Journal of Research in Environmental Science and Toxicology (ISSN: 2315-5698) Vol. 1(10) pp. 258-266, November 2012
Available online http://www.interesjournals.org/JREST

Full Length Research Paper

Industrial wastes management opportunities towards the Eco-Industrial Estate development of the Northern Region Industrial Estate of Thailand

[1]Verawat Panyathanakun, [1,2]Supawan Tantayanon, [1]Charit Tingsabadh and [*3]Kitikorn Charmondusit

[1]Technopreneurship and Innovation Management Programs (TIP),
Chulalongkorn University, Bangkok 10330, Thailand
[2]Green Chemistry Research Laboratory, Department of Chemistry, Faculty of Science,
Chulalongkorn University, Bangkok 10330, Thailand
[3]Eco-Industry Research and Training Center, Faculty of Environment and Resource Studies,
Mahidol University, Salaya, Nakhon Pathom 73170, Thailand

Accepted November 13, 2012

The industrial activities tremendously consumed resources to make firms' profit while consequentially generate wastes. The problem of resource shortages and solid waste management became a constraint for industry on sustainability goal in developing Asian countries such as Thailand. In order to reach the sustainability goal, industrial waste is one important key within the environmental category, which can increase the efficiency of resources by reusing, recycling and recovering. By deploying the concept of Industrial Ecology, which attempts to provide a profound shift from a linear model to a closed-loop model closely resembling the cyclical flows of ecosystems, the Northern Region Industrial Estate (NRIE) of Thailand is in the process of transforming to the Eco-Industrial Estate. Here, the industrial symbiosis or wastes and by-product exchange is theoretically possible. This paper attempted to analyze types of wastes, amount, and disposal methodologies currently deployed by the firms. In order to utilize the wastes, the possibility of industrial symbiosis activity is studied based on available data provided by the estate. Findings and recommendation for further study are discussed and proposed at the end of this paper.

Keywords: By-product exchange, eco-industry, eco-industrial estate development, industrial ecology, industrial wastes management, industrial symbiosis

INTRODUCTION

Although industries and technologies have brought forth economical wealth for many countries, a greater propensity for the destruction of natural resources and surrounding environments also existed. The idea of striking a balance between technology, natural resources and environment has become mandatory for the industries.

According to the industrial system, it will be perceived as the most effective if raw material is converted into products with zero effluent (Liwarska-Bizukojc et al., 2009). Admiration of the nature becomes an innovative idea to deal with the impact of environment on human life. The nature demonstrates efficient recycling of its resources and helps the application of industrial ecology (IE) gains more recognition among industries, institutions, and academics. The IE implication suggested that the traditional industrial system should behave in a similar manner as nature (Frosch and Gallopoulos, 1989).

However, the perfect type of the IE must be a closed-loop boundary similar to the nature system but in reality, it is very difficult to intentionally plan, design and manage. The different in economical, societal, cultural and ecological characteristics make a particular region unique from others. The ultimate objective of industrial ecology is the reduction of environment impact resulting from

---

*Corresponding Author E-mail: kitikorn.cha@mahidol.ac.th

manufacturing activities as well as increasing business efficiency and competitiveness (Cote an Hall, (1995). Therefore, creating a sustainable industrial ecosystem requires knowledge and understanding of its application. Additionally, the potential of connectedness and cooperation in wastes and by-products utilization within an industrial estate is significantly increased (Korhonen, 2007).

The eco-industrial estate development

Scheme and Concept

The Eco-industrial estate "…is a community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in order to manage environment and resources, energy, water and materials issues" (Lowe and Evans, 1995). As firms are working together, this community of businesses will seek a collective benefit that is greater than an individual company would have realized when individual optimized its interests (Cote and Cohen-Rosenthal, 1998). Therefore, the connecting of individuals in the industrial network is very critical. It could help reduce environmental deterioration by firms' synergetic activities to exchange their wastes and by-products (Gibbs and Deutz, 2005).

Researchers stated that the more differentiated enterprises in one location, the greater the chance of a sustained ecosystem (Liwarska-Bizukojc et al., 2009). Therefore, diversity of producers, consumers and decomposers result in the sustainable Eco-Industrial Estate (Tudor et al., 2007; Heeres et al., 2004). The concept of diversity was additionally proven from cases wherein at least one industrial decomposer or producer present in the eco-industrial system will enhance the proper industrial metabolism. The "Kalundborg model", in particular, demonstrated that networking and cooperation among firms within the estate were crucial for the success of the model.

Drivers and Barriers

There are two main sources of drivers to develop an Eco-Industrial Estate (Hemel and Cramer, 2002). The external drivers are comprised of customer demands, government regulation, and industrial initiatives. The innovation opportunities, increasing of product quality, and new market opportunities represented the internal influential factors. Fang, Cote, and Qin argued that the success of Eco-Industrial Estate development in China depended not only on the continuous support of government, but also the real mutual benefits of enterprises who participate in the Eco-Industrial development projects (Fang et al., 2007)

However, some key barriers have to be eliminated prior to achieve the expected performance. An organization and its members somehow do not perceive that environmental issues are under their responsibility. Even though they agreed in principle, unclear environmental benefits still remain. Meanwhile, they may lack knowledge and skills to find alternative solutions that best fit the organization in solving particular issues (Hemel and Cramer, 2002). Researchers indicated that the state's environmental laws and regulations were also very important to turn the Eco-Industrial Estate into reality (Heeres et al., 2004). Through these barriers are perceived, the management of organization is always overlooked. Further critique by a group of researchers suggested that inter-organizational networking and the level of collaboration reflected the success of industrial ecology and industrial symbiosis (Gibbs and Deutz, 2005). Networking will play a crucial role in the development. Effective networking will influence the efficiency of the organization itself and enhance the exchange activities within the network.

Learning from Cases of Eco-Industrial Estate Development

The concepts of eco-industrial estates and sustainable development were implemented worldwide. Depending on regional context and characteristics, the mandatory approaches vary from estate to estate. The eco-industrial parks, eco-town, and industrial cluster and zero emissions efforts are all types of eco-industrial concepts applied in Japan. Process and quality system improvements are presented as a core idea to achieve economic gain and growth. Japan encouraged firms to meet the international environmental standards such as ISO 14000 series as it could help industries better prepare their capability and readiness (Morikawa, 2000).

In some cases in Asia and Australia, the implementation of a synergetic and industrial clustering concept helps make eco-industrial estate development successful. Government support and direct involvement in the EIP project in these regions are crucial for success (Roberts, 2004). In China, another approach was employed as the government initiated and led the Circular Economy concept (CE) to establish closed-loop industrial activities that could help transform the unplanned industrial estate into eco-industrial estate (Fang et al., 2007). This finding, however, conflicted to what some researchers reported that the Eco-industrial parks in the United States of America (USA) achieved less success than the projects in the Netherlands because the US government could not develop trust among industrial sectors (Heeres, 2004). Countries in central Europe emphasized the symbiosis network or by-product exchange. By imitating the Kalundborg model, financial success was a crucial incentive in attracting and encouraging industrial sectors to participate in the exchange. However, some researchers, based on their experienced, from various cases, noticed that the industrial symbiosis or by-product exchange were not easy tasks. Key success factors and limitations in specific location will promptly be studied (Sakr et al., 2011). These implied that manner and approach to eco-industrial system development will depend on regional economic, environmental, political, and resource capabilities.

With pressure by customers and stakeholders, the global organizations and industries have to emphasize and focus on environmental sustainability. Minimizing wastes and lessening material and energy consumption are those corporate practices which aim to have no harmful impact on the environment and ecosystems (Hershauer, 2008). Sustainable development is an evolutionary step for society and industry which involves many activities related to ecology, economy, sociology and institutions. Material, waste and energy flow analysis are key processes in the eco-industrial system management (Wallner, 1999). Hence, ideas and data from the analysis are very crucial and always become original sources of many public policies and trade regulations (Schiller, 2009).

The technology and management approaches, when appropriately chosen, will help create value for firms and their customers (Rainbird, 2004). Under the eco-industrial perspective, there are many ways to add value. Some examples include encouraging clean product and technology, promoting the collaboration among various actors and formulating a new industrial cluster to enhance the members to gain higher value (Liangjian et al., 2008).

Business paradigms are continually adapted to enhance firm's competitiveness. The ecological and environmental activities are becoming new business opportunities. The green supply chain (GSC), for example, emerged by integrating environmental thinking into the supply chain management. Therefore, a firm's process, such as design, sourcing, manufacturing, delivery through end of life product and waste disposal will need to be re-thought in order to minimize and reduce the ecological impacts (Srivastava, 2007). To achieve the least negative impacts, a firm's activities are needed to change from end-of-pipe control practices to the precautionary activities. Industrial wastes and by-products generated from the industrial production process must be emphasized as disposal and wastes movement are becoming issues of concerns to everyone nowadays.

EIE Development in Thailand

The Industrial Estate Authority of Thailand (IEAT), established in year 1972, is a state enterprise under the Ministry of Industry. As a governmental mechanism, IEAT is responsible for the development and establishment of industrial estates throughout Thailand. Apart from those roles, the IEAT aims to support the private business sector by encouraging and providing instruction on effective management systems. The IEAT aims to achieve the eco-industrial settlements under basic core principles, which are sustainability of economics, society, environment and quality of life.

In 2000, the IEAT introduced the industrial ecology concept, which was designed to encourage firms to better utilize and obtain value from waste through the concepts of reuse, recycling, and waste minimization. Additionally, it launched the initiative project called the Eco-Industrial Estate Development (EIED), which was implemented during the 2001-2004 period. The Eastern-Seaboard Industrial Estate, the Northern Region Industrial Estate, Bang-poo Industrial Estate, Map Ta Phut Industrial Estate, and Amata-nakorn Industrial Estate were selected from established location as pioneers to implement the concept.

In 2004, the progress of the pioneer industrial estates was reported in the 2nd International Conference and Workshop for Eco-Industrial Development. Some degree of achievement in creating awareness, promoting collaboration and gaining financial benefit from projects was recorded. However, the lack of knowledge and experience of the participating companies in the industrial estates, as well as a lack of awareness among staff and public were indicated as improvement needs. Furthermore, the taxation system of the export zone seems to create high barriers of waste exchange among members. Technical support on cleaner technology was also requested by members. However, the EIED project was discontinued in 2004. Trust and mutual benefit among project stakeholders rarely existed, and this was the crucial cause that obstructed the continuation of the project.

In year 2009, Thailand industrial investment was severely impacted from the environmental problem in the Map Ta Phut industrial estates. Learning from the crisis, the Eco-Town project was proposed by the Ministry of Industry in early 2010. The sustainability development and EIED concept were re-launched and planned to run during the 2010-2014 period. Recently, a broader scope and approach to the eco-industrial system were announced to the public. The scope was expanded from EIE development to EIE and networking development (EINs) (IEAT, 2011). The project was initially launched in 2010 at three industrial estates as a pilot group of the 1st phase of development. They consisted of the Bang Poo Industrial estate, the Northern Region Industrial Estate, and the Eastern Seaboard Industrial Estate. Gradually increasing 3 EINs per year to reach a total of 15 estates by 2014 is the ultimate target. And, the 2nd phase is now under way to transform the rest

Table 1. The IEAT Business Model Initiatives' 5 categories and 22 areas

Categories	Objectives	Area
Physical	To achieve a proper landscaping plan and good infrastructure development	1. Eco-design 2. Eco-center
Economic	To achieve growth and sustained economy	3. Economy of industries 4. Growth of local 5. Economy of community 6. Marketing 7. Transportation and logistics
Environment	To encourage the efficient use of resources	8. Water management 9. Air pollution management 10. Industrial wastes 11. Energy 12. Noise 13. Health and Safety 14. Environmental monitoring 15. Industrial process 16. Eco-efficiency
Social	To encourage a better quality of life for people	17. Quality of life of worker 18. Quality of life of community
Management	To establish a systematic management process and continuous improvement	19. Collaboration 20. Improvement of quality of people 21. Improvement and maintenance of management system 22. Information and report

of the industrial estates in Thailand to completely achieve eco-industrial estate indicators by 2019. The set of business model initiatives in 5 categories and 22 areas by the IEAT were announced in a conference conducted in September 2010 and are described in Table 1 (IEAT, 2011).

Case of the Northern Region Industrial Estate of Thailand

In Thailand, there are currently 45 industrial estates in operation, covering 15 provinces. In total 11 estates are operated by IEAT and 34 of them are jointly operated with investors. Jointly operated between the IEAT and investors, the Northern Region Industrial Estate of Thailand (NRIE) is located in Lamphun province in the north of Thailand, on Lampang-Chiangmai highway. The total area of the estate is 706.92 acres and has been in operation since 1985. As of August 2011, there are 61 companies in total located in the NRIE. Electronics companies, Metal, Parts, and Tool and Machinery, Food and Agriculture, and Pharmaceutical companies comprise the majority, and account for 36%, 20%, 15%, and 7% respectively as indicated in Table 2 (IEAT, 2011).

Practically, industries in the Industrial Estate of Thailand have to request permission to transfer and dispose wastes and non-used materials. The permission is granted annually by Department of Industrial Work (DIW), Ministry of Industry of Thailand. In this study, the 3 years of data of industries' permission to transfer and dispose of wastes, authorized and approved by DIW, were retrieved and analyzed.

Industrial Wastes in the Northern Region Industrial Estate

This paper aims to analyze whether there is an opportunity to transform the NRIE to the eco-industrial estate. Industrial wastes are the focus. The data of waste amount in three consecutive years, 2008 to 2010, was investigated. The positive signal was observed as the downward trend of hazardous wastes ratio was significantly reduced from 99.14% in 2008 to 79.37% in 2010 (Table 3).

The electronics cluster, Metal, Part, and Tool and Machinery, and Furniture are top three clusters that generated the most hazardous wastes amount (98.65%, 98.98% and 98.94% in 2010, 2009, and 2008 respectively). The Electronics cluster alone generated over 70% of the total amount of hazardous wastes

Table 2. Type of industrial cluster in the NRIE

Cluster	No. of Members	Percent (%)
Electronics	22	36
Metal, Parts, and Tool and Machinery	12	20
Food and Agriculture	9	15
Pharmaceutical	4	7
Furniture	3	5
Jewelry	3	5
Textiles	2	3
Miscellaneous	6	10
Total	61	100

Table 3. Trend of Industrial Wastes in the NRIE

Waste Type (x1000kgs)	Y2010	Y2009	Y2008	3-yr Average
Hazardous	54,185.39	60,088.08	49,380.84	54,552.77
Non-Hazardous	14,079.80	653.90	425.30	5,053.00
Total Wastes	68,265.19	60,741.98	49,810.14	59,605.77
Hazardous Ratio	79.37 %	98.92 %	99.14 %	91.52 %

Table 4. Industrial Hazardous Wastes in the NRIE

Cluster	Industrial Hazardous Wastes (x1000 kgs.)				
	Y2010	Y2009	Y2008	Total	3-yr Avg
Electronics	41,282.89	42,487.08	34,281.94	118,051.91	39,350.64
Metal, Parts, and Tool and Machinery	6,758.50	10,966.00	8,242.40	25,832.90	8,655.63
Food and Agricultural	500.00	231.00	65.00	796.00	265.33
Pharmaceutical	-	-	-	-	-
Furniture	5,403.00	6,021.00	6,337.00	17,761.00	5,920.33
Jewellery	104.00	373.50	369.50	847.00	282.33
Textiles	127.00	-	84.00	211.00	70.33
Miscellaneous	10.00	9.50	5.00	24.50	8.17
Total	54,185.39	60,088.08	49,384.84	163,524.31	54,552.77

annually (Table 4). The record presented a non-significant different amount of non-hazardous wastes in 2009 and 2008 generally as illustrated in the Table 5. In 2010, the non-hazardous waste shot up tremendously in two clusters, Food and Agricultural, which contributed 10,033 tons, and Jewelry which contributed 3,252.20 tons (out of 14,079.80 tons in total). However, it was revealed that those increasing number came from factories which just started reporting the waste amount legally.

According to the regulation determined and standardized by the Ministry of Industry of Thailand, 19 major types of wastes and 37 disposal methodologies are classified. The majority of hazardous wastes generated by industries in the NRIE were (1) wastes from shaping and physical and mechanical surface treatment of metals and plastics (code12), (2) wastes from thermal processes (code 10), and (3) waste packaging, absorbents, wiping cloths, filter materials and protective clothing (code15) as illustrated in Table 6.

Regarding the methodologies to dispose wastes (Table 7), the sorting to sell and other recovery and recycle methods seem to be normal practices. However, using the production process wastes as co-material in cement kiln tremendously increased.

The 2010 data, which was 20 times higher than that of 2008, encouraged management of the NRIE and industries to pay more attention to such rapid growth amount. Moreover, the type of wastes and disposal

Table 5. Industrial Non-Hazardous Wastes in the NRIE

Cluster	Industrial Non-Hazardous Wastes (x1000 kgs.)				
	Y2010	**Y2009**	**Y2008**	**Total**	**3-yr Avg**
Electronics	36.00	43.70	37.00	116.70	38.90
Metal, Parts, and Tool and Machinery	506.50	100.30	1.20	608.00	202.67
Food and Agricultural	10,033.00	38.00	60.00	10,131.00	3,377.00
Pharmaceutical	11.00	5.00	-	16.00	5.33
Furniture	214.60	214.60	214.60	643.80	214.60
Jewellery	3,252.20	101.80	52.50	3,406.50	1,135.50
Textiles	15.50	150.50	51.00	217.00	72.33
Miscellaneous	11.00	-	9.00	20.00	6.67
Total	14,079.80	653.90	425.30	15,159.00	5,053.00

Table 6. Waste Type in the NRIE (unit x 1000Kgs)

Code	Waste Type	Y2010	Y2009	Y2008	Sum
1	Wastes resulting from exploration, mining, quarrying, Physical and chemical treatment of minerals	-	5	-	5
2	Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing	10,000	-	20	10,020
3	Wastes from wood processing and the production of panels and furniture, pulp, paper and cardboard	200	200	206	606
4	Wastes from the leather, fur and textile industries	25	29	34	88
5	Wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal	15	15	11	41
6	Wastes from inorganic chemical processes	106	116	41	262
7	Wastes from organic chemical processes	818	1,874	1,248	3,940
8	Wastes from the manufacture, formulation, supply and use (MFSU) of coating (paints, varnishes and vitreous enamels), adhesive, sealant and printing inks	189	431	289	909
9	Wastes from the photographic industry	-	-	-	-
10	Wastes from thermal processes	18,062	13,370	4,121	35,553
11	Wastes from chemical surface treatment and coating of metals and other materials; non-ferrous hydro-metallurgy	1,540	2,234	2,763	6,537
12	Wastes from shaping and physical and mechanical surface treatment of metals and plastics	16,487	17,366	16,162	50,015
13	Oil wastes and wastes of liquid fuels (except edible oils)	1,588	2,966	2,143	6,697
14	Waste organic solvents, refrigerants and propellants	1,831	1,325	1,061	4,216
15	Waste packaging; absorbents, wiping cloths, filer materials and protective clothing not otherwise specified	11,353	11,624	10,045	33,022
16	Wastes not otherwise specified in the list	2,131	3,672	2,370	8,174
17	Construction and demolition wastes (including excavated soil from contaminated sites	2,335	3,050	1,691	7,076
18	Wastes from human or animal health care and/ or related research	-	-	-	-
19	Wastes from waste management facilities, off-site waste water treatment plants and the preparation of water intended for human consumption and water for industrial use	1,586	2,466	7,605	11,657
Total		68,265	60,742	49,810	178,817

Table 7. Waste Management Method in the NRIE (unit x 1000 Kgs)

Code	Waste Management Method	2010	2009	2008	Sum
11	Sorting to sale	14,347	17,573	14,644	46,564
21	Storage	3	2	-	5

Table 7. Continue

31	Use as raw material substitution	-	-	200	200
33	Reuse container; to be refilled	-	-	1,000	1,000
39	Other reuse methods (specific)	-	-	20	20
41	Use as fuel substitution, burn for energy recovery	13,868	3,927	2,209	20,004
42	Fuel blending	10,245	11,297	12,405	33,947
43	Burn for energy recovery (specific)	5	230	2	237
44	Use as co-material in cement kiln or rotary kiln	8,383	4,123	433	12,939
49	Other recycle method (specific)	9,615	7,155	5,612	22,381
51	Solvent reclamation/ regeneration	1,785	1,134	1,044	3,963
52	Reclamation/ regeneration of metal and metal compounds	-	-	2	2
65	Physico-chemical treatment of wastewater	374	1,059	1,184	2,616
71	Sanitary landfill	1,703	3,064	2,009	6,776
72	Secure landfill	10	153	194	357
73	Secure landfill of stabilized and/ or solidified wastes	2,485	2,990	2,355	7,830
74	Burn for destruction	376	401	-	776
75	Burn for destruction in hazardous waste incinerator	362	312	72	746
76	Co-incineration in cement kiln	-	1,821	3,130	4,951
79	Other disposal methods (specific)	60	60	60	180
81	Collect and export	4,646	5,443	3,236	13,325
84	Animal feed	-	-	-	-
Total		68,265	60,742	49,810	178,817

methodologies were plotted in a matrix, which is shown in Table 8. The scatter pattern of various methods used to dispose a particular waste indicates non-homogeneity of wastes.

Looking at the top three wastes and disposal methodologies in Electronics, Metal, Parts, and Tool and Machinery, and Furniture cluster which contributed over 98% of the total wastes generated in the NRIE. Sorting to sale, Fuel blending, and specific recycle methods were indicated as the most popular practices that industries selected as approaches to manage the hazardous industrial wastes.

There are possibilities to make use of some industrial wastes demonstrated in many research papers. The Epoxy resin, for example, is the waste from the encapsulating processes of the Integrated Circuits (ICs) and semiconductor devices. It was classified as hazardous waste that required tight guidelines for control and disposal. In Thailand, it was required to be disposed by landfill and incineration in cement kilns at cement factories, while the result of studies revealed that it was possible to be used as filler for construction materials, PVC composites, paints, and adhesives. By pulverizing it into powder form, it is also able to be used as a decorating agent for an acrylic-resin-type construction material because it produced a marble-like appearance (Iji, 1998; Asakit 2007; Xu and Lu, 2010). This indicated that not only are advanced technologies crucial in mitigating and reducing waste, but also finding ways to utilize these wastes (rather than disposal) is mandatory.

Table 8. Mapping the Wastes Type and Disposal Method

Wastes Type

Wastes Management Method

Code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
11		x	x	x			x			x	x	x			x	x	x		x
21																x			
31																			x
33							x								x				
39		x																	
41							x	x		x	x	x	x	x	x	x			x
42					x		x	x		x	x	x	x	x	x	x	x		x
43							x	x				x				x			x
44							x	x		x		x	x		x	x			x
49			x				x	x		x	x	x	x		x	x	x		x
51							x	x						x		x			
52												x			x				
65						x					x	x				x			
71		x	x	x	x		x	x		x		x			x	x	x		x
72	x						x			x		x			x				x
73						x		x		x	x	x			x	x	x		
74										x						x			x
75							x	x		x		x		x	x	x			
76				x		x	x	x		x	x	x	x	x	x	x	x		x
79																	x		x
81											x	x			x	x	x		x
84																			

CONCLUSION

As the Northern Industrial Estate (NRIE) in Thailand is being pursued and transformed to the Eco-Industrial Estate, understanding the wastes amount and flows is mandatory. Wastes amount retrieved from 2008 to 2010 on three industrial clusters in the NRIE, which comprised of Electronics, Metal, Parts, and Tool and Machinery, and Furniture generated over 98% of total wastes.

The hazardous waste is in focus because it is the highest amount and it needs appropriate management as it may do harm to both human and environment. The idea of industry symbiosis or wastes and by-product exchange would be sustained if the industries' diversity was achieved (Liwarska-Bizukojc et al., 2009). The suitable mixture of producers, consumers, and decomposers within the estate could also result in the sustainable eco-industrial estate (Liwarska-Bizukojc et al., 2009; Tudor et al., 2007; Heeres, 2004).

However, prior to fully implementing the EIE at the estate or country level, more effort and effective collaboration from concerned parties is required. The estate's wastes profiles could be established by in-depth analysis of manufacturing process of individual firms. Moreover, appropriate disposal and management of hazardous wastes should be studied so as to provide recommendations to the firms.

Policy and regulation enforcement significantly impacts the process of environmental improvement (Walker et al., 2008). In this study, country laws and regulations with regards to the classification of type of hazardous and non-hazardous wastes must be reviewed and redefined in order to eliminate obstacles and impediments to utilizing the industries' wastes. Hence, these could enhance opportunities for the industrial symbiosis at the NRIE and other industrial estates in Thailand.

ACKNOWLEDGMENT

This research study was supported by the 90th Anniversary of Chulalongkorn University Fund (Rachadaphiseksomphot Endowment Fund). The authors would like to acknowledge the great support to the Technopreneurship and Innovation Management Programmes, Chulalongkorn University and Eco-Industry Research and Training Center, Mahidol University. The authors also thank to the NRIE staff for their support throughout the field study.

REFERENCES

Asakit K, Jyuhanang S, Pattavarakorn D (2007). Utilization of waste resin from electronic industry as reinforce material in PVC, Industrial and Research Projects for for undergraduate students meeting, Bangkok, Thailand.

Cote R, Cohen-Rosenthal E (1998). Designing eco-industrial parks: a synthesis of some experiences, J. Cleaner Product.,6:181-188.

Cote R, Hall J (1995). Industrial parks as ecosystems, Journal of Cleaner Production, 3:41-46.

Fang Y, Cote RP, Qin R (2007). Industrial Sustainability in China: Practice and prospects for eco-industrial development, J. Envir. Manag.,83:315-328.

Frosch RA, Gallopoulos NA (1989). Strategies for manufacturing, Scientific American, 261:144-152.

Gibbs D, Deutz P (2005). Implementing industrial ecology? Planning for eco-industrial parks in the USA, Geoforum, 36:452-464.

Heeres RR, Vermeulen WJV, de Walle FB (2004). Eco-industrial park initiatives in the USA and the Netherlands: first lesson, J. Cleaner Product., 12:985-995.

Hemel C, Cramer J (2002). Barriers and stimuli for eco-design in SMEs, J. Cleaner Product., 10:439-453.

Hershauer J (2008). Process guide for supply management environmental sustainability, Critical Issue Report, CAPS Research, October, 1-6.

Iji M (1998). Recycling of epoxy resin compounds for moulding electronic components, J. Mat. Sci., 33:45-53.

Industrial Estate Authority of Thailand (IEAT) Website (2011). http://www.ieat.go.th.

Korhonen J (2007). Environmental planning vs. systems analysis: Four prescriptive principles vs. four descriptive indicators, J. Envir. Manag., 82:51-59.

Liangjian W, Qiongfeng H, Hu W (2008). Industrial cluster upgradation of regenerated resources in Miluo City, China Population, Res. Envir., 18(2).

Liwarska-Bizukojc E, Bizukojc M, Marcinkowski A, Doniec A (2009). The conceptual model of an eco-industrial park based upon ecological relationships, J. Cleaner Product., 17:732-741.

Lowe EA, Evans LK (1995). Industrial ecology and industrial ecosystem, J. Cleaner Product., 3(1-2).

Morikawa M (2000). Eco-Industrial Development in Japan, Indigo Development Working Paper# 11, pp.1-11, RPP International, Indigo Development Center, Emeryville, CA.

Rainbird M (2004). Demand and Supply chains: the value catalyst, Int. J. Physical Distribut. Logistics Manag.,34(3/4):230-250.

Roberts BH (2004). The application of industrial ecology principles and planning guidelines for the development of eco-industrial parks: an Australian case study, J. Cleaner Product., 12:997-1010.

Sakr D, Baas L, El-Haggar S, Huisingh D (2011). Critical success and limiting factors for eco-industrial parks: global trends and Egyptian context, J. Cleaner Product., 19:1158-1169.

Schiller F (2009). Linking material and energy flow analyses and social theory, Ecological Economics, 68:1676-1686.

Srivastava SK (2007). Green supply-chain management: A state-of-the-art literature review. Int. J. Manag. Rev.,9(1):53-80,

Tudor T, Adam E, Bates M (2007). Drivers and limitations for the successful development and functioning of EIPs (eco-industrial parks): A literature review. Ecological Economics,61:199-207.

Walker H, Sisto LD, McBain D (2008). Drivers and barriers to environmental supply chain management practices: Lessons from the public and private sectors, J. Purchasing. Supply Manag., 14:69-85.

Wallner HP (1999). Towards sustainable development of industry: networking, complexity and eco-clusters, J. Cleaner Product., 7:49-58.

Xu WJ, Lu SY (2010). Recycling of waste cured epoxy molding compound as a filler in Poly (Vinyl Chloride) composites, International Conference on Chemistry and Chemical Engineering (ICCCE): 24-29.