7 ผู้ริเริ่มการประชุม ควรเป็นผู้แทนภาครัฐ										
2.8 การมีคณะกรรมการร่วมภาครัฐเอกชนในการแก้ปัญหาระเบียบข้อกฎหมาย										
2.9 ผู้ริเริ่มเป็นโรงงานเวียนกันเป็นผู้จัดการประชุมเพิ่มสร้างการมีส่วนร่วม (กรุณาเทียบกับ เจ้าของนิคมฯ)										
3.ปัจจัยด้านข้อมูล ของเสียโรงงาน และอื่นๆ										
3.1 การทำให้โรงงานเห็นประโยชน์การเปิดเผยข้อมูล										
3.2 การให้โรงงานเปิดเผยชนิดของเสียโดยยังไม่เปิดเผยปริมาณของเสีย(ในขั้นต้นของการวิเคราะห์)										
3.3 ผู้เชี่ยวชาญที่วิเคราะห์ข้อมูลต้องเป็นกลาง และมีความน่าเชื่อถือ										
3.4 การจัดทำสัญญาการรักษาความลับระหว่างผู้เชี่ยวชาญและโรงงาน										
3.5 ผู้เชี่ยวชาญ ได้รับค่าตอบแทน ที่ไม่ได้รับจากโรงงานโดยตรง(รับจากหน่วยงาน อื่นเพื่อความเป็นกลาง)										
3.6 ผู้เชี่ยวชาญ ได้รับค่าตอบแทน ที่ไม่ได้รับจากนิคมฯ โดยตรง (รับจากหน่วยงาน อื่นเพื่อความเป็นกลาง)										
3.7 ข้อมูลการเชิญชวนโรงงานที่จะมาเชื่อมโยง(Industrial symbiosis)										
4. ปัจจัยด้านการเงิน										
4.1 ควรมีกองทุนเพื่อสนับสนุนการดำเนินการ Symbiosis										
4.2 แหล่งเงินทุนเรียกเก็บจากโรงงานตามหลักการ polluters pay										

ปัจจัย	ระดับความเห็นผู้เชี่ยวชาญ		ความเห็นเดิม		ระดับการสนับสนุน การดำเนินการ Industrial Symbiosis					หมายเหตุ/ความคิดเห็นเพิ่มเติม
	median	ระดับ	Code	ระดับ	ขัดขวางอย่างมาก	ขัดขวาง	ไม่สำคัญ	สำคัญ	สำคัญมาก	
4.3 ควรมีการกำหนดส่วนลด polluters pay หากโรงงานมีการ Recycle ของเสียจากโรงงานตนเองมาใช้ประโยชน์										
4.4 ควรมีการกำหนดส่วนลด polluters pay ถ้าโรงงานมีการ Recycle ของเสียจากโรงงานอื่นมาใช้เป็นวัตถุดิบ										
4.5 ควรมีการสนับสนุนเงินช่วยเหลือในการลงทุนดำเนินการ Industrial symbiosis สำหรับโรงงาน										
4.6 ควรมีการสนับสนุนเงินช่วยเหลือช่วงดำเนินการ Exchange สำหรับโรงงาน										
4.7 การช่วยเหลือในข้อ 4.6 ควรช่วยเหลือตลอดไป										
4.8 การช่วยเหลือในข้อ 4.6 ควรกำหนดช่วงเวลาที่จำกัด										

Appendix C

Symbiosis Implementation Categorized by-product and waste

Center for industrial Ecology at Yale examining 200 resource exchanges, identified and grouped waste of implementing symbiosis in to 10 categories as shown in table below (Chertow, and Park, 2010).

Table 2.3 Categorized by-product and waste in Symbiosis Implementation

Waste category	Material description	Number of observations (n=199)	Percentage
Chemical waste	Spent solvents, Residual acids/alkali, sulphur, Industrial gases (CO_2, H_2), Activated carbon, and Spent catalyst.	54	27%
Metallic waste	Metal scraps(Iron, steel, stainless steel, copper, lead, zinc), Slag(blast furnace, steel, lead) Solder materials, bauxite residue, spent lead acid batteries	28	14%
Ash	Fly ash, bottom ash, mixed ash, burnt residue	26	13%
Organic waste	Food waste, biomass, fertilizer, other organic waste	23	12%
Sludge	Sewage sludge, refinery sludge, paper sludge, fibre muds, filter cakes	19	10%
Paper and wood waste	Cardboard, mixed paper, wood dust, chips, trimmings	15	8%
Non-metallic waste	Synthetic gypsum, construction and concrete waste, glass scrap, coal mine overburden, lime kiln dust, silica fume	14	7%
plastics and rubber Waste	Polystyrene, waste plastics, off-spec plastics, rubber scrap	7	4%
Oil waste	Used oil from chemical processes, edible oil from food manufacturing	7	4%
Others	Textile waste, fine materials, biogas, excess gas	6	3%

Source: Chertow M. and Park J. Y. (2010) Reusing Non-hazardous Industrial Waste across Business Clusters. In: T. Letcher, D. Vallero (Eds) WASTE: A Handbook of Waste Management and Recycling; Elsevier

From the symbiosis material in the table, it shows this material seen un-valuable such as spent solvents, spent catalyst, sulphur, ash, sludge, concrete waste etc., but it can be feed stock to other industries. The maximum implementation in the study is chemical waste followed by metallic and ash. The percentage graphical symbiosis can be shown in figure 2.18

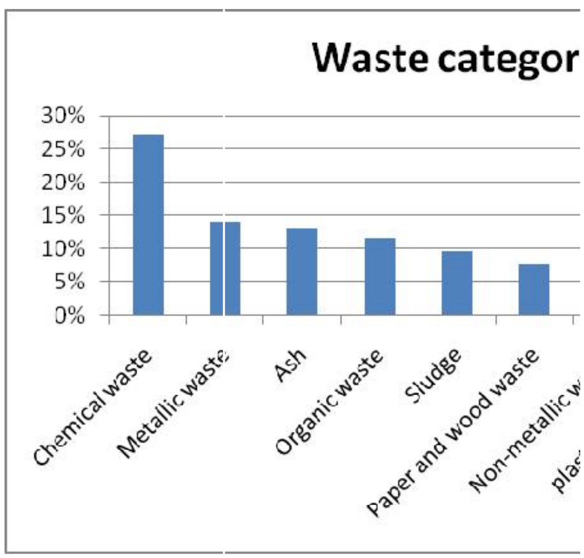

Figure 2.18 waste categorized in symbiosis project

Appendix D

Delphi technique

Delphi technique is a systematic decision tool or process in an issue without facing of expert group (http://202.143.130.99/files/delphi2.pdf). It gains convergence of expert opinion in real-world topic research such as policy investigation, predicting the occurrence of future events (Ulschak, 1983; Turoff and Hiltz, 1996; Ludwig, 1997 cited in Hsu, Sandford, and Brian, 2007). General survey methods aim to find out "*What is*" while Delphi technique strives to find out "*what could/should be*" (Miller, 2001 cited in Hsu et al., 2007). Delphi employs multiple iteration process to solicit expert consensus opinion of research topic. In each round process, experts feedback group's opinion and their judgments data last iteration to reassess their opinion in later iteration (Hsu et al., 2007). Delphi technique is notable in expert anonymity that can reduce the effects of dominant expert that can occur when using other method (Dalkey, 1972, cited in Hsu et al., 2007).

- **Delphi Process**

Delphi process normally iterates until consensus achieved that may be 4-5 rounds. Hsu et al. (2007) illustrated up to four rounds as follows:

Round 1: For the first round traditional Delphi process is open-end questionnaire. This collects expert specific opinion and information on target issue. After gathering experts' responses, researcher constitute well-structured questionnaire that will be used in second round.

In modification Delphi technique well-structure questionnaire may be created by other method if there are more available and useable information concerning to target issue.(Kerlinger, 1973).

Round 2: in the second round experts receive well-structured questionnaire and are asked to review and rate item to establish preliminary priorities among items. Then researchers analyze the data gathered from expert, and summarize statistical data such as mean, median, mode and deviation. The consensus begins formed and fruitful information that can be presented to participation experts in next round.

Round 3: in the third round, each expert receives a questionnaire including the statistical summarized information in previous round and are asked to revise his or her judgment or "to specify the reason for remaining outside the consensus"(Pfeiffer, 1968 cited in Hsu et al.,2007).

Round 4: in the fourth round and often final round, the list of remaining items, their rating, minority opinion, and items achieving consensus are distributed to the experts. This round provides a final opportunity for expert to *revise their judgment. Depending researchers consensus criteria, number of iteration may be three to five round (Delbecq, Van de Ven, and Gustafson, 1975; Ludwig, 1994 cited in Hsu et al.,2007).*

- **Expert Selection**

Experts selection in Delphi technique is the most important step because it relates to the results (Judd, 1972; Taylor and Judd, 1989; Jacobs, 1996 cited by Hsu et al.,2007). Selected Expert should be in disciplinary field of the research issue. For number of expert, Delbecq et al. (1975) suggest that "ten to fifteen experts could be sufficient if their background of the Delphi subjects is homogeneous." Ludwig (1997) documented that, "the majority of Delphi studies have used between 15 and 20 respondents".

- **Data Analysis**

Data analysis criterion is important for decision on consensus of experts' opinion. There are many examples criteria for instance, Ulschak (1983) recommended "80 percent of experts' votes fall within two categories on a seven-point scale". Green (1982) suggested that "at least 70 percent of expert rate three or higher on a four point Likert-type scale and the median has to be at 3.25 or higher".

Simple statistical technique is suggested in decision criterion in Delphi processes for example, mean, median and mode.

Gordon (2003), Armstrong (2001) suggested median more than mean because it can pull out effect of outlier and Hill and Fowles, (1975); Eckman, (1983); Jacobs, (1996) strongly favored for median for likert-type scale.

Inter-quartile range (IQR), range between first and third quartile, is used to measure dispersion of median that is consist of 50% of the observation. (Sekaran, 2003 cited in Heiko, 2012). Vet et al.(2005) stated that IQR is less than 1 point of likert scale, mean that more than 50% of expert opinion fall within 1 point, it is determine consensus.

- **Benefits and limitations of Delphi technique**

Benefits of Delphi technique

1) This can gather expert opinion without meeting that can save time and expenditure.
2) Result can be reliable because it is iterated expert opinion.
3) It is simple process and efficient.
4) Expert can be free to express their opinion and know result of expert opinion in each round. Each expert can change or insist his/her opinion.

- **Limitations of Delphi technique**
    1) Selected expert may not specialist in study issue.
    2) Expert may not cooperate in research.
    3) Researcher may be un-careful or may bias in analyzing the data.

Delphi process is a research technique that use group expert in finding result in a study issue. That is without expert facing.

BIOGRAPHY

Mr. Paitoon Termsinvanich was born in Bangkok on 10 August 1972. In 1994, he obtained his Bachelor's Degree in Electrical Engineering (B.Eng) at Chulalongkorn University. In 2004, he earned Master's Degree in Business Administration with concentration on Management (MBA) at Kasetsart University. After graduated engineering, he has been working as a consultant in ISO9001 (Quality Management) and Energy management at Energenius Co.,ltd,. Currently, he has been studying PhD in Environment, Development and Sustainability (EDS) Program at Chulalongkorn University. His main research interest includes industrial management and waste management. In the last year of her studying, he public article topic " Conceptual model for effective implementation of Industrial Symbiosis : A case study Map-Ta-Phut Industrial estate".