Clean Technology for the Crude Palm Oil Industry in Thailand

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Preface

Palm oil industry has become one of the rapidly growing sectors in Thailand. Regarding such expansion, the levels of pollution generated from the industry have been escalating. Besides, the drawback mainly found is surface water pollution which is consequential of either insufficient or improper disposal of wastewater and solid wastes. The purposes of this thesis were, therefore, (i) to assess the potential contribution of clean(er) technology to improve the environmental performance of the crude palm oil industry in Thailand; (ii) to analyse implementation barriers for cleaner production in crude palm oil industry; and (iii) to provide recommendations for overcoming these barriers. In short, the aim was to generate ideas for moving the crude palm oil industry towards sustainability. This research had been implemented in the framework of the "Cleaner Agro-industries: Agro-Industrial Transformations towards Sustainability-Southeast and East Asia in Global Perspective (AGITS)" Project, an academic cooperation between Chulalongkorn University, Chiang Mai University, the University of Malaya, the University Malaysia Sarawak and Wageningen University, The Netherlands. In the framework of this project, generously funded by the INREF funds of Wageningen University, to which I am very grateful.

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Contents

Abbreviations

AFTA	Asian Free Trade Area
BET	Brunauer-Emmett-Teller
BOD	Biochemical Oxygen Demand
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CP	Cleaner Production
CPKO	Crude Palm Kernel Oil
CPO	Crude Palm Oil
CPOA	Crude Palm Oil Association
CT	Clean Technology
CTU	Clean Technology Unit
DEIE	Department of Environmental Impact Evaluation
DIP	Department of Industrial Promotion
DIW	Department of Industrial Work
DLA	Department of Local Administration
DOE	Department of Environment
DOH	Department of Health
EFB	Empty fruit Bunch
EGAT	Electricity Generation Authority of Thailand
EIA	Environmental Impact Assessment
EID	Eco-industrial Development
EMS	Environmental Management System
EMT	Ecological Modernization Theory
FFB	Fresh Fruit Bunch
GHGs	Green House Gasses
GDP	Gross Domestic Product
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit
HACCP	Hazard Analysis and Critical Control Point
IEAT	Industrial Estate Authority of Thailand
ISO	International Organization for Standardization
MDF	Medium Density Fiberboard
MITI	Ministry of International Trade and Industry
MNRE	Ministry of Matural Resource and Environment
MOAC	Ministry of Agricultural and Cooperatives
MOI	Ministry of Interior
MOInd	Ministry of Industry
MOPH	Ministry of Public Health
MOSTE	Ministry of Science Technology and Environment
MPIC	Ministry of Plantation Industries and Commodities
MPOA	Malaysian Palm Oil Association
MPOB	Malaysian Palm Oil Broad
MPOPC	Malaysian Palm Oil Promotion Council

NEB	National Environmental Board
NEQA	National Environmental Quality Acts
NGOs	Non-Government Organizations
NOx	Nitrogen oxide
OECD	Organization of Economic Cooperation and Development
OER	Oil Extraction Rate
ONEB	Office of the National Environmental Board
O& G	Oil and Grease
ONREPP	Office of the National Resources and Environment Policy and Planning
PCD	Pollution Control Department
PEO	Provincial Environmental Office
PIA	Provincial Industrial Office
POA	Provincial Administrative Organization
POMA	Palm Oil Miller’s Association
POME	Palm Oil Mill Effluent
PORIM	Palm Oil Research Institute of Malaysia
PORLA	Palm Oil Registration and Licensing Authority
PPHA	Provincial Public Health Office
RCA	Comparative Advantage Index
R&D	Research and Development
SMEs	Small and Medium Enterprises
RDB oil	Refined, Bleached and Deodorized oil
SS	Suspended Solids
TAO	Tambol Administration Organization
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
TS	Total Solids
UNEP	United Nations Environment Programme
USEPA	U.S. Environmental Protection Agency
WTO	World Trade Organization
WWTP	Wastewater Treatment Plant

Chapter 1
Introduction

1.1 Introduction to the palm oil industry

1.1.1 Historical development of the world palm oil

The oil palm has its origin in the tropical rain forest of West Africa, where it has been used as a source of oil and vitamins. It has been consumed for more than 5,000 years. Today the oil palm tree can be found in many tropical countries in Asia, Africa and Latin America (as shown in Figure 1.1). The important areas of oil palm cultivation in South East Asia is in the countries Malaysia, Indonesia, and Thailand, which produce about 80% of the world's palm oil (Gopal, 2001). Oil palm seeds of the Dura variety were introduced to Indonesia and Malaysia in 1848 and 1875 respectively. The first commercial oil palm plantation was established in Malaysia in 1917. The slump in rubber prices in the late 1920s encouraged the cultivation of the oil palm in Malaysia. At that time, Nigeria and Zaire were the world leading palm oil producers.

Figure 1.1 Map of the largest palm oil producing countries in the world (Zuur, 2004)

During 1960-1995, the palm oil industry in Malaysia showed a very rapid growth and it has been the world's leading exporter of palm oil since 1966. Malaysia has been the largest producer of palm oil since 1971, replacing Nigeria, which had been the major producer and exporter since the introduction of palm oil into the world market. Currently Malaysia produces more than 50% of the world's production, while Indonesia follows with almost 30%. Malaysia exports most of its production, unlike Indonesia, which consumes 60% of its annual products of palm oil. The world palm oil production during 1996-2000 is shown in Figure 1.2. On a global scale Thailand ranges fourth for the production of palm oil.

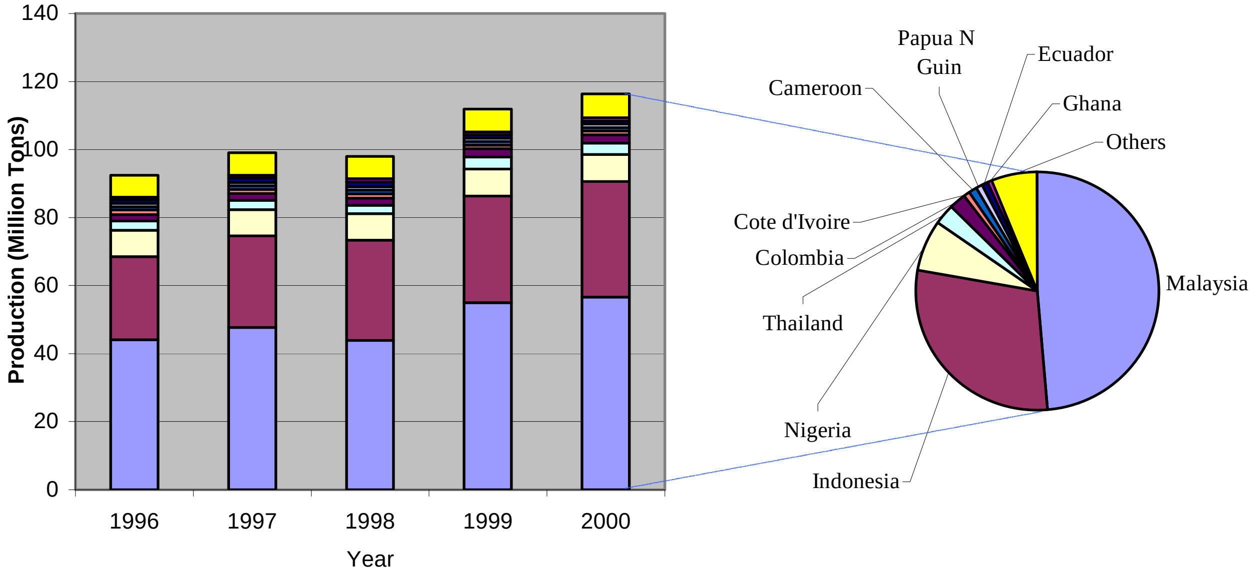


Figure 1.2 World palm oil productions 1996-2000 (Office of Agricultural Economy, 2002; MPOB, 2004)

Since 1982 palm oil has become the second most important vegetable oil in term of export, in the world's oil and fat complex, after soybean oil. In 2001 palm oil was the major traded oil, accounting for 40%, soybean oil came second with 22% of the global fat and oil trade. World consumption of palm oil increased from 1990 to 2000 with 7.7 million ton per year: from 11.41 million in 1991 to 21.8 million ton in 2000.

1.1.2 Palm oil products

Refined palm oil is used in both food and non-food applications. To most users, palm oil is familiar as refined golden yellow oil. In the refining process, palm oil can be divided in fractions at room temperature; liquid and higher- melting point substance. Various grades of oleins and stearins are available commercially. Palm oil is used in various food products, such as cooking oil, margarine, frying fats, shortenings, vanaspati, non-dairy creamer, etc. Palm oil is also used in non-food products. It can be substitute products derived from petrochemicals. Due to an increasing environmental awareness, these products have a bright future. Some examples of these non-food applications are given in Table 1.1.

Table 1.1 Non-food uses of palm oil products (Zuur , 2004)

Oleochemical	Application
Caprylic-capric acid mixture	Esters, surfactants
Caprylic acid (90%)	Plasticizers, lubricants
Caprylic acid (95%)	Chemical intermediates, etc.
Distilled palm kernel fatty acid	Surfactants, stabilizers, etc.
Lauric-myristic acid blend (70/30)	Surfactants, emulsifiers, stabilizers, textile
Lauric acid (90%)	Auxiliaries, esters, cosmetics
Double pressed stearic acid	Soaps, cosmetics, candles
Triple pressed stearic acid	Crayons, greases, monoglycerides, paper
Palmitic acid (70%)	Coating, buffing
Palmitic acid (90%)	Compounds, waxes
Stearic acid (65%)	Emulsifiers
Stearic acid – cosmetic grade	Surfactants, chemical intermediates, etc.
Stearic acid – rubber grade	Rubber, etc.
Oleic acid	Alcohols, alkanolamides
Methyl ester (C12-C18)	Detergents, metal, treatment
Fatty alcohol (C8-C18)	Detergents
Glycerine (99.5% purity)	Humectants, cosmetics
Glycerine (99.0%)	Esters, pharmaceuticals
Glycerine (99.5%)	Explosives, food, etc.
Soap noodles	Toilet soaps

1.1.3 Development of the palm oil industry in Thailand

Over the past decades, the Thai economy showed a sustained growth of more than 8% per annum. The reason was a substantial expansion in both domestic and export markets. Agricultural and natural resource extraction, rapid industrialization, rapid and concentrated urbanization, as well as increasing income and consumption characterize this economic growth path. Unfortunately, this bubble economy has plunged down in 1997 during the so-called Asian financial crisis. Since then the recovery of the Thai economy has been the prime goal of each government. In expecting a positive contribution to sustainable economic growth, the Thai government strongly promoted the development of the SMEs sectors late 1998. Being an agricultural country, the agro-industry was obviously one of the key sectors for boosting the SMEs. The palm oil industry has played an important role in the Thai economy because oil palm thrives well in Thailand**.** Apart from that, palm oil accounts for as much as 62% of the vegetable oil market, estimated to be worth 40,000 million Baht per annum (Research Department, Bangkok Bank Public Company Ltd., 2001). In 2004, consumption of palm oil in Thailand was roughly 570,000 ton per annum, rising by an average 11% annually. It is estimated that in 2006 the consumption will be up to 718,000 tons. Palm oil is a commodity that has the potential to expand well in the future (Research Department, Bangkok Bank Public Company Limited, 2001).

The palm oil industry refers to the whole complex of agricultural and industrial activities that are directly linked to the production of palm oil. The Thai palm oil industry has had a relatively late start in 1968, some 50 years behind Malaysia and 57 years after Indonesia. This industry began to actively expand when the government granted promotion to the private sector to set up palm oil extracting factories to process oil palm fruits, of which the output was rising rapidly. Moreover, promotion was given to produce palm oil to substitute for imports in 1974. Then, in 1977, the Board of investment granted investment promotion to the establishment of palm oil extracting and refinery industry.

During 1975-2000, the palm oil industry in Thailand showed rapid growth (Table 1.2). Since 1985 the area for oil palm cultivation in Thailand has more than doubled to 0.17 million hectares in 1995. Under the government's five-year plan (1996-2001) the area was doubled again to 0.29 million hectares in 2004 (Figure 1.3). In the southern part of Thailand particularly Krabi, Surat Thani, Chumphon, Trang and Satun are important provinces in palm growing. Fresh fruit bunches have to be harvested and transported to factories and have to be extracted within 24 hours. Otherwise the quality of extracted palm oil will deteriorate. Given this fact, the factories have to be located close to the palm growing areas. Crude palm oil (CPO) supplied by extracting factories has to be refined to obtain pure palm oil suitable for consumption or for use as raw material by the downstream industry. The palm oil, which has undergone the refining process, is called RBD oil (refined, bleached and deodorized oil). In 2002, there are altogether 25 crude palm oil mills and 11 refining factories in Thailand. Most refinery factories are set up in Bangkok and its environment, because the important market for palm oil is in the central region. At present (2003), the production capacity is 0.84 million tons of crude palm oil/year.

Table 1.2 Thailand: palm oil industry statistics (Office of Agricultural Economy, Ministry of Agriculture and Cooperatives, 2005)

Year	Harvested Area (x1000 ha)	FFB Yield (Tons/ha)	CPO Production (x1000 tons/ year)	CPO Yield (tons/ha)	Price of FFB (Baht/kg)	Price of CPO (Baht/kg)
1970	0.2	-	-	-	-	-
1975	5.6	-	-	-	-	-
1980	36.3	9.62	-	-	-	-
1985	82.2	11.43	205	1.88	-	-
1990	140.1	12.43	217	1.55	1.89	12.49
1995	168.1	15.34	403	2.39	2.05	15.87
2000	208.5	15.62	640	2.48	1.66	12.79
2001	216.0	17.90	1,000	3.57	1.19	10.70
2002	224.0	17.43	800	3.40	2.30	16.25
2003	279.2	17.56	844	3.46	2.35	17.83
2004	288.0	18.13	-	-	2.97	25.10

Note: FFB = fresh fruit bunch; CPO = crude palm oil

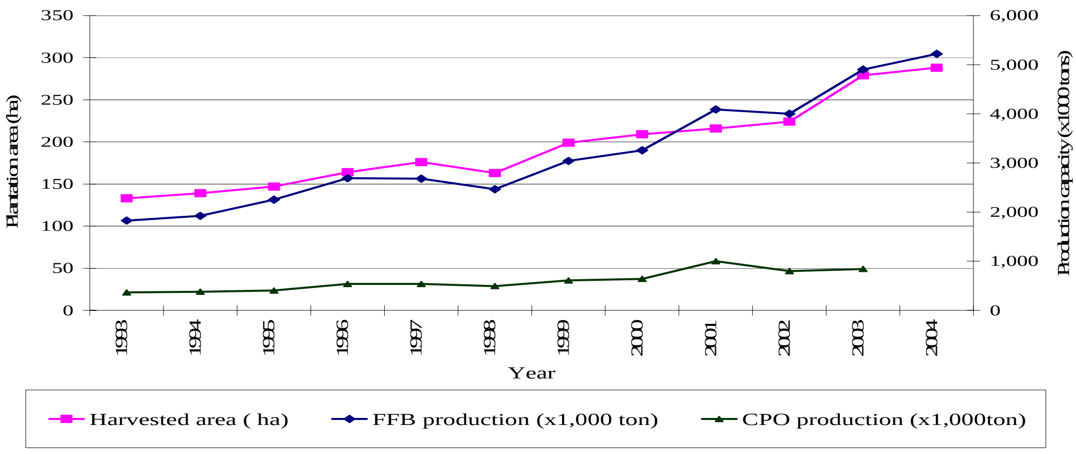


Figure 1.3 Plantation area and production capacity of crude palm oil in Thailand (Office of Agricultural Economy, Ministry of Agriculture and Cooperatives, 2005)

1.1.4 Thailand's trade of palm oil

Prior to 1982, the quantity of imported palm oil in Thailand depended on the price in the world market and the domestic costs in the palm oil industry. The expansion of import has increased rapidly from 5.4 million Baht in 1975 to 836 million Baht in 1980, due to the fact that the price of palm oil in world market was much lower than the domestic price. Most of the imported palm oil came from Malaysia in the form of RDB palm oil.

To protect the CPO industry in Thailand, the government imposed a high tariff wall and restricted import of palm oil products in 1982. After that import of palm oil has declined (shown in Table 1.3). In the last few years, the value of import increased again due to shortage of CPO in the dry season. Major types of palm oil imported are hydrogenated palm oil and CPO. Hydrogenated palm oil is used as raw material in many industrial processes.

Table 1.3 Quantity and value import and export palm oil in Thailand (Ministry of Agriculture and Cooperative, 2005)

Year	Export		Import	
	Quantity (x1000 tons)	Value (million Baht)	Quantity (x1000 tons)	Value (million Baht)
1975	-	-	-	5.4
1980	-	-	-	836.0
1985	-	-	-	97.0
1990	-	-	19.4	57.0
1995	13.8	224	20.5	340.0
2000	87.0	1,168	16.4	495.9
2001	222.0	2,376	23.9	724.1
2002	113.7	1,863	26.6	657.8
2003	176.6	3,282	40.7	1,045.0
2004	188.0	4,409	104.3	2,512.9

Since the production costs of palm oil in Thailand are higher than in for instance Malaysia and not competitive in the world market, palm oil export is low. The quantity and value of export of palm oil is about 5% of total Thai production. The value of export has increased to 3,282 million Baht in 2003. The major export markets are Malaysia, India and Burma. The major type of palm oil product is modified, hydrogenated palm oil. Within the Asian Free Trade Agreement palm oil is one of the 15 fast track industrial products, on which the tariff rates have to be reduced rapidly while control and protectionist measures have to be removed. However, the Thai authorities believe that Thai palm oil producers have still a considerable disadvantage compared to their Malaysian and Indonesian counterparts. Therefore, they have requested to remove this item from the fast tract list of commodities and enter it in the temporary exclusion list. This will allow Thailand more time for restructuring the industry. But after 2003, the tariff rates will be brought down from 20% to 0-5 percent in 5 years. When the Thai palm oil market has to open up to foreign competition, the palm oil industry will be strongly affected because the production costs of Thai crude palm oil are higher than Malaysia's (Figure 1.4).

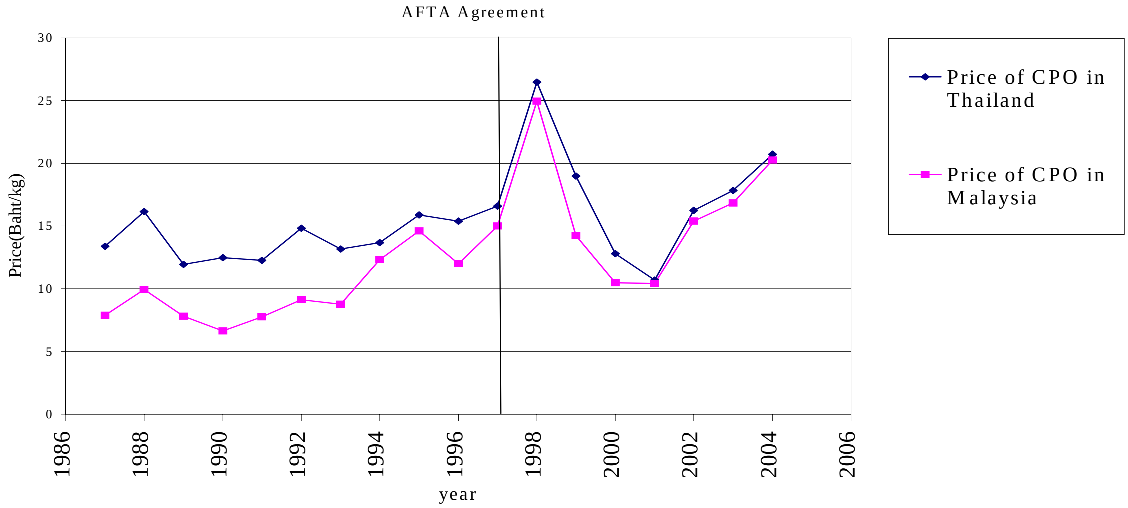


Figure 1.4 The price of crude palm oil in Thailand compared to Malaysia (Thailand Research Fund, 2004)

1.1.5 Comparison of production technology between Thailand and Malaysia

The advantage for the Malaysian palm oil sector is the suitable conditions for oil palm cultivation such as climate and soil conditions (Gopal, 2001). Moreover, Malaysia has intensive research and development to improve oil palm breeds (with a high oil content) and the management of plantation systems (Yusof, 2002). In 2002, the average yield is 18.3 ton of fresh fruit bunch (FFB)/hectare/year. In Thailand the average yield is 15.6 ton of FFB/hectare/year. The efficiency of FFB production and oil yield per hectare of Thai oil palm plantations are 15% and 28% lower than those in Malaysia, respectively. Due to the low amount of oil content in Thai FFB, crude palm oil production efficiency of Thai mills is 10 % lower than in Malaysia. Table 1.4 shows the comparison of crude palm oil production efficiency between Thailand and Malaysia.

Table 1.4 Comparison of CPO production efficiency between Thailand and Malaysia

	1 ha of mature palms (t/ha/year)	
	Thailand[1)]	**Malaysia[2)]**
No. of standard crude palm oil mill	25	352
Production capacity, million ton/year	0.8	17.4
FFB production, ton/ha/year	17.5	18.33
Oil yield, ton/ha/year	3.4	3.46
Oil content in oil palm fruit, %	17	23
Oil extraction, %	16.8	18.7

Note; 1) Office of Agricultural Economy, Ministry of Agriculture and Cooperative (2002)
2) Yusof, 2002

1.2 Environmental pollution of crude palm oil industry

There are 2 types of palm oil mills: dry processing mills and wet processing mills. Among the 50 crude palm oil mills, 25 factories are utilizing the standard wet production processes. The wet process differs from the dry process with respect to the oil extraction stage: the wet process applies large amounts of hot water and steam to convert palm fruits into a homogeneous oily mass before feeding into the continuous screw press to extract the palm oil (Kittikun, 1996). For the wet process, the extraction of palm oil from fresh fruit bunch involves 5 major operations - sterilisation, fruit separation, digestion, oil extraction and oil purification (Taiwo, *et al.*, 2000, see chapter 5). The entire crude palm oil process does not need any chemical as processing aid. Therefore, all substances found in the products, by-products, and residues originate from the fresh fruit bunch. However, there are a number of pollution problems at the production facilities, such as high water consumption, generation of high organic loaded wastewater, generation of large quantities of solid waste and air pollution.

The process to extract oil from fresh fruits needs large quantities of water and large amounts of wastewater are released. Crude palm oil mills require about one ton of water to process one ton of FFB, therefore they tend to be located close to a watercourse (Rock, 2001). In areas where the palm is grown and processed, palm oil mill effluents (POME) contribute significantly to surface water pollution. Besides that, POME contains acid and has a high organic load (Setiadi, *et al.*,1996). When discharged into watercourses the dissolved oxygen in the water will be depleted, affecting aquatic life and making the water unsuitable for consumption. It can be calculated that the waste generated from all Thai palm oil mills in 1996 is equivalent to the organic waste generated by 3 million people (Kittikhun, 1997).

Palm oil mills employ conventional biological treatment systems to treat their POME. The systems comprise of anaerobic and aerobic or facultative processes. 64 % of palm oil mills use anaerobic and facultative ponds in series. The alternative treatment options for POME are anaerobic and aerobic lagoons in series (29 %) or an anaerobic digestion tank and facultative ponds in series (7 %). It has been observed that nearly all mills in Thailand are unable to treat their wastewater to meet the effluent standard. This effluent BOD limit is achievable if the treatment systems are well designed and operated. Environmental impact problems from

POME usually occur in the rainy season, especially with mills located close to communities and/or with mills that do not own an oil palm plantation. The overflow from the wastewater treatment plant causes heavy water pollution to the waterways nearby. On top of that, the anaerobic ponds produce methane and carbon dioxide. These are released as gases into the air. Carbon dioxide and certainly methane are so called green house gases (GHGs), which effect global warming. Results from analysing the quantity of GHGs produced from anaerobic ponds showed that the amount of generated methane and carbon dioxide equals 9 and 3.7 m^3/ton FFB or 6.3 and 2.6 million m^3/year, respectively. Another problem for mills located nearby communities is bad smell from poorly managed effluent treatment systems. POME contains large amounts of grease and oil, which are not decomposed by anaerobic bacteria under the given circumstances. They accumulate and cover the surface of the pond and cause odour emission. Thus, it can be concluded that such wastes pose a serious threat to the environment and the quality of life in rural areas, unless proper pollution measures are taken.

Palm oil mills also produce significant quantities of by-products/solid waste, such as empty fruit bunch, fibres, shell, decanter cake and ash from the boiler. Only 23% of raw materials are products, the rests are waste/ by-products. Most of the by-products can be reused in the production process or in other industries. Fibres (14%) are used as fuel in boilers to generate steam and energy, required for the mill operation. Shell (6%) and empty fruit brunch (EFB) (24%) are sold for use in other industries. However, there is a lot of solid waste that has to be treated before disposal. These wastes include 0.03 million ton/ year of decanter sludge and 0.05 million ton/ year of ash. The problems of solid waste management in factories are improper storage and handling of solid waste material and improper land application techniques or practices for solids waste. These wastes consequently cause bad smell and dust that affect the surrounding communities.

Palm oil mills are generally self-sufficient in terms of energy due to the availability of adequate quantities of fibre and shell materials, which are used as solid fuel in the steam boiler. It is estimated that the maximum power potential in a Thai CPO mill is 323 GWh/year and the maximum power capacity is 59 MW. The problems associated with the burning of these solid fuels are the emissions of dark smoke and carbon dioxide. The smoke emission from biomass cogeneration is 1,277 ton particulate matter, 406,570 ton CO_2, 496 ton NO_X and 709 CO (Duval, 2001). To avoid problems with nearby communities and local authorities, mills employ a cyclone as air pollution control equipment for particulate removal. However, most mills are unable to treat their particulate matter to meet the emission standards.

1.3 Environmental protection development of Thai crude palm oil industry

1.3.1 End-of-pipe approach

The majority of legislation in Thailand follows a command and control approach. The current regime of (water) pollution control focuses on end-of-pipe approaches to control pollution. This approach has been successful in raising awareness on environmental issues among industrialists, but the government is facing difficulties in law enforcement and compliance

(White, 2001). To avoid problems with communities and local authorities, crude palm mills improve their environmental performance by improving their waste treatment system, for example by constructing more ponds to keep wastewater and by installing higher capacity boilers. Most POME treatment plants have been constructed to meet a BOD concentration limit. This effluent BOD limit is achievable if the treatment systems are well designed and operated. Nevertheless, it is observed that not all crude palm oil factories can treat their wastewater to meet the effluent standard at all time. In practice, medium-sized crude palm oil industries have difficulties dealing with their environmental problems (Gombult and Versteege, 1999).

1.3.2 Cleaner production approach

In general, the best way to reduce the impact of waste is to reduce the amount of waste that needs treatment or disposal. The crude palm oil mills can reduce environmental impacts through the implementation of pollution prevention measures, also known as cleaner production options. These measures can also result in decreasing costs of production (Jeswani, 2001). The cleaner technology concept is not new to the crude palm oil industry in Thailand. Since 1994, the Department of the Industrial Works has been actively promoting the cleaner technology concept. Experiments have been done in the Thai crude palm oil industry with assistance from international donor agencies and experts. These experiments have introduced and prepared environmental management guidelines for the crude palm oil industry, and have introduced cleaner technologies: reducing wastes, improving their utilization and improving their treatment (The Department of Industrial Works, 1999). Between 1999 and 2001, the promotion of cleaner production has been implemented in the crude palm oil industry through the support of government and international donor agencies. The result is an increasing number of mills that implement cleaner technology strategies and approaches. Although there are obvious environmental and often also economic benefits in implementing cleaner production strategies, cleaner production can and often does entail investments.

1.3.3 Development in environmentalism: Industrial ecosystem

End-of-pipe treatment is sometimes unavoidable and necessary to minimize environmental burden. Cleaner production aims to minimize waste streams at the source. Industrial ecology on its turn tries to find an appropriate reuse for the remaining waste streams. The idea of industrial ecology is to first understand how the industrial system/metabolism works and then to restructure it into a sustainable industrial ecosystem. Although cleaner production is already a more integrated approach than end-of-pipe solutions, it still is often restricted to only one process. In industrial ecology, an industry is considered in its relations with other industries and economic actors: an industrial ecosystem. During the last decade, environmental researchers have worked on a new academic discipline, industrial ecology, with the mission to design zero-emission industrial processes (Aryes and Simonis, 1994; Graedel and Allenby, 1995; Allenby, 1999). Industrial ecology is an attempt to model the industrial system after the natural ecosystem, with the goal to optimise resource consumption and minimize waste discharge to the environment. Industrial ecology ideas have hardly been used in the Thai palm oil industries.

1.4 Research objectives

The aim of this study is to assess the potential contribution of clean(er) technology to improve the environmental performance of the crude palm oil industry in Thailand, to analyse implementation barriers for cleaner production and to generate ideas for moving the crude palm oil industry to more sustainability. The specific objectives of this study are as follows:

- To evaluate the existing environmental performance of the crude palm oil production processes in Thailand.
- To assess the feasibility of clean technology options and waste exchange to improve the environmental performance of the crude palm oil industry in Thailand on the basis of cleaner production frameworks and industrial ecology theory.
- To develop a physical–technological model of an almost zero waste industrial ecosystem for the Thai crude palm oil industry.
- To identify and analyse the factors, actors, and barriers for the implementation of clean technology options and the waste exchange in crude palm oil factories.
- To generate ideas for improving the environmental performance of the Thai crude palm oil industry via a comparison with Malaysia’s technologies, regulatory framework and economic structure of palm oil production.

1.5 Structure of thesis

The thesis is divided into nine chapters. In Chapter 2, concepts of industrial environmental reform are presented. The development and aspects of correlating theories that are dealing with sustainability and that are applicable to industrial processes are described. Discussions focus on development of industrial waste management and technological innovation including end-of-pipe treatment, cleaner production, and industrial ecology concepts. It appears that all these theoretical approaches aim at environmental protection by reduction of resource consumption and minimization of waste emission. Integrating these approaches into a broader perspective could be a promising approach for pushing industrial systems toward more sustainable ones. Chapter 3 deals with a methodology and research method to analyse current palm oil industries, and design an integrated model of cleaner production for these industrial systems. A systematic methodology is elaborated in detail and case studies are selected for further analysis. Chapter 4 gives a review on environmental management of the industry in Thailand. Environmental institutions and environmental legislation dealing with the crude palm oil industry are discussed. Chapters 5 and 6 are dealing with case studies to apply the approaches for greening crude palm oil industry in Thailand. Five palm oil mills in Thailand were selected for more a detailed analyses of the dynamics of clean technology development and introduction. The differences in production processes and locations are taken as core selection criteria. A detailed analysis of waste generation and its environmental impacts is followed by an investigation of the possible technological solutions to improve the environmental performance of the mills. These solutions will contribute to make parts of the process more efficient or reduce the environmental burden. Chapter 5 is devoted to study in detail a specific palm oil factory that is situated close to a community and represents the best practice in clean technology options at present in Thailand. The other four case studies and a physical–technological model of an almost zero waste industrial ecosystem is presented and developed in Chapter 6. Chapter 7 executes a triad network analysis on the palm oil industry in Thailand to create a complete overview of the institutes and actors in environmental reform of the crude palm oil mills. The roles of the different actors in the economic, political and societal networks on the application of the physical-technological model of the palm oil mill are analysed. Then the barriers for the introduction of cleaner production are identified. Chapter 8 compares the environmental reforms of the crude palm oil industry of Thailand and Malaysia. The technological and institutional arrangements of the crude palm oil industry of Malaysia will be analysed, with a focus on the learning moments for Thailand. Chapter 9, the final chapter, comprises the conclusions and recommendations.

Chapter 2
Conceptualizing industrial environmental reform

2.1 Development of industrial waste management

Industry plays an important role in economic development and enhancing the economic welfare of the population. Despite obvious benefits of industrial development, it frequently causes damage to the environment and human health.

Prior to the 1950s, the prevailing response of industries to environmental pollution was to ignore the problem. Industrialization was still confined to a relatively small number of nations. In these countries industries dumped waste materials from manufacturing processes into the environment on a large-scale without any serious treatment. At that time the problems on a global scale were relatively small, although locally severe environmental deterioration and health problems were witnessed. Many industrialists were rather unaware of the consequences of their actions and the public had little knowledge of the impacts of industrial waste on the environment. No serious legislative or policy framework for the environment was in place in the industrialized countries, except national nature protection regulations.

The rapid growth in industrial production greatly increased the demand for natural resources and contributed to severe environmental degradation, which impacted the quality of life of significant parts of the population in the industrialized world. Several publications (such as Rachel Carson's *Silent Spring*, the MIT report *Limits to Growth* and the *Blueprint for Survival*) not only gave evidence of increasing academic and popular concern for the deteriorating quality of life, but also further triggered awareness among large categories of the population. Public campaigns, emerging new social movements and regulatory actions by national states put pressure on industries to start treating their waste and remove pollutants before discharging their non-products to the environment. The second half of the 1960s and the early 1970s formed a period of regulatory, technological and civil society innovations with respect to environmental pollution. This phase was formative for an approach that dominated industrial waste management for at least two decades, if not more. In the current industrial waste management approaches of most industrialized and industrializing countries the central elements of that period are still in place.

However, the ever expanding use of virgin natural resources for manufacturing and the proliferation of end-of-pipe treatment and disposal of generated waste started to be discussed and criticized against ideas of resource sustainability and preventive environment management. As a result, new ideas were being developed and put into practice in the 1980s. Figure 2.1 shows the development of industrial waste management practices in four phases. Different industries in different countries are in different stages or phases of this industrial waste management model. But the key challenge at the moment in most of the Southeast Asian industrializing economies is to move – in terms of Figure 2.1 – from b) towards c) and d). Figure 2.1d represents ideal future industrial practices that meet the goal of zero wastedischarge. All residues/by-products from production processes can be reused/recycled, both in the same firm/industry and in other sectors of the economy.

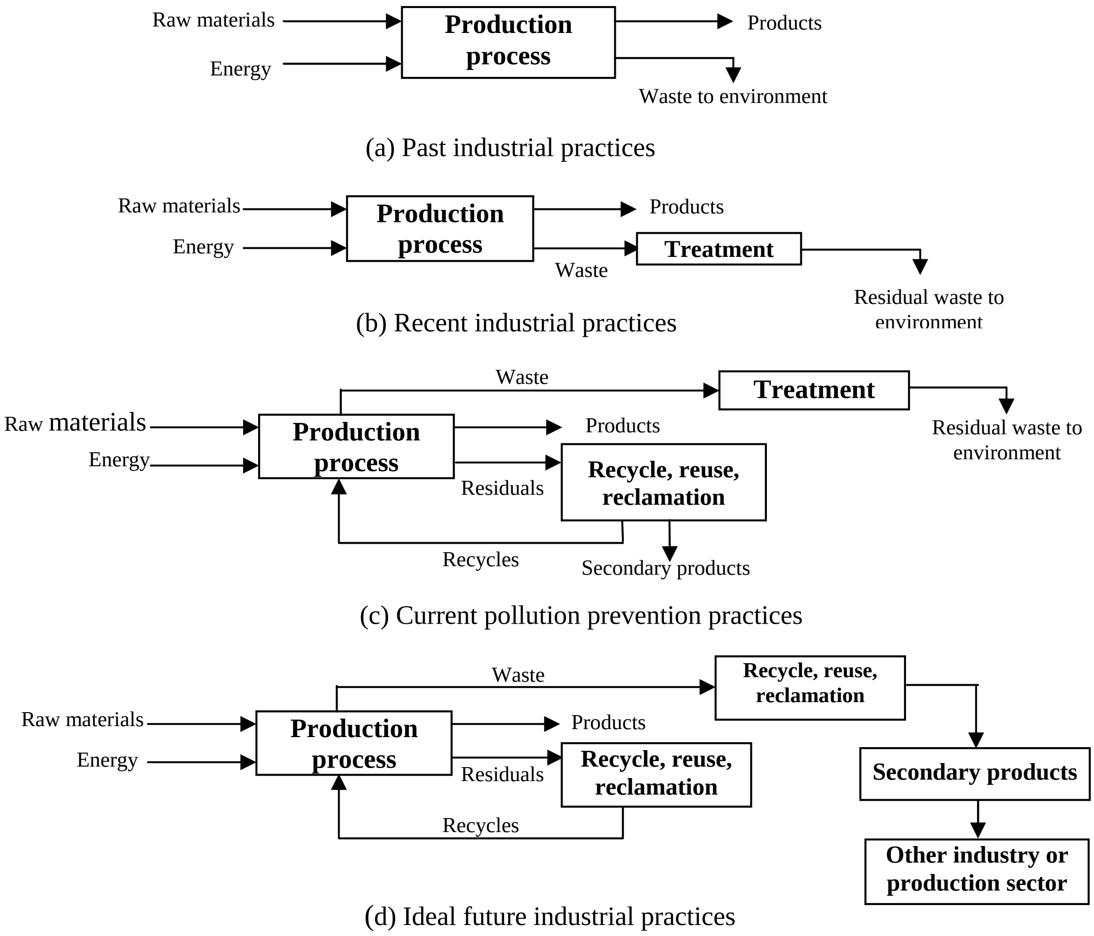


Figure 2.1 Development of industrial waste management practices (Adapted from Bishop, 2000)

Ecological modernization: from curative to preventive approaches

Before the idea of sustainable development became an integral part of every production system, environmental protection was carried out through end-of-pipe technologies (Visvanathan and Kumar, 1999; cf. Figure 2.1b). This end-of-pipe pollution control approach was traditionally connected to a command-and-control regulatory style, where the state established top-down environmental standards to regulate the discharge of pollutants. When emission and environmental quality standards became more stringent, the cost of end-of-pipe treatment became higher and started to affect the production costs of industries. Besides the high costs, end-of-pipe treatment did not really eliminate pollutants, but merely transferred them from one medium to another. The limitations of end-of-pipe treatment triggered environmental decision-makers and researchers to search for other alternative methods of pollution control. During the last decade, the responses came in various forms, with a common denominator in the movement towards preventive approaches rather than curative ones. Environmental experts began focusing on cleaner production, waste minimization. Even a new academic discipline, industrial ecology, was born with the mission to design zero-emission industrial processes (Aryes and Simonis, 1994; Graedel and Allenby, 1995; Allenby, 1999). These preventive approaches were found to be more cost-effective than add-on systems of treatment. Also, industrial wastes may still possess economic value (Tsai and Chou, 2004). Today, the relevance and importance of cleaner production issues has been well understood and documented by many case studies (UNEP/IEO, 1993; *Journal of Cleaner Production*; *Journal of Industrial Ecology*). Despite all the advantages in theory, the application of the cleaner production concept in small and medium sized industries has often not been substantial, especially in industrializing economies (Visvanathan and Kumar, 1999). A number of barriers exist that limit the widespread implementation of cleaner production in a company. These barriers can be classified into economic, technical, attitudinal, and organizational barriers (cf. Dieu, 2003; Phuong, 2002).

With the development of more preventive approaches in cleaning industrial production, state interventions also started to change. The pure command-and-control strategy started to shift to the inclusion of more cooperative or even voluntary approaches. In addition, the use of economic instruments and market dynamics in environmental regulation started to gain ground towards the end of the 1980s and throughout the 1990s. The diversification of policy instruments and the new policy strategies are tightly linked with a movement towards more preventive approaches, as the fine-regulation of productions processes and the formation of waste linkages between different productive firms could not be handled by the state via a top-down command-and-control approach. The active involvement of market actors and polluters themselves became an essential element in the movement towards more preventive approaches. This development is further theorized and elaborated in the theory of ecological modernization (Spaargaren and Mol, 1992; Weale, 1992; Mol, 1995; Murphy and Goldson, 1995; Spaargaren, 1997; Gibbs, 2000). Within the idea of ecological modernization the change from the conventional regime of environmental reform, characterized by curative end-of-pipe technologies, command-and-control regulation and a dominant state, towards a new regime is analysed. This new preventive regime sees different technologies, different regulatory approaches, and different actors. Table 2.1 summarizes the main transformations between the two regimes in four institutional categories.

It comes as no surprise that theoretical reflections and practical experiences of these transformations in industrial environmental reform have started in the industrialized countries. The core ideas of ecological modernization have been first coined against the background of developments in Europe (cf. Mol and Sonnenfeld, 2000). In the OECD countries the changes in regulatory styles and technological approaches to industrial environmental problems have been first experimented upon. With the industrialization process in South-east Asia and the global spreading of ideas, concepts and experiences in industrial environmental management, we can expect to see the emergence of these innovations also in Thailand.

In this chapter, the focus will be primarily on the technological dimension of this regime shift in industrial environmental reform. We will subsequently introduce and analyse the concepts of end-of-pipe treatment, cleaner production/technology and industrial ecology, to be used in the following chapters, to analyse actual and potential industrial environmental management strategies for the Thai palm oil production.

Table 2.1 Changes in technology, economy, state and civil society according to ecological modernization ideas

Institution	Indicator	Transformation
Technology	• Waste management	• End-of-pipe technology → Clean technology , industrial ecology
Economy	• Environment responsibility • Production • Product	• State → also market and economic agents. • Cleaner production • Green products • Certification of product and process. (EMS, ISO 14000)
Political institution	• Role of state agencies • Environmental policy approach	• Top down dirigism → Negotiated rulemaking. • Commander → Facilitator • Curative and reactive → Preventive • Exclusive → Participatory policymaking. • Centralized → Decentralized • Command and control → also economic and voluntary approach
Civil society	• Environmental NGOs' participation.	• Outside Commentators → Negotiator

2.2 End-of-pipe treatment

2.2.1 End-of-pipe mechanism

In the early environmental policies of the 1970s, policy-makers realized that pollutants had exceeded the assimilative capacity of the environment (Hwa, 2005). There were efforts to establish environmental standards to regulate the discharge of pollutants. A first environmental regulation was developed as a traditional command and control regulation (The Parliamentary Office of Science and Technology, 2004). The command and control regime is a regulatory approach mainly consisting of emission and ambient standards established by a governmental agency as national goals. Standards are set up to formulate the various targets that polluters must comply with (the command). Monitoring and enforcement is required to ensure compliance with these standards (the control). This approach for minimizing industry's environmental impacts originated in western countries and was adopted by many Asian nations during their industrialization phases.

Command and control is based on three categories of environmental standards to improve environmental quality: ambient standards, emission standards, and technology standards (Matsuoka, 2005). Ambient standards have to be set up firstly in accordance with the various targets to maintain a safe environmental quality. Then, emission standards are set to indicate the amount of emission allowed for each polluter in order to control the pollutant from each source. The emission standards (performance standards) set an overall standard for polluters, and give firms alternative methods to achieve the standards. The technology standards specify the technology and method that polluters must adopt to meet the standard (for example: seatbelts).

Through various instruments, such as licenses, command and control approaches have been successful in dealing with environmental problems initially (Huber, 1985). Command-and-control approaches have been adopted as the most common strategies to implement environmental policies, because they are simple and clear, and it is relatively easy to plan future achievements of a successful implemented environmental standard (Matsuoka, 2005). Command and control regulation has achieved some successes, especially in reducing air and water pollution. However, command and control regulations were often based on end-of-pipe solutions and did not support radical innovations. These regulations give the manufacturer little reason to pursue changes of the core production processes or product designs (Austin, 1999). Implementation and enforcement of command-and-control rules involved also high costs, and emissions from diffuse sources were difficult to control (e.g. agriculture) (The Parliamentary Office of Science and Technology, 2004). As a reaction to the shortcomings and failures of command-and-control regulation the use of economic instruments became more widespread (Austin, 1999). This policy aims to control pollution by harnessing the power of market incentives. It provides financial incentives for producers to reduce pollutant release to the environment. Table 2.2 presents the differences between command and control instruments and economic instruments.

Table 2.2 Comparison between command and control instrument and economic instrument

	Command and control instrument	Economic instrument
Pollution control measure	- End -of- pipe treatment	- More flexibility in dealing with emission reduction.
Regulatory agencies	- Government actors (local government)	- Government actors and other economic actors
Governmental agency involved	- Environmental department	- Ministry for Environment, R&D institutions and respective sectorial ministries
Cost for compliance	- Impose additional cost to firm	- Lower overall cost (cost-effective)
Cost for monitoring	- High	- Lower
Technology development	- Standards technology depending on the stringency of emission standards	- Triggering technical innovations and R&D efforts

2.2.2 The Concept of end-of-pipe treatment

In command and control, all the industries are expected to comply with stated emission standards. Failure to comply can result in fines, imprisonment or closure. This approach reflects a curative, end-of-pipe approach or waste treatment strategy to control pollution. The companies have to treat their waste to meet emission standards. This resulted in the installation of much end-of-pipe pollution control and waste clean-up technologies. Pollution control equipment has been to fit with chimneys and effluent pipes. A great number of treatment plants apply biological, physio-chemical or chemical processes to treat different kinds of industrial wastewater, solid wastes and air pollutants.

These approaches reduce the direct release of some pollutants to achieve regulatory compliance, but do not really solve the environmental problems. Many times they shift pollution from one environmental medium to another. Besides this, technology causes extra costs for investment and operation. However, this approach is still one of the most used pollution treatment methods to handle unavoidable wastes and emission of pollutants. The generation of waste in a production process is still unavoidable. In current pollution prevention practices, total elimination through source reduction or recycling is hardly ever the case. There always are some residues that cannot be prevented or reclaimed. The remaining pollution requiring treatment after source reduction and recycling has a greatly reduced volume, thus making treatment easier and much less expensive**.** After treatment, the remaining wastes are directly discharged to the environment at levels that the environment can support, or to a secure landfill. Aside from waste minimization/pollution prevention, industrial waste treatment technologies still need to be developed and regulatory emission standards are necessary where waste/pollution can not be totally eliminated through source reduction, process modification and production management (Tsai and Chou, 2004).

2.2.3 End-of-pipe treatment: Advantages and disadvantages

Advantages. The implementation of end-of-pipe treatment methods depends heavily on the pressure from environmental authorities to control industrial pollution of firms. In most countries an environmental policy of command and control approaches has been adopted to provide incentives for polluters to introduce and operate pollution treatment facilities. End-of-pipe abatement is still widely used as it has many advantages such as: low capital investment; application of standard technology; easy implementation due to its add-on character; easy to handle by regulatory control; profitable for environmental industry. Jackson (2000) stated that fast and less costly solutions make end-of-pipe treatment methods attractive for firms with strict budgets and limited funds. Most given advices from commercial consultants is based on the use of add-on technology. Besides these reasons, firms - especially SMEs - have limited knowledge and awareness of the various possibilities for symbiosis of ecological and economic aspects in business innovations. Consequently they mostly adopt end-of-pipe treatment systems to comply with the emission standards.

Disadvantages. Although end-of-pipe treatment control strategies have resulted in the reduction of negative environmental impacts from industrial production, they focus on the symptoms and not on the basic causes of environmental problems (Khan *et al*, 2001). The end-of-pipe strategy of pollution treatment has proven to be useful in reduction of pollutants, but it is not adequate for efficient use of limited resources. Jackson (1993) concluded on the problems associated with this approach:

- “end-of-pipe abatement in one medium risks transferring pollution from that medium to another, where it may either cause equally serious environmental problems or even end up as an indirect source of pollution to the same medium.

- Although not as expensive as remediation of environmental damages, end-of-pipe abatement contributes significantly to the costs of production products.
- End-of-pipe abatement of pollution requires regulation through control legislation, which is often costly and cumbersome, leading to a potentially inefficient regulatory structure and problems of non-compliance.
- End-of-pipe abatement technology represents a significant technological market with an associated economic inertia, which encourages the continued generation of waste and works against any attempt to reduce pollution at the source."

Industry is accustomed to comply with command and control regulatory standards on performances of industrial waste treatment, though these regulatory measures have been less effective in controlling the problems of gross pollution and deducting future liability. It is increasingly recognized that these approaches face many drawbacks such as economic inefficiency, environmental ineffectiveness, no incentive for innovation and even democratic illegitimacy (Eckersky, 1995). With all limitations, the end-of-pipe approach is arguably curative, has a low environmental performance and is more costly and less sustainable than more proactive and preventive environmental protection approaches (Dieu, 2003). Matsuoka (2005) argued that command and control can be efficient when it is applied with a significant degree of flexibility and decentralization. In that case regulatory authorities need to understand the precise situation of pollution and the polluters as well as to decentralize the implementation of the regulation.

2.3 Cleaner production

2.3.1 Concept of cleaner production

Cleaner production is the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency and reduce problems and product risks to human beings and the environment (UNEP, 2001a). Cleaner production can be applied to processes used in any industry, to products themselves, and to various services provided in society. Cleaner production is a preventive strategy to minimize the impact of production and products on the environment by applying clean technologies and organizational measures. It includes organizational changes, motivation and training for good housekeeping as well as changes in raw materials, process technology and internal recycling. Cleaner production also refers to a mentality of how goods and services are produced with minimal environmental impact under present technological and economic limitations. Cleaner production is a 'win-win' strategy. It protects the environment, the consumer and the worker, while improving industrial efficiency, profitability, and competitiveness (UNEP, 2001b). Cleaner production is an integrated approach in handling waste and pollutants in industries (UNEP/IEO, 1993). It is a broad term that encompasses what some countries/institutions call eco-efficiency, waste minimization, pollution prevention, or green productivity (UNEP, 2001a). The concept is especially important for developing countries with energy and natural resources scarcity, and where the pace of environmental degradation is continuously increasing (Hamed and Mahgary, 2004).

Cleaner production differs from end-of-pipe treatment in that it increases production efficiency, while it eliminates or minimizes wastes and emission at the sources. By introducing material and energy flow management into the companies instead of end-of-pipe measures, cleaner production aims to avoid the generation of wastes and emissions and uses materials and energy as efficiently as possible (Murphy and Gouldson, 2001). Table 2.3 shows the differentiation between pollution control (end-of-pipe treatment) and cleaner production. Tsai and Chou (2004) concluded that cleaner production and waste treatment operationally interact with each other to achieve an integrated waste management system. They must be coordinated both in practice and in regulation. It would be profitable from both an environmental and an economic point of view if they interact or work complementary.

Table 2.3 Comparison between pollution control and cleaner production

	Pollution control	Cleaner production
Timing	- React and treat approach	- Anticipate and prevent
Target of application	- Waste after generation from process	- Raw material, work practices and technology improvement, final product/by-product, production process and service
Outcome element	- Compliance with state emission standards and reduced impact on the environment and human health	- Continuous production efficiency improvement and reduced risks to human beings and the environment
Innovative	- Technology only	- Technology integrated management change
Production process	- Concerns emission from the process	- Concerns raw material and energy, eliminate toxic raw materials, reduce the quantity of emissions and waste before they leave the process
Product Quality	- Not involved	- Reducing negative impacts along the life cycle of a product, from raw materials to its ultimate disposal
Service	- Not involved	- Concerns designing and delivering services
Operating Cost	- Maintenance costs	- Return as saving cost
Employee involvement	- Only environmental section	- All employees from top manager to workers
Company’s management	- Not involved	- Changing attitudes, applying know-how and improve technology

In USA, the US congress passed the Pollution Prevention Act in 1990, which specifically required the evaluation of new opportunities and approaches to eliminate the generation of waste (USEPA, 1992). Following many other governments, it established a hierarchy for determining how pollution should be managed. It is clear that source reduction is specified as the top priority for determining how waste/pollution should be managed, followed by recycling/reuse, treatment and disposal. Source reduction includes: material substitution; process substitution or elimination; good housekeeping and equipment maintenance; and water and energy conservation. Recycling is divided into two different alternatives: in-process recycling (material reuse or recycling) and end-of-pipe recycling (reuse and recycling related to production processes within the factory or reuse as raw material by other factories). Cleaner production covers the first two hierarchies: source reduction and recycling. Cleaner production/clean technology and pollution prevention are not identical, as pollution prevention includes management and production changes within the production process and does not include end-of-pipe recycling. The latter is covered by cleaner production.

2.3.2 Cleaner production approach

Cleaner production is an operational approach to incorporate a preventive approach to environmental protection in systems of production and consumption (Jackson, 2000). It is now the basis for the industrial approach to waste avoidance. In production processes of a company, cleaner production can contribute to sustainable development, as endorsed by Agenda 21: strategies to “protect the environment are less pollution, use all resources in a more sustainable manner, recycle more of the wastes and products, and handle residual wastes in a more acceptable manner” (OECD, 1995). Cleaner production can reduce or eliminated the need to trade off environmental protection against economic growth, occupational safety against productivity, and consumer safety against competition in international markets. Stevenson (2004) states that the present concepts of cleaner production go beyond the basic concepts of waste minimization and pollution prevention, to address the total production process and its upstream and downstream consequences. This includes substitution of raw material inputs with less toxic material, efficient use of raw material, and life-cycle consequences of production. Eder and Fresner (2001) conclude that there are various types of cleaner production measures that are typically identified and/or implemented in industries, as shown in Figure 2.2. From this figure, the emission of pollution can be reduced or eliminated by reducing raw materials and energy consumption, reuse/recycling of waste/by-product in the production processes, and reduction of waste disposal by recycling/reclaiming waste/by-products for other economic sectors.

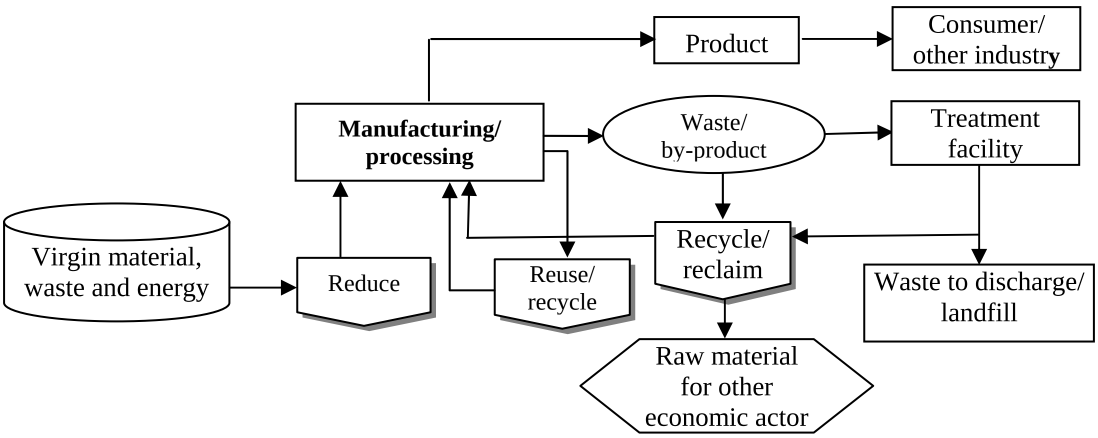


Figure 2.2 Hierarchy for cleaner production (adapted from Eder and Fresner, 2001)

According to UNEP (1994), cleaner production options can be divided into 5 types:

- Good housekeeping: Improvements of work practices and proper maintenance can reduce the use of materials and energy and produce benefit.

- Substitution of raw and auxiliary materials: Replacing hazardous materials with more environmentally benign materials to avoid environmental problems. These options may require changes in process equipment.
- Modifications of products: Changing product design can result in benefits throughout the life cycle of the product, including reduced consumption of raw material and energy, reduced use of hazardous substances, elimination of production steps with major environmental impacts.
- Process modifications: Minimize waste generation through improved operating efficiencies including internal reuse/recycling or introduction of waste into external recycling networks.
- New technology: Adopting new technologies can reduce resource consumption and reduce waste generation.

The cleaner production methodology usually follows a number of steps:

- Via an auditing process, a systematic balance of all the inputs and outputs of a company is conducted. Then waste and emissions are traced back to their respective source.
- The weak points and inefficiencies of material and energy use are identified and technological, behavioural, organizational options for both economic and ecological improvements are defined.
- Consequently, modifications of production processes and products lead to a situation with less waste and emissions.

It is by now a well-established fact that cleaner production cannot function in a vacuum, devoid of other supporting environmental tools. There are various tools and strategies that affect cleaner production implementation by industry. UNEP (2001) reports on new tools that relate to cleaner production such as: ISO14000 certification system; eco-labelling; cleaner production awards; economic incentives; financial and environmental accounting. To introduce cleaner production methods successfully, the small and medium sized companies often need support, for instance on technology and finances, from policy organisations and non-governmental organisations, R&D companies and environmental consultancies (Frijns and Vliet, 1999).

2.3.3 Barriers and constraints of cleaner production

In response to Agenda 21, several national and international institutions established programs to promote the use of environmentally sustainable technologies and the adoption of concepts and practices of CP in developing countries (Luken *et al*., 2004). As becomes clear from a review of the extensive literature, many clean technology options have been developed and are available in industry (Unapumnuk, 1999). Although there are obvious environmental and economic benefits in implementing clean technology strategies (e.g. optimum use of resources, reduced wastage and waste generation, reduced production- and waste management costs) the application of the clean technology in developing countries, and especially in SMEs, has not been substantial. Tsai and Chou (2004) analysed barriers for adopting pollution prevention in Taiwan and state that industrial pollution prevention and waste treatment interact with each other in achieving integrated waste management systems, and they must thus be coordinated both in practice and in regulation. Various authors have analysed barriers and constraints that persist and slow the progress towards CP implementation. (Visvanathan and Kumar, 1999; Frijns and Vliet, 1999; UNEP, 2001b, Hamed and Mahgary, 2004; Stevenson, 2004; Luken *et al*., 2004). These barriers fall mainly into four categories including technical, economic, attitudinal, legislative and organizational barriers (Table 2.4).

Table 2.4 Barriers for cleaner production implementation in industry

Barrier	Details	References
Technical barriers	• Lack of educated and skilled manpower • Lack technical know-how • Lack of access to CP technology • Weak national innovation system	Visvanathan and Kumar, 1999 Chiu & Peters, 1994 Hamed and Mahgary, 2004 Intarakumnerd *et al*., 2002
Legislative and organizational barriers	• Absence of incentive law and regulation to encourage the adoption of CP, such as market-based instruments. • Weak emission standards. • Ineffective enforcement and regulatory regime. • Weak monitoring and enforcement by state officers. • Lack of transparency and accountability in decision-making.	Stevenson, 2004. Hilson, 2000 Dieu, 2003 Stevenson, 2004 Wilderer., 2004
Economic barriers	• Lack of capital investment. • Lack of access to finance.	Visvanathan and Kumar, 1999 Hamed and Mahgary, 2004
Attitude barriers	• Negative attitudes to changing production processes or operations. • Lack of transparency in the industry. • Lack of environmental awareness.	Visvanathan and Kumar, 1999 Hamed and Mahgary, 2004 UNEP, 2001b

After a 5-year exposure to pollution prevention activities, the Federation of Thai Industries, through its Industrial Environment Management Program, summarized the constraints of cleaner production implementation in Thailand (UNEP, 2001b):

- “Lack of environmental awareness among Thai industrialists. The majority still perceives environmental protection as generating unnecessary costs, which they are not willing to bear.
- The small and medium sized industries lack the resources to start prevention programs and lack the initiative to seek external assistance. Moreover, financial obstacles are crucial.
- Many industrialists in Thailand lack effective management. They lack the basic knowledge of good (environmental) management and adequate evaluation tools such as environmental audits and impact assessments.
- Lack of information on pollution prevention techniques and methodologies amongst industrialist, and governmental agencies.
- Lack of a clear and consistent government policy on waste minimization.
- Lack of governmental mechanisms for pollution reduction and control”

Luken *et al*. (2004) reviewed seven programs promoting CP in developing countries by international organizations and concluded that: "[f]uture CP projects should consider how to involve more effectively the owners and production managers of the demonstration companies as advocates for CP. Also, more efforts should be made to involve governmental policy makers, academics and NGO's in helping to mainstream the CP concepts, approaches and technologies, so that more real progress can be made in helping each country to help itself on its journey toward becoming a sustainable society."

2.4 Industrial ecology

2.4.1 Concept of industrial ecology

Although cleaner production is already a more integrated approach than end-of-pipe solutions, it still is restricted to only one production process or one factory. In industrial ecology (IE), an industry or set of industries, with its relations to other industries and actors, is considered as an industrial ecosystem. The major advantage of industrial ecology is that it overcomes the shortcomings of end-of-pipe treatment and cleaner production, because it deals not only with individual firms. It strives to environmentally optimise material flow use from the perspective of a whole industrial (eco)system. Whereas cleaner production is process-oriented, industrial ecology is system-oriented and it covers both a long time frame and the whole array of manufacturing. Table 2.5 shows the differences between end-of-pipe treatment, cleaner production and industrial ecology approach.

Frosch and Gallopoulos (1989) first introduced a simple definition of an industrial ecology. This concept focuses on the relations among companies in a direct waste/by-product exchange. The idea of industrial ecology is based upon a straightforward analogy of a natural ecological system (Deanna, 1994; Hoffman *et al*., 2004). In nature, there is little or no waste. An ecological system operates through a web of connections in which organisms live and consume each other's products and wastes. In a similar way, every industrial activity can be interpreted as being linked to many other transactions and activities. A factory will have, and is linked to, many stakeholders or actors, such as raw material suppliers, customers, consumers, contractors, recyclers, etc. Roberts (2004) stated that the various actors in an industrial system can be interpreted in a way that is analogue to biological organisms. If production and consumption methods in human-controlled systems could be made to mimic the efficiencies of natural and biological systems, then greater sustainability would be ensured. It would show a way to address the growing amount of waste produced by industry and by a consumption-driven society. To this end, we need to identify new users and innovative techniques for using waste materials. This view provides the basis for thinking about ways to connect different waste generating activities from factories into a web, which can reduce the total amount of waste that is finally disposed (Deanna, 1994)
.

The industrial ecology concept certainly follows the principle hierarchy of environmental protection; i.e. first to reduce/avoid, followed by recycling and, if otherwise not possible, treatment and disposal of the waste in an environmental friendly manner. Its concept suggests several environmentally desirable changes in industrial production practices. These changes include improving the efficiency and productivity of industrial systems, minimizing waste by reducing raw materials consumption; reduction of the use of hazardous materials/substances by substitution with benign materials/substances; developing useful applications for waste products, and reusing manufactured products at the end of their first life (Graedel and Allenby, 1995; Erkman and Ramaswamy, 2001). Industrial ecology is used as a level beyond a company's internal cleaner production optimum, for instance by including product eco-design and extended product stewardship. The industrial ecology concept can be – and is - applied to all economic activities, including agriculture, mining, forestry, industrial production, and consumption. However, most of industrial ecology studies limit their application to manufacturing activities.

Table 2.5 The differences among end-of-pipe treatment, cleaner production and industrial ecology approach

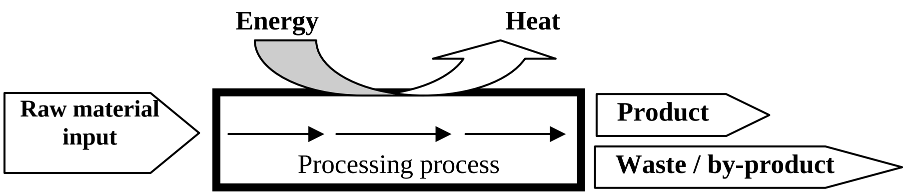
	End-of-pipe treatment	**Cleaner production**	**Industrial ecology**
Target of application	- Waste after generation from processes	- Raw material, work practices and technology improvement, final product/by-product, production process and service	- Close loop system (zero waste discharge)
Objective	- Reduction of pollutant emission to the environment	- Reduce resource consumption and waste generation	- Optimise industrial metabolism, reduce environmental impacts
Innovation	- Technology only	- Technology integrated with management	- Technology integrated with management
Production processes	- Concern on emissions from processes	- Concern on raw material and energy, eliminate toxic raw materials, reducing the quantity of emissions and waste before they leave the process	- Concern on utilization of waste/ by-product by other industries, Waste exchange
Application level	- Single company	- Single company	- Community of business
Co-operative approach	- Industries	- Industries and commercial	- Industries, commercial and residence

2.4.2 Industrial ecology approach

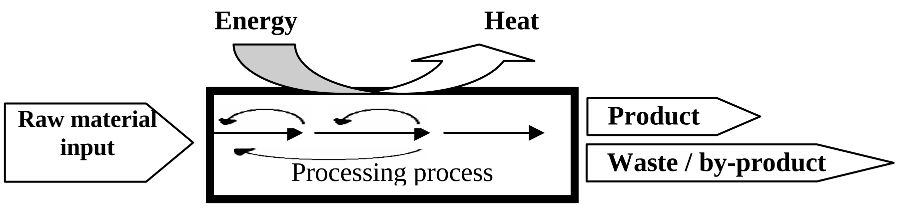
Industrial ecosystem

Industrial ecosystem is a conceptual model to apply industrial ecology to industrial development (Chiu and Yong, 2004). The system boundary of an industrial ecosystem is set up before analysis, and subsequently industrial ecology ideas and principles are applied to optimise the industrial system in terms of its environmental aspects.

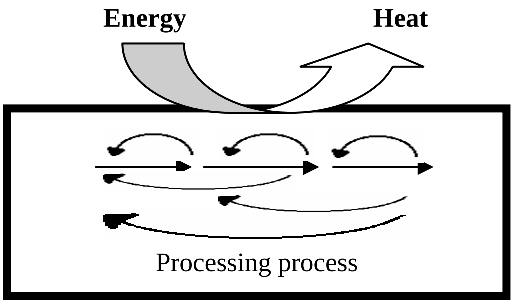
Three types or stages can be identified in the evolution of an industrial ecosystem. The Type I industrial ecosystem, is characterized by linear, one-way flows of materials and energy where the production, use and disposal of products occur without reuse, or recovery of energy or material (Figure 2.3). This type resembles an end-of-pipe approach as described earlier in this chapter. In the Type II industrial ecosystem, some internal reuse/recycling of waste/by-product or energy occurs, but there is still a need for virgin material input, and wastes continue to be generated and disposed outside the industrial/economic system. Type II can be referred to as the pollution prevention practices as described in the section of cleaner production, in which waste/by-product from production processes can be reused/recycled within each production step. It results in a reduction of resource consumption. Hypothetical the Type III industrial ecosystem would be characterized by complete internal cycling of materials. In the Type III industrial ecosystem model, material is highly conserved, no waste material is released, and little heat escapes. It reflects the goal of "zero discharge" adopted by several major companies (Allenby and Richards, 1994). A mix of Type I and Type II material flows can characterize current industrial ecosystems in Thailand (and in most other Asian industrializing economies).



(a) Type I industrial ecosystem



(b) Type II industrial ecosystem



(c) Type III industrial ecosystem

Industrial ecosystem boundary of firm/ cluster of firm

Figure 2.3 Type of industrial ecosystem (Adapted from Allenby and Richards,1994)

Material and energy flows in industrial ecology

Material and energy flows are two key aspects of industrial metabolism (Manahan, 1999) in industrial ecosystems. The material and energy flows in industrial production begin with virgin materials, which flow through cycles of the manufacturing processes, transportation/distribution, reuse/recycling, to end up finally as disposal (Erkman, 1997). Material flow analysis is an important tool to identify and quantify the material and energy input and output in industrial ecosystems. These data can be used to assess the impact of material and energy use and release to the environment, in order to subsequently design optimised options for improving the environmental performance of the industry/industrial system. According to Manahan (1999), based on an as complete knowledge as possible of a system of industrial metabolism, it is possible to optimise the industrial system for maximum efficient production, minimum waste and minimum environmental pollution by internalisation of the material cycle (closing). This means that the material cycle is closed as far as possible, in a way that materials need not to be shipped over long distance to be used. Local markets have to be developed for potential waste materials or such materials need to be locally upgraded to higher value products (Dillon, 1994; Dieu, 2003).

Boundaries of industrial ecosystems

To study the current state of an industrial ecosystem, we have to identify the system boundary and industrial metabolism to achieve the goals for the optimised use of materials and energy in an industrial ecosystem. Chao (1999) reported that four boundaries of industrial ecosystems can be distinguished:

- In-plant ecosystems, with in-plant reuse, recycling and waste minimization.
- Ex-plant ecosystems, with joint recycling of wastes among different plants in the same type of industry.
- Cross-industry ecosystems, with joint recycling of wastes among different industries, for instance in an eco-industrial park.
- Cross-border ecosystems, with joint recycling of wastes among industrial sectors and other sectors such as agricultural and mining.

Baas and Boons (2004) argued that there are three types of boundaries: the industrial sector, the product chain or network, and the regional industrial system. Roberts (2004) has yet another categorization by concluding that industrial ecology can be applied to eco-industrial development on three levels: micro-level (firms), meso-level (eco-industrial parks), and macro-level (regional and wider global networks of manufacturing activity centres. We will elaborate a little further on this last categorization, as it is most useful for our study.

Firm level. Applying industrial ecology at the factory level can achieve operational savings e.g. on energy and raw material demand, and reduce costs of waste disposal. It optimises all kinds of in-plant reuse, recycling and waste minimization options.

Eco-industrial parks. In principle, the eco-industrial park concept takes a systems approach, trying to optimise the industrial metabolism of a group of companies found in industrial estates, with the focus on decreasing their environmental impact. The major difference between eco-industrial parks and traditional industrial estates is the integration of an environmental (and sometimes social) agenda into the economic structure (Roberts, 2004). The concept of “eco-industrial parks” originated in the early 1990s and refers to areas where factories cooperate to make the most of resource use, namely through mutual recovery of the waste they generate or by reuse of waste generated by one firm as material in another (Erkman and Ramaswamy, 2001). Such firms in eco-industrial parks can reduce operational costs through sharing common suppliers and services and at the same time reduce the collection and disposal costs. Firms can reprocess waste material or sell it to firms in an eco-industrial park, who at their turn use these wastes as raw material or make use of recycled water or energy. In developing countries in Asia, the application of industrial ecology ideas is starting to become more common in industrial estates.

Regional level. The third model, the networked eco-industrial park system (NEIPS), emerges where industries seek opportunities for alliances and partnership to encourage the development of synergies through networks as well as spatial associations. NEIPS are not just a waste exchange system or market. They can be designed to encourage synergies between industries that deal in waste (Roberts, 2004). However, the results of completed and ongoing research projects in Germany's Rhine-Neckar region indicate that larger regional areas may be more suitable for closing material loops and creating sustainable industrial ecosystem than small areas (Steerr and Ott, 2004). For regional industrial systems, Baas and Boons (2004) conclude that they often consist of actors that are not automatically dependent on one another for their activities, in contrast with a product chain, where, i.e. suppliers and producers have a dependency relation. There is usually a (geographical) separation between the production system and the actors that consume the products. Consequently, it is more difficult to make a regional system sustainable compared to a product chain.

2.4.3 Industrial waste exchange

One industrial ecology opportunity for improved performance is industrial waste exchange, where collections of companies achieve material and energy efficiency through the reuse of by-products (Erkman and Ramaswamy, 2001; Malaviya, 2002). The waste exchange process connects waste generators with waste reusers and recyclers. The benefits of waste exchange include: reduced disposal costs, reduced demand of natural resources, reduced disposal quantities, and a potential increase in waste value (US EPA, 1994).

Although closing material loops by reusing and recycling wastes is a major part of industrial ecology, formal waste exchange services have been established to conserve resources and equipment. The first waste exchange service was established in Britain in 1942 (US EPA, 1994). Many North American and European nation-states and provinces have established formal waste exchange services and many of their outputs are quite promising. The numbers of waste exchange services appeared to be expanding rapidly during the last decade in North America. In 1999, there were more than 70 formal waste exchange services operating in major urban centres. However, the popularity is declining due to a lack of funding from governments, low levels of marketing by waste exchange facilitators, and already-established industrial networks that no longer require participation in a waste exchange centre or program.

There is also evidence of waste exchange applications in the industrial estates in Asia Pacific. Asian countries have been informally exchanging wastes for centuries. Three Southeast Asian countries, the Philippines, Taiwan and Indonesia, are currently operating formalized industrial waste exchange services. Most of these formalized initiatives were introduced by and partnered with international organizations, such as the United Nations Development Programme (UNDP) PRIME project in the Philippines. All these projects have comprehensive benefits, but there are still many barriers and difficulties. Chiu and Yong (2004) argue that unlike the usual way of applying industrial ecology as a technical tool, the Asian developing countries need to adopt industrial ecology as a strategic vision and a strategic approach to plan the economic, social and ecological development of their national economies. Only then can Asian developing economies avoid the same problems that occurred when the developed countries experienced industrialization.

2.4.4 Industrial ecology potential in Thailand

In Thailand, the concept of an eco-industrial park is new and is considered by the national government as a way of achieving more sustainable industrial development. It has embraced industrial ecology as a potential approach to economic development. The Industrial Estate Authority of Thailand (IEAT), technically supported by the German organization GTZ, applied the industrial ecology concept in some industrial estates, such as estates of the Estate Authority of Thailand at Map Tha Phut, Lampoon, Bang Poo, and Amata Nakorn. At firm level, the industrial ecology concept is misunderstood and treated with suspicion in Thailand. In general, a major question still is how the industrial ecology concept and waste exchanges can be successfully applied in Thailand, and under what conditions.

2.4.5. Strengths and weaknesses of the industrial ecology approach

Strengths. The idea of industrial ecology application is to improve total environmental quality, while satisfying the economic demands of industry, in a win-win situation (Roberts, 2004). Olderburg and Geiser (1997) argue that industrial ecology aims to optimise resource flows rather than just preventing pollution, and to promote sustainability rather than only reduce risk. The eco-industrial park concept promises to overcome a number of barriers of industrial pollution prevention, especially for problems relating to human factors. It has the potential to improve the sustainability of manufacturing by avoiding waste and converting by-products into reusable products or resources. It even appears to help stimulate economic growth, making the idea of industrial estates attractive for economic development (Erkman, 1997; Allenby, 1999).

Weakness. Several authors have reviewed the weaknesses of the current industrial ecology practices and analytical schemes. The planning of eco-industrial parks tends to be more specialized and needs higher levels of capital investment in infrastructure to support cleaner production and reduce environmental waste (Roberts, 2004). Bass (1998) states that the major weaknesses of this approach are: (1) it does not address issues of co-ordination (mechanism) within and between the separate (industrial) units and (2) almost ignores the institutional structures in which the organizations have to operate in an environmentally sound cooperation. Weaknesses of the preconditions of the industrial ecosystem in Asian developing countries are classified as (Chiu and Yong, 2004):

- Lack of complete understanding of eco-industrial development;
- Lack of funding and subsidies to promote industrial ecosystem education and information dissertation.
- Lack of a mindset to promote proactive utilization of industrial ecosystem as a strategic capability-building tool for national development.
- Lack of good governance, capability and transparency in the implementation of rules and regulations in many developing economics.

- Lack of proper technology and know-how.
- Insufficient management systems and practices.

Van Koppen and Mol (2001) conclude that, ‘if we want to bring industrial ecosystem perspectives from the design table more into practice, it seems essential to further develop an actor and socio-institutional perspective of these kind of industrial transformation’. Drawing more on social science perspectives on actors and institutions into industrial ecology analyses can fill this gap.

2.5 Conclusion

Environmentalism, through the years, developed from a protest movement to an institutionalised power. The first curative measures of end-of-pipe treatment are nowadays replaced by systematic methods of reducing the use of raw materials and generation of waste at the source. The idea of ecological modernization emphasizes environmental reform through new forms and styles of regulation, new partnerships of actors and agencies, innovative technological trajectories and the use of market dynamics. Here we have focused on two new models that are starting to replace the conventional idea of end-of-pipe diffusion via command-and-control regulation. By means of cleaner production it is aimed to minimize waste streams at the source. Industrial ecology on its turn tries to find an appropriate reuse for the streams and also wide partnerships that further induce non-state actors and institutions in environmental protection reform. These two approaches seem to be promising, also in handling environmental crises in Asian industrializing countries such as Thailand. To assess the value of the notions of cleaner production and industrial ecology for industrializing Asia, the improvement of the environmental performance of the crude palm oil industry in Thailand can function as a case study.

Chapter 3
Methodology and research methods

3.1 Introduction

This chapter aims at developing a methodology to analyse current palm oil industries. A design will be presented of an integrated model for cleaner production, especially focusing on clean technology, waste exchange and industrial ecology. Detailed case studies will be carried out on three different types of palm oil enterprises in Thailand. These studies include material balances, assessment of actual and potential technological options and actor network analyses.

The objective is: how to improve the environmental performance of the crude palm oil industry by identifying clean technologies, the theoretical and practical assessment of these technologies. Further it is necessary to analyse and access the possibilities and the potential for improving the environmental performance of the crude palm oil industry in Thailand, based on the combination and integration of existing clean technology and an industrial ecology approach. For this a case study is the most relevant methodology. Within the case study the issues are: to evaluate the environmental performance of existing production processes in Thailand, to identify cleaner technology options, to assess the feasibility of the cleaner production and waste exchange application in Thailand, to analyse the implementation barriers for Cleaner Production and to develop strategies to overcome these barriers. The research methods applied are: the study of relevant policy documents and statistics, a secondary analysis of existing studies on cleaner technology, impact assessments, and environmental performance in the crude palm oil industry, interviews with relevant key informants in the economic, policy and social networks surrounding the case study enterprises, and a review of best international experiences in crude palm oil processing, with a special focus on Malaysia. The methodology of this study can be divided into 4 main parts (Figure 3.1):

- Literature review. Secondary data collection and case study collection
- Cleaner production methodology
- Actor network analysis
- Generating ideas for improving the environmental reform of the crude palm oil industry in Thailand by learning from Malaysia's experiences.

3.2 Literature review and secondary data collection

The first step is to investigate the existing environmental performance of the crude palm oil production process in Thailand by gathering secondary data of relevant studies. The objective is to select representative case studies for analysing and designing a model of an industrial ecosystem of crude palm oil mill with minimizes waste. The selected case studies have to balance with the diversity of the industry regarding size, production design, and their environmental aspects. The details of this study step are showed in Figure 3.2.

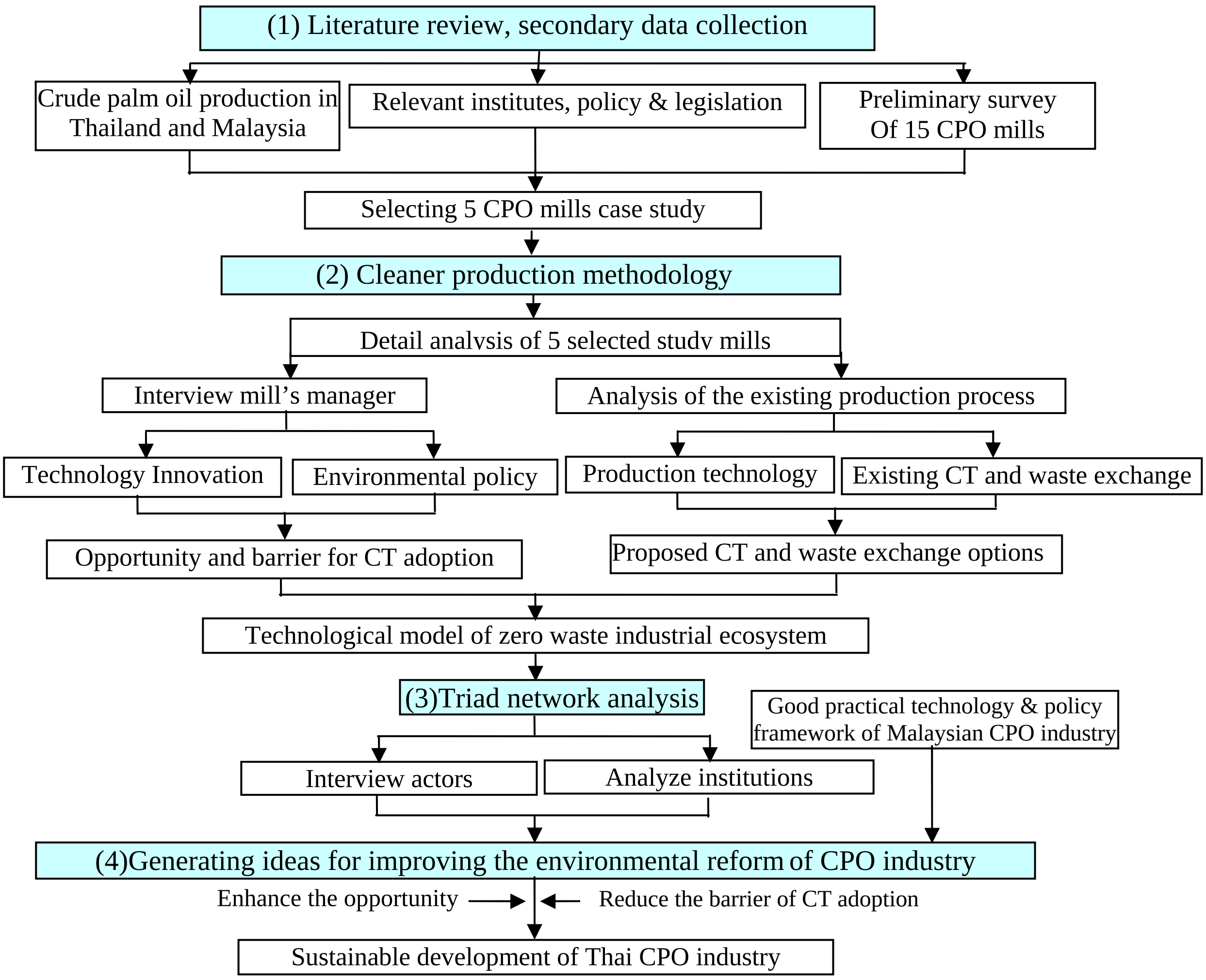


Figure 3.1 Methodology flowchart of this study

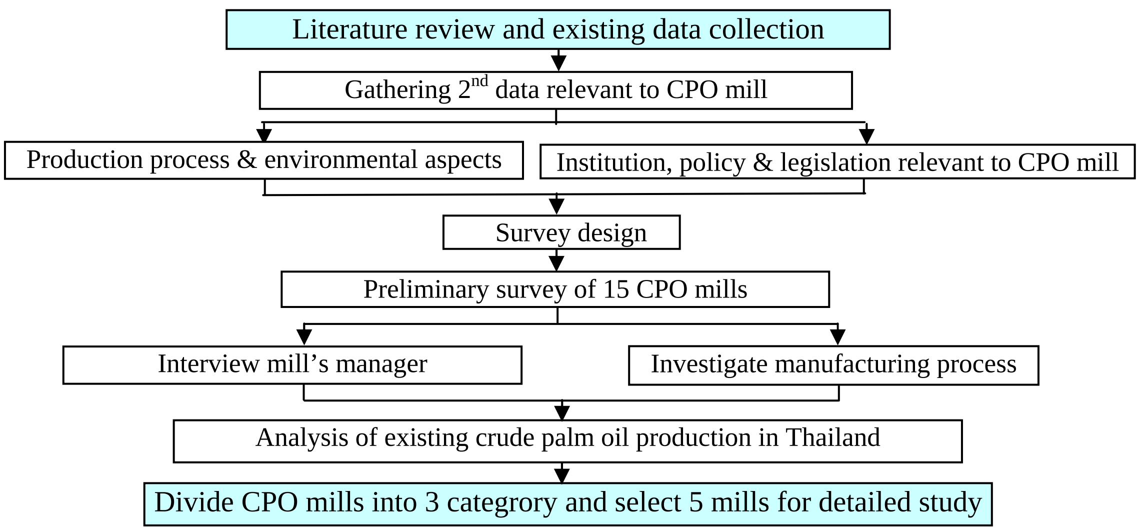


Figure 3.2 Literature review and existing data collection flowchart of this study

3.2.1 Literature review

The research begins with the collection of the secondary, existing data from literature on palm oil production processes and their environmental aspects, including clean technology and waste exchange applications, and the relevant institutions, policy and legislation from Thailand and Malaysia. In this step, an indicative inventory of the variations in size, investment costs, production capacity and location of crude palm oil industry has to be made to classify the mills into various categories. Subsequently the state-of-the art technology, clean technology options and environmental problems in each category of palm oil industry are identified.

3.2.2 Small survey

To evaluate the existing data on production process and environmental performance of the crude palm oil industry, a preliminary survey of the mills has been carried out. Out of 25, fifteen factories were included in a field survey and interviews. The field survey covers all provinces in which CPO factories are located in the southern region of Thailand. The fifteen factories were surveyed and actors interviewed during May 9, 2002 to June 29, 2002. The result of this survey is shown in Appendix B. Table 3.1 shows the variation of Thai crude palm oil factories. Detailed results of management interviews of the 15 factories are shown in Appendix B.

A questionnaire was used for collecting actual data. The reviewed secondary data were used to design an appropriate questionnaire. The questionnaire is divided into 5 parts: general information, production process data, waste generation and management data, environmental policy data and clean technology implementation data. The designed questionnaire is included as Appendix C.

The analysis of the existing data on production process, clean technology application and location of the factories are used to select representative factories for details on material and energy flow analysis.

Table 3.1 Crude palm oil factories in Thailand according to size

Size **(Investment cost, million Baht)**	**Big** (>200)	**Medium** (50-200)	**Small** (< 50)
- Investment cost, million Baht	260 - 859*	60 - 181	38 - 46
- No. of employee	136 - 385*	21 - 92	22 - 103
- Production capacity, ton CPO/ hr	55 - 60	25 - 60	20 - 25
- No. of mills in 2002	2	20	3
- No. of factory involved in preliminary survey	1	12	2
- No of selected case studies	-	5	-

Note: * = palm oil industry complex (a mill and a refinery)

3.2.3 Selecting case study

After the overall study of the palm oil processing industry in Thailand, five companies are selected for more detailed analyses on the dynamics of clean technology development and introduction. Besides more practical criteria (such as availability of data and access to companies) the differences in production processes and locations are taken as core selection criteria. Factories are classified into 3 groups depending on their production technologies:

1) Best practice in clean technology options: Improved processes, such as the use of a modified decanter (decanter and separator in series) for the oil recovery process.
2) Standard processes: such as a decanter as only means for oil recovery.
3) Standard process, for instance a separator as only means the in oil recovery process. This will represent the poor practices in the cleaner production approach.

For the location factors important considerations are the distance to communities and location within palm plantations. From the literature these factors proved to be relevant for cleaner technology and waste exchange practices. Other factors of relevance were not used initially for case selection. The result of the selected case studies is shown in Table 3.2.

Table 3.2 Factories representative for different technology and location

Oil recovery technology	Location	
	Close to community	Far from community
Modify decanter	Factory A	Factory B
Decanter	Factory C	Factory D
Separator	-	Factory E

3.3 Cleaner production methodology

The objective of this methodological step is to analyse and assess production processes and waste generation that cause environmental impacts to be able to redesign the production process and waste exchange. The goal is to minimize waste and impact to the environment. A systematic methodology to achieve better environmental performance of the crude palm oil industry consists of 6 steps (Figure 3.3):

Step 1 : Analysis of the existing production process.
Step 2 : Analysis of material and energy flow.
Step 3 : Selection of appropriate possibility for prevention and minimization of waste generation.
Step 4 : Identifying and designing potential clean technology options waste exchanges, including recycling and re-use option.
Step 5 : Analysis of appropriate waste treatment.
Step 6 : Develop a physical-technological model for an industrial system to move towards a zero waste industrial system.

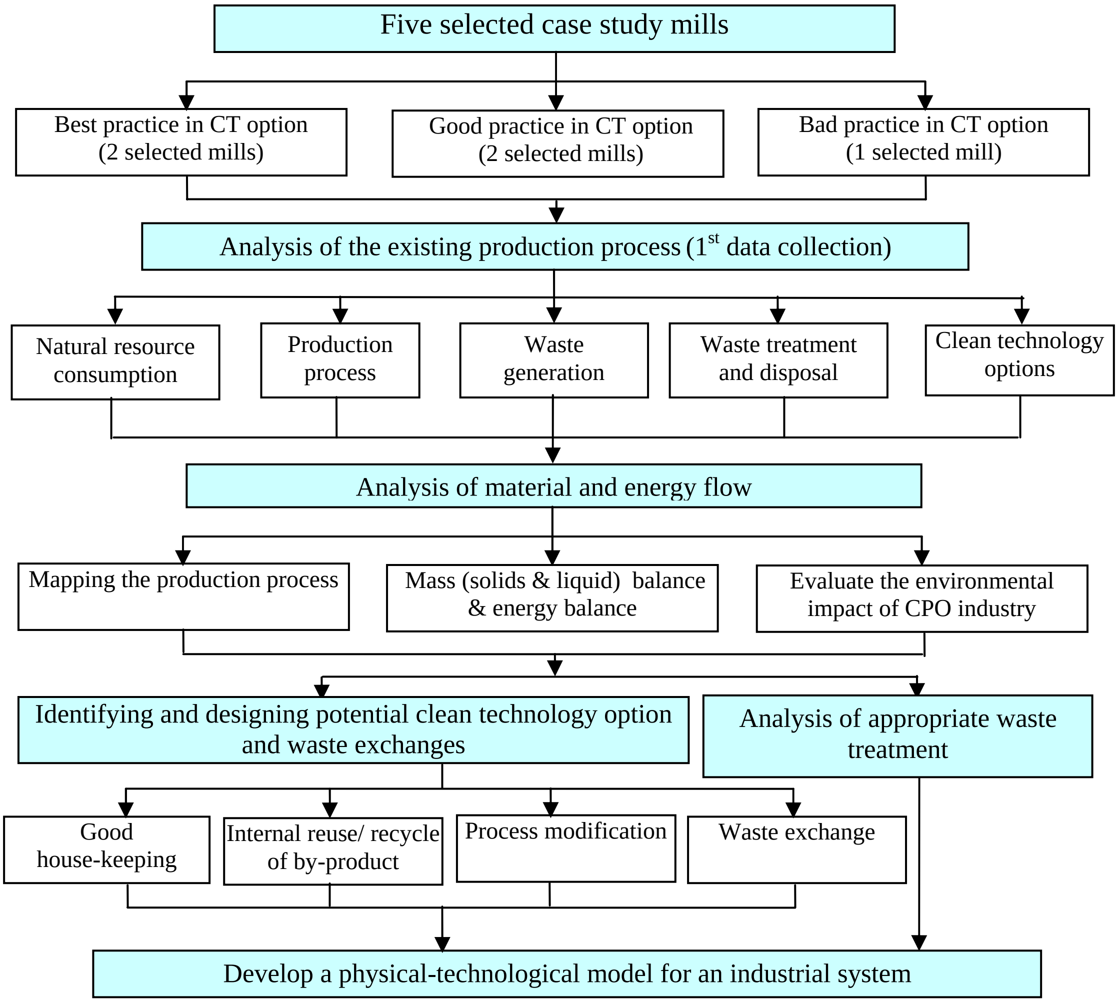


Figure 3.3 Flowchart of pollution prevention methodology

3.3.1 Analysis of the existing production process

The objective of this step is mapping the technological profile of the production process. This analysis usually starts at individual factories. In this study data on state-of -art technology and clean technology application, source of waste generation, environmental impacts and barriers for clean technology implementation were collected.

3.3.2 Analysis of material and energy flow

The second step is the analysis of material and energy flows that run through the industrial system. This assessment will start with an inventory of the process flow data to identify the flows of material and energy, sources of waste generation and quality and generation of waste from each production process. For each case study company the following steps are investigated:

- ***Investigating manufacturing processes of the selected factories***

Collecting general information about the factory and the way it deals with various waste streams (wastewater, solid waste, air pollution). Handling methods are compiled during the field visit through discussion and interviews with the industry's management.

- ***Mapping the production process and the organizational structure of the management***

The process description starts with drafting lists of unit operations. Identification of raw material inputs and waste generation from each processing step is mapped in an oil extraction process flow diagram. The organizational structure of the management is identified.

- ***Water use identification***

This section looks into various steps of water usage in the process, including required quality and quantity. Water requirement is either in the form of steam or hot water.

- ***Wastewater generation in each processing step***

This phase focuses on various sections of wastewater generation in quantity and quality. Data are collected from company recording systems and direct measurements. Wastewater is sampled from various sources in the production process and in the wastewater treatment plant.

- ***Energy consumption in production process***

Assessment of energy utilization and electricity consumption rate and quantity in the production process.

- ***Material and energy balance***

The purpose of making a material balance is to account for the consumption of raw materials during the process, and to identify and investigate the losses via waste emission from the process. From the process description, the varieties of waste generation rate, energy input, power and process steam requirements are compiled in a material balance.

- ***Evaluation of the environmental impact of CPO production***

The impact of crude palm oil industrial production on the environment is assessed, regarding both natural resources used and industrial pollution.

3.3.3 Identifying and designing potential clean technology options and waste exchanges

The third step focuses on the prevention of waste generation, minimization of waste and waste exchange. All data collected in the first and second step are used as guidelines and inspiration to select appropriate possibilities for minimization of environmental impacts from crude palm oil production. The details of this step consist of the following:

- ***Clean technology options***

This step concentrates on identifying, analysing and designing potential internal recovery, recycling and re-uses option.

Comparison of environmental performance of each category of CPO mills. Data from analysing natural resource use and pollution loading are used to determine the key indicators of production efficiency of the crude palm oil industry. Environmental performance indicators are identified and used to determine excessive consumption of resources and excessive waste generation by comparing the different case study companies, and comparing those with international literature.

Identification of clean technology options. Data on clean technology options adopted in each factory are collected and identified. Of these technologies the theoretical and practical assessments are made.

Evaluation of the optimal clean technology option. All previous data on environmental performance indicators and clean technologies available within industry will be used to assess the selected possibilities for prevention and minimization of waste generation within crude palm oil industry in Thailand.

- ***Waste exchange***

In this section, the current situation in the application of waste exchange options for reuse/recycling in other industries and in the agricultural sector are derived from literature. The optimal options are selected to satisfy the goal of a 'zero waste discharge plant'.

3.3.4 Analysis of appropriate waste treatment

The forth step is waste treatment. This entails the identification of remaining wastes that need to be treated before discharging into the environment. End-of-pipe treatment technologies are usually helpful for a complete removal of remaining contaminants. To be able to select appropriate waste treatment knowledge of the quantity and quality of the waste is important. The treatment technology should be selected based on emission standard requirements, final targets, available technologies and economic efficiency.

3.3.5 Development of a physical-technological model for an industrial ecosystem

The concept of an industrial ecosystem is based on the relations among companies in a direct waste/by-product exchange to reduce the total amount of waste. Combinations of the previous step are used to develop a physical-technological model for an industrial system of the crude palm oil industry. Technical options to approach an almost zero waste industrial ecosystem are selected based on the considerations of environmental protection, available technology and economic feasibility.

3.4 Actor network analysis: Analysis of the implementation barrier for cleaner production

The last step is the actor network analysis. Results from the above steps are used to form a systematic methodology that leads towards an almost zero waste industrial ecosystem in a crude palm oil mill. However, actual application of the physical-technological model might face severe difficulties and barriers, since the industrial system as a whole and the institutional environment might have conflicting interests. Industries are often confronted with a lack of coordination and are not isolated entities, but are related to- and embedded in complex social-economic conditions. No matter how innovative, original and closed the designed industrial system is in terms of its substance flows, this does not guarantee any success in terms of application and implementation of the whole model or even parts of it. To transform the developed model for an industrial ecosystem from the design table to reality, it is essential that the complex social, economic and political relations between the industrial system and actors and institutions outside are analysed in depth. Only by understanding the existing relations of the industrial systems with, among others, government agencies, other economic entities and social actors, it is possible to (i) identify the existing barriers that hamper the implementation and introduction of some or all of the alternatives of the physical-technological model, and (ii) to design the necessary transformations and changes in these social, political and economic relations and institutions to facilitate, support and enhance the possibilities of implementing some or all of the physical-technological options. In other words, an analytical tool is needed to provide the concepts and methodology to analyse existing interactions and relations between actors within and outside the industrial system, as well as the institutions that govern and structure these interactions and relations.

3.4.1 Triad network model

Mol (1995) developed a methodology to analyse the changing interactions within the institutional environment of an industrial sector in an era in which environmental consideration push for major industrial transformations. This so-called 'triad-network'-approach encompasses a study of the policy networks, economic networks and societal networks in which an industrial sector is embedded. The triad network approach is an instrument for studying the role of several stakeholders and institutions in bringing about environmental improvements of industrial firms via technological and organizational change. To understand the interactions between a company, the authorities and other stakeholders, the network model is used. From a company's point of view, there are three networks (Figure 3.4):

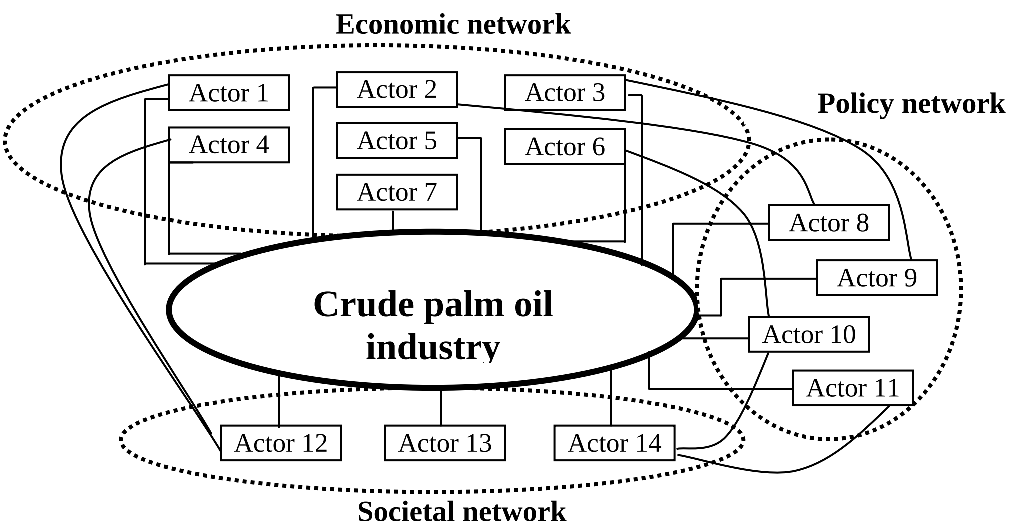


Figure 3.4 Triad networks relevant to crude palm oil factory

***Policy network**:* focuses on the relationship between government and industry from a political-administration point of view. Studying policy networks involve the main policy processes and dynamics, the (institutionalised) interaction patterns and power relations, the division of tasks among governmental agencies, the role of intermediary organizations, innovative private-public partnership constructions, etc.

***Economic network**:* This network consists of interacting organizations, which have economic goals and rationality as their principal motive for interactions. There is a vertical connection and integration between them: from raw materials to consumers. Horizontal relations and integration refer to competition from other firms and interaction via branch associations. Economic actors are businesses and their representative organizations, other competing firms, utility suppliers, equipment suppliers, credit organizations such as banks, consumers and customers, etc.

***Societal network**:* The societal networks deal with industry-civil society interactions. These can consist of NGOs, communities, research and training institutions, employees association, labour organizations, and also their connection**.**

The network model will be useful in analysing and understanding the institutions involvements and interactions between a company and its social environment. Such network analyses can be used to identify both the main mechanisms and dynamics in pushing environmental reform, as well as the implementation barriers that hinder cleaner production application in industry. Following such analyses a strategy can be developed to improve the introduction and implementation of options by taking away these barriers.

As well as investment in new technologies, companies can also improve their environmental performance through organizational change and the introduction of new managerial techniques. Organizational innovation can not only bring economic and environmental gains, but it can also have a positive impact on the environment into which technologies must be introduced, and thereby enhancing the potential for clean technologies to be integrated into existing system. Finally, companies can explore the potential for improving their environmental performance by integrating environmental concerns into their strategic as well as their operational management process.

3.4.2 Network analyses

This method is used for analysing the interactions among actors or stakeholders, who have an influence on the environmental performance and the introduction of technological and management options in palm oil companies. Examination of these interactions is carried out through in-depth interviews with semi-structured questionnaires. This analysis will identify the external and internal implementation barriers that exist between the company and its institutional environment. Table 3.3 illustrates various interviewed key informants.

This study also interviews the crude palm oil industry's management and enterprise's environmental manager in each of the selected companies, to assess the feasibility of implementing the various options, the network relations of the industry with social, economic and policy networks, the attitudes within the company on cleaner production options, the organization fitting of these options, and the various barriers that these options might meet. Then the internal implementation barriers of cleaner production can be identified.

Table 3.3 Number of interviewed relevant actors

Network	Key informants	Number of persons
Policy	Central level: DIW; PCD	2
	Provincial level: PIA;	1-2 / province
	Local Level: TAO; PAO	1/ sub-district
	Company level	1-2/ mill
Economic	Planters; recyclers;	1-3
	Refinery	2
	University; CPO association; Bank	1-2
Societal	Surrounding community	3-5 /mill
	NGOs	2 persons

3.4.3 Identify barriers to move the CPO industry to more sustainability

Through the triad network analysis, barriers for the adoption of cleaner production implementation and for approaching a zero waste industrial ecosystem of the crude palm oil industry in Thailand can be identified.

3.5 Learning from Malaysia

3.5.1 Overview of the palm oil industry in Malaysia

In this study, Malaysia is representative for having the best international experience in crude palm oil processing, with a special focus on research on and development of clean technology and waste exchange. Malaysia is the world's largest producer and exporter of palm oil products since 1989 (Yusof, 2002). This industry used to be the worst source of water pollution in the country. In the 1970s the Malaysian government had experience in overcoming the pollution generated by this industry by applying a regulatory package with a licensing- and pollution charge system. Moreover the government has set-up a specific governmental agency together with palm oil industry associations, which has enhanced the environmental performance of the industry. The technology and regulatory framework dealing with the crude palm oil industry in Malaysia is reviewed.

3.5.2 Comparison of the network between Thailand in Malaysia

The triad network model is also applied for analysing the interactions among actors or stakeholders, who have an influence on the environmental performance improvement of the Malaysian palm oil industries. The results from the actor network analyses of Thai CPO mills and an overview of the palm oil industry in Malaysia are used to identify the differences and similarities in the economic network, policy network and societal network.

3.5.3 Malaysian lessons for better environmental management

The last step consists of the development of ideas for improving the environmental reform of the crude palm oil industry in Thailand by comparing the Malaysian technologies, regulatory framework and institutional arrangements, with respect to ‘best environmental practices’ in the crude palm oil industry.

Chapter 4
Industrial environmental management organizations and regulations

4.1 Introduction

At present, most Thai industries are still resource-based, e.g. agro-processing, and mineral processing such as cement, power generation and natural gas production, instead of science-based. Thus economic growth and industrial development have been achieved at the expense of the environment and the country's natural resource base (Reutergardh and Yen, 1997). Hillebrand (1998) reported that there are three reasons for Thai industry to improve its environmental performance. First, the pollution load from manufacturing has reached unsustainable levels. Second, export-oriented companies which are not moving to cleaner production are likely to face enormous difficulties in surviving in export markets. Third, Thailand needs to meet its obligations under Agenda 21.

This chapter will present an overview of the Thai environmental policy framework that companies are embedded in. In section 4.2, the organizational structure and the role that different actors play in environmental policy and management are described. The subsequent section presents the development and actual state of Thailand's environmental law and policy, with an emphasis on the legislation concerning pollution control, cleaner production and industrial ecology. The governmental policy towords palm oil industry is addressed in section 4.4. Finally, in the last section the main conclusions on the existing environmental policy and management structure in Thailand are drawn.

4.2 Governmental environmental organization and actors

Until 1991, the National Public Administration Act was promulgated which provided three basic levels of public administration in Thailand: central, provincial, and local administration, (see Figure 4.1). Thailand is divided administratively into provinces, districts and sub districts. The provincial governors and district officers are the main authorities in the provincial administration and act as the representatives of the central government in the provinces. Administrative power is, however, centralized at the level of the national administration. The Department of Local Administration, under the Ministry of the Interior, is in charge of provincial as well as local administration. Other ministries and departments of the central government also have their branch offices in the provinces. The provincial administration has the authority and functions as local governments and is essentially an appointed agent of the central government, through the Ministry of the Interior. At present, there are 2 types of local administrative organizations in Thailand. The general type, which exits in every province, is composed of: 1) Provincial Administration Organization, which covers all areas in the province, 2) Municipalities, urban areas with a crowded population and high level of development; and 3) Tombol (sub district) Administration Organization whose jurisdiction is over the area of a particular sub district outside the boundaries of municipalities. The second special type of local administrative organization consists of two forms of local government: 1) Bangkok Metropolitan Administration; and 2) the City of Pattaya.

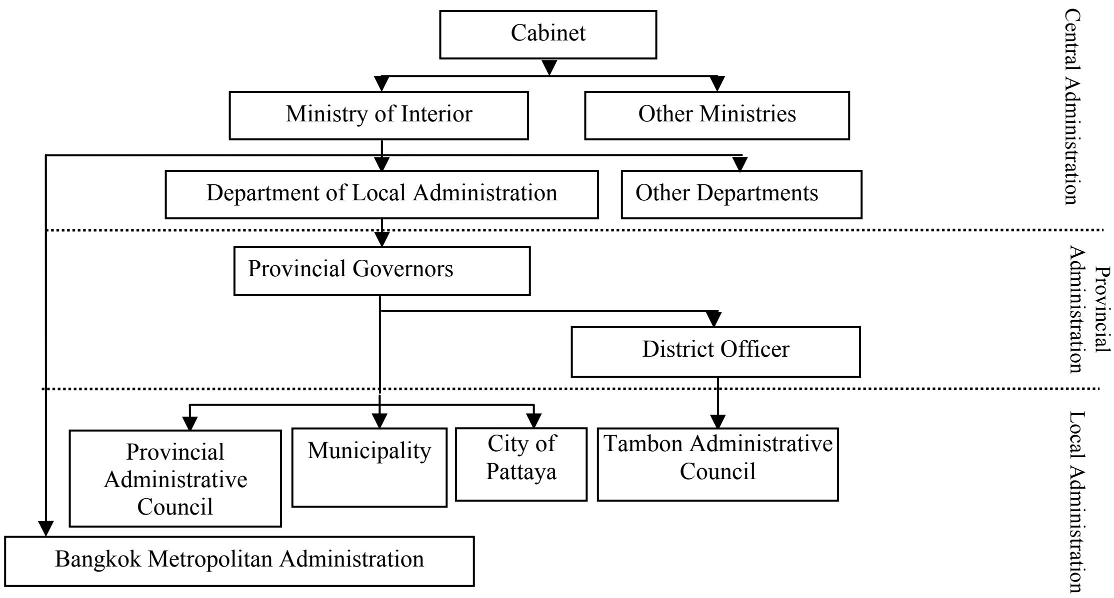


Figure 4.1 Thailand's administrative structure

The provincial administration is headed by provincial governors and district officers. The country is administratively divided into 75 provinces. A governor and his deputies head the administration of a province. Provinces are administratively divided into a number of districts, headed by district officers falling under the responsibility of the Provincial governor. A district is divided into sub districts (*Tambon)* which are headed by a sub district chief (*Kamnan)*. A sub district consists of several villages, headed by village heads. This form of administration comes under the concept of decentralization, which means that the central government delegates some of its power and authority to officers who work in provinces and districts. These officers are working for various ministries and departments and carry out their work according to laws and regulations assigned by the central government. At present, the provincial administration consists of 75 provinces (excluding Bangkok), 795 districts, 81 minor districts, 7,255 subdistricts and 70,865 villages (data of February 2001). Under the 1997 Constitution, decentralization of responsibility for environmental actions to the provincial governor was implemented and environmentally protected areas where sound environmental management actions are urgently required were identified.

The 1997 Constitution started decentralization of public service functions to local governments. The Constitution aims to facilitate public service delivery and ensures that they are responsive to the needs of the community. Local government in Thailand is organized in 6 different forms, equally distributed among urban and rural areas. Urban-based forms of local government include: The Bangkok Metropolitan Administration, the Municipality, and the City of Pattaya. Rural-based forms of local government include :

- The Provincial Administrative Organization (PAO) that constituting local government at a provincial level ;

- The Tambon Administrative Organization (TAO) constituting local government at a subdistrict level; and ;
- The Sukhapiban or Sanitary Committee, a local government in a rural centre, often referred to as a sanitary district.

Local Administration in Thailand is based upon the concept of decentralization, which allows local people to participate in local affairs under specified laws and regulations. People can elect their own leaders to run their own local government. Each PAO and TAO draws up its own development plan that details the problems and proposes solutions for its locality. The provincial administration superimposes the authority and functions of local governments and local government is essentially an appointed agent of the central government, through the Ministry of the Interior.

Environmental policy and management with respect to industry in Thailand can be divided into 4 main levels: (1) national level, (2) provincial level, (3) local level and (4) company level. The general organization chart of industrial environmental management in Thailand (in 2003) is visualized in Figure 4.2.

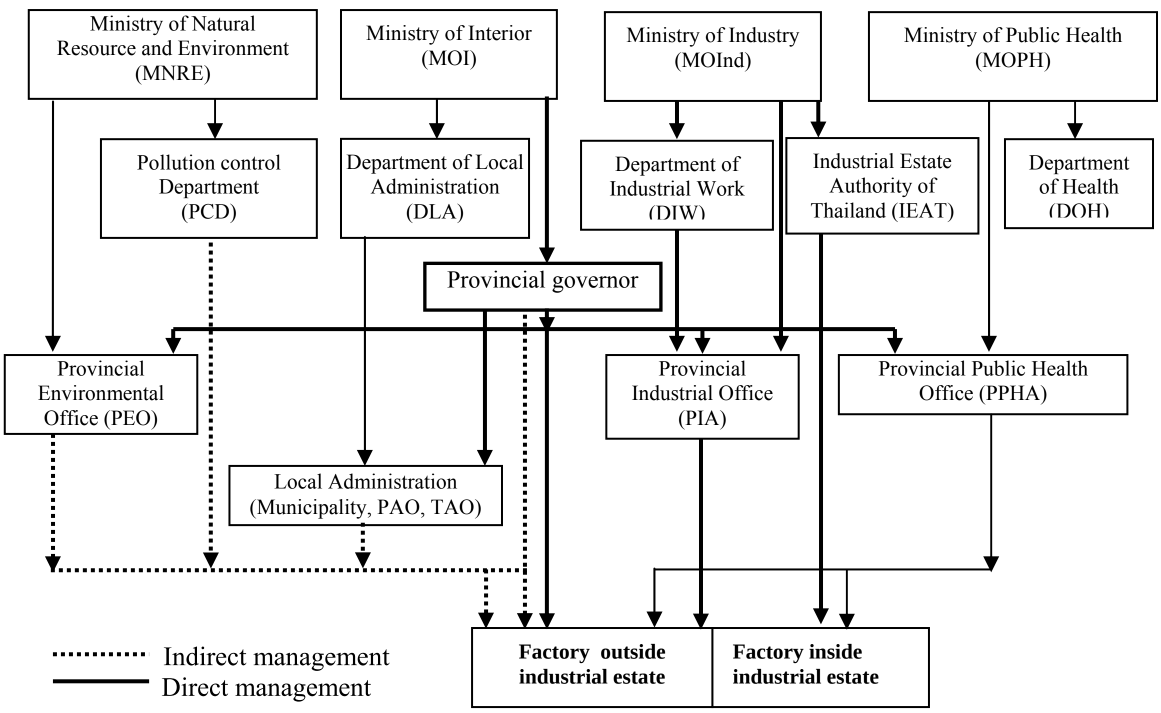


Figure 4.2 General organization flowchart of environmental management of industry in Thailand

The different tasks on industrial environmental policy and management are fragmented over various governmental organizations. The Ministry of Industry (MOInd) is the main agency for environmental policy towards industry. It is directly responsible for the formulation and operation of environment policies towards industries. The Ministry of Natural Resources and Environment (MNRE) is responsible for the formulation of emission / effluent standards and is required to take action on public complaints related to pollution. The Ministry of Interior (MOI) has authority in the management of local authority. Meanwhile the Ministry of Public Health (MOPH) has responsibility for the provision of public health of both workers and the community. The central administration has a main role in developing the policy framework, standards and guidelines and as a control and enforcement agency. These policies and guidelines are implemented by the Provincial Agencies. At the provincial level, the Provincial Industrial Agency (PIA) has responsibility for the regulation of the discharges and other nuisances from factories. The PIA is under direct management of the Provincial Agency. Below we elaborate on the tasks and responsibilities of the various governmental environmental organizations:

4.2.1 National level

At the national level, environmental management is conducted on a national basis by the Ministry of Natural Resources and Environment (MNRE). In addition, the MOInd, MOI and MOPH together with their constituent departments, enjoy broad jurisdiction over numerous natural resource sectors. However, the environmental regulation of industrial production is the responsibility of Department of Industrial Works (DIW) under MOInd.

4.2.1.1 Ministry of industry

The Ministry of Industry considers itself to be the leading agency in helping to strengthen large industries, small and medium enterprises, and entrepreneurs to be more competitive in the world market, and to assist them in the development of a better quality of life of Thai people. The main duties of MOInd are as following (MOInd, 2004):

- “To provide guidance for up-to-date industrial business and advice related to industrial business.
- To create business opportunities and an environment that is conducive to investment and business.
- To promote and extend the competitive potential at the global level of industry, small and medium enterprises, community enterprises and entrepreneurs.
- To supervise industrial business to insure the achievement of balanced and sustainable development”.

By 2003, the MOInd had 9 departments with 5,650 staff (MOI, 2004). These departments include Office of the Permanent Secretary, Office of the Minister, Department of Industrial Works, Department of Industrial Promotion, Department of Primary Industry and Mines, Thai Industrial Standard Institute, Office of Industrial Economics, The Official Thailand Board of Investment, Cane and Sugar Board. One of the more powerful departments within the ministry is the Department of Industrial works.

Department of Industrial Works
The DIW under MOInd is directly responsible for regulating industrial pollution and giving support for industrial operations in the country. DIW has authority to control, oversee, promote and support Thailand industrial operations according to the Factory Act (B.E. 2535), the Dangerous Substances Act (B.E. 2535), Gaseous Prevention Acts (B.E. 2535), and The Machinery Registration Act (B.E. 2514 and B.E. 2533). The organization of diagram of DIW is shown in Figure 4.3. Its main duties are as follows (DIW, 2004) :

- "To enhance the capacity and efficiency of industrial operations in Thailand to grow and remain competitive in world market.
- To provide information on industrial inventory.
- To be the center of information on industrial machines, chemicals, hazardous substances and volatile substances.
- To represent and protect the benefits of the Kingdom in the international arena for concerning issues on environment, safety and security of the country.
- To regulate pollutant discharge and other nuisances from factories.
- To control, oversee and engage in industrial businesses in the area of environment, preservation, sanitation and energy saving".

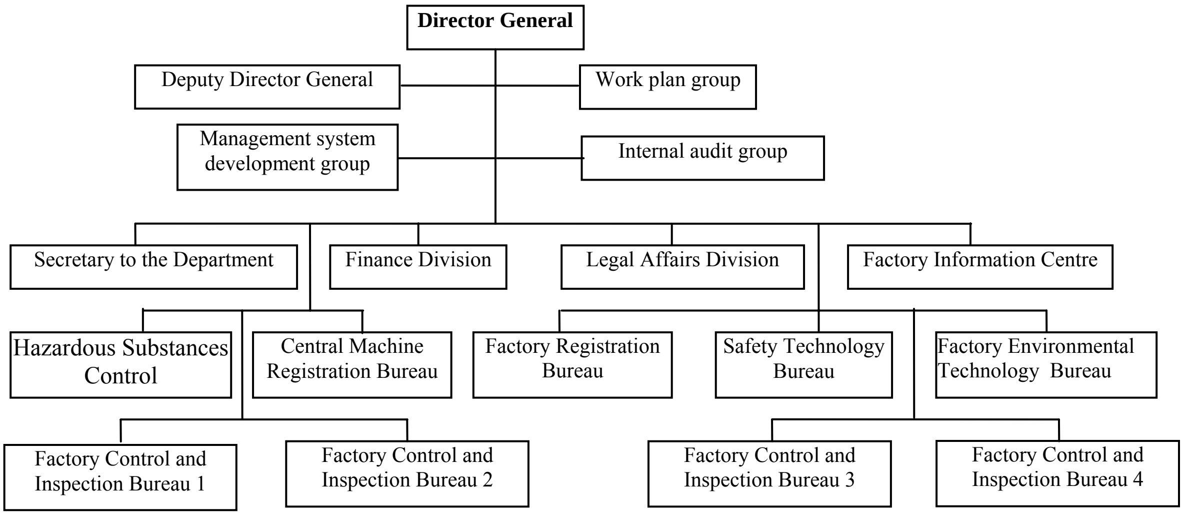


Figure 4.3 Organization chart of Department of Industrial Works (DIW, 2004)

There are 13 divisions within the department. The responsibilities and authorities of each division are summarized in Table 4.1. Currently (2004), the enforcement of industrial pollution regulation rests with the DIW's Factory Control and Inspection Bureau 1 to 4. The Provincial Industrial Administration (PIA) is a representative agency of MOInd in each province. The regulation of pollution from industrial production in each province is part of their responsibility. The Factory Environmental Technology Bureau is responsible for research and development on industrial production, including clean technology. The clean technology unit with 6 staff under the Factory Environmental Technology Bureau is responsible for the promotion of clean technology for Thailand's industry. They have formulated a policy and a program on CP promotion (2000-2006). The policy has been elaborated by the DIW staff, representatives from the industry, several governmental organizations, and experts from various institutions, along with advisors from abroad. The program has received support from the Danish Cooperation for Environment and Development DANCED), since August 1998. This CP policy comprises objectives, targets and action plans for implementing cleaner technology in the Thai industry. It also indicates a timeframe, responsible parties and supporting organizations for each CP activity (DIW, 2004).

Table 4.1 Responsibility of the divisions within Department of Industrial Works (DIW, 2004)

Division	Responsibility	Employee (No.)
1. Secretariat of the Department	-Link between the MOInd's policys on Industry and the policy implementation by relevant agencies within the Department	24
2. Finance Division	- Finance	40
3. Legal Affairs Division	- Law and legal affairs	20
4. Factory Information Centre	- Centre of national information and data on industry, environment, safety and machine	33
5. Hazardous Substances Control	- Responsible for controlling chemical in order to prevention impact and dangerous from chemical and other activity according to Dangerous Substance Act (B.E.2535)	57
6. Central Machine Registration Bureau	- Responsible for controlling machine and other activity according to The Machinery Registration Act (B.E. 2514 and B.E. 2533)	38
7. Factory Registration Bureau	- Responsible for issuing, checking and revoking factory licenses and activity according to Factory Act (B.E.2535)	43
8. Safety Technology Bureau	- Responsible for controlling, checking and developing safety and health in factory activity	46
9. Factory Environmental Technology Bureau	- Responsible for setting policy on industrial environmental management and promoting the application of innovation technology in industry	85
10. Factory Control and Inspection Bureau 1	- Responsible for controlling and checking industrial works of the factory in the central region according to the Factory Act (B.E.2535)	44
11. Factory Control and Inspection Bureau 2	- Responsible for controlling and checking industrial works of the factory in the north-east region according to the Factory Act (B.E.2535)	46
12. Factory Control and Inspection Bureau 3	- Responsible for controlling and checking industrial works of the factory in the northern region according to the Factory Act (B.E.2535)	57
13. Factory Control and Inspection Bureau 4	- Responsible for controlling and checking industrial works of the factory in the southern region according to the Factory Act (B.E.2535)	44
14. Director and Management Group		50

The Factory Registration Bureau is responsible for the formulation of policy and plans for the registration of a factory, and checking and certifying factory licenses and activities according to Factory Act B.E.2535. Only factories that have installed more than 50 horses-power-machinery have to apply for a license before starting construction and operation. After registration, the company has to apply for a renewed license every 5 years. There are about 62,433 factories that need to have a license in Thailand (DIW, 2001).

The Factory Control and Inspection Bureau 1 to 4 are accountable and responsible for controlling and checking industrial works according to the Factory Act (B.E.2535). They have representatives in the Industrial Works section in PIA. There are 400 officials who work for Factory Control and Inspection Bureau 1 to 4. At the national and provincial levels, they are responsible for monitoring and inspecting all 124,079 factories in the country (DIW, 2001). About 20,000 registered factories are classified as water-polluting, air-polluting and hazardous waste generating companies. In addition, dealing with complaints from community on pollution related to production process is the responsibility of this department and the PIA. Hence, due to the sheer size of their task and their under staffing, the capacity of the officers to enforce existing rules and regulations is weak (Hillebrand, 1998). They encounter difficulties in enforcement. In addition, the command-and-control nature of the existing environmental legislation does not give many incentives to companies to invest in environmental technologies or to go beyond compliance.

Industrial estate authority of Thailand

The industrial Estate Authority of Thailand (IEAT) is a state enterprise attached to the Ministry of Industry. It is chartered to implement the government's industrial development policy, especially on the development of industrial estates. Its objective is to ensure orderly and planned industrialization of the industries. Since 1972, twenty-nine industrial estates have been established, solely or jointly managed by IEAT. An industrial estate in Thailand is recognized as a preferential treatment area because the investors are eligible for incentives and privileges from the IEAT Act and Board of Investment's policy. IEAT has responsibility for issuing license for individual factories in the estate, specifying minimum standards for wastewater pretreatment before discharging to the central wastewater treatment plant, stack emission standards according to the MOInd and allowable emission loads based on the area and according to the condition in the environmental impact assessment report of the estate (IEAT, 2004).

The IEAT has responsibility for 29 large industrial parks throughout the country. It has been developing criteria that applied converts an industrial estate into an eco-industrial estate. These criteria focus on energy and waste conservation, recycling, industrial symbiosis and by-product synergies. IEAT, in collaboration with German Technical Cooperation (GTZ) is the first agency in Thailand to apply the industrial ecology concept. The vision is "to apply the industrial ecology concept as the main strategy for future Thai industrial estate development", with the objective to reduce environmental impacts and enhance business and social performance. Pilot projects started between 2002 and 2005 and take place in 5 locations namely: Map Ta Phut Industrial Estate, Northern Region Industrial Estate, Bang Poo Industrial Estate, Eastern Seaboard Industrial Estate and Amata Nakorn Industrial Estate (IEAT, 2004).

4.2.1.2 Ministry of natural resources and environment

Ministry of Natural Resource and Environment (MNRE) was created in 2002. The environmental tasks and responsibilities of the former Ministry of Science, Technology and Environment have now been transferred to the new MNRE. MNRE consists of 9 departments namely: The Office of the Permanent Secretary, Office of the Minister, Department of Environmental Quality Promotion (DEQP), Department of Groundwater Resources, Department of Marine and Coastal Resources, Department of Mineral Resources, Department of National Parks, Wildlife and Plants, Office of the Natural Resources and Environmental Policy and Planning (ONREPP), the Pollution Control Department (PCD). The main departments under MNRE with responsibility for industrial pollution control are ONREPP and PCD (see Table 4.2). These departments are further divided into several divisions and regional offices, which take charge of specific environmental tasks and responsibilities at the national and provincial levels. The responsibility over natural resource management resides primarily with the sect oral ministries.

Table 4.2 Departments under MNRE and their responsible (MNRE, 2004)

Department	Responsibility
Office of the Natural Resources and Environmental Policy and Planning (ONREPP)	- To formulate policy and plan for natural resources and environment conservation and administrative management. - To coordinate the formulation of natural resources and environmental management plan. - To appraise Environmental Impact Assessment (EIA) reports on projects.
Department of Pollution Control (PCD)	- To support the formulation of national policy and plans of environmental quality conservation and promotion in respect to pollution control, - To formulate and recommend environmental quality and emission/effluent standards, - To monitor the national environmental quality - To develop systems, methodologies and technologies, which are appropriate in application to the better management of water quality, air quality, noise pollution, hazardous substances and solid waste - To take actions on public complaints related to pollution

Office of the Natural Resources and Environmental Policy and Planning

ONREPP has an important agency overseeing the industrial pollution mitigation is: the Environmental Impact Evaluation Bureau (DEIE). The DEIE acts as the secretariat of the expert committees to scrutinize environmental impact assessment reports according to the Enhancement and Protection of Environmental Act B.E.2535. Another major division related to industrial activity is the Office of Environmental Fund. This office was established in 1992. Its objectives are promotion and conservation of the quality of the environment via financial incentives. This includes support to local administration, state enterprices and the private sector by providing loans with a low interest rate.

Pollution Control Department

The PCD was established on June 4, 1992 under the Ministry of Science, Technology and Environment B.E. 2535(1992), as a result of the Enhancement and Conversation of the National Environment Quality Act B.E. 2535 (1992). At the national level PCD is responsible for setting environmental quality standards and emission/effluent standards from various sources. MOInd also applies effluent standards for industrial sources based on PCD’s standard.

One of the main functions of PCD is to monitor national environmental quality and to prepare an annual report on the state of the environment.

Another function of PCD relate to industrial pollution is to take action following public complaints on pollution. After receiving a complaint, PCD will inspect and sample the environment surrounding the source of pollution. If there is any contamination of the environment due to the factory emission, PCD will sent a report to DIW in order to control and enforce the factory to improve their environmental performance. PCD itself has no control and enforcement responsibilities regarding industrial pollution.

4.2.2 Provincial level

Decentralized government agencies including Provincial Industrial Office (PIA), Provincial Environmental Office (PEA) and Provincial Public Health Office (PPHA), all under the provincial administration, have responsibilities in the management of industrial operations, environmental quality and public health, respectively (as described previously in section 4.2). PIA is the branch office of MOInd in the province. DIW also has their representatives in PIA office, in the Industrial Work Section. The scope of tasks related to industries of PIA includes: issuing and revoking factory licenses for each enterprise in the province; controlling, checking and developing safety and health quality in factory activity, controlling and checking production process of the factory in the province according to the Factory Act (B.E.2535). The number of staff in Industrial Work Section differs between different provincial, for instance 5 in the case of Trang and Suratthani Province, 6 in case of Chumporm, 3 in case of Krabi Province. These staff members are responsible for production activities including waste treatment and environmental issue in all factories in the province. Factory inspection results, problems and compliants are reported monthly to DIW. In the 4 provinces included in this study, Industrial work section in each PIA report to the Factory Control and Inspection Bureau 4 of the DIW.

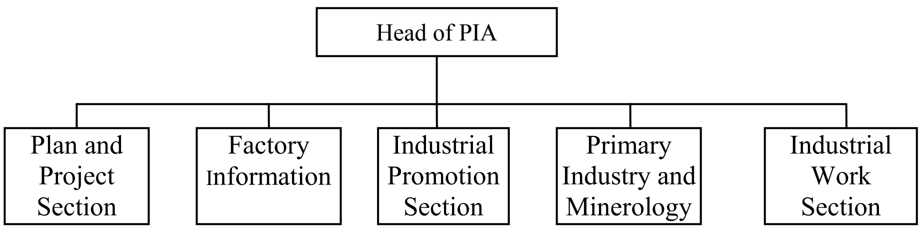


Figure 4.4 Organization chart of the Provincial Industrial Office

4.2.3 Local level

4.2.3.1 The Tambon Administration Organization

Structure and administration of TAO

The Tambon Council and Tambon Administration Organization Act of B.E.2537 (1994) raised the status of Tambon councils to juridical persons and Tambon councils with a certain income level set by the law were upgraded to TAOs. This Act provides the functions, both mandatory and optional, that are under the responsibility of the TAO. The TAO consists of the TAO Council and the Executive Committee of the TAO (Figure 4.5).

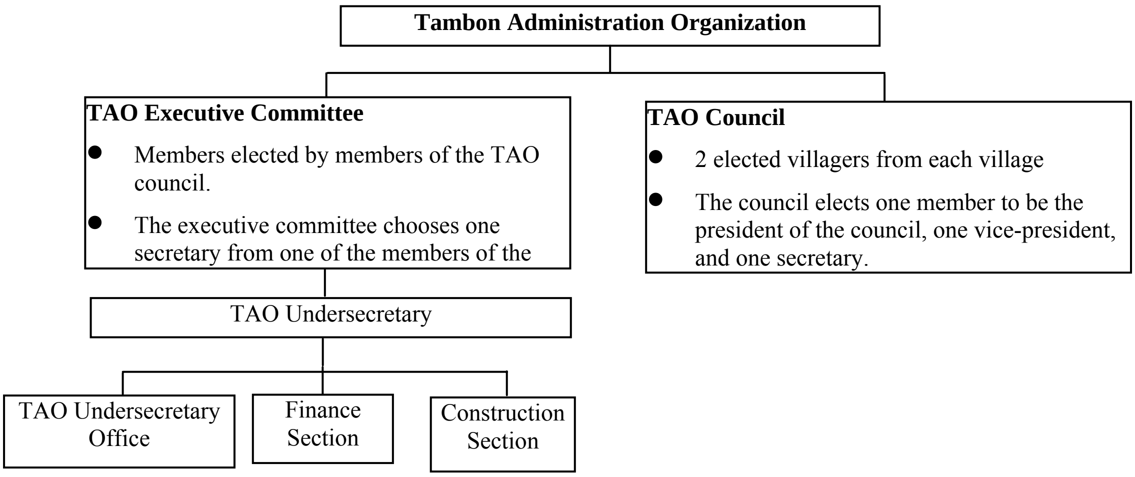


Figure 4.5 Structure of the TAO according to the Tambon Administration Organization Act, 1994

The TAO executive committee has the function of drafting local development plans, preparing an annual budget, and administering and implementing the tasks specified in the plan. The TAO executive committee works with the TAO council to draft rules and regulations for the locality. In addition, the TAO may pass regulations concerning the functions mentioned above, to the extent that these rules do not conflict with existing laws. Functions are also assigned to the local administration by various laws, such as Public Health Act, 1992, the Building Control Act, 1979, amended in 1992,Local Support Tax Act,1965, etc.

4.2.3.2 Province Administration Organization

PAO and municipality has the same mandatory and operational functions as TOA. The organization chart of a POA is shown in Figure 4.6.

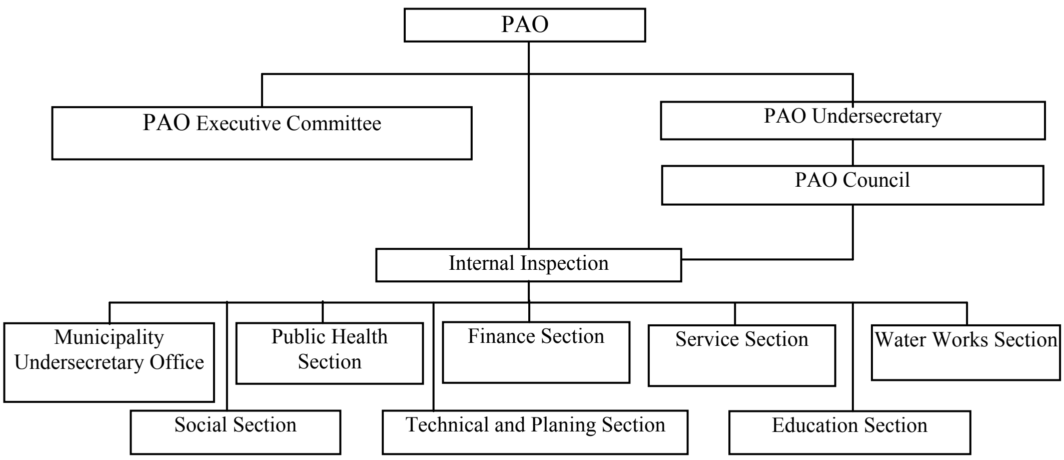


Figure 4.6 The organization chart of Province Administration Organization

4.2.3.3 Environmental management by local government

According to the enhancement and conservation of National Environmental Quality Act of 1992, provincial and local authorities are allowed to formulate their own environmental management plans.

Due to the enhancement and conservation of National Environmental Quality Act of 1992 any province which has its territory designated as an environmentally protected area or pollution control area or any province which desires to enhance and conserve the environmental quality, is eligible to formulate an action plan and submit it to the National Environment Board (NEB) for approval. The NEB is set up for controlling and supervising these plans at the national level. At the provincial and local government levels, the Sub-Committee for Provincial Environmental Quality Management under the Committee for Provincial Development is set up as an advisory committee for environmental management. The Provincial Action Plan should be in accordance with the Environmental Quality Management Plan and should take into account social conditions in the area. Crucially, it emphasizes public participation from all parties and at all levels.

The roles and functions of local government in managing the local environment

The roles and authorities of the TAOs in managing the environment are specified in the TAO act, 1994. The law empowers the TAOs to provide for waterways and walkways, maintain roads, waterways, and public parks, dispose of trash, and protect and maintain the environment. The Department of local Administration Ministry of Interior proposed an operational guideline, 1998-2000, to comply with the Constitution and to follow the policy of decentralizing authority to the local levels. This guideline significantly improves the roles position and functions of the Department of Local Administration, its local staffs, sub-district chiefs, and village heads, and put them in line with the Constitution. It means among other that:

- The central authorities must change their operations from a commander to a facilitator.
- Provinces and districts must act as supporters and coordinators of the various local governments in the area.

According to the The Tambon Council and Tambon Administration Organization Act (B.E.2537), local government has the authority to collect land tax from the factory, so that TOAs can increase their income from those factories. With these and other finds, TOA have to manage their environmental quality effectively. Since the villagers have the power to remove TAO executive members from office, there is a strong tendency to be more transparent and effective in both industrial and environmental management. The important task of TOA is to balance between industrial development and the management of natural resource in their area.

4.2.4 Company level

Similar to most enterprises in Asia, many factories in Thailand also have :

- Lack of information on environmental management as well as environmental technologies.
- Time constraints of company management who are responsible for many tasks.
- Lack of human resources with direct responsibility for environmental protection.
- Lack of manpower and awareness for environmentally sound production.

Illustrative of the role of actors in company environmental management, are the results of a survey of 15 crude palm oil mills in Thailand. Only some of the 15 companies conduct environmental protection activities voluntarily. One of the surveyed mills had a separate environmental management section. Environmental management of mills is usually an additional task of the production section or the management board of the mill. In most cases, the chief engineer has responsibility for environmental pollution in the factories, they have often not been trained on environmental knowledge or have only participated in some short training courses. Table 4.3 presents the position of environmental management tasks in the organization structure of the 5 selected case study enterprises.

Table 4.3 Environmental management at enterprise level in the case studies

Factory	Place of environmental management tasks	Main environmental protection activities
Factory A	- Production engineer (by engineer) and - Quality control section (by chemist)	- Applying cleaner production - Operation of waste treatment plant
Factory B	- Production engineer (by engineer) and - Quality control section (by chemist)	- Applying cleaner production - Operation of waste treatment plant
Factory C	- Environmental management section	- Operation of waste treatment plant
Factory D	- Production engineer (by engineer)	- Operation of waste treatment plant
Factory E	- Production engineer (by engineer)	- Operation of waste treatment plant

4.3 Environmental legislation

4.3.1 General introduction to industrial pollution control policy in Thailand

The concept of industrial pollution control in manufacturing was first addressed in the 3rd National Economic and Social Development Plan (1971-1976). The Fourth Plan (1977-1981) called for measures including the issuing of environmental impact assessment (EIA) as part of the procedure for issuing industrial permits. During the Fifth Plan (1982-1986) environmental problems related to industry were identified. The Sixth (1987-1991) and Seventh plan (1992-1996) started to address more directly and proactively the environmental consequences of the rapid economic and industrial growth in Thailand (Reutergarh and Yen, 1997). Although the 7th National Plan assigns high priority to environmental issues, the actions are geared heavily toward end-of-pipe treatment with little emphasis on pollution prevention. It is apparent that pollution prevention policies and guidelines were lacking. However, cleaner production policy has been addressed in the 8th and 9th National Economic and Social Development Plan. The 9th National Economic and Social Development Plan (2001-2006) emphasizes on the importance of Thailand's competitiveness and cites cleaner production as one of the principal strategies to achieve this. The National Master Plan on Cleaner Production, developed in accordance with the International Declaration on Cleaner Production, was signed between Thailand and UNEP in 1998. The National Plan, enacted on 17 January 2002 and approved by the Government on

March 26, 2002, seeks to introduce cleaner production principles that can be applied on various activities and sectors, and to identify measures and tools to ensure consistency in their application.

4.3.2 Development of environmental law and legislation

This section will briefly review the historical development of the national environmental laws and policy. In 1969, the Factory Act was established to regulate environmental disruption by factories. The Thai government entered the environmental protection field for the first time in 1971 when pollution of the Mae Klong River by sugar mill wastes became a source of controversy. However, more systematic introduction of environmental management and environmental laws really started in Thailand in 1975, when Thailand's first National Environmental Quality Act was passed (Reutergarh and Yen, 1997). As a result of this, the Office of the National Environmental Board (ONEB) and the National Environmental Board (NEB) was set up as a central agency to coordinate environmental management among governmental agencies. ONEB has authority in policy coordination, while implementation and enforcement were and still are the responsibility of other agencies such as DIW.

Around 1978, the new laws to mitigate pollution and environmental damage were set up. An environmental impact assessment system was created under provision of the 1978 Enhancement and Conservation of National Environmental Quality Act. However, the existing laws and regulations failed to reduce pollution from industrial production. During 1975-1992, the pollution and environmental problems from economic development continues to increase. The government recognized that the command and control approach alone is inadequate and ineffective to control the pollution load from the industrial sector. There is no incentive for the industry to reduce its pollution or go beyond compliance. In 1992, the government passed new laws and revised existing laws, such as the Factory Act 1992, the Enhancement and Conservation of National Environmental Quality Act 1992, the Hazardous Substances Acts, the Public Health Act 1992. The adjustment of the regulatory framework focused-among others- on the application of economic instruments by introducing the polluter-pays-principle. The new Acts radically changed the organizational structure on environmental protection in Thailand. The National Environmental Board (NEB) was upgraded, with the Prime Minister as Chairman, and the ONEB was replaced by three environmental departments under MOSTE: OEPP, EQP and PCD. PCD forms the present secretariat of the new NEB. Under the Constitution, the Decentralization Act and the 9th National Economic and Social Development Plan (2001-2006) include significant reforms for MOI, MOInd and MNRE, among which the reorganization and decentralization of departments and the development of innovative environmental policies and programs.

4.3.3 Environmental legislation concerning pollution control

Industrial pollution control was initially addressed by the Factory Act of 1969. In 1975, The Enhancement and Conservation of National Environmental Quality Act (NEQA) enacted the National Environment Board as the main policy, planning and coordination body, with ONEB as its secretariat. Under this Act, ambient quality standards (including guidelines for their use) and Environmental Impact Assessments (EIAs) procedure and regulation were developed and established. Implementation of pollution control policies, including the establishment of emissions standards, monitoring of sources and enforcement of regulations, were the responsibility of DIW in the Ministry of Industry.

Hence, NEQA was revised in 1978 and 1992 with the following key features (ONEB, 1992):
- Broadening the scope of environmental and pollution control.
- Upgrading NEB to become an active policy making center and establishing the Environmental Fund to assist polluters in controlling the eliminating of pollutants.
- Decentralizing the environmental management authority to provincial and local levels
- Promoting participation of the private sector in managing the environment. Promoting the role of the NGOs in environmental matters.
- Expanding the role of the Department of Pollution Control in MOSTE in establishing effluent and emission standards, monitoring and enforcement actions.
- Implementing a "Polluters Pay Principle".

Table 4.4 shows a selection of the most relevant environmental laws for industrial pollution control :

Table 4.4 Major environmental legislation regarding industry

	Purpose
Framework laws	
-Enhancement and conservation of the National Environmental Quality Act 1975, amended in 1978 and 1992	-Established ambient quality standards, EIAs, emissions standards, and monitoring of sources and enforcement of regulations -Implementing a "Polluters Pay Principle".
-Notification of MOSTE on types and sizes of projects or activities of government agencies, state enterprises or private persons required to prepare an Environmental Impact Assessment Report 1992	-Decentralizing the environmental management authority to the provincial and local levels
Pollution Control	
-Factories Act 1969, amended in 1975 and 1992.	-Regulates and prescribes the location and environmental pollution control of factories
-Hazardous Substances Act 1967, amended in 1976, and 1992	-Control over the full range of hazardous substances used in industrial processes
-Poisonous Substances Act 1967, amended in 1973	-Control of the import, export, manufacture, marketing, storage, transport and use of toxic substances.
- The Machinery Registration Acts 1971 and 1990	- Control and monitor the equipment employed in factory works
-Notification of Ministry of Industry Concerning Industrial Effluent Standards 1982	- Setting industrial effluence standards.
-Notification of Ministry of Industry concerning manufacture and use of toxic substances 1982	- Setting standards for manufacturing and use of toxic substances
-Notification of Ministry of Industry concerning storage and disposal of toxic substances 1982	- Setting standards for storage and disposal of toxic substances
- Notification of Ministry of Industry concerning tax exception for ISO certified factory 2004	- Tax exception for ISO 14000 and ISO 18000 certified factories
-Public Health Act 1941, amended in 1992.	-Monitoring and preventive measures for environmental health
Energy	
-Energy Conservation Promotion Act 1992	-Regulations for energy conservation in factories and large buildings
-Notification concerning duty reduction on energy efficiency and environmental technology 1998	

4.3.4 Environmental legislation concerning cleaner production

Cleaner production is in line with existing national policies that emphasis the promotion of industrial development; such as :

- 8th National Economic and Social Development Plan (1997-2001).
- 5 Years Industrial Restructuring Plan (1998-2002).
- Environmental Management Plan (1999-2006).
- 9th National Economic and Social Development Plan (2002 -2006).
- National Master Plan on Cleaner Production (2002-2011).

A list of the main policies involved in cleaner production is shown in Table 4.5.

Table 4.5 Main policies involved in cleaner production (PCD, 2002)

	Year	Strategies/ measures
- 8th National Economic and Social Development Plan	1997-2001	- Created balance between production and natural resource/environment protection - Promote industries with low environmental impacts by providing special support to industries who employ reduction, re-cycling and reuse technology - Science and technology development to create a foundation for sustainable development transfer of production and environmental technology to industrial sectors, clean technology implementation, as well as development of environmentally sound and product design.
- 5 year Industrial Restructuring Plan	1998-2002	- Promote clean technology implementation to reduce pollution in 13 industrial sectors
- National Environmental Management Plan	1999-2006	- Support for clean technology implementation and energy conservation, to solve urgent environmental problems.
- 9th National Economic and Social Development Plan	2002 -2006	- Cleaner production as one of the principal strategies to achieve competitiveness
- National Master Plan on Cleaner Production	2002-2011	- Implementation of cleaner production in the sectors of industry, agriculture, tourism and services, financial , and banking, education

Since 1994, the government and private sector have undertaken various projects and activities to promote cleaner production in major industries. During the initial phase, projects obtained both financial and technical support from international organizations through governmental agencies (DIW), private organizations, associations and academic institutions. Therefore, DIW, under the Ministry of Industry, formulated. Policy and a Program on Cleaner Production Promotion (2002-2006). The policy and program aim at developing competitive capacity of the industrial sector through the use of clean technology that would reduce production cost as well as pollution. It aims at establishing tools to respond and promote the adoption of CP in wider ranges of industries. These policies and activities were consistent with a number of policies emphasizing industrial development promotion, for example, the Industrial Restructuring Plan of the MOI, the Master Plan on Small and Medium Enterprises (SMEs) Development of the Department of Industrial Promotion (DIP), and the Energy Conservation Program under the

Energy Conservation Act (En Con Act B.E. 2535. The Plan and Program was approved by the Industrial and Environmental Management Sub-Committee on June 20, 2000.

In January 2002, the National Environmental Board approved the National Master Plan on Cleaner Production prepared by PCD. It forms part of the 9th National Environmental Management Plan (2002 -2006), which has as Strategy No. 2: to protect the environment by using specific management and technology, eco-efficiency, and cleaner production which reduce pollution and production costs. This cleaner production plan contains 6 main strategies and 103 operational measures for the years 2002-2011. The plan gives an integrated vision for the nation to proceed with implementation of cleaner production in the public and private sectors, including industry, agriculture, tourism and service, finance and banking, and research and development. The main responsible organization for implementation is the Ministry of Natural Resources and Environment.

The six main strategies of the plan to enable cleaner production development and implementation in Thailand are :

Strategy 1: Changes in laws and regulation.
Strategy 2: Policy and budget changes.
Strategy 3: Promotion of cleaner production in industry, agriculture, tourism and service, finance and banking, and research and development.
Strategy 4: Use of Economic instruments.
Strategy 5: Human resource development.
Strategy 6: Public relations.

There are governmental, financial, academic and non-governmental organizations that promote clean technology activities. The governmental institution responsible for cleaner production for industrial sector is MOInd. Measures for industrial sector which are implemented by MOInd are (DIW,2002) :

- “Prioritize the significance and establish database on industries where cleaner production will be promoted.
- Establish code of practice and manual on the implementation of cleaner production for industries, according to its significant priority.
- Establish a system of monitoring and certifying industrial operators that implement cleaner production.
- Establish a registration system for cleaner production (CP) auditors.
- Support industries in the Industrial Estate Zone to implement cleaner production
- Support SMEs to implement cleaner production .
- Increase the role of large industrial operators to be a leader who could help support smaller ones in implementing cleaner production”.

4.3.5 Legislation concerning industrial ecology

Thailand has embraced industrial ecology as a potential approach to economic development of industrial estates through cooperation between the Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) and the Industrial Estate Authority of Thailand (IEAT). IEAT has been the first agency in Thailand to work with this concept and has begun preparation plans for implementation year 2000, with the first operational phase set for 2002-2005. Locations for 5 eco-industrial pilot projects have been identified Map Ta Phut industrial estate, Northern Region Industrial Estate, Amata Nakhon Industrial estate and Bang Poo Industrial estate and Eastern Seaboard Industrial estate. The organizational structure of IEAT shows a division in 4 working groups (IEAT,2003) :

Group 1 Policy support for Eco-Industrial Development (EID)
Group 2 Capacity Building in EID
Group 3 Pilot projects at 5 industrial estates
Group 4 New Eco-industrial estates, with pilot project of Rubber City

In Thailand the industrial ecology concept has been applied in Industrial estates, but not in individual companies. But waste exchange has been one of the operational measures in the National Master Plan on Cleaner Production. The main implementing agency there is MOInd. However, there is no law governing the reuse/recycling of industrial waste in Thailand. This is different in Taiwan, where Taiwan's EPA, in cooperation with the ministry of Economic Affairs, has changed the regulatory system to promote industrial waste reuse and pollution prevention. This program in Taiwan not only provides technical assistance and financial incentives, but also enhances resource reuse and conservation through an Industrial Waste Exchange Information Service Center (Tsai and Chou, 2004).

4.4. National policy on CPO industry

Though the oil palm industry started its development in 1968, the government initiated the promotion of palm oil extracting factories in 1974 and palm oil refinery factories in 1977. Serious government concern, with the efficiency of palm oil production emerged when palm oil became one of the core economic sector in the Fifth Social and Economic Development Plan (1983-1986). The government announced the establishment of palm oil Agro- Economic Zones in 10 provinces in the southern part of Thailand in order to enhance the plantation area and to improve the efficiency of oil palm production under Oil Palm Development Plan (1984). The Board of Investment (BOI) has promoted the vegetable oil industry, including palm oil, since 1962. In 1984 BOI granted investment promotion to the integrated and export-oriented businesses and industries that used palm oil as raw material. This BOI promotion resulted to the establishment of 10 palm oil plantation companies, 14 extraction plants and 3 refinery plants by 1994.

The current policy of the Ministry of Agricultural and the Cooperatives**,** outlined in the oil palm and palm oil development plan of 2000-2006, has an objective to increase the average production to 3 ton/ rai and to increase oil content from 17% to 19%. It also aims to further expand the area for plantation. It is expected that in 2006, the area will increase to 2 million Rais. In Surajthani province, 0.43 million rais are currently used to grow palm oil and the area could be increased with 0.4 million rais. It is expected that in the future Surajthani will be the most important province in the for the palm oil production in Thailand.

When the comparative advantage index (RCA) is applied, Thailand's potential to compete in the world market shows to be lower than 1. Thailand is not able to meet the domestic demand. The cost for production is still high because Thailand has to import oil palm seed from other countries and the plantation system is not efficient. Malaysia has a noticeable higher production result 18.33 ton FFB per ha compared to 16.5 tons FFB/ha for Thailand.

At present, the existing cumulative production capacity of all Thai palm oil mills is more than the FFB productivity. In 2003, the FFB production was approximately 4 million ton FFB, but maximum production capacity of all 25 wet-process factories is approximately 740 ton FFB/ hr or 5.3 million ton FFB/ year (with 300 operation days/ year and 24 hour/ day). Therefore average factories currently operate at 75% of their full design capacity. However, the government, through the Ministry of Agriculture and Cooperatives, aims to increase oil palm production by promoting oil palm plantation. A budget of 2,400 million Baht is arranged in the 9th National Economic and Social Development Plan (B.E. 2545-2549) for this.

$$RCA = \frac{Xij / \sum Xij}{Wj / \sum Wj}$$

where:

Xij	=	Value of export product j by country i
∑Xij	=	Total value of all export of country i
Wj	=	Total value of product j in the world
∑Wj	=	Total value of all products in the world

The RCA concept is based on the idea that a country that can produce a goods at lower cost than other country, that country should export the goods in higher ratio than average value of world export.

Chapter 5
Industrial ecosystem : A case study of a crude palm oil mill located in a community

5.1 Introduction

This chapter presents the results of a plant survey of factory A, which is, as already mentioned in chapter 3, representing the best practice in clean technology of the crude palm oil industry in Thailand. The detailed process flowchart, mass balance, raw material and energy consumption and environmental impact will be shown. The existing environmental performance of factory A is analyzed based on waste generation, environmental impact, adoption of clean technology options and waste exchange. Then the possible solutions for the existing environmental problems of the mill will be proposed. The assessment of the available clean technology options and the improvement of the environmental performance are executed on the basis of clean technology and industrial ecology theory. This chapter will also present a physical-technological model of an almost zero waste industrial ecosystem for factory A, created by integrating all options as discussed in this chapter.

5.2 Production process and environmental aspects

Factory A was established in 1978. It covers an area of 137,600 m^2 in the Surathani province, about 10 km from the city center. The total staff and workers employed in the company are 110 persons. The production capacity is 45 ton fresh fruit bunch (FFB)/hour or 173,000 ton FFB/year. This factory has implemented many clean technologies and also applies an environmental management system (EMS). The reason for clean technology application is to increase the oil yield, to minimize waste production and to reduce water consumption. The factory also got ISO 9000 certified to meet the requirement of the refinery.

5.2.1 Production process

The extraction of palm oil from fresh fruit bunch involves five major operations: fruit separation, sterilisation, digestion, oil extraction and oil purification. In the production process, large amounts of water and energy are needed to convert palm fruits into crude palm oil. Figure 5.1 and 5.2 show flow diagrams of the crude palm oil production in factory A, representing applied advanced oil recovery technology. Figure 5.3 shows the mass balances of the production process in factory A, which are based on the processing of 1000 kg FFB.

Results from this study show that a standard wet processing mill consumes a large amount of water in the production process and produces a large amount of wastewater. Furthermore, this industry has a high demand for energy. The most important use for energy in the factories, as is also the case in factory A, is electricity. However, most of the crude palm oil mills are self-sufficient regarding energy. We will discuss in more detail the most important treatment

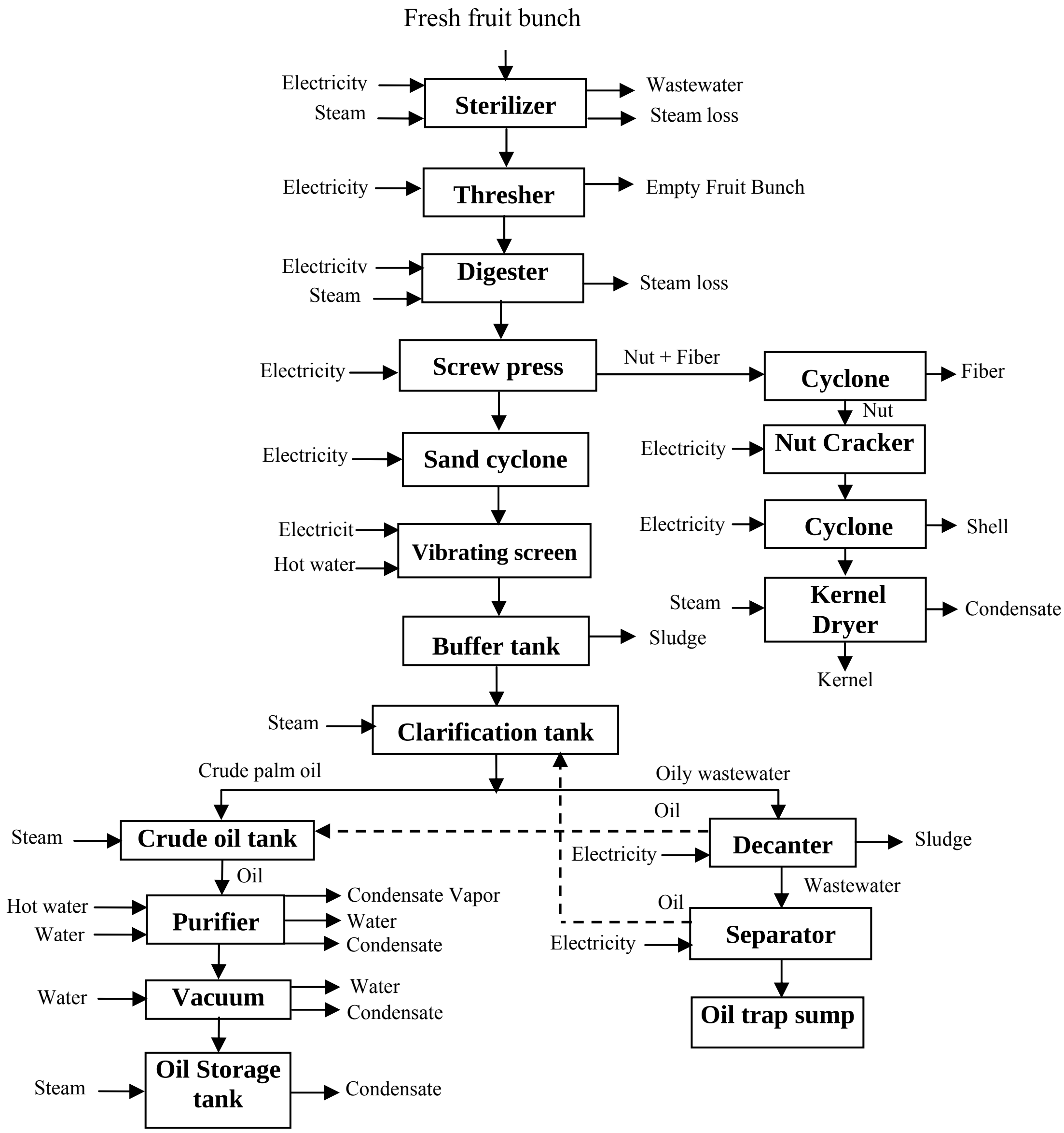


Figure 5.1 Schematic flow diagram of crude palm oil production in factory A

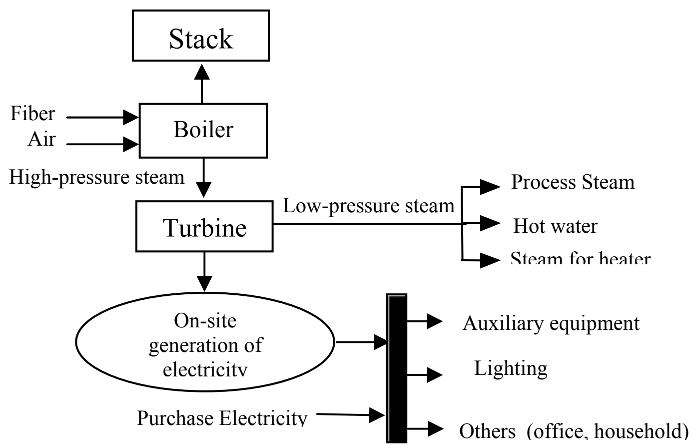


Figure 5.2 Schematic energy flow diagram of factory A

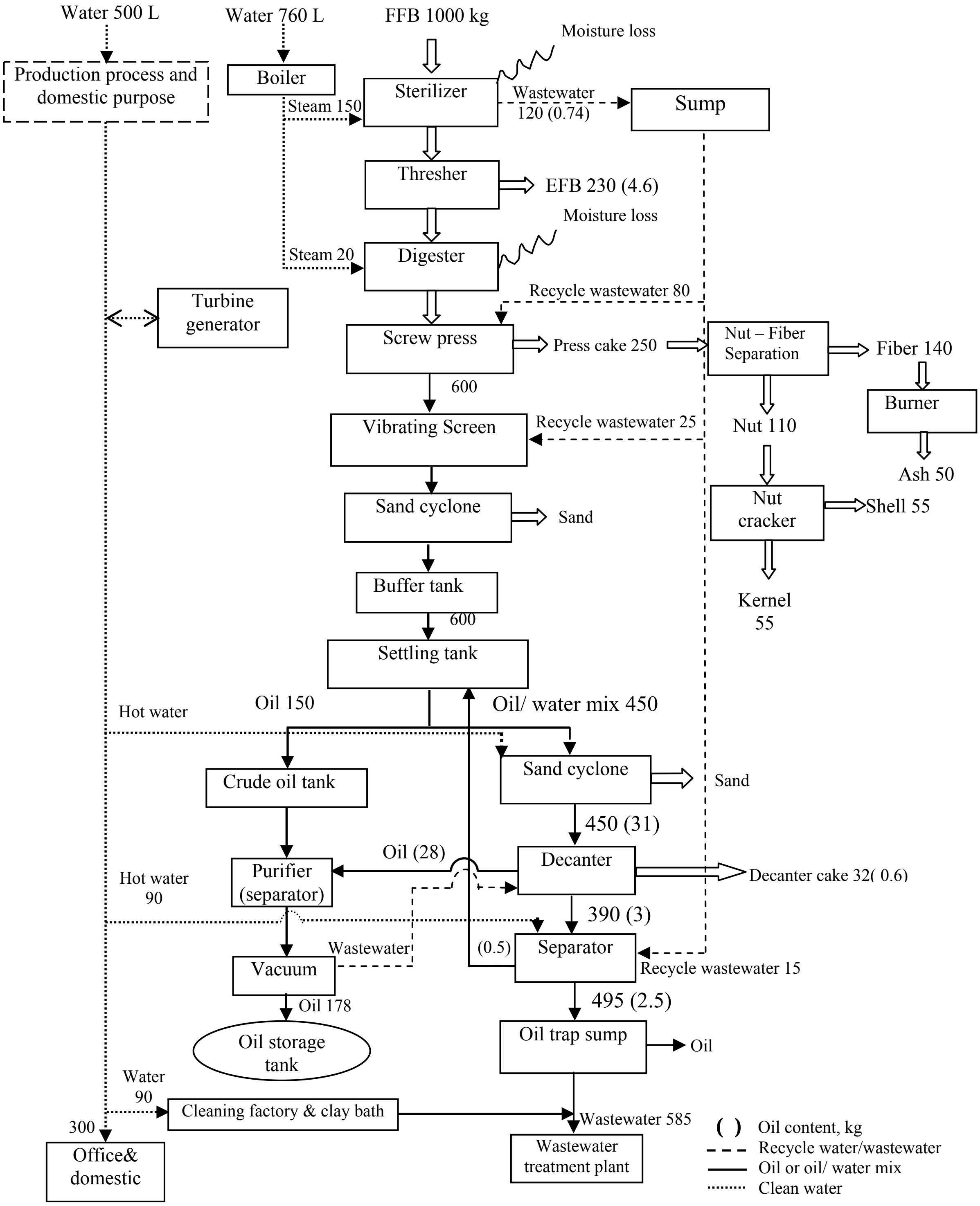


Figure 5.3 Mass balance of production process of factory A

Steps and/or equipment in the production process in section 5.2.4.

The production process of factory A is as follows:

Reception, transfer and storage of fresh fruit bunch. The fresh fruit bunches are harvested and transported to the palm oil mill by trucks for immediate processing. At the mill, they are unloaded on a ramp and put into containers with a capacity of 2.5 tons each.

Loading ramp

Sterilization. Sterilization of the fresh fruit bunch is done batch wise in an autoclave with the application of steam at 120 –140 °C at 3-3.5 bar, for 75 min. The objectives of the sterilization are: to prevent the formation of fatty acids, to facilitate stripping of fruits, and to prepare the fruit fiber for subsequent processing.

Autoclave

Bunch stripping. The containers with the sterilized bunches are emptied into a rotary drum thresher where the fruits are separated from the bunch stalk. This processing step generates 230 kg empty fruit bunch (EFB)/ton FFB.

Thresher

Digestion. The separated fruits are carried into digesters and mechanically converted into an extractable oily mash.

Extraction. The oily mash is fed into a continuous screw press system where the oil is extracted. The extracted crude palm oil is collected and flows to the purification section. The remaining press cake is transported to a separation system consisting of air clarifiers and cyclones for drying and separating the nuts and fibers. Kernels are recovered from the nuts in the nutcrackers. Fiber and shells are sent to the boiler and used as fuel.

Screw press

Clarification and purification of the crude palm oil. The crude palm oil from the presses is a mixture of palm oil (25% - 35%), water (45% - 55%) and fibrous material varying in proportions.

- ***Screening.*** A small amount of hot water is added to the raw oil and passed through a vibrating screen to separate fibrous particles. The oil after sieving still contains large amounts of suspended solids and water.
- ***Sand removal***. A sand cyclone is used to separate sand from the oil.
- ***Suspended solid separating.*** The conventional procedure to separate oil from water is the settling tank method. Steam is used to heat the system and to maintain the temperature at 90 ^{o}C. Oil floats to the top of the tank and is collected by a funnel, and flows into the crude oil tank.

Settling tank

- ***Oil purification***.
  - *Separation of fine suspended solids***.** The final purification step is done by centrifugation of the crude oil from the settling tank to remove water and fine suspended solids.
  - *Drying and cooling*. After centrifugation the crude oil still contains water, which is removed by a vacuum evaporation system. The dried crude oil is kept in storage tanks before selling to an oil refinery.
- ***Treatment of sludge (oil/water mix) from settling tank***. The sludge from the settling tank is collected in the sludge tank and subsequently treated to recover oil. To protect the equipment in the subsequent process steps against clogging, the sand is separated from sludge by a sand cyclone. The sand cyclone is cleaned by discharging the accumulated sand to the drain, followed by the injection of hot water.
- ***Oil recovery***. The sludge is collected in a sludge tank and then pumped to a decanter (three-phase centrifuge) and a separator (two-phase centrifuge) for oil recovery. To enhance the separator efficiency, it is common practice to add water during centrifugation. The separator will generate more wastewater than the decanter process. The recovered crude oil is pumped to the settling tank.

Separator

The cake from the screw press after oil extraction is broken up and the fiber is removed from the kernel nut in the air cyclone. The fiber is then blown through a cyclone to the boilers where it is used as fuel. The kernel nut is cracked and the kernel and the shell are separated by a clay water bath. The produced kernel is dried to reduce its moisture to prevent molding, and subsequently stored in a silo.

Factory A adopted and introduced many clean technology options including good housekeeping, reuse & recycling and technology change. An overview of apparatus, equipment and other measures is given below:

- Application of a modified decanter for recovery of oil from wastewater and construction of an oil trap sump to remove oil from the wastewater before this goes to wastewater treatment plant (WWTP).
- Installation of a buffer tank to separate sludge from crude oil before this flows to the settling tank to enhance oil separation in this tank (improvement of settling tank).
- Installation of a 2^{nd} bunch stripper to enhance fruit separation from the bunch stalk to reduce oil loss from EFB.
- Recirculation of sterilized condense to the screw press and vibrating screen to reduce water use and recover oil.
- Recycling of hot water from the vacuum dryer for cleaning the decanter and separator.
- Recycling steam condensate (temp 100 ^{o}C) from the nut drier tank to use as boiler feed water.

5.2.2 Inputs

Raw material demands. The raw materials needed for production processes are fresh fruit brunch, clay, alum, anionic polymer, diesel oil, salt, electricity and water. Raw material demands of the factory are shown in Table 5.1. Clay is used for preparing the solution to separate the shell from palm kernel. Alum and anionic polymer are used in the water treatment plant before introduction into the production process. The factory consumes water from a nearby channel free of charge.

Electricity demand. Electricity is the dominant source of energy for the production process. The total energy consumption of all electric machines used in the production process is about 17.11 kWh/ ton FFB. The electricity is obtained from two sources: a turbine generator installed in factory, and the government supplier. The electricity generated in the factory is about 85% of total electricity consumption (15.3 kWh/ ton FFB). The small power plant in the mill incorporates a water tube boiler with a steam production capacity of up to 20 ton of steam/hour. Fiber obtained from the production process is used as fuel for the power plant. About 3.3% of total electricity consumption in factory is used for the office buildings.

Table 5.1 Demand of raw materials for the production process of company A

Item	Usage purposes	Unit	Consumption
Fresh fruit bunch	Basic material for production of crude palm oil	ton/year	173,000.0
Clay	Separate shell from kernel	ton/year	257.1
Alum	Water treatment	ton/year	4.5
Anionic polymer	Water treatment	ton/year	0.6
O_2 scavenger [1)]	Feed boiler water treatment	ton/year	235.0
Sodium chloride [2)]	Feed boiler water treatment	ton/year	21.4
Diesel fuel oil	Generator	L/year	4,200.0
Electricity	Lighting and production	kWh/year	2,960,000.0
Surface water	Steam generation, turbine generator and production process	m^3/year	207,600.0

Note : 1) Used to prevent corrosion of water tubes in boiler.
2) Used to regenerate resin for boiler feed water treatment.

Fuel demand. Fuel used in the production process consists of 0.024 L diesel oil/ton FFB. Diesel oil is used for the diesel generator to start up the boiler and generator.

Water supply demand. A crude palm oil mill uses much water in the production process. Channel water is the water source. This water is treated by coagulation and filtration. Alum and polymer are used as coagulant and flocculant in the clarifier. The average water consumption is equal to 1.20 m^3/ton FFB or 720 m^3/day. A detailed overview of the water usage in the factory is shown in Table 5.2. The quantity of water consumption per ton FFB does not differ among crude palm oil factories due to the fact that most of water is used as boiler feed and turbine cooling water. Cooling water of the turbine is recycled in the production process for cleaning machines and domestic purposes.

Table 5.2 Water demand for the crude palm oil production process of factory A

Unit process	Consumption	
	m^3/ton FFB	m^3/day
Boiler feed water for steam generation and turbine generator	0.76	272
Low pressure steam leaving the turbine generator is (re)used in		
• Sterilizer	0.15	54
• Digester	0.02	7
• Other machines such as nut dryer, or storage tanks (crude oil storage tank, hot water storage tank)	0.33	211
Water used in the production process and domestic purposes (reused water from the cooling system of the turbine)	0.50	180
• Screw press	(0.08)*	(29)*
• Vibrating screen	(0.025)*	(9)*
• Separator	0.09 (0.015)*	32(5)*
• Cleaning separator & decanter, clay bath	0.09	32
• Miscellaneous usage	0.32	116
Total water consumption	1.26	452

Note:* Numbers between ( ) indicate quantity of condensed sterilization water reuse in screw press, vibrating screen and separator.
Production capacity is 360 ton FFB/day

Water in this factory is required for the following processes:

- For power generation, as cooling water for the turbine used to generate electricity.
- For sterilization and digestion steam from the boiler is applied to autoclave to facilitate the stripping of fruit from FFB and to digestion in order to facilitate homogenization.
- For extraction to remove the oil from the fiber.
- For oil recovery from the sludge (concentrated wastewater from oil clarification tank). The water is used as dilution water for the sludge to adjust the concentration of the sludge before going to the separator.
- For removal of large particles from the oil by a vibrating screen. Hot water is used to clean the surface of the vibrating screen.
- Miscellaneous usage such as heating of the equipment/machines, cleaning machines (decanter and separator) and floors.

5.2.3 Output

Product. The average processing capacity of the company is 45 tons FFB/hour. At 8 hours operation, processing 360 tons of FFB/day, an average total amount of 63.2 tons of crude palm oil is produced. The maximum production capacity of the company reaches 1000 tons FFB/day (24-hr. operation) during the high season of palm fruit. In 2002, the average production capacity of the company was about 60% of the designed processing capacity. The actual production capacity of the company depends on the amount of fresh fruit bunch that can be purchased. The quantity of crude palm oil and palm kernel equal 40,000 and 11,000 tons/year respectively. This factory operates 300 days/year. The quality of crude palm oil of the company is indicated by the following parameters:

- % Free fatty acid less than 5%
- % Moisture content less than 5%
- % Contaminants less than 0.01%
- Iodine value 50 – 55

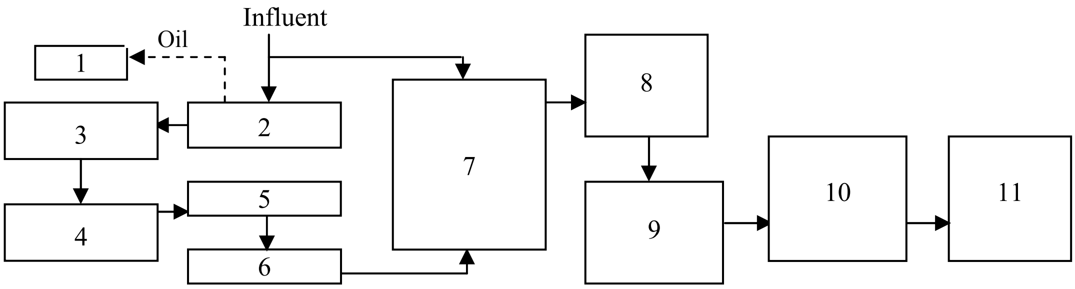
Wastewater generation. The main sources of wastewater are the sterilization process and the oil separation process. The combined wastewater from the production process resembles brown concentrated slurry with a high organic content. The results from analysis of the raw wastewater from the production process show that the biological oxygen demand (BOD) and the chemical oxygen demand (COD) are very high: 52.2 and 68.3 g/L respectively (Table 5.3).

Table 5.3 Characteristics of the wastewater from the production process and wastewater treatment plant of factory A (October, 2002)

Sampling point	pH	BOD_5 (mg/l)	COD (mg/l)	SS (mg/l)	TS (mg/l)	TKN (mg/l)	TP (mg/l)	O&G (mg/l)	Color (pt.Co unit)
Sterilizer	4.93	44900	-	18000	-	-	-	6170	-
Separator	4.76	79200	-	72270	-	-	-	5220	-
Raw wastewater	4.83	52200	68341	30933	57650	1020	40	7250	10000
Pond 3	8.20	458	4307	2400	15080	372	20	78	4833
Pond 6	8.63	108	2036	691	8420	98	8	19	4000
Pond 8	8.69	255	2092	500	11725	104	6	15	4900
Pond 9	8.90	80	1926	373	11200	120	5	4	4600
Pond 11	9.37	36	963	100	7497	38	0.4	0	1750
Thailand's Eff. Standard	**5-9**	**20**	**120**	**50**	**3000**	**200**	-	**5**	-

The ratio of BOD and COD is 0.76, which means that the organic compounds in wastewater are easily biodegradable. It has been found that the BOD of the wastewater after anaerobic digestion (anaerobic pond 3) is reduced to 458 mg/L (99.1% BOD removal efficiency). The total solids (TS) and suspended solids (SS) in the wastewater are very high too: 57.7 and 30.9 g/L respectively. The SS in the wastewater originate from the fine particles of the fibers that contaminate the oil-water slurry while pressing fiber. Wastewater from this industry also contains high amounts of nitrogen and phosphorus containing compounds. The oil content in the wastewater is 7,250 mg/L. Raw wastewater also contains high color concentration (10,000 pt. Co unit).

The wastewater treatment plant consists of anaerobic ponds and oxidation ponds in series. The first 2 ponds are used for the separation of oil from the wastewater. The 3^{th} – 7^{th} ponds are anaerobic digestion ponds. Pond 8, 9 and 10 are oxidation ponds and the last pond is polishing pond (Figure 5.4). The wastewater in the last pond still contains a high concentration of TS, COD and color. Most parameters do not meet the Thai effluent standards given for BOD, COD, SS and TS. Therefore most of the crude palm oil industry has to store their wastewater in their ponds and has to prevent overflowing in the raining season, in general also factory A. The total volume of the treatment ponds in factory A is 335,000 m^3 and the detention time of the wastewater in the treatment plant is about 700 days (wastewater generated is about 450 m^3/day). The wastewater evaporates to the atmosphere during the dry season. Consequently the color intensity and TS of the wastewater in the final pond is high. At present the data of wastewater characteristics from this factory indicate a high potential of heavy pollution.



Pond 1	Oil collecting pond(20*38*2 m^3)	Pond 5	Anaerobic pond (20*75*3.5 m^3)	Pond 9	Oxidation pond (80*95*4 m^3)
Pond 2	Oil trap pond (30*75*3.5 m^3)	Pond 6	Anaerobic pond (20*75*3.5 m^3)	Pond 10	Oxidation pond (82*100*4 m^3)
Pond 3	Anaerobic pond (30*25*3.5 m^3)	Pond 7	Anaerobic pond (110*191*4 m^3)	Pond 11	Maturation pond (78*106*4 m^3)
Pond 4	Anaerobic pond (30*25*3.5 m^3)	Pond 8	Oxidation pond (110*120*4 m^3)		

Figure 5.4 Layout of wastewater pond system of factory A

Solid wastes and by-products. Solid wastes and by–products generated in the palm oil extraction process are: empty fruit bunches, fibers, shell, decanter cake and ash from the boiler. The quantities of these materials are summarized in table 5.4. Solid waste can be reused in the production process, oil palm plantation or sold to other industries. The problems of the solid waste management in this factory are improper storage and handling of the solid waste material and the disposal techniques on the land.

Table 5.4 Quantity of solid wastes/by-products generated form the factory A (October, 2002)

Source	Solid waste/ by-product generated	
	kg/ton FFB	ton/day
Empty fruit bunch	230	83
Fiber	140	50
Shell	55	20
Decanter cake	32	12
Ash	50	21

Note: based on production capacity of 360 ton FFB/day

Air pollution. Particulate matter and smoke are generated from the burner/boiler in the wet process factories due to incomplete combustion of the solid residues. Palm oil mills are generally self-sufficient in terms of energy due to the availability of adequate quantities of fiber and shell materials used as solid fuel in the steam boiler and electrical power generator.

At present, the production activities of company A have not caused serious pollution to the environment and surrounding communities, even though this factory is located very close to them. This is due to a proper management of the wastes, such as:

- Wastewater is stored at the site of the company. All wastewater generated is stored in the treatment ponds without discharge to the environment.
- Most solid wastes or by-products can be sold or stored in the factory before transport to reuse as land filling. Decanter cakes, which cause bad smell are disposed everyday.
- This factory uses fiber as fuel in the boiler. Fiber causes low particulate matter emission, resulting in a low impact of air pollution from the factory.
- Relatively small amounts of oil accumulate in the anaerobic pond because the percentage of oil loss in the wastewater is low.

5.2.4 Material and energy balance

A more detailed discussion of the material and energy balances of the production process is presented below:

5.2.4.1 Mass balance of sub-processes

Sterilization

Sterilization of the FFB is done batch wise in autoclaves in batches of 20 to 30 ton, with the application of steam at a temperature of 120 – 130 °C (pressure about 3 bar) for 75 min. The mass balance of sterilization process is shown in Figure 5.5. The purpose of sterilization is:

- Prevention of a free fatty acid increase in the fruit due to microbial conversion.
- Facilitation of stripping of the palm fruit from bunch stalk.
- Preconditioning of the nut and minimize kernel breakage during processing and nut cracking.

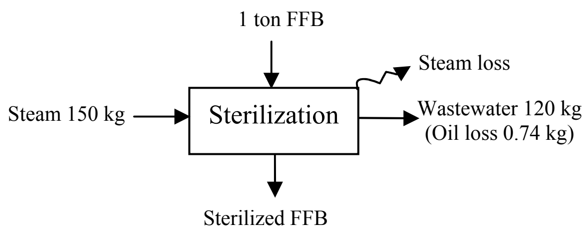


Figure 5.5 Mass balance of the sterilization step

After sterilization, steam is blown out for 10 minutes to release pressure in the autoclave. The sterilized condensate is released and collected in a sump by gravity flow. One ton of FFB generates 0.12 m^3 condensate as wastewater that contains 0.74 kg of oil. This condensate is pumped for reuse to the screw press, vibrating screen and separator to reduce the water consumption and to recover oil from the wastewater.

Thresher

Two rotary drum strippers are used for separating the sterilized fruit from the bunch stalks. Empty fruit bunches (EFB) from the first stripper are fed to the second stripper to minimize fruit loss with the EFB. This method can increase oil yield by 10 %. This process generates 230 kg EFB /ton FFB (Figure 5.6).

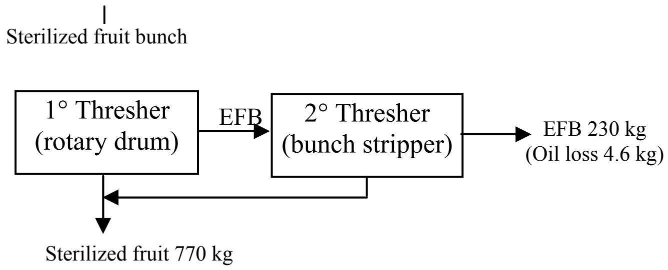


Figure 5.6 Mass balance of thresher step

Digestion

The fruit is fed into a vertical steam heated vessel with stirring arms (digesters). Here the fruits are treated mechanically to convert them into a homogeneous oily mash. The temperature in the digester is maintained at 90 °C. Steam is pumped into the digester to facilitate homogenization (Figure 5.7). The mash is subsequently fed into the oil extraction press.

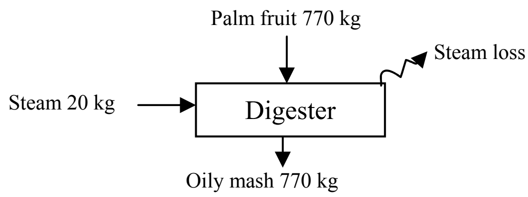


Figure 5.7 Mass balance of digestion step

Oil extraction and solid waste/ by-product separation

Palm oil is extracted by means of a continuous screw press system. The extracted oil is collected and sent to the purification process to separate water and suspended matter from the oil. Hot water is fed into the screw press to minimize oil loss in the pressed cake (fiber and nut). The pressed cake is transported to a separation system consisting of air clarifiers and cyclones for recovery of the nuts and fibers. The nuts and fibers are dried during this separation process by hot air, which is indirectly heated by steam to a temperature of 135 °C. Kernel is recovered from the nuts in centrifugal crackers and sold to a kernel oil mill. Fiber is sent to the burner for steam production. Ash from the burner is estimated at 50 kg/ton FFB. Figure 5.8 shows mass balance of oil extraction and solid waste/by-product separation step.

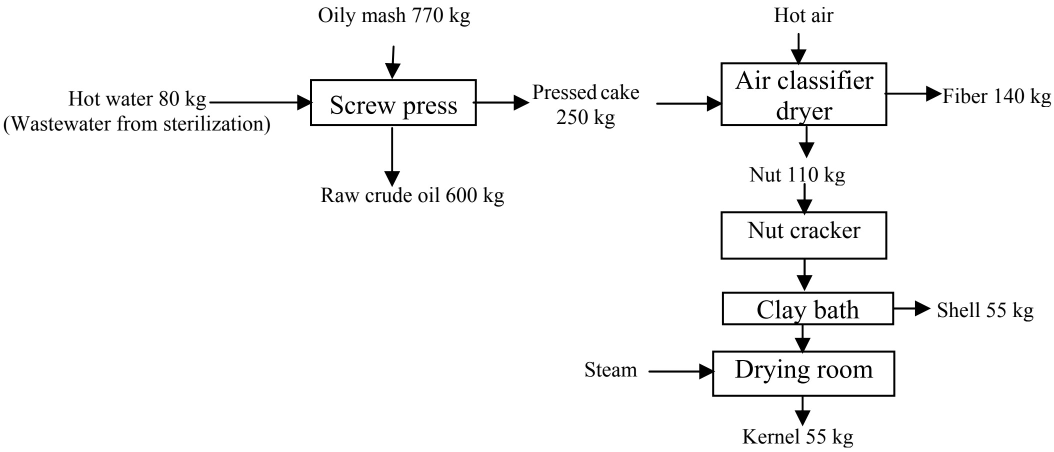


Figure 5.8 Mass balances of oil extraction and solid waste/by-product separation step

Oil purification

The raw crude oil is pumped to a vibrating screen, and subsequently to a sand cyclone to separate fibers and sand from the liquid phase before going into the settling tank. The mass balance of oil purification process is shown in Figure 5.9 and 5.10.

- ***Vibrating screen.*** Raw crude oil flows to a vibrating screen to remove coarse solids. The solids recovered from this screen have a high oil content and are conveyed back to the digester. For improvement of the oil clarification, hot water is added to the raw oil before it passes through the screen.
- ***Sand cyclone***. Raw oil is pumped to a sand cyclone to remove fine sand, which is necessary to avoid erosion problems in the equipment of the purification section. The collected sand is drained out every 30 minutes.

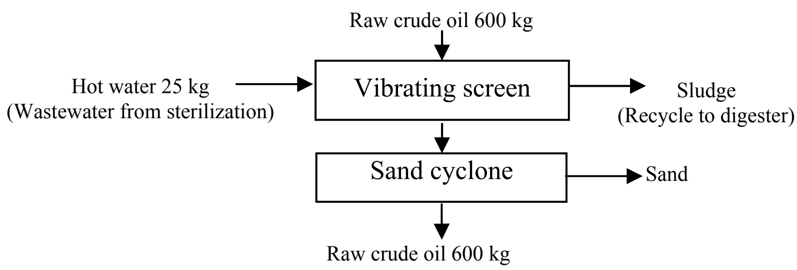


Figure 5.9 Mass balance of suspended solids removal step

- ***Settling tank***. The continuous settling tank method is the conventional method for separation of oil from water and suspended solids. Closed steam heating coils heat the raw crude oil in the tank to facilitate gravity separation. The lighter phase (oil) is collected by a funnel system and sent to a system for further purification. The settled oily sludge is collected in the sludge tank and is further processed in a decanter and separator.

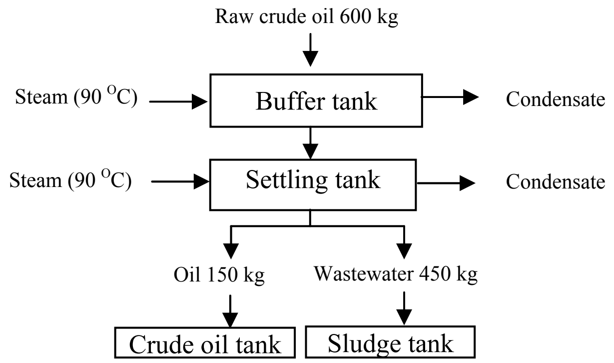


Figure 5.10 Mass balance of oil clarification step

- ***Purifier.*** The light phase (oil) from the clarification tank is fed into a crude oil tank and then to a purifier. This purifier consists of a two–phase centrifuge used for solid removal. This process step generates small volumes of wastewater due to the low suspended solids content in the raw crude oil.
- ***Vacuum tank***. The moisture content in the oil is removed by a vacuum evaporation system. The dry crude oil is kept in storage tanks and sold to a refinery. The temperature of the oil (60 °C) in the storage tank is maintained with steam coil heating.

Treatment of wastewater (bottom sludge) from settling tank

The bottom sludge from the settling tank has a high oil content (7% of sludge) and a high concentration of organic substances. To recover oil and decrease the organic load of the wastewater, the settling tank sludge is further treated as follows:

- ***Sand cyclone***. The bottom sludge is sent to the sand cyclone (hydrocyclone). This cyclone separates sand from wastewater. The accumulated sand is then drained. The wastewater generated is 5L/ton FFB (Figure 5.11).
- ***Decanter.*** The purpose of the decanter is to remove remaining solids (fine particles) and water from the sludge leaving the sand cyclone and to recover oil. The oil is sent to a purifier.
- ***Separator***. Sludge is pumped to the separator for oil recovery. Hot water is added to the sludge to improve the oil separation efficiency.

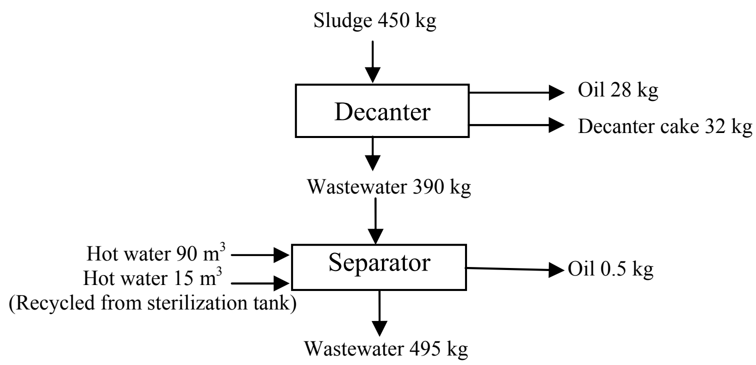


Figure 5.11 Mass balance of sludge treatment step

5.2.4.2 Mass balance of production process

Material balance. This balance only considers the (dry weight) flow of all raw materials through the production process including product, by-product and solid waste. The mass balance in terms of dry weight of material is based on 1 ton of fresh fruit bunch (wet weight) and can be expressed as follows:

Mass of fresh fruit bunch = mass of crude palm oil + mass of kernel + mass of empty fruit brunch + mass of fiber + mass of shell + mass of decanter cake + total solids in wastewater + mass of solid waste

Or:

1,000 kg*(1-0.35)(35% moisture content) = 178 + 55 (1-0.05) + 230 (1-0.3) + 140 (1-0.3) + 55 (1-0.1) +32 (1- 0.8) + 34 + mass of solid waste (sand, soil, etc.)

Or: 650 kg = 579.1+ mass of solid waste

This means: Mass of solid waste = 70.9 kg

Thus, the amount of dry solid waste is 70.9 kg/ton FFB. This amount of solid material (sand, spilled raw material, etc.) is disposed as waste to the environment. The mass balance for material flows in terms of dry weight are described in Figure 5.12.

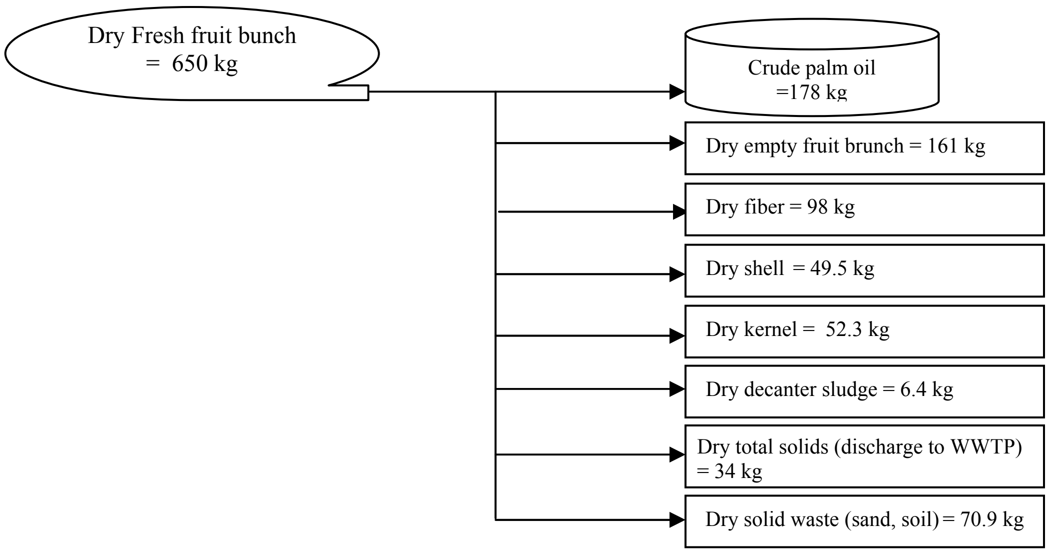


Figure 5.12 Mass balance in terms of dry weight

Liquid material balance. The total water use in the mill is 1.2 m^3/ ton FFB, of which 0.5 m^3/ton FFB is used for the production processes, and 0.085 m^3/ ton FFB is recycled in production process. The generated wastewater is 0.59 m^3/ on FFB. The volume balance of liquid material flows is described in Figure 5.13.

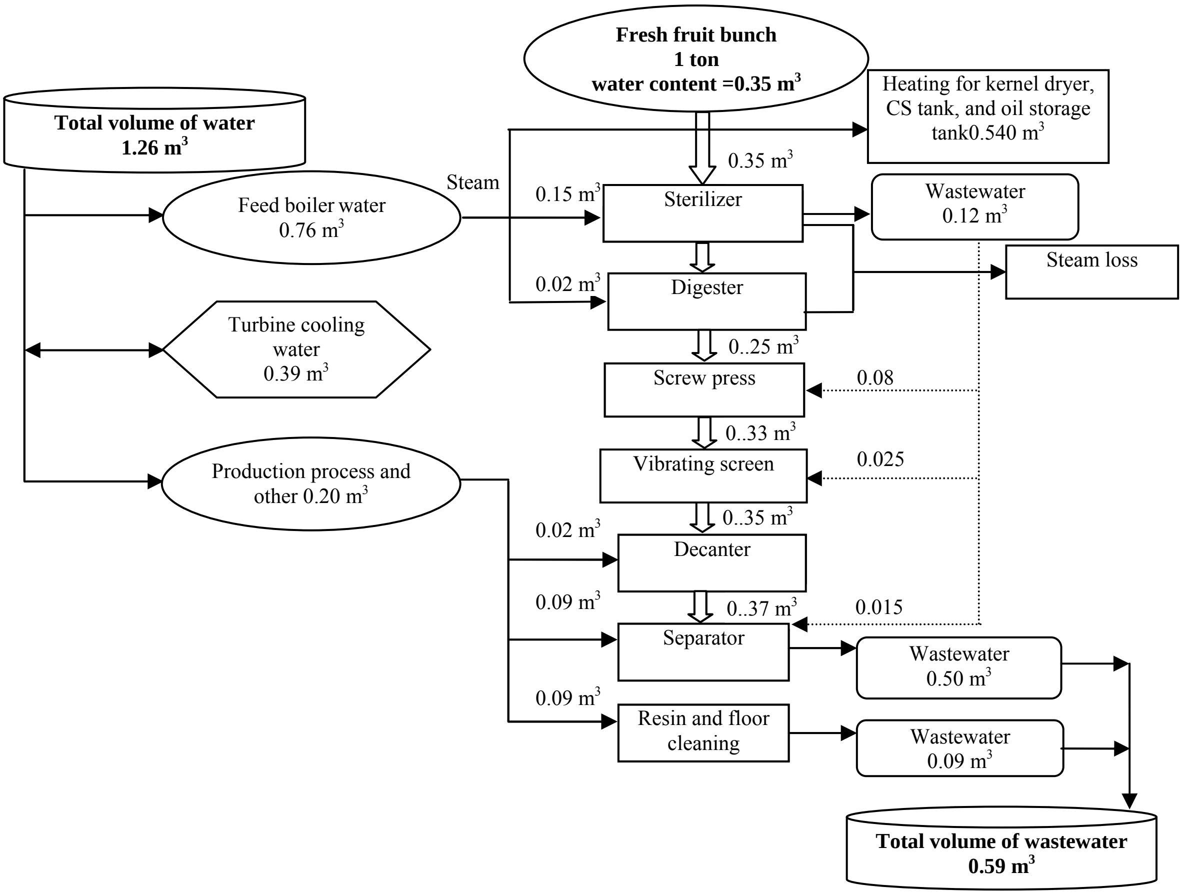


Figure 5.13 Water balance of factory A

5.2.4.3 Energy balance

Energy Analysis

Thermal energy and electricity are the two main forms of energy utilized in the palm oil mill. Process steam is supplied by a cogeneration system to produce both electricity and steam. The factory uses a backpressure steam turbine for power and heat generation. Waste materials from the production process are mainly composed of fiber and shells. These are used as fuel to produce steam. Fiber and shell is fed to the boiler in a ratio of 80:20. The amount needed is 165 kg fuel/ton FFB or 59 ton/day. The feed water needed is 0.76 m^3/ ton FFB. The output steam generates about 0.56 ton of steam/ton FFB. The steam is then expanded through a turbine to generate an output power for the process. The electricity generator provides about 510 kW (5,492 kWh/day) during 8 hours of operating processes. The factory is co-generating electricity during all operating days and purchases electricity for start up purposes and during non-operating hour. A cogeneration system, using a backpressure steam turbine, consists of a combustion chamber, boiler and steam turbine.

Combustion chamber. The fuel is burnt to process heat requirements. The temperature of flue gas from the stack is 360 ^oC. A dust collector collects the fly ash. The bottom ash is removed manually at the gate. These ashes (fly ash and bottom ash) are collected and disposed of as waste. For processing 1 ton of FFB 165 kg fuel is burnt to gain an amount of energy of

2,114,000 kJ. This energy is used to heat 760 kg boiler feed water from 70 ^oC to 240 ^oC. The main energy losses in the combustion chamber occur in the stack flue gas. A detailed energy analysis in factory A is shown in Table 5.5.

Table 5.5 Energy balance of production process of factory A

Unit operation	Inlet				Outlet			
	Flow	Temp ^oC	Mass kg	Energy MJ	Flow	Temp ^oC	Mass kg	Energy MJ
Boiler	Make up water (plus recycled condensate) Fiber & shell	70 30	780 165	140 2,110	Steam genrated Exhaust steam Stack loss, Other loss (blowdown, radiation, convection, etc.)	240 240 360	400 200 -	1,120 630 400 100
	Total			**2,250**	**Total**			**2,250**
Electric generation	Cool water out Steam	35 240	390 400	10 1,120	Steam Electricity (kWh) Exhaust steam	140 -	350 15.3	950 55 125
	Total			**1,130**	**Total**			**1,130**
CPO production	Steam Electricity (kWh)	140 -	350 15.3	950 55	Crude oil Wastewater Exhaust steam Energy loss	55 90 130	178 588 130	0.5 221 355 428.5
	Total			**1,005**	**Total**			**1,005**

Boiler. The boiler generates high-pressure steam by transferring heat to the incoming high-pressure boiler feed water. The boiler is a water-tube with a capacity of 20 ton/hr. The boiler provides steam to generate enough electricity to supply the whole demand in the factory. For processing 1 ton of FFB, 400 kg steam (1,120 MJ) is needed to generate enough electricity for the production process. The main energy losses that occur in the boiler are due to exhaust steam, stack loss and others such as: blow down water, radiation and convection.

Turbine. In the steam turbine, the incoming high pressure steam is expanded to a lower pressure level, converting the thermal energy of high pressure steam to rotating blades, kinetic energy and finally into electrical energy. The on peak load of this factory is 658 kWh. From a survey it is clear that the electricity generator provides about 510 kWh or 15.3 kWh/ton FFB (55,080 kJ/ton FFB). The extracted steam from a backpressure steam turbine meets the heat demand at pressure levels higher than the exhaust pressure of the steam turbine. Total energy loss in the production process of factory A is 2,110 MJ per ton FFB processed. 50% of energy loss occurs in the boiler. The rest, 38% is lost in the production process. Power and steam from the turbine are supplied to the production process. The details of electricity supply in the production process are shown in Fig. 5.14.

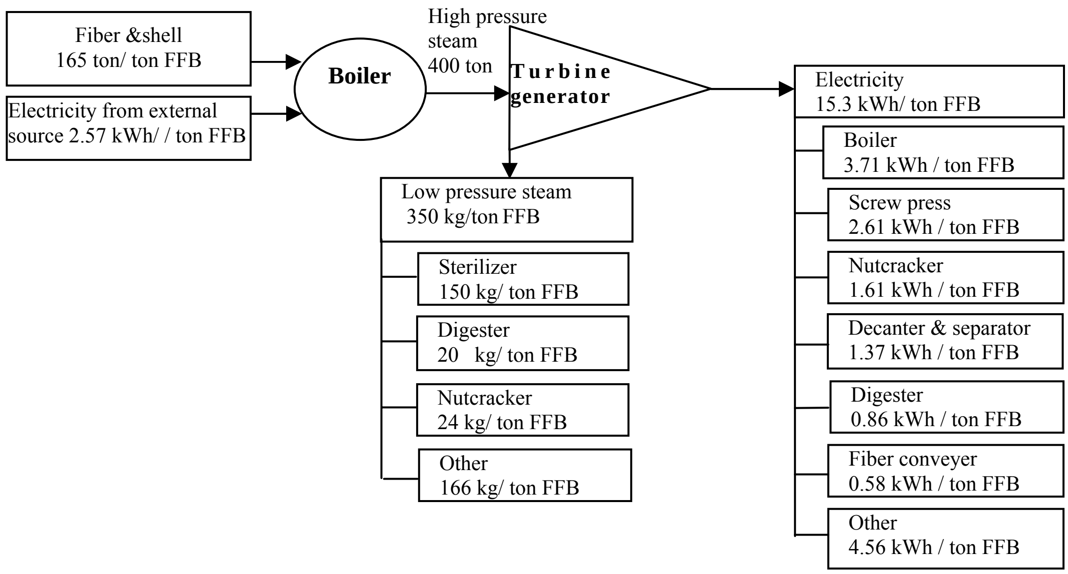


Figure 5.14 Energy balance in the production process of factory A

Steam after use for generating electrical power (350 kg/ton FFB) is sent to the sterilizer, digester and other steps in the production process, to control the temperature of the production process. The excess steam in the sterilizer has to be blown out from the sterilizer once a pressure of 3.2 bars is reached. After sterilization the steam is released until the pressure in the sterilizer is 1 bar. For the temperature control system, the steam is sent to a steam coil in the hot water tank, settling tank, nut dryer tank and oil storage tank and finally blown out. From Table 5.5 it can be seen that energy input in production process is about 2,250 MJ/ton FFB and that energy output in the form of enthalpy in crude palm oil and high temperature wastewater is about 221 MJ/ton FFB. Finally, energy is lost from by-product/ waste and wastewater by temperature decrease. Most of the energy loss is from the steam exhaust. Figure 5.15 shows the energy balance in the crude palm oil production of factory A.

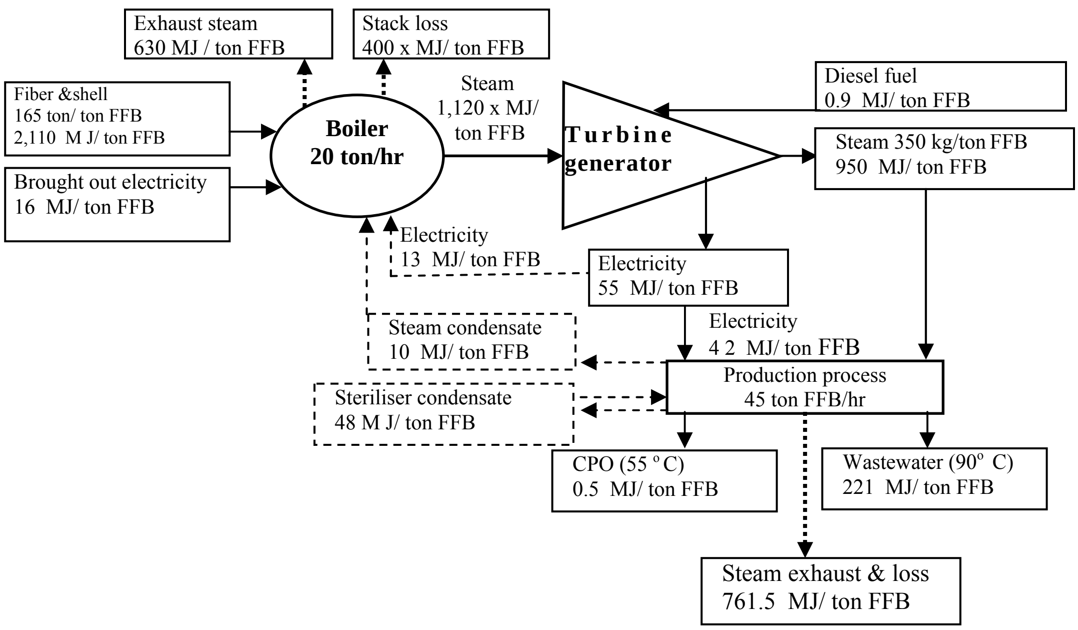


Figure 5.15 Energy balance in the production process of factory A

5.2.5 Cost Analysis

The cost benefit analysis of the crude palm oil factory is established to find out the economic performance. From the data obtained from the factory, the profit/loss from crude palm oil production can be estimated. The FFB price depends on the CPO costs. Generally the price of fresh fruit bunch varies depending on the season of the year. During the wet season, fresh fruit bunch costs 1.5 - 2 Baht per kg. During the dry season, the fresh fruit bunch costs 3-4 Baht per kg (year 2002). The fresh fruit bunch is more available in wet season.

Production costs consist of the expenditure for purchasing fresh fruit bunches, electricity, diesel fuel, chemicals, labor and machine maintenance. The company earns money from selling crude palm oil, palm kernel, shell and empty fruit bunch. The total production costs and income are described in Table 5.6. For depreciation, the calculation is based on 20 years or equivalent to 5%/year of total investment capital (including machinery and buildings). This investment capital amount is 180 million Baht.

Table 5.6 Production costs per ton crude palm oil of factory A (2002)

Items	Unit	Amount	Unit cost	Total cost (Baht/ day)	Cost (Baht/ ton FFB)	Cost (1) (Baht/ton CPO)
Variable cost						
FFB*	ton/ day	360	1,500 Bath/ ton FFB	540,000	1,500.0	8427.0
Electricity	kWh/ day	925.2	3.01 Baht/ kWh	2,785	7.7	43.5
Diesel fuel	L/ day	68	15 Baht/ L	1,020	2.83.0	15.9
Raw water production**	kg/ day	308.8	8.7 Baht/ kg	2,687	7.5	41.9
Chemical cost**	kg/ day	531	13.32 Baht/ kg	7,076	19.7	110.4
Fixed cost (2)						
Labor	person/ day	120	165 Baht/ person	19,800	55.0	309.0
Maintenance cost	Bath/ year	12,000,000	-	33,000	91.7	515.0
Depreciation	% / year	5	9,000,000 Baht/year	30,000	83.3	468.5
Total (2)					1,767.7	9,931.2

Note 1 EU= 50 Baht
* Price of empty fruit bunch varies between 1,500-4,000 Baht/ ton.
** Cost of water supply and chemical are estimated in figure 5.17
(1) Extraction efficiency = 17.8%
(2) Not including office expresses and cost of distribution. (~10% of total cost)

Figure 5.16 illustrates the income from selling product and by-products of factory A. It is clear that the income from selling by-products is very low compared to that from the product. Figure 5.17 summarizes costs of water treatment and chemicals for processing fresh fruit bunch.

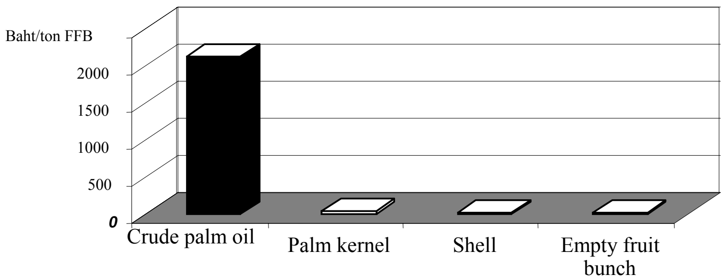


Figure 5.16 Income per ton of fresh fruit bunch processing (Baht/ton FFB) of factory A (2002)

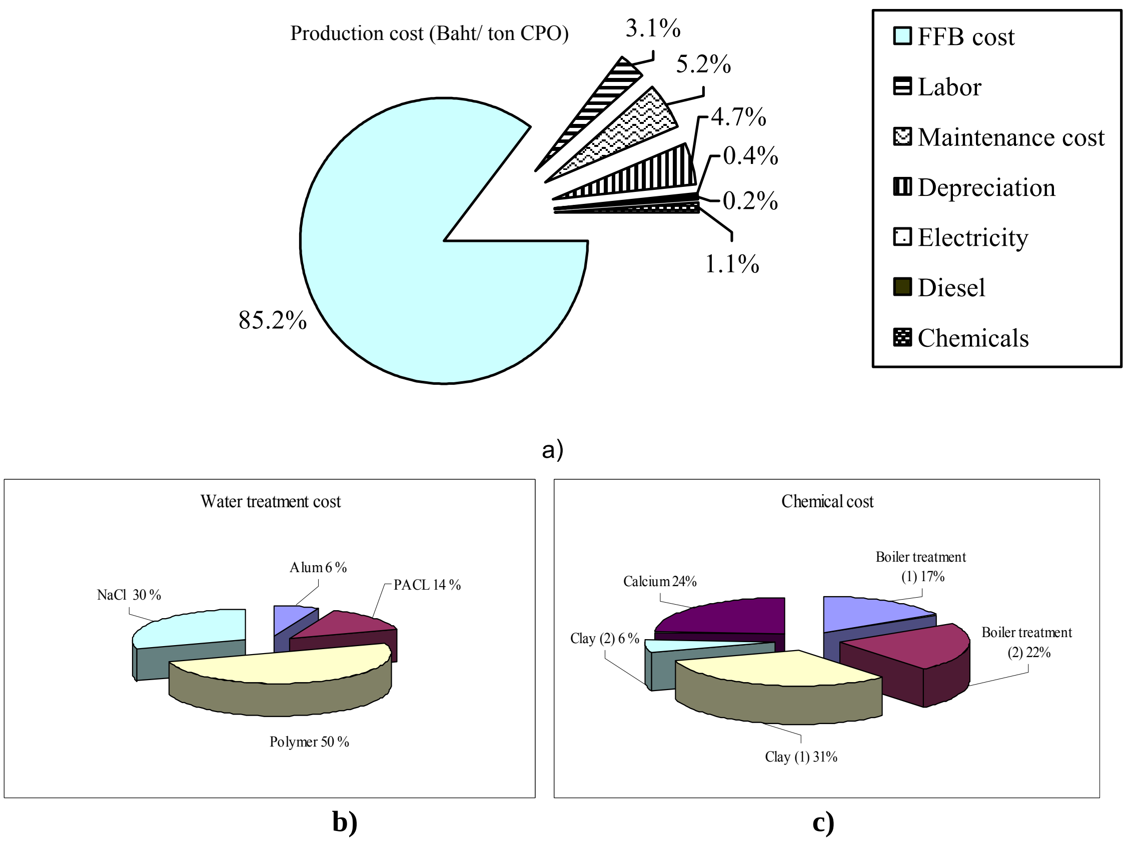


Figure 5.17 Costs of CPO production consumed by factory A (2002)
a) Total production cost; b) Water treatment cost and c) Chemical cost

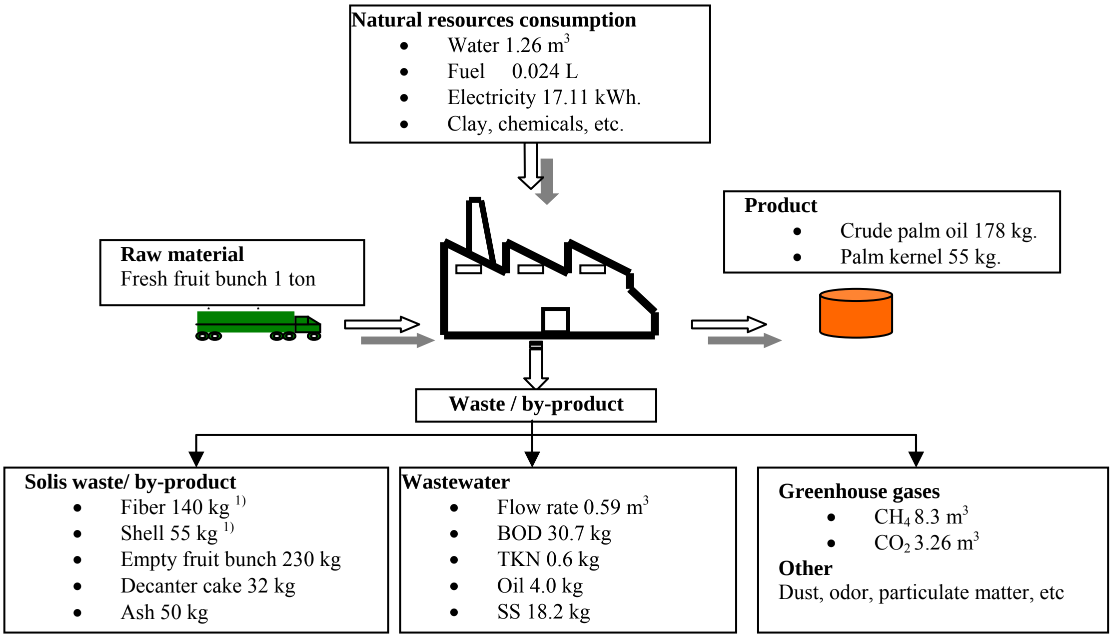
5.3 Existing environmental performance of factory A

5.3.1 Waste generation

The substances found in the products, by–products and residues originate from the fresh fruit bunch. However, there are a number of pollution problems at the facility, such as high water consumption, generation of wastewater with a high organic content, generation of a large quantity of solid waste and emissions of greenhouse gasses. The pollution problems which have an environmental impact on the people living in the vicinity of the factories are inefficient wastewater treatment and smell from the anaerobic ponds. Figure 5.18 shows the waste generation from Factory A.

5.3.2 Existing Industrial ecosystem in factory A

The crude palm oil industry is applying a number of industrial ecosystems for waste recycling and abatement of emission. The nature of these ecosystems can be differentiated in in-plant, cross industrial and cross-border measures. The details of these three types of measures of factory A are as follows:



Note: 1) Part is used as energy source

Figure 5.18 Waste generation from factory A

1) In-plant Ecosystem (clean technology option)

- **Beneficial use of fiber and shell in boiler**

Factory A operates a cogeneration system, using fiber and shell as fuel in the boiler, to produce high pressure steam, which is expanded in a steam turbine to produce electricity. Table 5.7 shows the chemical composition and caloric value of fiber and shell. Low-pressure steam is used in the manufacturing process for sterilization, digestion, and purification, and also for controlling the temperature in production process. The electricity generated is used to supply the mill's electricity requirement, which is estimated at 15.3 kWh per ton of fresh fruit brunch processed. Based on 1 ton FFB processed 135 kg of fibers and 30 kg of shell are burned to supplement the steam required in the production process.

Table 5.7 Chemical composition on dry basis of fiber and shell (Mahlia et al., 2001)

Element	Fiber	Shell
H (%)	6.0	6.3
C (%)	47.2	52.4
S (%)	0.3	0.2
N (%)	1.4	0.6
O (%)	36.7	37.3
Ash (%)	8.4	3.2
Gross caloric value (kJ/kg)	17,400	19,500
Net caloric value (kJ/kg)	11,300	17,500

- **Recycling of sterilizer condensate**.

After the production of electricity, the steam is sent to the sterilizer. Sterilization of FFB is done batch wise in an autoclave with a 20-30 ton FFB load capacity. The amount of sterilization condensate is about 0.12 m^3/ ton FFB. This wastewater is recycled to the screw press and vibrating screen to reduce the amount of hot water needed for these processes. This is shown in Figure 5.3 and 5.13. Moreover, the sterilizer condensate contains about 0.62 % oil, which is recovered as crude oil in the settling tank.

For factory A, with an operation capacity of 173,000 ton FFB/year, an one-off investment of approximately 135,000 Baht for pumps, tanks etc., this option saves on water production costs about 62,000 Baht per year. The water production costs are expected to be 3.0 Baht/m^3 (year 2002). The recovery of oil from the recycled wastewater is about 0.74 liter/ton FFB. Benefit from this increased oil yield is 1.28 million Baht per year. Total profit for this option is around 1.34 million Baht per year.

- **Recycling of excess steam condensate**

A portion of steam from the turbine is used for drying kernels in the kernel drying silo and a portion is used in the vacuum dryer to eliminate water from the crude palm oil. In the last stage condensate is generally discharged as wastewater. This condensate is recycled in the mill. Condensate from the kernel dryer is reused as boiler feed water and condensate from vacuum dryer for cleaning the decanter and separator. These options reduce the water consumption and wastewater generation. An additional benefit of this approach is the energy saving for heating water to 90 °C (Fig 5.19). It is estimated that approximately 0.03 m^3 of hot water per ton FFB is saved by recycling the excess condensate.

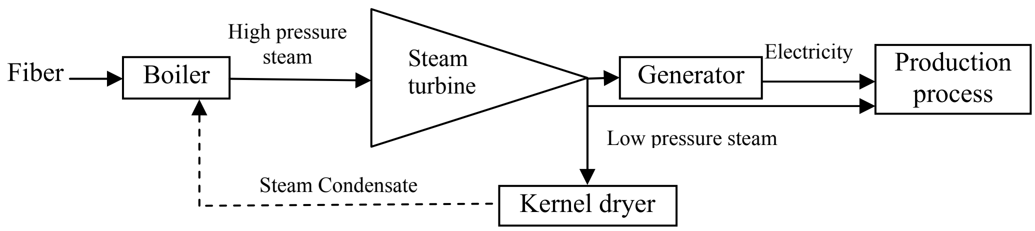


Figure 5.19 Recycling of condensate to the boiler

2) Cross-industry ecosystem

- **Shell as fuel in cement factory**

Fiber and shell are used as boiler fuel in the factory. However, fibers alone are more than sufficient as fuel for the boiler. A part of the shell is sold as solid fuel for cement and brick factories. One ton of shell sells for 170 Baht. Another use of shells is for the production of activated carbon, which should be further investigated.

3) Cross-border ecosystems

- **EFB as a substrate for straw mushroom cultivation**

At present, EFB is returned back to the field as media for growing straw mushroom (a special type of mushroom). EFB is used directly as a substrate for mushroom cultivation. About 30 kg of mushrooms can be harvested from 1 ton of EFB and sold for 45 Baht/kg mushroom. The factory sells EFB for 150 Bath/ton. After the mushroom harvest, EFB is available as palm fertilizer. Analysis of its composition indicates that it contains high amounts of plant nutrients. Figure 5.20 shows the flow diagram of mushroom cultivation on EFB.

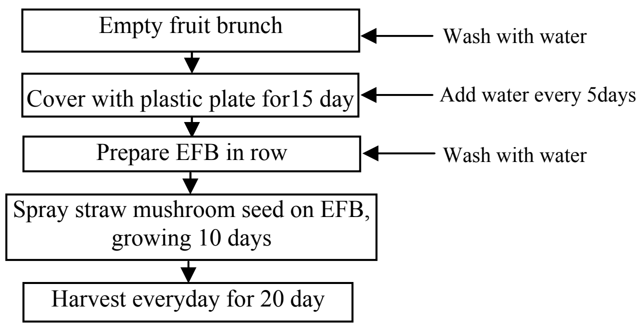


Figure 5.20 Flowchart of straw mushroom cultivation using empty fruit bunch as media

5.3.3 Model of existing industrial ecosystem of factory A

Figure 5.21 presents a diagram of the crude palm oil mill A. For the purpose of an environmental evaluation, the estimated mass balances are based on processing 1000 tons of fresh fruit bunch per day, harvested from 18,000 hectares of oil palm plantation area, producing 178 ton of crude palm oil and 55 ton palm kernel for selling to the oil refinery industry. The production process generates about 590 m^3 of wastewater, 230 tons of empty fruit bunch, 140 tons of fiber, 55 tons of shell and 32 tons of sludge from the decanter.

In conclusion, only 23 % of the raw material is product (oil and kernel), the rest is by-product and waste. Even though most of the by-products can be sold or reused, there is a lot of waste that has to be treated before disposal. These wastes include 590 m^3 wastewater, 50 ton ash and 32 ton decanter sludge. Since factory A is located far from the plantation area, recycling of wastewater for irrigation is not an option because the transportation is very expensive. Meanwhile, coconut plantation areas nearby the factory do not want the wastewater for irrigation. So, the wastewater has to be stored in ponds without discharge. The company pays to transport the decanter sludge and ash everyday, because these wastes cause bad smell and dust, which are a nuisance to the people in the vicinity of the factory.

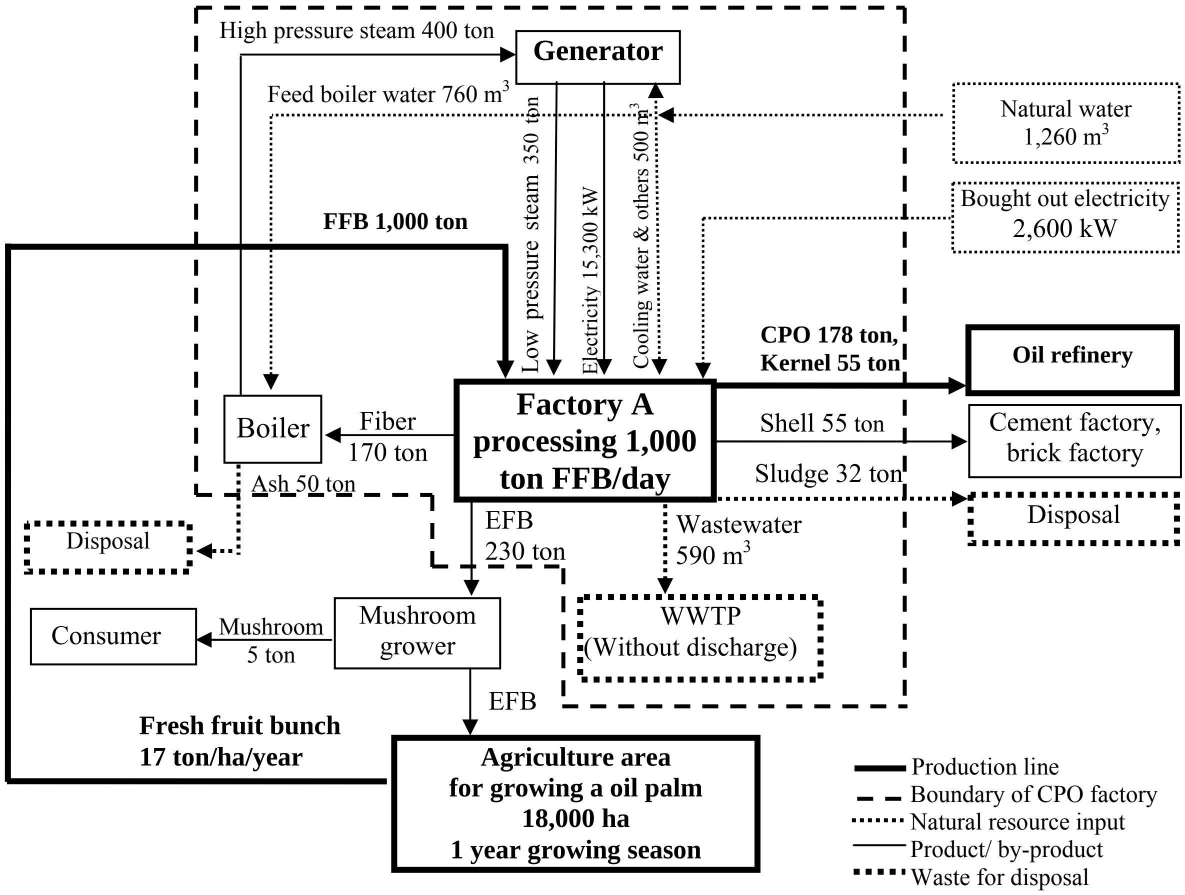


Figure 5.21 The existing industrial ecosystem model of factory A

5.4 Improving environmental performance of factory A.

This paragraph deals with possible solutions for the existing environmental problems of factory A. The options proposed here will aim to improve the environmental performance of this factory and also to make the palm oil production in this factory environmentally more sustainable. Based on many researches, both in Thailand and Malaysia, only the solutions that can be implemented easily will be discussed.

Residues from the crude palm oil processing of factory A consist of empty fruit bunches, shells, fiber, decanter cake, ashes and wastewater. Some of them are already beneficially used. Residues, such as EFB and shells, are already reused/ recycled as solid fuel; other options, with more added values, will be discussed. For wastes which have to be disposed, such as decanter sludge and ash, possible solutions will be proposed based on recent research.

Possibility for offsite reuse and recycling of each kind of solids non-product will be also describes.

5.4.1 Alternative reuse/recycle of empty fruit bunch

- ***Organic composting***

At present, EFB are sold for 150 Baht/ton EFB, which corresponds with about 6 million Baht/year. EFB can be used as medium for mushroom cultivation in the plantation area. EFB can also be used as a soil cover material in the oil palm plantation to preserve moisture and reduce soil erosion. The fertilizer value is high. The N, P_2O_5 and K_2O content in EFB is 0.8%, 0.006% and 2.79% respectively (Unapumnuk, 1999). On the basis of nutrient content alone, these materials can be directly applied to the plantation area as fertilizer. When EFB is used conventionally as soil cover material, it takes almost a year to decompose. To transport this product is costly.

Composting is a method to be used to produce organic fertilizer from this by-product. Composting reduces the volume and the transportation cost of this bulky by-product by 50%. Unapumnuk (1999) studied the application of composting technology for complete mixtures of EFB, decanter sludge and urea (as N source). The test set-up was a batch process carried out in heaps, with a size of 2m x 2m x 1m and covered with plastic. The piles required turning and addition of water to control the moisture content to a level of 50%-60%. The composting piles were set up at an initial C:N ratio of 39:1 and showed a rapid degradation rate and maturated in 80 days. The maturated compost contained N, P_2O_5 and K_2O equal to 2.26%, 3.3% and 2.25%, respectively. The value of the nutrients in 1000 tons compost, based on the cost of chemical fertilizer is 135,529 Baht (whole sale market Bangkok, 1991). Table 5.8 shows the composition of EFB, decanter sludge and compost (dry basis), indicating compost has a higher plant nutrient content than EFB and decanter sludge.

Table 5.8 Composition of EFB, decanter sludge and compost (dry basis) (Unapumnuk,1999)

	EFB	Decanter sludge	Compost
Moisture content (%)	68.7	77.3	55
C, %	51.1	50.2	-
N, %	0.81	1.39	2.26
P_2O_5, %	0.006	0.96	3.3
K_2O,%	2.79	6.5	2.25
Boron, ppm	10	-	-

- ***Extraction of oil from EFB***

Another alternative reuse of EFB is extraction of oil. EFB has an oil content of 2%. Kittikhun (2002) studied the process of oil extraction from EFB by using a screw press with a capacity of 30 ton FFB/hr. In this study the EFB is first chopped and then pressed to extract the oil. The pressed EFB can be used as fuel in the boiler. The gross caloric value of EFB is about 18,000 kJ/ kg, which is more or less the same value as for fiber. The benefits are an increase of kernel of 1% and of oil yield of 0.5%. For factory A, when processing 173,000 ton FFB/year, the profit from this processing step can be calculated as follows:

- Profit from 1% kernel increase:

Kernel increase	=	173,000 ton FFB production/year *1%
	=	1,730 ton/year
Price of kernel	=	500 Baht/ton kernel
Profit from selling kernel	=	1,730*500 = 865,000 Baht/year

- Profit from 0.5% extra oil yield increase:

CPO increase	=	173,000 ton FFB production/year * 0.5%
	=	865 ton/year
Price of CPO	=	10,000 Baht/ton CPO
Profit from selling extra CPO	=	865* 1,000 = 8,650,000 Baht/year.

- Total profit from selling CPO and kernel = 9,515,000 Baht/year

The profit from this alternative option is higher than directly selling EFB. However, the possible pollution effect in this case is a higher BOD and SS load in the wastewater, since the extracted oil from EFB has a high suspended solids concentration, which has to be removed from the crude oil in the oil clarification step.

- ***Pulp and paper***

The EFB can also be used as pulp source. The Palm Oil Research Institute of Malaysia developed a method for the use of fibers from EFB to produce pulp and paper of high quality. Of the three types of oil palm fibers, being EFB, frond and trunk, the fiber from EFB is shortest. Table 5.9 shows morphological properties of fibers from the oil palm compared to hardwood and soft wood.

Table 5.9 Morphological properties of fibers from oil palm, hardwood and soft wood (Kamaruddin et al., 1997)

Property	EFB	Frond	Trunk	Hardwood	Softwood
Average fiber length, mm	0.67	1.03	1.37	0.83	2.39
Width of fiber, mm	0.012	0.015	0.02	0.015	0.27

Processing of EFB into pulp and paper can be achieved by two methods

- Kraft Pulp Method. Digestion of biomass with white liquor at 165^{o}C for 3 hours.
- Kraft Anthraquinone (Soda AQ) method. Conventional pulping with Anthraquinone as additive to improve fiber strength.

The paper made from empty fruit bunch has good tear strength properties and excellent opacity. The brightness is good (40%) compared to hardwood pulp (25%-30%). Sheet properties of Bleach Kraft Pulp are given in the table 5.10.

Table 5.10 Properties of Bleach Kraft Pulp (Kamaruddin et al., 1997)

Raw material	Opacity (%)	Density (g/m^3)	Tear (mNm^2/g)	Burst kPa m^2/g	Air permeability (sec)
EFB	80.6	0.63	11.7	4.5	10
Hardwood	74.1	0.63	9.5	4.5	15
Softwood	62,7	0.64	13.1	7.6	22

- ***Medium density fiberboard***

Another alternative use is medium density fiberboard (MDF) produced from EFB. The manufacture of MDF using EFB was studied in 1986. Husin *et al*. (2003) stated that EFB can be used for MDF production. The strength properties, measured as compression strength, exceeded 200 kg cm^{-2} as stipulated in JIS A 1408 for fiberboard. Ramli (2002) concluded that pretreatment of the fiber by using water or NaOH to remove its residual oil, significantly improved the MDF performance and eliminated delaminating during consolidation of the panels (Table 5.11). The results also showed that NaOH was more effective than water for removing oil. However, a poorer fiber was obtained with a higher bulk density, which also reduced the mechanical and physical properties. The dimensional stability of rest of the part met the commercial standard.

Table 5.11 Comparison of mechanical and physical properties of EFB, MDF after pre-treatment with water and NaOH using the National Particle Board Association (NPA) Standard (Ramli, 2002)

Pretreatment	Mechanical property				Physical property					Density
	Resin %	MOR MPa	MOE GPa	VIB KPa	WA2 %	WA24 %	TS2 %	TS24 %	LE 50/90	Davg kg/m^3
Hot water	4	34.3	2.4	785	52	61	25	27	0.58	1041
	6	7.9	3.0	827	44	51	15	17	0.31	1057
2% NaOH	4	19.3	1.7	655	78	82	41	44	0.60	1089
	6	27	2.2	689	64	74	33	36	0.56	1025
MDF property of NPA Standard		24.1[a]	2.1[a]	689[a]	-	14.6	-	11.9[b]	0.35[a]	-

Note: MOR= modulus of rupture; MOE= modulus of elasticity; WA2,WA24= water absorption at 2 and 24 hr; TS2, TS24= thickness swelling at 2 and 24 hr and LE= linear expansion at 50/90% RH; Davg= average density; a=National Particle Board Association 4-73.(11); b= Average values for higher density MDF (0.88SG).

5.4.2 Added value product from shell

In the crude palm oil extraction process, shell is a by-product. About 55 kg of shells are generated from processing 1 ton of FFB. Only 20% of shell is burnt together with fiber, the rest is sold as fuel in cement factories and brick production. The price of shell is approximately 170 Baht/ton. Conversions of the shell to a product with a higher added value, such as activated carbon, will directly turn the by-product into a resource for another industry. Commercial processes to produce activated carbon use a variety of raw materials including peat, coal, wood and coconut shell. Any cheap substance with a high carbon and low ash content can be used as raw material for the production of activated carbon. Shell from FFB has similar properties as coconut shell, but the B.E.T. surface area showed that shells have a higher specific surface than coconut shells, and therefore shell is likely to be a precursor for the production of activated carbon. The study of activated carbon production from shell using different activation procedures is shown in table 5.12. The yield of activated carbon prepared by zinc chloride activation shows a higher yield than when activated by steam. However, the cost of chemicals for the zinc chloride activation method is very high compared to the steam activation method for palm shell activated carbon. For commercial palm shell activated carbon, made in Nigeria (trade name MIDAC), the price ranges between 1,000 and 1,526 US$/ton. In general, the application of activated carbon is for color adsorption, particulate coagulation and de-chlorination in distilleries, bottling companies, refineries, chemical industries and used in water purification equipment and water filter cartridges.

Table 5.12 Properties of activated carbon from palm shell compared to coconut shell

Description	Minsirinun (1999)	Suravattanasakul (1998)	Panyawathanakit (1997)	Commercial Coconut shell
Carbonization	400^{o}C for 1 hr	750^{o}C for 3 hr	400^{o}C for 1 hr	No information
Activation	800^{o}C for 3 hr with zinc chloride	pyrolysis with air 30 min. before steam activation	900^{o}C for 1 hr with air	No information
Activating agent	Zinc chloride	Steam	Steam	
Yield (%)	33.83	12.18	19.31	18.8
Iodine number(mg/g)	1069	767	779	976
Methylene blue number (mg/g)	600	189	137	500
B.E.T.surface area (m^2/g)	1099	670	697	900

Factory A generates 5.5% of shell from processing 1 ton of FFB. In the year 2003, 173,000 ton of FFB was processed; the total amount of shell generated was about 9,515 ton. The preparation of activated carbon by activation with steam gives a yield of 19 % of shell (Panyawathanakit,1997). The factory has excess steam from the boiler for an activated carbon production capacity of 10 ton per day. The activated carbon can be sold for about 40,000 Baht /ton, gaining 72 million Baht/year, at an investment cost for the equipment of 30 million Baht. Based on the above figures, Factory A has a great potential for turning the abundant supply of these by-products into products with a high added value.

The preparation of raw materials involves sorting out of dirt and crushing the material to a suitable size. The crushed material is dried. The first step in the production of activated carbon is the carbonization of the shell to char at 400^{o}C for 1 hr. Then the char is crushed further to a smaller size, followed by activation with steam at 800^{o}C for 1 hr. This activated carbon could be used in commercial application (iodine adsorption higher than 600 mg/ g).

Figure 5.22 shows the optimum condition for the production of activated carbon from shell prepared by steam activation in a fixed reactor.

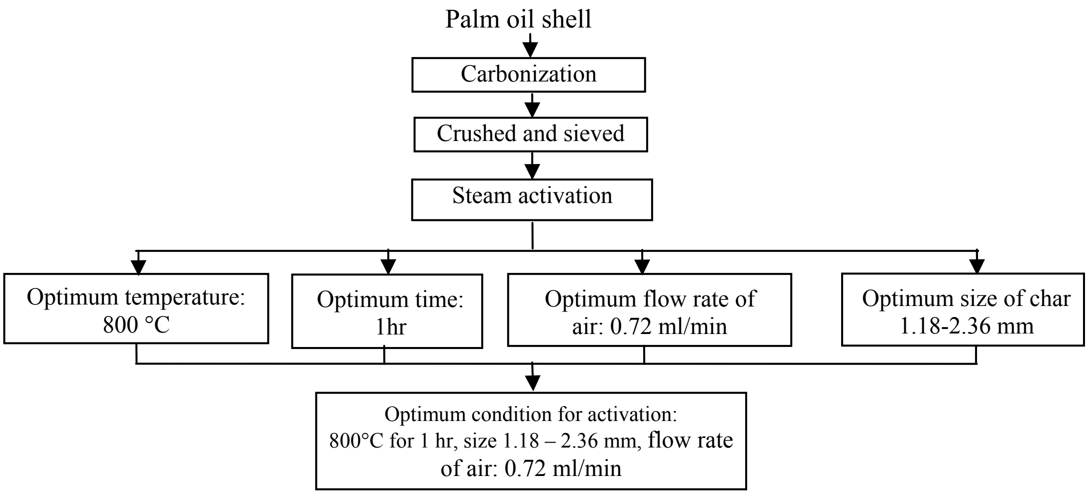


Figure 5.22 Production of activated carbon from shells by steam activation (Panyawathanakit, 1997)

Besides the combustion of the shells, pyrolysis is possible. From the research of Kawser (2000) it follows that pyrolysis yields liquid oil, solid char and gas. The liquid was found to contain a very high concentration (43.3%) of phenol and its derivatives (cresol, catechol, guaiacols and syringol). These components are considered to be chemicals with a high added value, if they can be produced in a sufficiently high quality. However, costs of these processes are also very high.

5.4.3 Reuse of decanter sludge

The mill employs a decanter for the recovery of oil from the wastewater. The generated decanter cake can be utilized as fertilizer. However, decanter sludge has a high potential as animal feed. The chemical composition of the sludge is shown in Table 5.13.

Table 5.13 Chemical composition of decanter sludge

	Fresh decanter sludge	
	Thailand	**Malaysia (Hutagalung, 1977)**
Moisture content, %	70-80	93.1
Crude protein, %	12.5	12.4
Ash, %	-	11.2
Phosphorus, %	0.8	0.18
Magnesium, %	0.4	0.25
Potassium, %	0.2	-
Zinc, mg/L	-	1,075
Iron, mg/L	-	1,757
Gross energy, MJ/kg	-	19.6

Decanter sludge has a moisture content of about 75%. It has a high protein content. However, if kept for more than 24 hours, it ferments and produces a bad smell. In order to sell this by-product to a feed mill, the sludge has to be dried. The mill could use low-pressure steam from the boiler to dry the decanter sludge. An indirect horizontal dryer could be used to dry the decanter solids to a low moisture content (90% total solids) (Fig. 5.23). The dry decanter product can be made into commercial grade pellet animal feed.

For factory A with a production of 173,000 ton/year this means:

- Amount of decanter sludge is 32 kg/ton FFB. The moisture content of the decanter sludge is 75%.
- Dry decanter cake production is 0.032* (100-(75-10))/100 * 173,000 = 1,938 ton/year.
- Dry decanter cake can be sold for 500 Baht/ton.
- Value of decanter cake = 1,938 * 500 = 968,800 Baht.

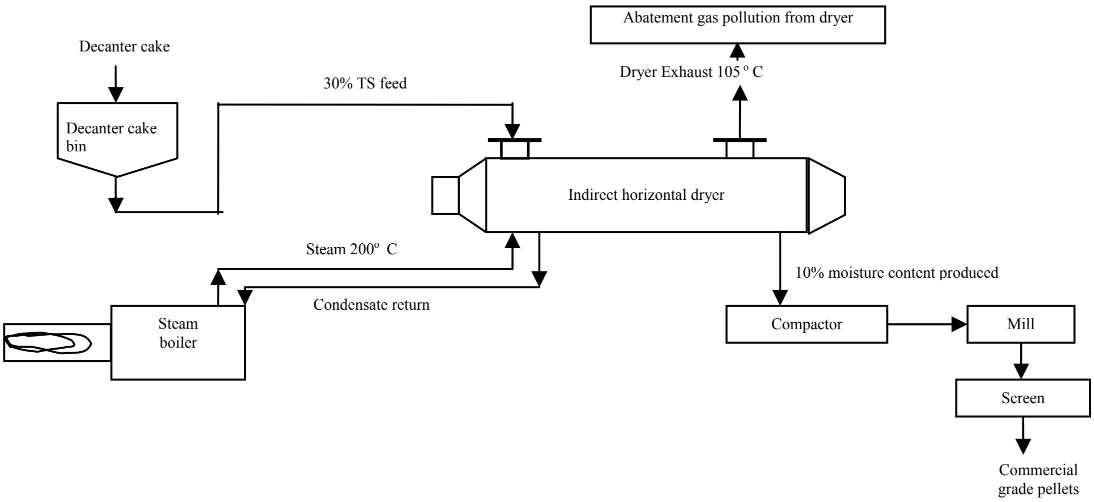


Figure 5.23 Indirect, horizontal dryer used in decanter cake drying

Perhaps, one idea would be to promote the use of the fresh decanter sludge (15-25% dry matter) for finishing pigs which, compared to younger animals, have a greater capacity to effectively use larger amounts of more liquid feeds. This approach might require supplementation to increase the crude protein content to the level of cereal, as well as some molasses to improve palatability. It would have to be used immediately to avoid fermentation and also preferably near the mill to avoid transportation of the product. Several authors (Devendra *et al*, 1981; Hertrampf, 1988 and Abu *et al*., 1984) reported the use of this sludge instead of maize at a level of 15-30% to reduce feed costs.

Hutagolung *et al*. (1977) investigated the use of the sludge as pig feed. Two types of mixing meal were used in this study: type I, 35% palm oil sludge, 32.5% cassava root meal and palm kernel cake and type II, 32% palm oil sludge, 17% palm kernel cake, 17% grass meal and 34% cassava root meal. He concluded that it is economical viable to replace 50% maize (the regular diet constituent) with mixing meal, which gave a saving of 0.02 RM per pig per day and an extra dollar profit of 0.08 and 0.01 RM per kg gain, respectively. The later option could be applied in factory A too. The sludge could be recycled as animal feed for small farm households in the Surat Thani Province, because there are many small dairy farms in the southern region of Thailand. For this feed, decanter cake will be dried to 30 % moisture content before selling to farmer.

5.4.4 Reuse of fly-ash

The boiler of crude palm oil factory uses fiber and shell (ratio 4:1) as energy source. The fly ash of this biomass fuel is a mixture of SiO_2, CaO, K_2O, P_2O_5, MgO and Al_2O_3 (59.16, 8.0, 7.6, 4.74, 4.13 and 1.9 %, respectively). This fly ash can be used directly, to replace Portland cement up to 10% in weight. This is a high added value application; provided the carbon content is less than 8.5 % and the physical and chemical properties are reasonably stable. Another option for reuse of fly ash is for partial cement replacement up to 40% in concrete block production (Juratawai, 2004). The mixture of material for concrete blocks in ratio of aggregates: fly ash: water is 1:2.75:0.485. For aggregate material, the ratio of Portland cement: fly ash is 9:1. Table 5.14 summarized the effect of fly ash ratio on compressive strength development after 28 days under curing conditions. The results showed that concrete blocks with fly ash from palm oil mills as aggregate are possible. The compressive strength is 164 kg/cm^2, which exceeds the standard at 25 kg/cm^2.

Table 5.14 Compressive strength of concrete blocks compared to normal mortar after 28 days under curing conditions (Juratawai, 2004)

% fly ash replacement	Compressive strength		Production cost
	kg/cm^2	%	Baht
0	300	100	6.00
10	254	84.7	5.45
15	233	77.7	5.18
20	208	69.3	4.90
30	176	58.7	4.36
40	164	76.7	3.81

5.4.5 Added Value Products from Fiber

Fiber can be densified into briquettes or pellets to improve their handling and combustion properties and could be sold as fuel. Husain, *et al*. (2002) reported that fiber and shell could be used to produce solid fuel by densifying the material into briquettes of 40-60 mm in diameter with a moderate pressure of 5-13.5 MPa in a hydraulic press. The fiber and shell are dried and ground to powder of 60-75 um. The raw materials, at a ratio of fiber: shell: starch: hot water of 6:4:1:5 are mixed and subsequently molded. The briquette has good resistance against mechanical disintegration. The gross caloric value, ash content and moisture content are about 16.4 MJ/kg, 6%, and 12%, respectively.

5.4.6 Alternative use as fertilizer or sustainable treatment of wastewater

Analysis of the wastewater from factory A indicates high quantities of oil and organic substances as the main contaminants. BOD, COD, SS, TKN and Oil are about 52.2, 68.3, 30.9, 1.0 and 7.3 g/L, respectively. The organic components in the wastewater are biodegradable and could be reused as fertilizer or for biogas recovery and electricity regeneration.

5.4.6.1 Fertilizer

POME (palm oil mill effluent) contains about 94.2% water and 5.8% total solids. By evaporation technology water can be recovered and the residual solids utilized. Ma (1999) presented a commercial scale evaporation plant using a multi-stage evaporation system. Efficient evaporation of the water is achieved by taking advantage of the available heat of fresh POME with its average temperature of 80^{o}C and applying a vacuum of 600 mm Hg to lower the boiling point to about 60^{o}C. A high solid concentration in the effluent is achieved due to introduction of a forced-circulation system to pump the concentrate liquid. The concentrated sludge is an appropriate raw material for fertilizer production, while the presence of small quantities of oil does not affect the product quality. Table 5.15 shows the nutrient composition of the concentrated sludge, Table 5.16 illustrates the quality of distillate from evaporation. The concentrate contains about 13.5% of essential amino acids, therefore it can be used for making other products like animal feed, or as a feedstock for fermentation products. The distillate has a low solid content of 150 mg/l and can be reused in production process. However, there have been numerous attempts to convert palm oil mill effluent into viable animal feed sources. Most methods have been discontinued due to the large initial capital investment required, and particularly to the cost of fuel for dehydration

Table 5.15 Nutrient analysis of POME concentrate from evaporation (Ma, 1999)

Parameter	Concentrated POME
Moisture content (%)	80.0
N, %	2.07
P_2O_5, %	0.96
K_2O,%	6.5
Calcium (CaO), %	0.023
Magnesium (MgO), %	0.396
Manganese (MnO), %	0.003
Iron, %	0.007
Sodium, %	0.04

Table 5.16 Quality of distillate from evaporation (Ma, 1999)

Parameter	Concentration
Appearance	Clear to slightly turbid
pH	5-6
COD, mg/L	100-600
BOD, mg/L	20-150
Total solids, mg/L	150
Oil & grease, mg/L	10
Total nitrogen, mg/L	20

5.4.6.2 Wastewater treatment

1) Biogas recovery and anaerobic treatment

The major source of wastewater generation in factory A is the clarification process. The general characteristic of the wastewater is the high organic concentration. The water is acidic and has a high oil and solids content, and a high temperature. The composition is 94.2 % water, 0.7 % oil and 5.8 % total solids including 3.1% suspended solids, mainly debris from fiber (cellulose). Because the wastewater contains biodegradable organic material, the treatment system consists of anaerobic/oxidation ponds. At present, wastewater from the production process is treated by a pond system, including anaerobic ponds and facultative ponds as described in section 5.2.3. A disadvantage of this system is that the effluent does not meet the effluent standard.

A review literature shows that it is feasible to recover biogas from POME by using an anaerobic digester tank. From 60 ton FFB/hr palm oil mill operations, during 20 hr/day, approximately 20,000 m^3 of biogas can be obtained per day. The gas has a caloric value of 53,000 kcal/ m^3. The biogas contains about 65% methane and 35% CO_2 (Ma, 1999) Biogas production from POME in Thailand, on pilot and full scale, using a completely mixed anaerobic digestion tank with a capacity of 2,300 m^3, at a flow rate of 300 m^3/day can generate 6,000 m^3 biogas/day with 60% methane (Kochapansunthorn, 1998). The biogas can be used as fuel in the boiler for steam and electricity generation. The use of methane for power generation could be considered, but most palm oil mills are self-sufficient in power. The mill could sell electricity to Electricity Generation Authority of Thailand. Another advantage of anaerobic digestion is the 95.5% BOD reduction. The construction costs of the closed anaerobic tank system, including gas engines for the electricity production of the produced biogas, is 18.4 million Baht (~ 10,000 Baht/m^3 of wastewater per day). The pay back time for this system, when calculating saved electricity as an income, will be about 4.3 years.

Another alternative to reduce costs for treatment of wastewater and production of gas is the covered lagoon system. The investment costs is approximately 5,000 Baht/m^3 of wastewater per day. For factory A, with daily capacity of 300 m^3/day, this would cost around 15 million Baht. The pay back period, when calculating saved electricity as an income, will be about 2.5 years. The efficiency of BOD reduction will be 60 %. The BOD reduction will generate 0.8 m^3 of biogas/kg of BOD removed. Table 5.17 shows the efficiency of POME treatment using a completely mixed anaerobic digestion tank and a covered lagoon system.

Results from the measurements at factory A showed that about 71 % of methane and 29 % CO_2 are generated in the first anaerobic pond. It is estimated that biogas generation is 0.3 m^3/kg BOD of digested POME or 13 m^3/m^3 of POME (9.3 m^3 methane/m^3). This figure is more or less in agreement with the literature mentioned above. This wastewater treatment situation at factory A can be significantly improved by introducing a completely mixed anaerobic digestion tank, which reduces the COD and BOD of the effluent and produces collectable methane. The methane can be used for fuel in the boiler or for power generation. The electricity can be sold to the Electricity Generation Authority of Thailand.

Table 5.17 Comparison of completely mixed anaerobic digestion tank and covered lagoon system

	Completely mixed anaerobic digestion tank 1)	Covered lagoon system 2)
Investment cost, million Baht	18.4	15
Construction cost, Baht/ $m^3$of wastewater per day	10,000	5,000
Pay back period, years	4.3	2.5
BOD removal efficiency	95.5	60
Biogas production, m^3/day	6,000	4,000
Wastewater after treatment:		
• BOD, mg/L	2,300	20,000
• COD, mg/L	3,000	26,000

Note: 1) Kochapansunthorn, 1998 and Lavanprasert, 2003
2) Biomass one-st, 2004op Claring House, 2004

2) Complete treatment system

Wastewater characteristics

The quantity of wastewater generated from Factory A is 0.6 m^3/ton FFB. This means that about 101,000 m^3 of wastewater needs to be handled every year. Fresh POME is acidic and contains a high concentration of organic and suspended matter. The wastewater is discharged to a treatment pond at a temperature of 80-90°C. The BOD, COD and oil & grease concentration of this wastewater is 52.2, 68.3 and 7.2 g/L, respectively. The BOD:N:P ratio is equal to 100:1.9:0.07. The nutrient content in wastewater is too low for a completely aerobic biological treatment system. However, POME can be effectively treated by anaerobic reactor or pond, followed by an aerobic post treatment (oxidation pond; facultative pond; another aerobic treatment system e.g. aerated lagoon). In this case substantially less oxygen is necessary compared with a completely aerobic treatment system. The characteristics of the wastewater from factory A are given in table 5.18 and resemble the properties of other crude palm oil mills effluents in Thailand. Compared to Malaysia, the oil content and suspended solids in wastewater from Thai crude palm oil mill wastewater is higher.

Table 5.18 Characteristic of raw wastewater from crude palm oil mills in Thailand and Malaysia

parameter	Factory A	Thailand(1)	Malaysia(2)	Eff. standard in Thailand
Temperature, °C	80-90	80-90	80-90	45
pH	4.83	4.81	4.7	5-9
BOD, mg/L	52,200	46,500	25,000(3)	20
COD, mg/L	68,300	51.000	50,000	200
SS, mg/L	30,900	34,600	18,000	50
Oil& grease, mg/L	7,250	6,200	4,000	5
TKN, mg/L	1,020	1,100	750	200
TP, mg/L	40	47	-	-
Amount of wastewater, m^3/ ton FFB	0.6	0.64	0.5	-

Note: (1) Average value of the five studied factories in Thailand, 2002
(2) Yeoh, 2004
(3) BOD_3, 3 days at 30 °C

Factory A employs a lagoon system as wastewater treatment system. An anaerobic first stage followed by a facultative treatment. As discussed before, the wastewater in the final pond still contains high amounts of COD and BOD (960 and 34 mg/L) and does not meet Thai effluent standards. The effluent is kept in the pond without discharging. This system is used by about 90 % of the Thai palm oil mills. The reasons that Thai palm oil mills have adopted the lagoon systems for treating their POME is of the low capital and operating costs. In fact, looking to the composition of the wastewater, BOD/COD ratio and the temperature, it can be expected that anaerobic treatment is a very serious option. It is observed that not all crude palm oil factories can treat their wastewater up to a level that meets the effluent standard at all times. However, a serious drawback of the lagoon system is the emission of the greenhouse gas. Only one mill in Thailand uses anaerobic treatment: completely stirred tank reactors equipped with a biogas recovery system. The required effluent COD and BOD limits are achievable if the treatment systems are well designed and operated.

Crude palm oil secondary wastewater treatment system

Many researches (Yeoh, 2004; Faisal and Unno, 2001; Borja *et al*., 1996) indicated that an anaerobic biological treatment system potentially offers a lot of benefits for the treatment of POME. It has been recognized that a first-stage treatment of the wastewater using anaerobic technology, in which the methane is recovered for reuse, is the best option. The reason for this is the high organic concentration in POME and no aeration is required, thus a less high energy demand compared to an aerobic biological system. Chin *et al*. (1996) stated that experience in South-East Asia has shown that facultative and anaerobic biological treatment processes can effectively treat POME. He evaluated the treatment efficiency of a pond system consisting of 8 ponds in series, treating 600 m^3/day of POME, at an overall HRT of more than 60 days in a Malaysian crude palm oil mill. He found that the effluent quality was not up to the Malaysian discharge standard of 100 mg/L of BOD. However, he recommended that the final effluent, containing COD: N: P in a ratio of 159:18:1, gives sufficient nutrients for further treatment by the aerobic treatment system to meet with the effluent standard. A study of comparable treatment of POME, from a mill of similar capacity using an anaerobic-aerobic treatment system, showed that the treated effluent met the discharge standard of BOD at 100 mg/L. The use of conventional anaerobic lagoons to treat POME is characterized by long residence times, often in excess of 20 day, necessitating large areas of land or large digesters (Borja *et al*., 1996). Moreover, the lagoon is quite difficult to control and monitor due to the size and configuration. The greatest environmental problem is the emission of methane to the atmosphere. Another problem of the lagoon system is the accumulation of sludge in these ponds, which reduces the pond treatment capacity and consequently shortens the HRT. Therefore the bottom sludge has to be removed to improve the treatment efficiency (Chin *et al*., 1996). This, however, is a difficult task. In practice, the bottom sludge is removed and dumped near the pond. Mills have to face the pollution problem with large amounts of sludge and the bad smell generated during drying the sludge. However, the most common treatment systems adopted by the crude palm oil mills, both in Thailand and Malaysia, are lagoon systems. In Malaysia, only a few mills have reported the use of closed-tank anaerobic bioreactors equipped with a biogas recovery system.

The application of modern high rate anaerobic digester technologies for POME treatment has been investigated in lab tests: continuously stirred tank reactor (Kochapansunthorn, 1998); anaerobic baffled reactor (Faisal and Unno, 2001); thermophilic up-flow anaerobic filter (Mustapha, 2003); high rate anaerobic fixed film (Chaiprasert, et al., 2003); thermophilic digestion (Yeoh, 2004). Table 5.19 shows some data of the research on the various types of wastewater treatment of palm oil wastewater. Not all these systems are applied in crude palm oil mills yet. Kochapansunthorn (1998) reported bench-scale experiments with continuously stirred tank reactor (CSTR) digesters. It was found that the system removed 90% of the COD at a hydraulic retention time of 20 day. A full scale CSTR system is now adopted by a Thai crude palm oil mill (Biomass One-stop Claring House, 2004).

Table 5.19 Lab scale results of various wastewater treatment processes for treating POME

Parameters	Pond system (Chin, 1996)	Completely stirred tank reactor (Kochapansunthorn, 1998)	Thermophilic digestion (Yeoh, 2004)	High rate anaerobic fixed film (Chaiprasert, 2003)	Anaerobic baffled reactor (Faisal and Unno, 2001)	Thermophilic upflow anaerobic filter (Mustapha, 2003)
Operating temp, ^{o}C	35 - 40	42 - 52	55	-	-	55
Organic loading rate, $kgBOD/m^3.d$	0.2 - 0.35	0.8 - 1.0	1.88 - 3.52	-	1.6 - 5.33	2.6 - 4.9
Influence COD, mg/L	-	-	-	-	1,600	55,000
Minimum retention time, day	30	20	7	-	3	-
HRT, day	30 - 135	20 - 30	7- 13	3 - 4	3 - 10	5 - 10
Treatment efficiency, %	>90	>90	>96	>90	87 - 95	94%
Effluent COD, mg/L	<150	1,250	2,320 - 4,910	-	754 - 3,630	-
Biogas production rate, $m^3 / m^3.d$	-	0.4 - 0.6	2.64 - 4.96	0.4 - 0.5	0.82 l/g COD	0.6

Yeoh (2004) studied the effect of temperature on the anaerobic digestion process by comparison of systems operated at digestion temperatures of 45 ^{o}C, 50 ^{o}C and 55 ^{o}C. He revealed that methane production was significantly enhanced by thermophilic conditions compared to mesophilic conditions. It was also found that methane yield from the thermophilic digestion increased with increasing the temperature of the system. With the temperature at 55^{o}C, the COD removal efficiency was 96%, which was higher than with mesophilic digestion. Table 5.20 shows the process parameters used for the comparative economic analysis. Biomass One-stop Claring House (2004) reported that a CSTR system is suitable for treating POME. With a treatment plant capacity of 4,000 m^3, treating wastewater at a flow rate of 300 m^3/day (6,000 kg BOD load/day) 4,500- 6,000 m^3 biogas/day can be generated. This biogas can be used for generating 2.4-3.5 million kW/year electricity by using gas-engine 300-400 kW generators. The investment costs are 0.38 million EU and the pay back period is approximately 4 year.

Table 5.20 Process parameters for CSTR and thermophilic anaerobic digestion system of palm oil mill effluent

Parameter	CSTR[1]	Thermophilic anaerobic digestion[2]		
		Temp.45 °C	Temp.50 °C	Temp.55 °C
Operating parameter				
Digestion temperature, °C	42 - 52	45	50	55
Minimum retention time, day	8	10.9	9.2	7.0
Minimum effective reactor volume, m^3	4,000	4,950	4,150	3,200
HRT, day	13-8	20.6-11.0	17.3-9.2	13.3-7.1
BOD loading rate, kg/day	0.8-1.0	1.21-2.27	1.45-2.71	1.88-3.52
Biogas production rate, m^3 / m^3 POME/ day	1.5-2.0	1.11-2.09	1.44-2.68	2.65-4.96
Effluent BOD, mg/L	1,250	1,230-4,890	2,500-5,000	2,320-4,910
Cost-benefit analysis				
Capital cost, million Euro	0.38	0.97	0.98	1.2
Payback period, year	4	9.6	8.6	6.7
Electricity generation, million Euro per year	0.13	0.22	0.24	0.34

Note: Mill capacity of 45 ton FFB/hour, wastewater load at 240-450 m^3/day
(1) Kochapansunthorn, 1998; Capital cost including reactor, biogas and generator
(2) Yeoh, 2004; Capital cost including reactor, biogas, generator and land application

In Malaysia, the anaerobic digesters are operated as a conventional high rate system with an organic loading of 4.8 kg VS/m^3/day. The HRT is about 10 days, operating in a temperature range of 42-50 °C. The biogas produced is used for heat and electricity generation. The digester liquor is applied to the plantation nearby as fertilizer. Yeoh (2004) reported field data on the operation of two 3,700 m^3 CSTR digesters and indicated that the digestion temperature was maintained at 44-52 °C by the inherent heat of the influent alone. The temperature variation was 2-4 °C and no operation difficulties had been experienced with these temperature fluctuations.

Crude palm oil tertiary wastewater treatment system

In Thailand, preliminary studies with post treatment of crude palm oil mill effluent show the feasibility of reducing color, SS and COD level. Sub-surface flow constructed wetland (SSFCW) and EC treatment are an efficient method for crude palm oil mill wastewater treatment. The advantage of SSFCW treatment is high SS removal efficiency; less operating cost; and no sludge disposal required. Nusuk (2003) studied the use of a pilot scale of subsurface flow constructed wetland (SSFCW) as a tertiary treatment for treating POME. The wetland beds were filled to a depth of 0.45 m with 3-5 mm sized gravel and reeds were planted with *Typha sp*. in density of 4 plants per m^2 on the full scale beds. Result from experiments showed that SSFCW was effectively in removing color and reducing the SS and COD. The significant reduction in SS could have contributed for the reduction in COD and color. At HLR of 1.3 cm/ day, SSFW unit can treated SS to levels lower than 50 mg/L. However, COD concentration in effluent has still higher than the Thai effluent standard. This is due to COD in wastewater from matulation pond is significantly high and mostly contains hardly biodegradable organic matter. This is confirmed by the ratio of BOD/ COD of wastewater which is 0.05.

Muensita (2004) reported that the optimum condition of electrocoagulation for treating POME from matulation pond is at a voltage of 10 volt and a retention time of 30 min. Result from the study showed that voltage and reactive time influenced the treatment efficiency. The removal efficiency of COD, SS and color were achieved at 51.84%, 62.58% and 91.77%, respectively. However COD and SS concentration in effluent can not meet the Thai effluent standard as shown in Table 5.21.

Table 5.21 Removal efficiency of EC treatment and SSFCW treatment.

	Removal efficiency, %			Concentration, mg/L		
	COD	SS	Color	COD	SS	Color
SSFCW treatment (HLR 1.3 cm/d)[1)]	52.68	87.43	53.33	1,454	39.2	93
EC treatment (10V, 30 min)[2)]	51.84	62.58	91.77	1,233	62.6	21.5
Thai effluent standard				200	50	-

Source: [1)] Nusuk , 2003; [2)] Muensita, 2004

Purposed wastewater treatment tlant for factory A

Based on literature several sustainable options for treatment of wastewater can be set up. At present, wastewater from the production process is treated and stored in ponds as described above. The new more sustainable wastewater treatment system is schematically showed and described below. The plant will treat POME and recover methane for power generation and make an effluent quality suitable for discharge in the river nearby the factory. In this case, it is possible to apply a closed ideally mixed anaerobic tank system (CSTR) followed by an anaerobic pond and an aerobic treatment (aerated lagoon) and a post wetland treatment system. The design parameters of each unit in the system are summarized in Table 5.22 and a flowchart of the wastewater treatment technology is presented in Figure 5.24.

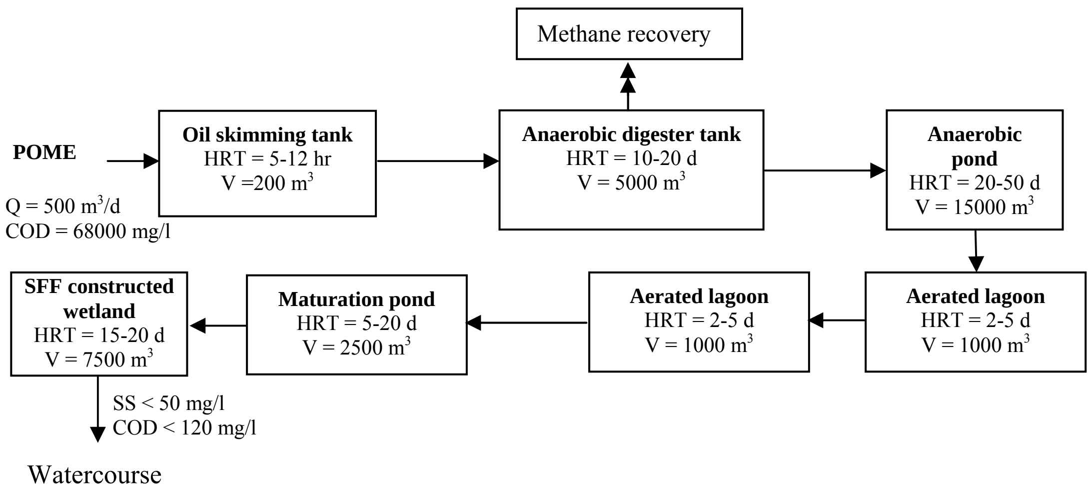


Figure 5.24 Proposed WWTP for crude palm oil mill wastewater located far from a plantation area

Table 5.22 Designs parameter of the propose WWTP for a crude palm oil factory

Parameters	Unit	Oil skim tank	Anaerobic digestion tank	Anaerobic pond	Aerated lagoon	Maturation pond	Wetland
HRT	day	5 - 12	10 - 20	20 - 50	4 - 10	5 - 20	15 - 20
Organic loading rate	Kg COD/m^3-d	-	5 - 10	0.1 - 0.5	-	<0.014	-
Arial loading rate	Kg COD/m^3-d	-	-	0.02 - 0.05	-	-	-
Solids loading rate	Kg SS/m^3-d	-	1- 5	-	-	-	-
Volume	m^3	200	5,000	1,5000	2,000	2,500	7,500
Surface area	m^2	140	380	4000	400	1800	10,000
Treatment efficiency	%(by COD)	-	90	90	50	50	60
Effluent COD	mg/l	-	7000	700	350	180	80

- ***Oil skimming tank.***

Since POME has a high oil content (~ 1%), the objective of the oil-skimming tank is to reduce oil contamination in the wastewater. Oil removal in the wastewater results a reduction of BOD/COD prior to biological treatment. For the anaerobic digestion tank, oil removal from the wastewater can efficiently increase the mass transfer between microorganisms and dissolved organic material in the wastewater, because an oil film can cover the microorganisms.

- ***Anaerobic digester tank*.**

Since POME has a very high solids content (31 g/l), the anaerobic digestion tank system (CSTR) is recommended in this study. The temperature of the digester will be in the range of 42-52°C, close to thermophilic digestion where the organic removal efficiency is high. The objective of this unit is to remove BOD, COD and SS by using anaerobic bacteria. The COD removal efficiency is expected to be higher than 90% (see Table 5.22). However, the wastewater after treatment will still contain a high organic load, which has to be treated further by an additional biological treatment system. The by-product from the anaerobic digester tank is biogas, which can be used as fuel in the boiler or for electricity generation, as previously mentioned in section 5.4.5. The advantages of anaerobic treatment are:

- Able to cope with high organic loads
- Generates little sludge in the digestion tank
- Requires a low COD:N:P ratio for the anaerobic bacteria
- Generates biogas as a by-product
- No oxygen required

Biogas production rate from CSTR is expected to be 0.4-0.6 m^3/m^3 day. Biogas produced from POME contains 60-70% methane. This biogas can be used as fuel.

- ***Anaerobic pond***.

Since a large portion of the easily biodegradable organic content in the wastewater is removed in the anaerobic digestion tank, effluent from this unit process will contain organic matter that is less biodegradable (low BOD/COD ratio). The objective of the anaerobic pond is to remove suspended solids and BOD/COD from the wastewater. The anaerobic digestion tank is used for pretreatment of contaminated wastewater and recovery biogas. The other benefits of anaerobic digestion tank are to reduce organic loading in wastewater before feeding to the anaerobic pond and at the same time to reduce GHGs emission to the atmosphere. Because of the pretreatment in the CSTR the volume of the anaerobic pond can be reduced. The organic load that goes down, which makes it possible to decrease the HRT in the anaerobic pond.

- ***Aerated lagoon***.

The objective of the aerated lagoon is to remove the residual organic contents and color in the wastewater. Since an anaerobic treatment system cannot produce wastewater that meets the Thai effluent standards, an aerated lagoon is used for removal of BOD, COD and color in the wastewater. The final effluent from this proposed wastewater treatment system could meet the effluent standard.

- ***Maturation pond***.

Since effluent from the aerated lagoon will have a high sludge content, maturation ponds will be used to remove suspended solids in the wastewater through gravity sedimentation. A long retention time will result in a further biodegradation by microorganisms reducing the organic and SS contents in the wastewater.

- ***Constructed wetland***.

The objective of the constructed wetland is to remove suspended solids, COD and color. The effluent from the maturation pond will still contain SS (algae and microorganisms), color and nutrients (N). A subsurface-flow constructed wetland can remove SS, nitrogen and color efficiently. The effluent characteristics should then meet the effluent standards and can be discharged to near by channel.

5.4.7 Physical – technological model of an almost zero waste industrial ecosystem

A physical – technological model of an almost zero waste industrial ecosystem at factory A is created by integrating all options as discussed in this chapter. This model represents a crude palm oil factory, located in a community and far from an oil palm plantation area, where there is no reuse option for solids waste (ash, decanter cake) and wastewater in an oil palm plantation area. The material flow network of the model is depicted in Figure 5.25.

In this model, the crude palm oil production of factory A is used as a starting point for the model. The existing oil palm plantation area, a new designated concrete block enterprise, modification of the existing wastewater ponds to recover biogas and the construction of an activated carbon plant are all designed to reach a model of a zero waste industrial ecosystem This situation can be significantly improved by introducing an anaerobic digestion system, which reduces the COD, BOD and SS of the effluent and converts the organic substrate into biogas. Results showed that about 70 % of methane and 22 % CO_2 are generated in anaerobic pond No.1. It is estimated that biogas generation equals to 0.5 m^3/kg COD of POME digested or 32 m^3 of biogas/m^3 of POME.

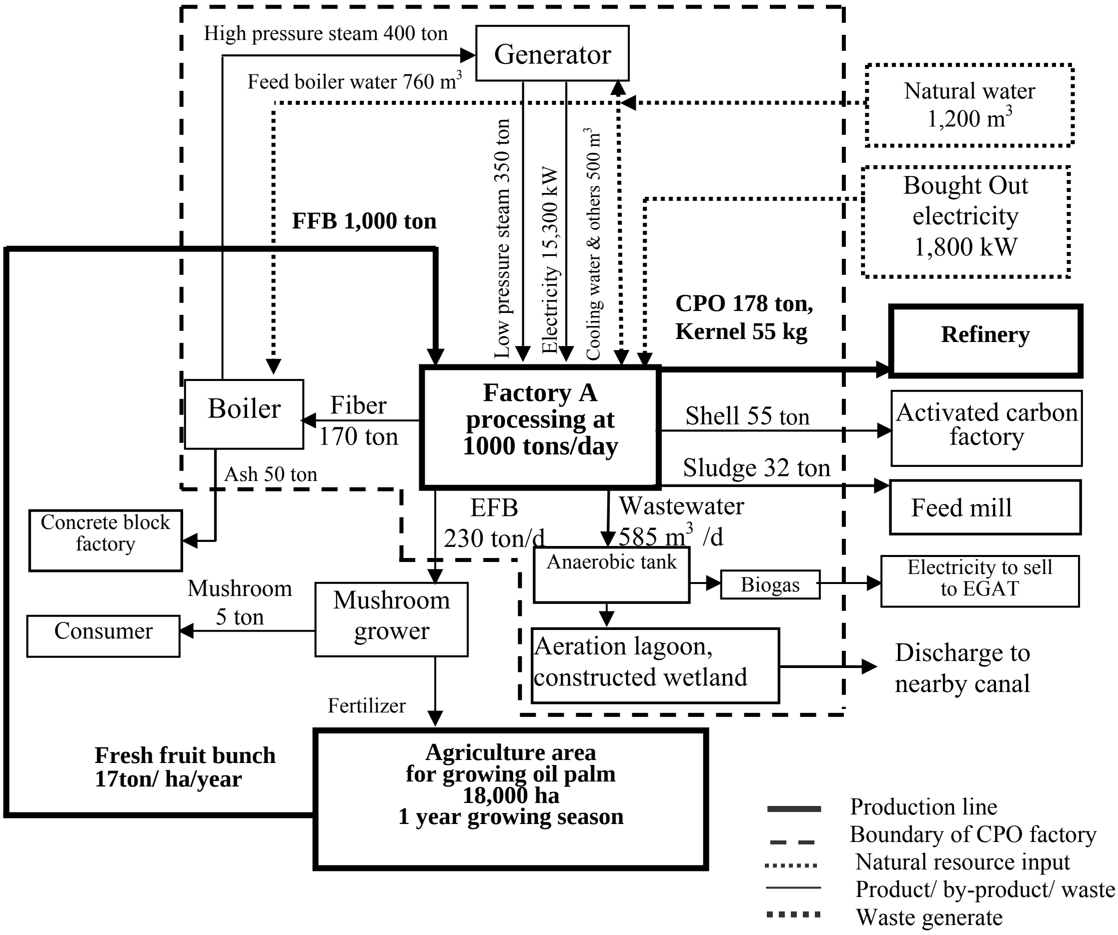


Figure 5.25 Material balance of the proposed physical-technological model of an almost zero waste industrial ecosystem at factory A

5.5 Conclusion

During the last decade, developments have taken place in the crude palm oil industry to make this industry environmentally more sustainable. In factory A awareness of the environmental pollution made the way for the adoption of the clean technology approach. However, there are still a number of pollution problems in the production process of factory A, such as the high organic content of the wastewater, generation of large quantities of solid waste and emission greenhouse gasses. These pollution problems have an environmental impact on the community surrounding the factories. Industrial ecology theory is applied to improve the environmental performance of the factory and also to make the palm oil production more sustainable. The proposed solutions for the problems are based on recent research:

- By-products such as empty fruit brunch, fiber and shells are already reused/ recycled. The other alternative options that may have potential as more added value products are using shell as raw material for activated carbon, empty fruit bunch for pulp& paper and medium density fiber broad and fiber for briquettes production.
- Waste such as decanter sludge can be sold to animal feed mills after drying with excess steam as a heat source.
- Recovered biogas from the palm oil mill wastewater treatment can be used as fuel for the boiler to generate steam used in the production process or as fuel for the gas turbines to generate electricity, which can be sold to the Electricity Generation Authority of Thailand.

Chapter 6
Crude palm oil industry in Thailand: Existing technology, environmental performance and improvement options

6.1 Introduction

All the palm oil factories in Thailand have a more or less similar production capacity however with a different environmental performance. From a brief overall study of the palm oil processing industry in Thailand, five companies were selected for a more detailed analyses of the waste generation, environmental impact, dynamics of clean technology and waste exchange development and its application. The five factories are classified into three groups depending on their production technologies and locations as follows:

- Factories using modified decanter processes: characterized by the use of a decanter and separator in the oil recovery process. These will represent the best practice currently in clean technology in Thailand.
- Factories using standard decanter processes: characterized by the use of a decanter in the oil recovery process. These will present good improvement in clean technology.
- Factory using standard process, characterized by the use of a separator in the oil recovery process. This will represent a small improvement in clean technology.

For the location factors important considerations are distance to communities and location within palm plantations. According to the literature these prove to be relevant for cleaner production practices.

This chapter starts with an introduction of the five selected crude palm oil mills (section 6.2) In this introduction a brief overview of the existing crude palm oil production technologies and current environmental problems is given. Section 6.3 describes the environmental performance of crude palm oil production processes in Thailand in more detail, material inputs, products, byproducts and wastes of individual companies and their environmental implications. Data from this section, including data from chapter 5, are used for a more detailed analysis of factors that affect the environmental performance of crude palm oil industry in Thailand. This will be described in section 6.4 and will be used as a foundation for further development of a physical-technological model of an almost zero waste industrial ecosystem for the palm oil industry. This model is presented in section 6.5. The final section presents concluding remarks of the case study.

6.2 Introduction of selected factories

The crude palm oil production technologies of five factories, different in type of productions: process and type of location and way of oil recovery from wastewater, are characterized as follows:

This chapter contains an article published as Chavalparit, O. Rulkens, W.H., Mol, A.P.L. and Khaodhair, S. (2006). Options for Environmental Sustainability of the Crude Palm Oil Industry in Thailand through Enhancement of Industrial Ecosystems. *Environment, Development and Sustainability* 8 (2):271-287.

- Factory A and B recover extra oil from wastewater by using a modified decanter. Mill A is situated closed to a community, while Mill B is located faraway. However, they have implemented many clean technology options as the same kind of options mentioned in chapter 5. Compared to almost all other factories in Thailand, the existing environmental performance of these two factories is better. Source reduction of water and oil loss is the primary waste reduction technique.
- Factory C and D employ a decanter to recovery extra oil from wastewater. Factory C is located in a residential area, while factory D is located in an oil palm plantation area and far from a community. They have good housekeeping and good maintenance practice. The environmental management tries to prevent environmental problems by reduction of waste generation at the source and by means of end of pipe treatment.
- Factory E recovers extra oil from wastewater by using a separator. However, this factory has a poor environmental policy. There is not very much concern with source reduction techniques or investment in high technology equipment such as a decanter. The factory is situated far from a community (not in a plantation area).

The general data of the five selected factories such as location, production capacity, products, motivation for clean technology adoption, type of wastewater treatment plant, etc. are summarized in Table 6.1.

Table 6.1 Comparison of general data of the five selected factories (2002)

	Factory A	Factory B	Factory C	Factory D	Factory E
Location	Close to community	Far from community	Close to community	Far from community	Far from community
Area, hectare	~13	~16	~13	~16	~16
Production capacity, ton/ hr	45	60	40	60	30
Investment cost (million Bath)	180	142	90	183	97
Production capacity (ton FFB/year)	173,000	250,000	200,000	200,000	120,000
Products:					
• Crude palm oil (ton/year)	40,000	42,500	34,000	40,000	10,000
• Kernel (ton/year)	11,000	8,000	12,500	11,000	3,400
Owner of oil palm plantation	Yes	No	No	Yes	No
Clean technology adoption	Best practice	Best practice	Good practice	Good practice	Poor practice
Reason for clean technology adoption	- Increase oil yield - Minimize waste - Reduce water use	- Increase oil yield - Minimize waste - Reduce water use	- Minimize waste - Reduce water use - Comply law	- Increase oil yield - Minimize waste	-
Recover extra oil from wastewater	Modified decanter	Modified decanter	Standard decanter	Standard decanter	Separator
ISO certification	ISO 9000 certification	ISO 9000 certification	ISO 9000 certification	-	-
Wastewater treatment plant	Anaerobic pond & oxidation pond	Anaerobic pond & oxidation pond	Anaerobic digestion tank & anaerobic pond	Anaerobic pond & aeration pond	Anaerobic pond & oxidation pond

Note: 1 EU = 40 Baht

6.3 Environmental performance of the crude palm oil industry in Thailand

6.3.1 Production process

Two main products produced from the oil palm fruit are crude palm oil (CPO) and crude palm kernel oil (CPKO). CPO is obtained from the mesocarp (fiber) and CPKO is obtained from the endosperm (kernel). A general schematic diagram of an oil mill in Thailand is given in Figure 6.1. The oil milling process begins with steaming the fresh fruit bunch under pressure (sterilization) for a prescribed period to condition the fruits. The sterilized bunches are then threshed to separate the fruits from the bunch stalks. The fruits are digested and then pressed to obtain the crude oil. Next this oil water-mixture undergoes a separation process before the oil is purified and dried prior to storage. The water phase forms the bulk of raw palm oil mill effluent, which is treated in wastewater treatment plant or treatment pond. Figure 6.1 shows, besides a general depiction also the different sub-process of crude palm oil production of five case study factories.

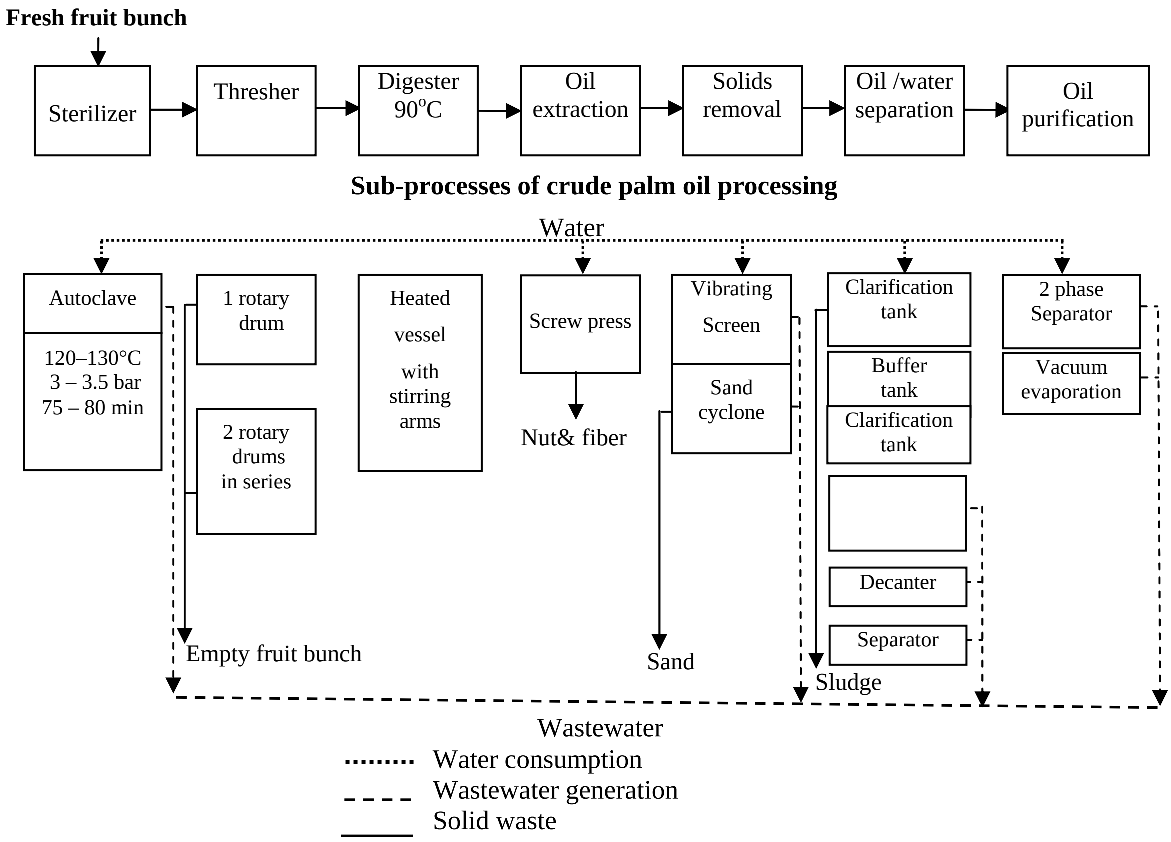


Figure 6.1 Schematic diagram of an oil mill in Thailand including different sub-processes of 5 selected firms.

The major differences between the five studied factories are the oil/water separation sub-processes such as: modified decanter; decanter; separator. Results from analysis of the wastewater show that different techniques in oil recovery result in different amounts of oil loss in the wastewater. Oil loss in the wastewater is the most important indicator for a factory to improve the efficiency of the production process. Table 6.2 shows for the five factories the amount of oil loss in the effluent of each step of the production process. The total oil loss in the wastewater varies from 2.6 to 6.7 kg/ton FFB (average 4.58 kg/ton FFB). Factory A and B employ a modified decanter and reuse the wastewater from the sterilizer in the production process, so the oil loss in the wastewater is lower (4.0 and 3.5 ton / ton FFB respectively) compared to factory D and E, which employ a standard decanter and a separator (8.0 and 7.2 ton / ton FFB respectively).

Table 6.2 Oil loss in the wastewater from the five studied factories

Mill	Oil recovery technique			Oil loss in wastewater (kg/ ton FFB)				Oil loss to wastewater treatment plant (kg/ ton FFB)	
	Oil recovery equipment	Oil trap tank	Wastewater reuse in production process	Sterilizer	Decanter	Separator	Combined wastewater	Oil trap tank (1)	Oil trap pond (2)
A	Decanter-separator	-	Sterilizer to screw press	(0.4)	3	2.5	4.0	-	0.1
B	Decanter-separator	-	Sterilizer to separator & screw press	(0.8)	8.2	3.9	3.5	-	0.1
C	Decanter	yes	-	1.1	1.6	-	3.6	2.6	-
D	Decanter	yes	Sterilizer to vibrating screen	3.0	4.0	-	8.2	6.7	-
E	Separator	yes	-	0.3	-	6.5	7.2	6.1	-

Note: Combined wastewater includes also wastewater from machine cleaning
( ) Wastewater reuse in production process
(1) Recovered oil from oil trap tank is reprocessed in the production process
(2) Recovered oil from oil trap pond can be sold as second grade oil

6.3.2 Production efficiency

Fresh fruit bunch production efficiency

The oil palm plantations in Thailand are planted with a density of 150 palms per hectare. Table 6.3 gives an overview of the average oil yield and waste generation. The current average yield is 14-18 tons of FFB/ ha/year (average 16.5 tons of FFB/ ha/year). Each palm yields about 110 kg of FFB per year. An average planting cycle of a palm tree is about 25 years for an efficient productivity. Therefore, the average total production of FFB is 2.75 ton per palm tree or 413 ton per hectare. The average yield of oil from oil palm fruit is 17 %. The FFB production is approximately 4 million ton FFB/year, but the maximum production capacity of all 25 wet-process factories is approximately 740 ton FFB/ hr or 5.3 million ton FFB/ year (with 300 operating days/ year and 24 hour/day). Thus the factories currently operate at an average 75% of their full design capacity. CPO production efficiency in

Thailand is 16.8% as shown in Table 6.3. The oil yield of Thai oil palm plantation is 2.75 ton/ ha/ year.

Table 6.3 The average oil yield and waste generation from the five selected mills in Thailand in 2002

	Wet weight (ton/ha/year)	Dry weight (ton/ha/year)	%
Fresh fruit bunch	16.50 [(1)]	10.60 [(1)]	
Oil yield	2.75 [(1)]	2.75 [(1)]	
Oil content in oil palm fruit, %	-	-	17.0 [(1)]
Oil extraction, %	-	-	16.8 [(1)]
Empty fruit bunch	3.96	2.60	
Fiber	2.31	1.60	
Shell	1.00	0.90	
Wastewater	10.56	0.64	

Note [(1)] Data from Department of Agriculture Technology, 2002

Crude palm oil production efficiency

Figure 6.2 shows the average composition of FFB and mass balances in the production process of the five studied factories based on dry weight basis. Results from the five case studies show that only 23.2 % of the raw material is product (CPO and palm kernel), the rest is by-product and waste. Most of these by-products can be reused in the production process or by other industries e.g.: fibers (10% of the total dry weight) as fuel in boilers, shell (5% of the dry weight) and empty fruit bunches (24% of the dry weight) to use in other industries. However, there is a lot of waste that has to be treated before disposal or discharge. These wastes include ash: 5%, decanter sludge: 3.2%, and wastewater.

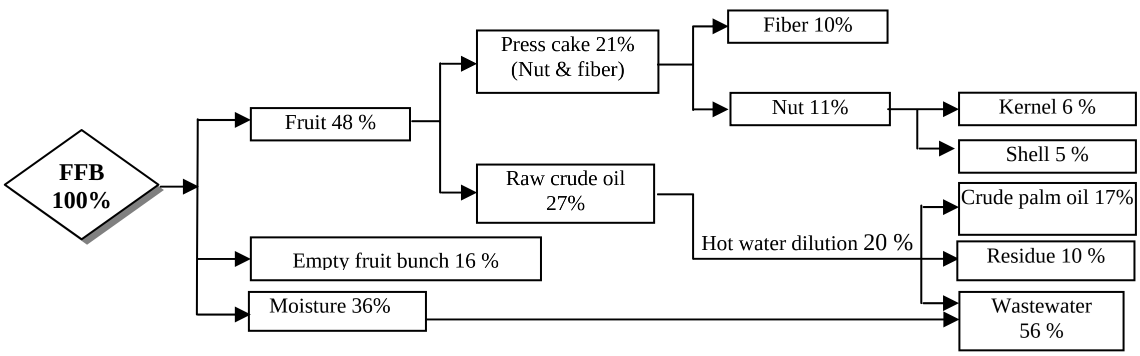


Figure 6.2 The average composition of fresh fruit bunch (% dry weight.)

6.3.3 Natural resource use

Electricity consumption

The results from the study of the five crude palm oil factories show that electricity is the dominant source of energy for the production process. The average total energy consumption of all electric machines used in the production process is about 23.4 (10.5-55) kWh/ton FFB. The electricity used in these mills is obtained from 2 sources; a turbine generator installed in the factory and electrical energy purchased from an electricity generation authority of

Thailand (EGAT). The electricity generated in the factory is about 84 % (72-95%) of the total electricity consumption. The small power plant in the mill incorporates a water tube boiler with a steam production capacity of up to 20-30 ton / hour. Fiber and shell obtained from production process is used as fuel for the power plant.

Fuel consumption

Externally purchased fuel used in the production process consists of 0.12 liters diesel oil/ ton FFB. This diesel oil is used for the diesel generator to start up the boiler.

Water consumption

A crude palm oil mill uses substantial quantities of water in the production process. Canal water is the water supply source. The average water consumption is 1.26 m^3/ton FFB. A detailed overview of water usage in the five selected factories is shown in Table 6.4. The water consumption per ton FFB does not differ much between the five crude palm oil factories due to the fact that most of water is used as boiler water and turbine cooling water. Cooling water for the turbine is recycled in the production process for cleaning machines and domestic purposes. It has been estimated that in the year 2002 the crude palm oil industry in Thailand consumed about 5 million m^3 of water.

Table 6.4 Water usages and wastewater generation at 5 selected crude palm oil mills

Factory	FFB (ton/day)	Water input (m^3/ton FFB)			Wastewater (m^3/ton FFB)
		Total	Boiler	Production & cooling water	
A	359	1.2	0.76	0.50	0.59
B	387	1.0	0.47	0.53	0.51
C	530	1.1	0.54	0.56	0.58
D	1650	1.3	0.51	0.75	0.54
E	223	1.3	0.75	0.55	1.03

6.3.4 Environmental pollution

The entire crude palm oil process needs only very small amounts of chemicals as a processing aid. Therefore, all substances found in the products, by–products and residues originate from the fresh fruit bunch. However, there are a number of pollution problems at the factories, such as a high water consumption, generation of wastewater with a high organic content, generation of a large quantity of solid waste and air pollution. Table 6.5 gives an overview of the air emission, wastewater and solids waste.

Wastewater generation

In the wet process operation, large quantities of water are utilized during the extraction of crude palm oil. Results from a survey show that the water consumption in the production process is in the range of 1.0-1.3 m^3 / ton FFB. About 53-79 % of the used water ends as palm oil mill effluents (POME). The other part is lost as steam, mainly through exhaust gases from the sterilizer. The total pollution load of biochemical oxygen demand (BOD), suspended solids (SS), oil, total Kjeldahl nitrogen (TKN) and total phosphorus (TP) in the process wastewater for the five selected factories is shown in Table 6.6.

Table 6.5 Summaries of the emissions associated with crude palm oil production

Process	Air emission	Wastewater	Solid waste
Loading ramp	-	Oil contaminated WW	-
Sterilization	Steam blow down	High organic WW	-
Bunch stripping	-	-	Empty fruit bunch
Oil extraction	-	-	Fiber, shell
Oil clarification	-	High organic WW	Decanter cake
Oil purification	-	High organic WW	-
Steam generation	Mainly particulate matter	-	Ash

Table 6.6 Pollution load from the five selected crude palm oil factories

Factory	Water consumption (m^3/ton FFB)	Wastewater (m^3/ton FFB)	Pollution load from production source (kg /ton FFB)				
			BOD	SS	OIL	TKN	TP
A	1.2	0.56	30.7	18.2	2.5	0.6	0.02
B	1.0	0.51	20.3	19.9	3.9	0.1	0.01
C	1.1	0.58	29.1	21.6	3.7	0.2	0.05
D	1.3	0.54	25.1	15.1	6.6	0.5	Not detected
E	1.3	1.03	43.1	30.3	6.5	0.2	Not detected

It can be estimated that the total amount of wastewater from palm oil mills in Thailand in 2003 was 2.6 million ton/ year. Comparing this with domestic sewage in terms of BOD this is equivalent to the amount of wastewater annually generated by 5 million people. The estimated pollution load from the entire crude palm oil industry in Thailand can be summarized as follows:

- Wastewater generation 2.6 million m^3/ year.
- Oil loss in wastewater 10,400 ton/ year.
- BOD in wastewater 77,220 ton/year.
- SS in effluent 79,900 ton/ year.
- TKN in effluent 2,600 ton/ year.

The average BOD and SS load in wastewater are 30.8 and 22.5 kg/ ton FFB, respectively. The BOD load varies with the SS contamination in the wastewater. Factory A, B, C and D installed a decanter in order to recover extra oil and to separate SS from the wastewater. Wastewaters from these factories contain a lower organic load compared to Factory E that does not employs such a decanter. Oil loss in the wastewater varies from 2.5-6.5 kg/ton FFB.

Factory A achieves the lowest oil loss in the wastewater. TKN and P load varies between factories. There are two main sources of wastewater from crude palm oil processing. Table 6.7 shows the characteristics of wastewater composition from various sources of factory A. Table 6.8 shows the total pollutant load from different sources. It is clear that the main source of pollutants is from the decanter & separator step.

Table 6.7 Characteristics of wastewater from various process steps of factory A in 2002

Source of wastewater	pH	BOD_5 (mg/l)	COD (mg/l)	SS (mg/l)	TS (mg/l)	Oil (mg/l)	Color (pt.Co unit)
Sterilizer	4.93	44,900	76,186	18,000	49,680	6,165	9,500
Decanter & separator	4.76	79,200	126,592	72,267	94,060	5,215	20,000
Combined wastewater	4.83	56,050	79,360	30,933	57,650	7,250	10,000

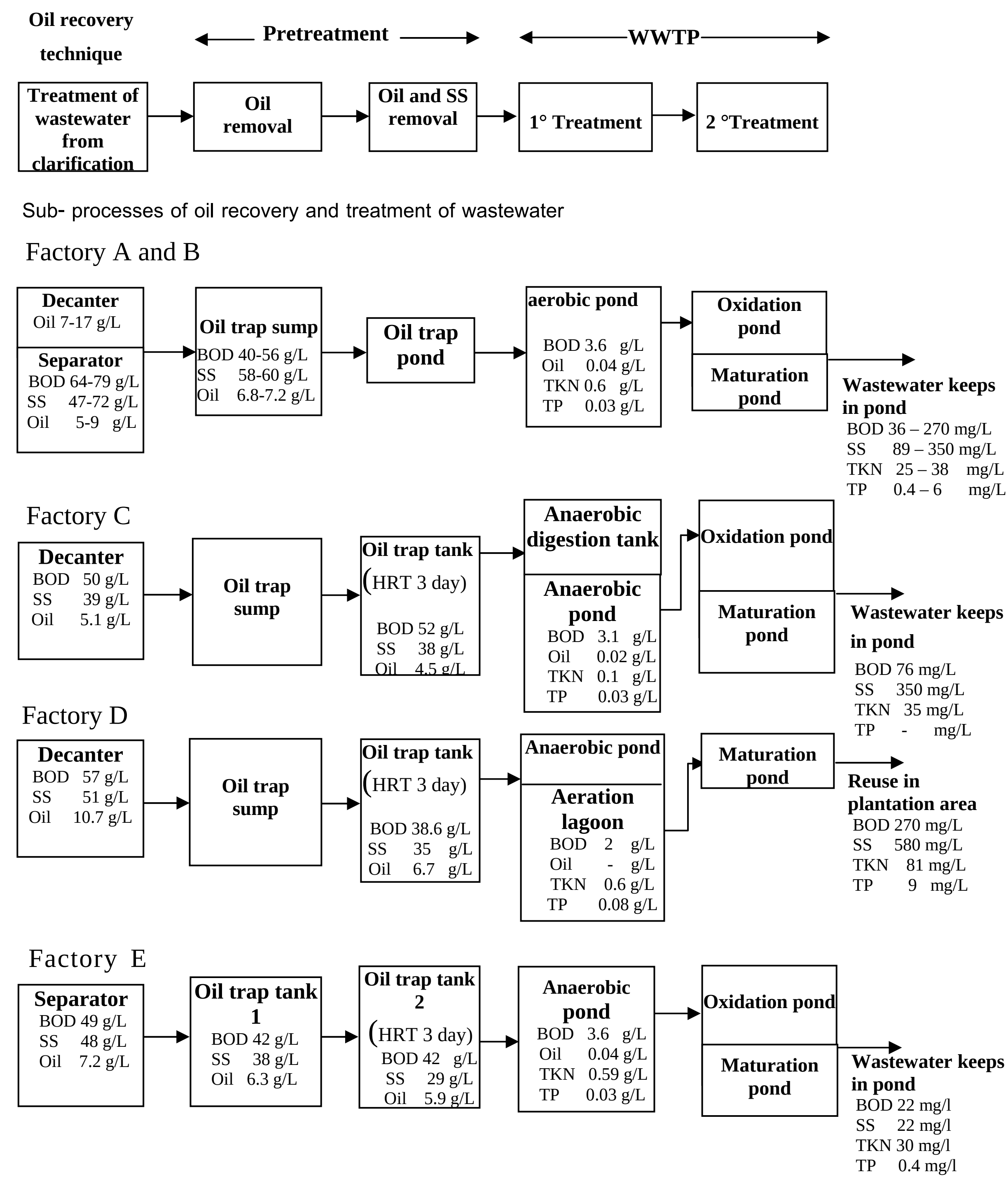
Table 6.8 Total pollution from various process steps of factory A in 2002

Source of wastewater	Wastewater (m^3/ton FFB)	BOD_5 loading (kg/ton FFB)	COD loading (kg/ton FFB)	SS loading (kg/ton FFB)	TS loading (kg/ton FFB)	O&G loading (kg/ton FFB)
Sterilizer	0.12	5.33	9.05	2.14	5.90	0.7
Decanter & separator	0.49	33.2	49.35	28.17	36.67	2.5
Combined wastewater	0.59	33.2	46.79	18.24	33.99	4.0

Wastewater from the sterilizer contains a high oil concentration (0.74 kg/ton FFB). This wastewater can be recycled in the production process in order to recover oil. Factory A and B do recycle wastewater from the sterilizer in the production process such as vibrating screen; separator; digester.

Wastewater treatment

Palm oil mills employ conventional biological treatment systems to treat their POME. The systems comprise of an anaerobic pond or a combination of an anaerobic and aerobic system. The application of different treatment systems for POME are anaerobic and oxidation ponds (64 %), anaerobic pond and aeration lagoon (29 %) and anaerobic digestion tank and oxidation ponds (7 %). It has been observed that all mills cannot treat their wastewater to meet the effluent standard. Therefore, this wastewater is kept in ponds without discharge. The environmental impact of the wastewater occurs always in the rainy season. Overflow of the wastewater treatment plant deteriorates the surface water body surrounding the mills and has a negative effect on the water consumption by the surrounding community. Wastewater treatment systems applied in the five selected factories and the characteristics of influent, wastewater after anaerobic treatment and effluent from the final pond are summarized in Figure 6.3.



Note : wastewater quantity from separator is 2 times higher than decanter .

Figure 6.3 Schematic flow diagram of sub processes of wastewater treatment plant

Air pollution

Air pollution (particulates and smoke also some CO_2) is generated from the burner/boiler due to incomplete combustion of the solid residuals. The average value of particulate matter from boilers of the selected factories is about 717 mg/ m^3 (in the range of 590-890 mg/ m^3).

Green house gases

The anaerobic ponds produce methane and carbon dioxide. These are released as gases into the air. Carbon dioxide and certainly methane are so called green house gases (GHGs), which effect in global warming potential. Results from sampling and analyzing the quantity of GHGs produced from factory A's anaerobic pond can be summarized as follows:

- 1 kg COD removal produces 0.5 m^3 biogas.
- 1 m^3 of wastewater produces 20 m^3 biogas.
- Biogas contains 70% CH_4 and 29% CO_2.

The total wastewater generation from the CPO industry in Thailand is 2,560,000 m^3/ year, so the methane and carbon dioxide release to the atmosphere is about 36 and 15 million m^3/ year respectively.

Solid waste and by – products

Solid waste and by–products generated in the palm oil extraction process are: empty fruit bunches, fibers, shell, decanter cake and ash from the boiler. The quantities of these materials are summarized in Table 6.9. In 2003 palm oil production generated the following amounts of process residues: 0.6 million ton fiber, 0.2 million ton shell, and 0.9 million ton empty fruit bunches. The residues, such as EFB and shells, are already reused/ recycled as solid fuel. Other alternative options for reuse will be discussed in the next section. Reuse options for wastes, which are currently disposed (decanter sludge and ash) will be proposed in section 6.5.

Table 6.9 Amount of solid waste/by-products generated in the five selected factories

Source	Solid waste generated (kg / ton FFB)					
	Factory A	Factory B	Factory C	Factory D	Factory E	Mean
Empty fruit bunch	230	300	230	220	240	240
Fiber	140	150	140	140	140	140
Shell	55	40	40	60	45	60
Decanter cake	32	50	57	30	0	42
Ash	50	77	17	Not detected	Not detected	48

Figure 6.4 shows the palm oil waste generation (per ton FFB production) from the crude palm oil industry in Thailand based on the data on five selected case studies.

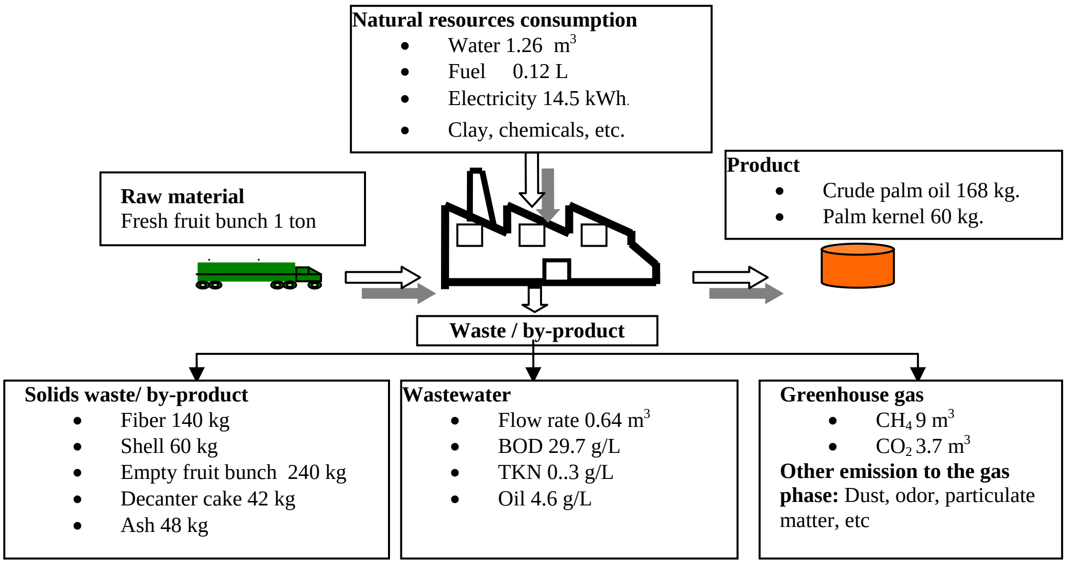


Figure 6.4 Average amount of waste generation (per ton FFB) from 5 studied mills

6.4 Factors effecting environmental performance of CPO industry

The production efficiency, water consumption, steam consumption and waste generation from crude palm oil production of the five selected factories are summarized in Table 6.10. Oil production efficiency varies in each factory. There are many factors involved in the environmental performance of the crude palm oil industry.

Table 6.10 Comparison of indicators of crude palm oil industry

Indicator	Average data		Data of factory				
	Thailand	Malaysia*	A	B	C	D	E
Oil production, %	16.8	18.7	17.8	17.0	16.5	16.4	15.5
Feed boiler water, ton/ ton FFB	0.6	0.40	0.76	0.47	0.54	0.51	0.75
Water consumption, ton/ ton FFB	1.2	No information	1.2	1.0	1.1	1.3	1.3
Electricity consumption, kWh/ ton FFB	23.4	15 - 17	15.3	10.5	19.9	16.6	5.5
Wastewater generation, m^3 / ton FFB	0.64	0.66	0.59	0.50	0.58	0.55	1.03
Oil loss in WW, kg / ton FFB	4.60	6.60	4.0	3.5	2.6	6.7	6.1
BOD loading in WW, ton/ ton FFB	29.8	No information	30.7	25.0	29.1	21.3	43.1
SS loading in WW, ton/ ton FFB	22.0	33.0	18.2	24.6	21.6	15.3	30.3

Note: * Yusoff (2004)

6.4.1 Company level

From the results of this study it can be concluded that both the oil recovery technique and management per company have an influence on the environmental performance of the crude palm oil industry.

Technological aspects
The impact of crude palm oil industrial development on natural resources depends on their production process and clean technology adoption in each factory. The types of machines employed in each step of the production process in all CPO mills are not very different (as shown in Figure 6.1). However the oil recovery equipment employed in each mill is different. In this study, the oil recovery equipment is divided into 3 categories: modified decanter (decanter and separator in series), decanter and separator. In Table 6.11 the production efficiency and waste generation of various techniques are given.

Table 6.11 Comparison of environmental performance of the CPO industry

Indicator	Oil recovery technique		
	Modified decanter	**Decanter**	**Separator**
Oil production, %	17.4	16.4	15.5
Wastewater generation, m^3/ton FFB	0.54	0.57	1.03
Oil loss in WW, kg / ton FFB	3.75	4.7	6.1
BOD loading in WW, ton/ ton FFB	27.9	25.2	43.1
SS loading in WW, ton/ ton FFB	21.4	18.5	30.3

From Table 6.11 we can conclude that pollution load from a factory that is employing a decanter is lower than from a factory that employs a separator. A decanter is used to remove oil and suspended solids from wastewater while a separator is used for remove only oil from wastewater.

Management aspects
Summarizing the results of a factory survey combined with interviews with the management of the 5 selected factories on environmental performance shows:

- Factory A and B have the best environmental management performance compared to factory C, D and E for the following reasons: they want to reduce environmental impact to the community through reduction of waste, reduce costs, and they believe that it is right thing to do. The existing environmental performance of these factories regarding resource consumption and pollution load is better than the other factories. They cooperate with several universities to conduct research on waste reduction and production efficiency improvement. The companies have an environmental policy and try to achieve the policy targets. Source reduction is the primary waste reduction technique.
- Factory C and D have a good environmental performance. Management tries to prevent environmental problems through reduction of waste both by source reduction and end of pipe treatment. The planning is on a long-term time frame. They engage in

environmental management systems. Laws and environmental regulations are still the most important factors for improving waste treatment techniques.

- Factory D has a poor environmental performance. The factory does not have a clear environmental policy. The top manager is not concerned about source reduction techniques or investment in high technology equipment such as a decanter. Considering natural resource consumption factory C has a poor environmental performance.

The management factors (features) that influences the environmental performance of the five selected companies are shown in detail in Table 6.12

Table 6.12 Classification of environmental performance of the five selected crude palm oil factories on the basis of environmental management

Management factors	Factory A&B	Factory C&D	Factory E
Management approach	Problem preventing	Problem preventing	Problem solving
Time horizon	Long term	Long term	Short term
Top management involvement	Long term involvement	Long term involvement	Non existent
Organization	Company wide	Plant	Unit operation
Manager responsible for environment	Production engineer	Environmental sector	Non existent
Driving force	Minimize waste, benefit improvement	Laws and regulation, minimize waste	Laws and regulation
Strategy	Prevention	Prevention, Cure	Cure
Pollution reduction techniques	Source reduction, recycling	Good housekeeping, source reduction	Treatment
Training	Frequently	Frequently	Non existent
Research & development	Focus on new opportunity	Compliance-oriented	Non existent
Use of resource	Effective	Effective	Ineffective
Communication	Mostly top-down	Mostly top-down	Top-down
Technology	Continuous integration	Continuous integration	Compliance-oriented

6.4.2 Community level

Since the environmental impact from the crude palm oil industry affects mainly the surrounded community, this section will focus on the effect of community on the environmental performance of crude palm oil industry in Thailand. The location of CPO mill close to a community or far from a community will be discussed. The results could be used to find ways to improve the environmental performance of CPO industry in Thailand. From the five selected factories factory A and C represent a close to community and factories B, D and

E represent a far from community situation. Factory D also represents a factory situated in a oil palm plantation area.

Oil production efficiency

The percentage of oil production is the relative quantity of crude palm oil produced (ton) from fresh fruit bunches. The percentage of oil production in the five selected mills varied from 15.5 to 17.8% (average 16.4%). The percentage of oil produced varies per factory, depending on the oil recovery technologies used. Factory A and C are situated closed to a community and can achieve a higher oil production efficiency of 17.15 % compared to factory B, D and E (Average 16.3%) as shown in Table 6.13.

Table 6.13 Comparison of production efficiency (%) of five CPO mills using different oil recovery processes

Machine	Location	
	Close to community	Far from community
Modified decanter	17.8	17.0
Decanter	16.5	16.4
Separator	-	15.5
Average	17.15	16.3

Natural resources use

Water consumption Table 6.14 shows the typical amount of water used by the 5 selected factories. It is clear that their overall usage is not very different between the two groups due to the fact that the main water consumption in the production process is boiler water and the mills employ the same boiler capacity.

Table 6.14 Comparison of water consumption (m^3 / ton FFB) of five CPO mills using different technology and at different location

Machine	Location	
	Close to community	Far from community
Modified decanter	1.2	1.0
Decanter	1.1	1.3
Separator	-	1.3
Average	1.15	1.2

Energy consumption The results from a survey of the five crude palm oil factories show that the technology employed in each factory has an effect on the total energy consumption. The electricity used in the mill with the most advanced technology (modified decanter) is the lowest as shown in Table 6.15.

Table 6.15 Comparison of electricity consumption (kWh/ ton FFB) of CPO mills at different technology and location

Machine	Location	
	Close to community	**Far from community**
Modified decanter	15.2	10.5
Decanter	19.9	16.6
Separator	-	55

Environmental pollution

Oil loss in wastewater Oil loss in wastewater is the most important indicator of oil production efficiency. It indicates the efficiency of the extraction unit and oil recovery technique. The average oil loss in wastewater from the production process is 3.38 kg / ton FFB. The quantity of oil loss in wastewater depends mainly on the oil recovery technique from the wastewater. Factories that are situated close to a community have a lower oil loss in the wastewater than those that are situated far from a community. The details of oil loss in each category are shown in Table 6.16.

Table 6.16 Comparison of oil loss (kg/ton FFB) in wastewater from CPO mills

Machine	Location	
	Close to community	**Far from community**
Modified decanter	2.5	3.5
Decanter	3.7	4.7
Separator	-	6.7

It can be concluded that communities have a positive effect on environmental performance of the crude palm oil industry by stimulating the reduction of pollutant load. This also results in an increased production efficiency of the millers. However, communities do not have an effect on raw material consumption. Table 6.17 shows the environmental performance indicators of two different location categories of crude palm oil mills. Factory A and factory C, which are located close to a community, can reduce oil loss and pollutant load in the wastewater to a lower level than factory B, D and E which are located far from a community.

Table 6.17 The average value of environmental performance indicators of different location crude palm oil mills

Indicator	Close to community	Far from community
% Oil production	17.15	16.13
Water consumption, ton/ ton FFB	1.15	1.20
Electricity consumption, kWh/ton FFB	17.6	27.3
Wastewater generation, m^3/ton FFB	0.57	0.77
Oil loss in WW, kg / ton FFB	3.30	5.10
BOD loading in WW, ton/ ton FFB	29.9	29.8
SS loading in WW, ton/ ton FFB	19.9	23.4
BOD concentration in final pond, mg/ L	56	109

6.5 Improving environmental performance of the crude palm oil industry in Thailand

6.5.1 Technical options for improving environmental performance

Depending on where the wastes are generated and recycled, the industrial ecosystem of crude palm oil industry can be divided into 2 levels (Figure 6.5):

- Clean technology/ pollution prevention or in-plant industrial ecosystem approach.
- Waste exchange or cross industry ecosystem approach: includes recycling of wastes between industrial sectors and other sectors such as the agricultural sector.

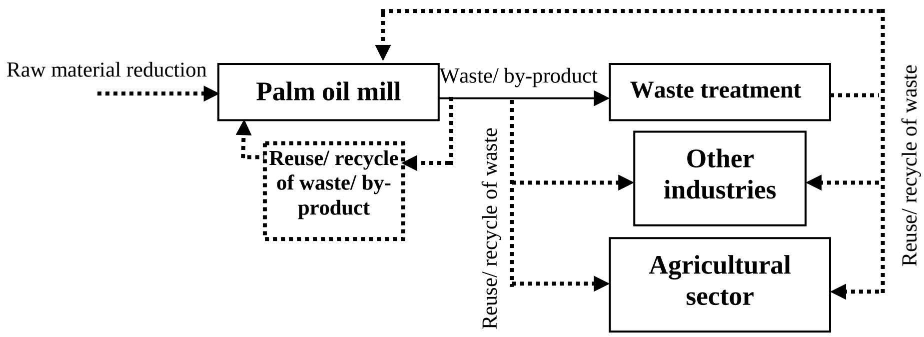


Figure 6.5 In-plant and cross industry waste reuse/ recycle

An overview of the technical options for improving the environmental performance of a crude palm oil mill is briefly summarized in Figure 6.6. Several clean technology options have already been implemented in order to increase production efficiency and to reduce water consumption and energy use in production process. The important option, as already mentioned is using a modified decanter for the recovery of oil from the wastewater because use of a modified decanter can reduce oil loss in wastewater, reduce hot water consumption and remove suspended solids from the wastewater.

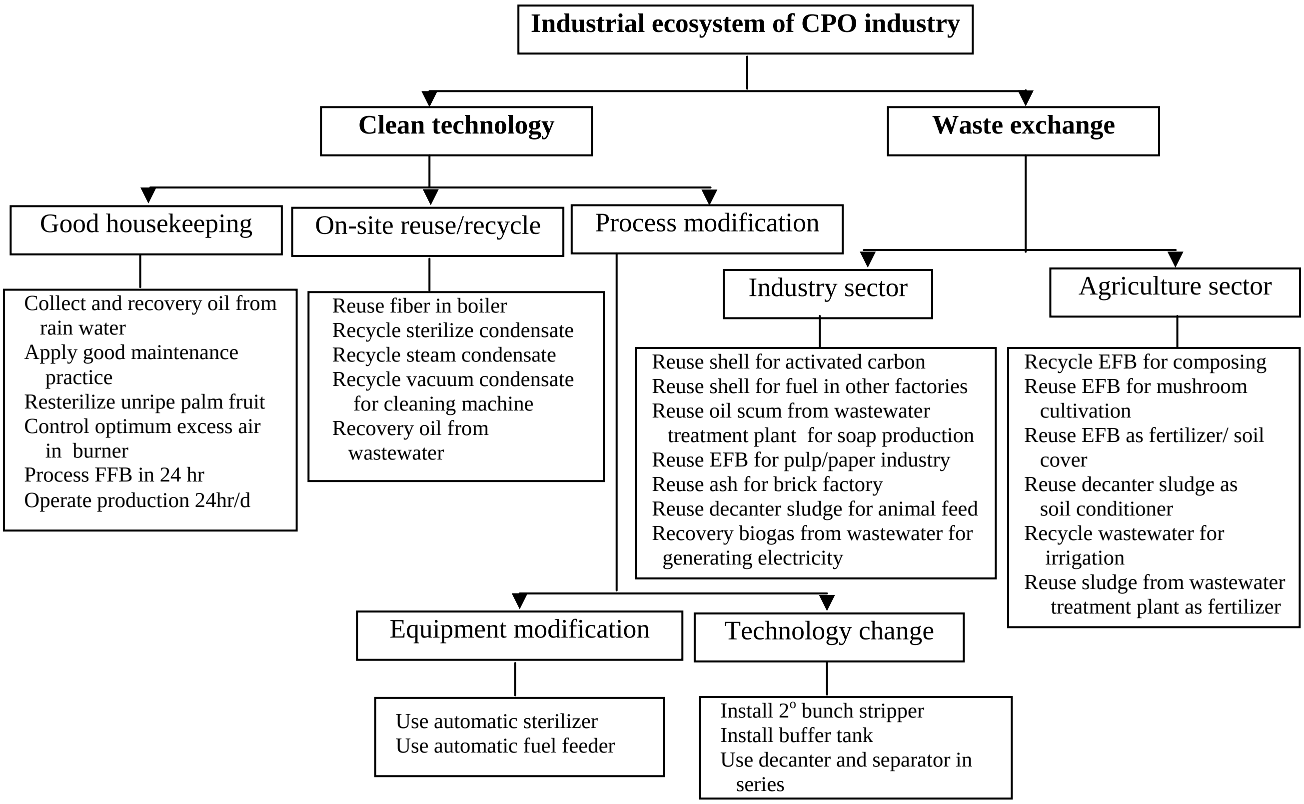


Figure 6.6 Waste management options for improving environmental performance of a crude palm oil mill.

6.5.2 Clean technology for minimizing the generation of waste/ by-product

For waste and by-products, which are unavoidable such as wastewater, empty fruit bunch, fiber, shell, decanter cake and ash that can be reused, a possible solution to reduce or eliminate their impacts on the environment is the implementation of clean technology. According to the three aspects of clean technology, the first one is the working procedures, which encompass optimization of “good housekeeping” and “good maintenance practice”. The second one is on-site reuse/recycle of waste. The third one is process modification. A process modification is installation of equipment in order to reduce oil loss or enhance production efficiency. In practice, clean technology available in the crude palm oil is emerging from good housekeeping and reuse and recycling of waste. Various measures can be taken to address environmental problems found in the crude palm oil industry. The following clean technologies have been adopted to minimize the level of pollution, as well as increase the efficiency of CPO production.

1) Good housekeeping

- Process fresh fruit bunch within 24 hour after harvesting to avoid excessive production of free fatty acids by the natural enzymes present in the fruit.
- Collect wastewater from loading ramp in order to recover oil and prevent oil contamination of land and surface water.

- Apply good practice in solid waste handling such as solid waste separation and application of certain fractions as soil cover material or reuse/ recycling in the palm oil plantation area as soon as possible to reduce dust and bad smell in the mill area.
- Separate fresh fruit bunch into 2 categories: ripe and unripe fruit to control optimal conditions for sterilization, since time for sterilization of ripe fruit is shorter than for unripe fruit.
- Apply good maintenance practice.
- Control excess air/ fuel ratio at 0.4 in burner to reduce energy consumption.

2) On-site reuse/ recycling

- Reuse fiber and shell as fuel in boiler.
- Recycle sludge from vibrating screen to digestion tank.
- Recycle sterilized condensate to screw press and vibrating screen to reduce hot water use and to improve the recovery of oil from wastewater.
- Recycle hot water from vacuum tank for cleaning decanter and separator.
- Recycle steam condensate (temp 100 ^{o}C) from kernel drying tank for reuse as feed boiler water to reduce water use and energy for heating water.

3) Process modification

- Employ an automatic autoclave for optimal sterilization conditions.
- Collect remaining unripe palm fruit to resterilize manually in order to reduce oil loss.
- Install 2nd bunch stripper to enhance fruit separation from bunch stalk to reduce oil loss from EFB.
- Install buffer tank to separate the sludge from the crude oil before flow to the settling tank to enhance oil separation, and remove sand from sludge.
- Employ decanter for recovering oil from the wastewater and construct an oil trap sump to remove oil from the wastewater before it goes to wastewater treatment plant.
- Reuse excess steam from the boiler for drying decanter sludge.

Figure 6.7 summarizes current in-plant reuse/ recycles options of oil, steam condensate and solid waste in crude palm oil production.

6.5.3 Waste exchange

Waste exchange is popular in the crude palm oil industry and is already applied on a large scale. Typical examples are shown in Figure 6.8.

1) Recycling of waste among the industrial sector

The details of alternative options for reuse/ recycling of by-product/ waste from the crude palm oil industry to other types of industries were previously mentioned in section 5.3 and 5.4. These options can be briefly summarized:

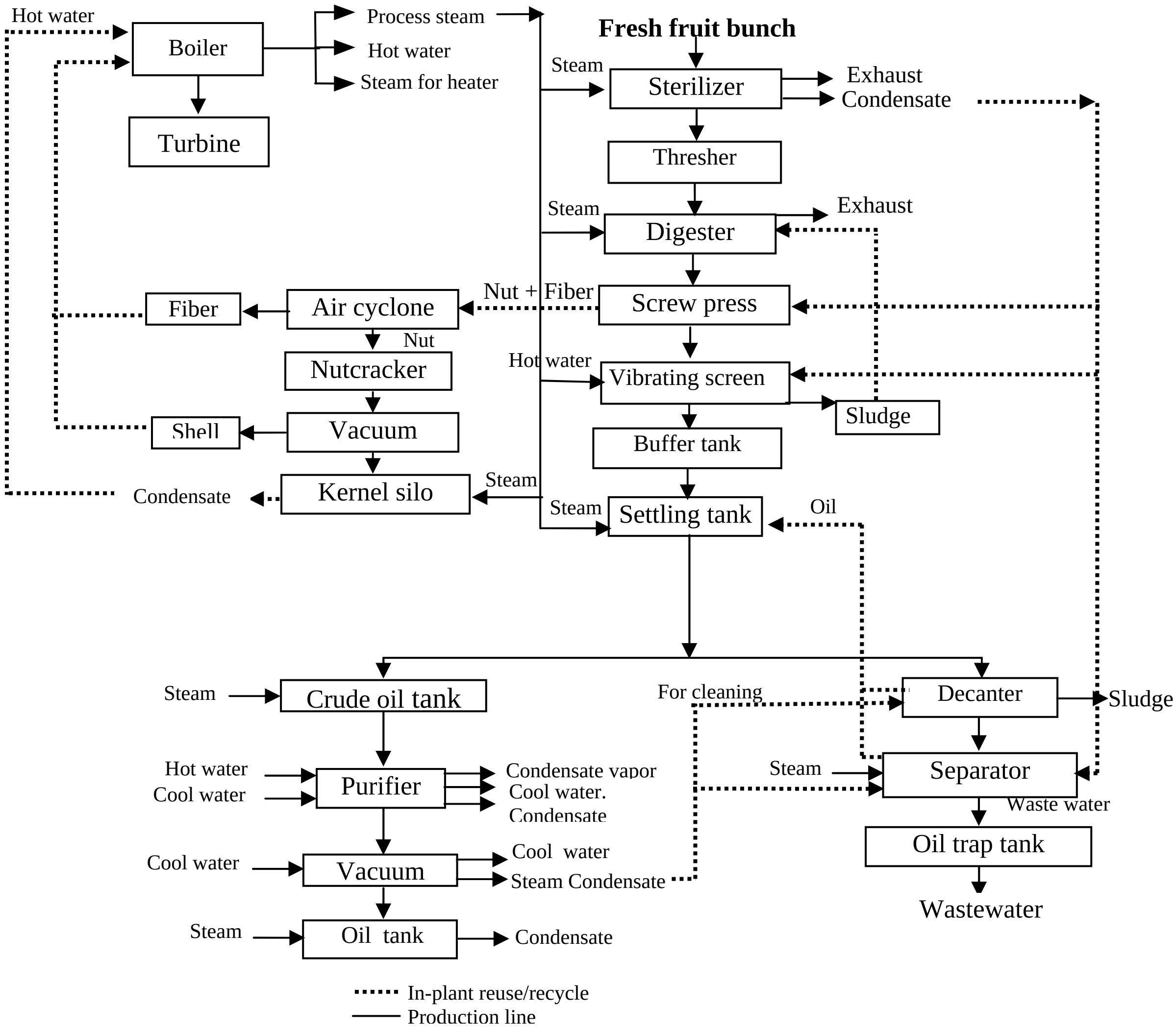


Figure 6.7 On-site reuse/ recycle in crude palm oil factory

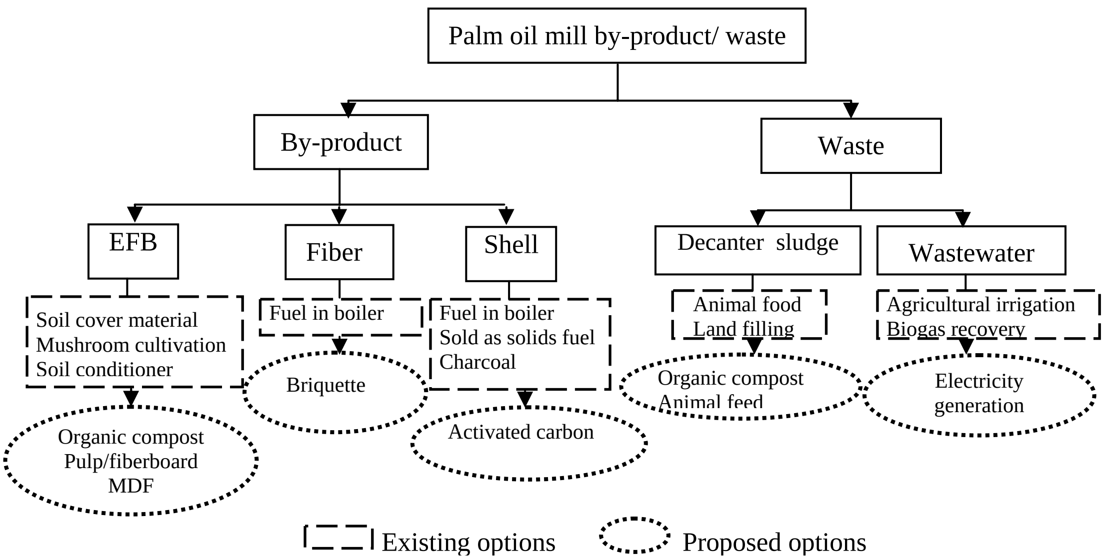


Figure 6.8 By-product/ waste application

- Reuse shell as fuel in cement factory.
- Recycle shell as raw material for activated carbon production (not adopted in Thailand).
- Recycle of empty fruit bunch as fiber for making pulp and paper and medium density fiber board (not adopted in Thailand).
- Recycle of fiber for briquette production (not adopted in Thailand).
- Recycle decanter sludge as animal feed.
- Recycle fly ash as substitute for cement for concrete block production (not adopted in Thailand).
- Recovery of biogas for generating electricity and sell to Electricity Generation Authority of Thailand.

2) Recycling of waste in agricultural sector

These options can be summarized as follow:
- Reuse empty fruit bunch as media for mushroom cultivation.
- Reuse decanter sludge as compost (not adopted in Thailand).
- Recycle wastewater after anaerobic treatment for irrigation in oil palm plantation area.
- Recycle sludge from wastewater treatment plant for soil conditioning.
- Recycle fly ash from boiler as fertilizer in oil palm plantation area.

6.6 Technological model of an almost zero waste industrial ecosystem

The absolute optimum in waste minimization involves a system in which no waste stream is discharged into the air or water, or onto the land and no external energy source is used. This is not possible in practice. However, these goals can be approached as much as possible by reuse/ recycling the waste materials of one plant as the raw material for another with a minimum of transportation. Based on the analysis of the existing material and energy flows of the five selected crude palm oil mills, this section continues to develop an integrated model of an almost zero waste industrial ecosystem for the crude palm oil industry. First however, we will discuss the existing industrial ecosystem in the crude palm oil industry. Data given in the following section are derived from the average data from five studied mills.

6.6.1 Existing industrial ecosystem in the crude palm oil industry

Figure 6.9 presents a schematic diagram of an existing crude palm oil mill, dealing with a partly environmentally balanced industrial complex. For this complex system, the estimated mass balances are based on the extraction of 1000 tons of fresh fruit bunch, harvested from 18,000 hectares oil palm plantation area, producing 168 ton of crude palm oil and 60 ton palm kernel for selling to an oil refinery. The production process results in the generation of about 640 m^3 of wastewater, 240 ton of empty fruit bunch, 140 ton of fiber, 60 ton of shell and 42 ton of decanter sludge (average data from five selected mills). Most of these by-products can be reused in production or sold to other industry. However, there is a substantial amount of waste that has to be treated before disposal. For a crude palm oil mill that is situated close to a community, these wastes include 640 m^3 of wastewater, ash and decanter sludge. Since the transportation costs are high, these wastes cannot be reused in the oil palm plantation area. For decanter sludge and ash, the mill pays for transport to a disposal or landfill daily. Because the wastewater effluent does not satisfy the standard, the wastewater is treated and kept in ponds without discharge. Differently, for a crude palm oil mill located in a plantation area, such wastes can be reused as fertilizer in the plantation area. Mills that are located close to communities have to pay more attention to the amount of waste generation than those that located in plantation areas.

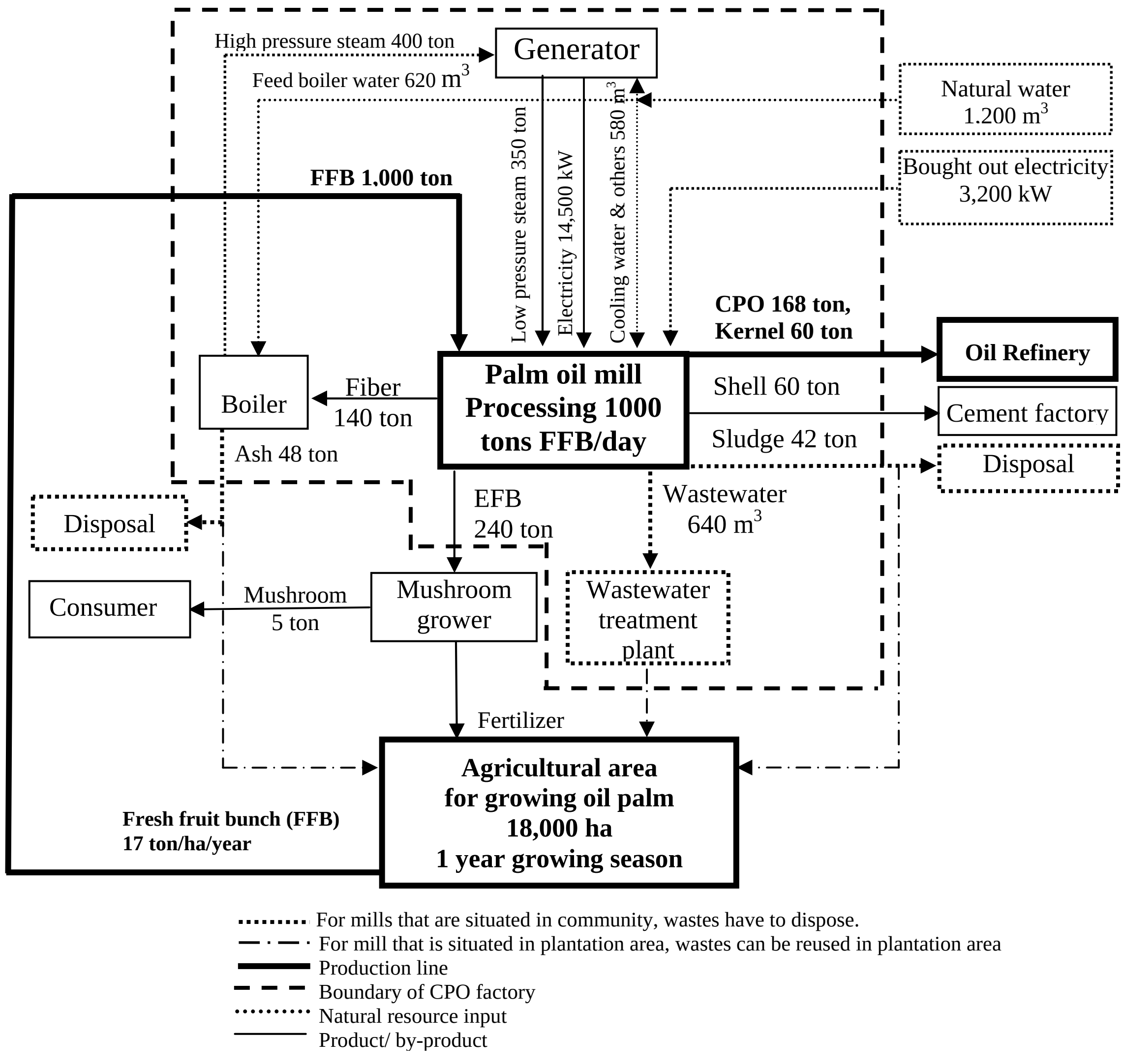


Figure 6.9 The existing industrial ecosystem model of five case study factories either situated close to a community or in a plantation area

6.6.2 The almost zero waste industrial ecosystem models for crude palm oil mill in Thailand

This section continues to develop a model of an almost zero waste industrial ecosystem for the crude palm oil industry. As described in the previous chapter crude palm oil mills in Thailand are scattered and most are located at the main roads close to the communities. Only

17% of the mills are located in plantation areas. The integrated selected technical options to develop an almost zero waste industrial ecosystem model, differ from each other for the two different types of oil mill locations. The first model deals with a crude palm oil mill that is located close to the community and the second model with a crude palm oil mill that is located in/ close to an oil palm plantation area.

Proposed physical-technological model of an almost zero waste industrial ecosystem of mill located close to a community

The crude palm oil factory located close to a community cannot reuse their by-products such as ash, sludge from decanter and wastewater in the plantation area. The material flow network of a model for such a palm oil mill is depicted in Figure 6.10. In this model, the crude palm oil production of the mill is used as a starting point. Modification of the oil palm plantation area, new designation of feed mill enterprise, modification of the existing anaerobic ponds to recover biogas and reuse this gas as fuel for boiler, construction of activated carbon plant are all designed to reach a model of an almost zero waste industrial ecosystem.

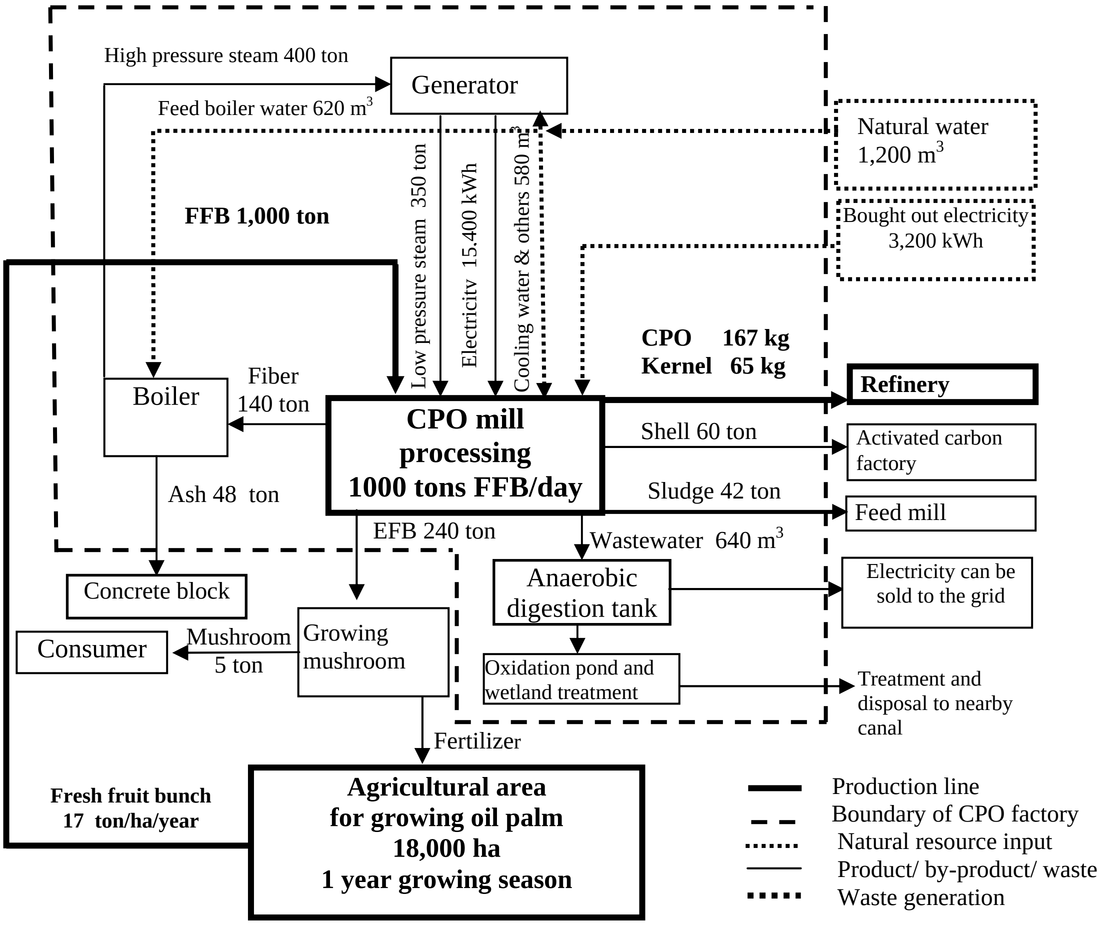


Figure 6.10 Material balance of the proposed physical-technological model for an almost zero waste industrial ecosystem of a mill located close to community

Proposed physical-technological model of an almost zero waste industrial ecosystem of a mill located in a plantation area

Figure 6.11 presents a schematic diagram of an almost zero waste industrial ecosystem of a crude palm oil mill that is located in a plantation area. Approximately 18,000 ha of land are required for harvesting 300,000 tons of FFB as feedstock for extraction at a rate of 1000 tons per day. EFB, decanter cake and wastewater from a crude palm oil mill have a high K, N, P and Mg content and can be used as fertilizer in the oil palm plantation area. From calculations based on the extraction of 300,000 tons/ year, the amount of the nutrients content of EFB are equal to 402, 30, 1230 and 90 tons of N, P, K and Mg, respectively. For wastewater, the quantities of N, P, K and Mg are equal to 64.3, 5.3, 37.8, and 378 tons/year, respectively. These residues are used as fertilizer to replace a portion of a commercial fertilizer needed in the plantation area to grow oil palms.

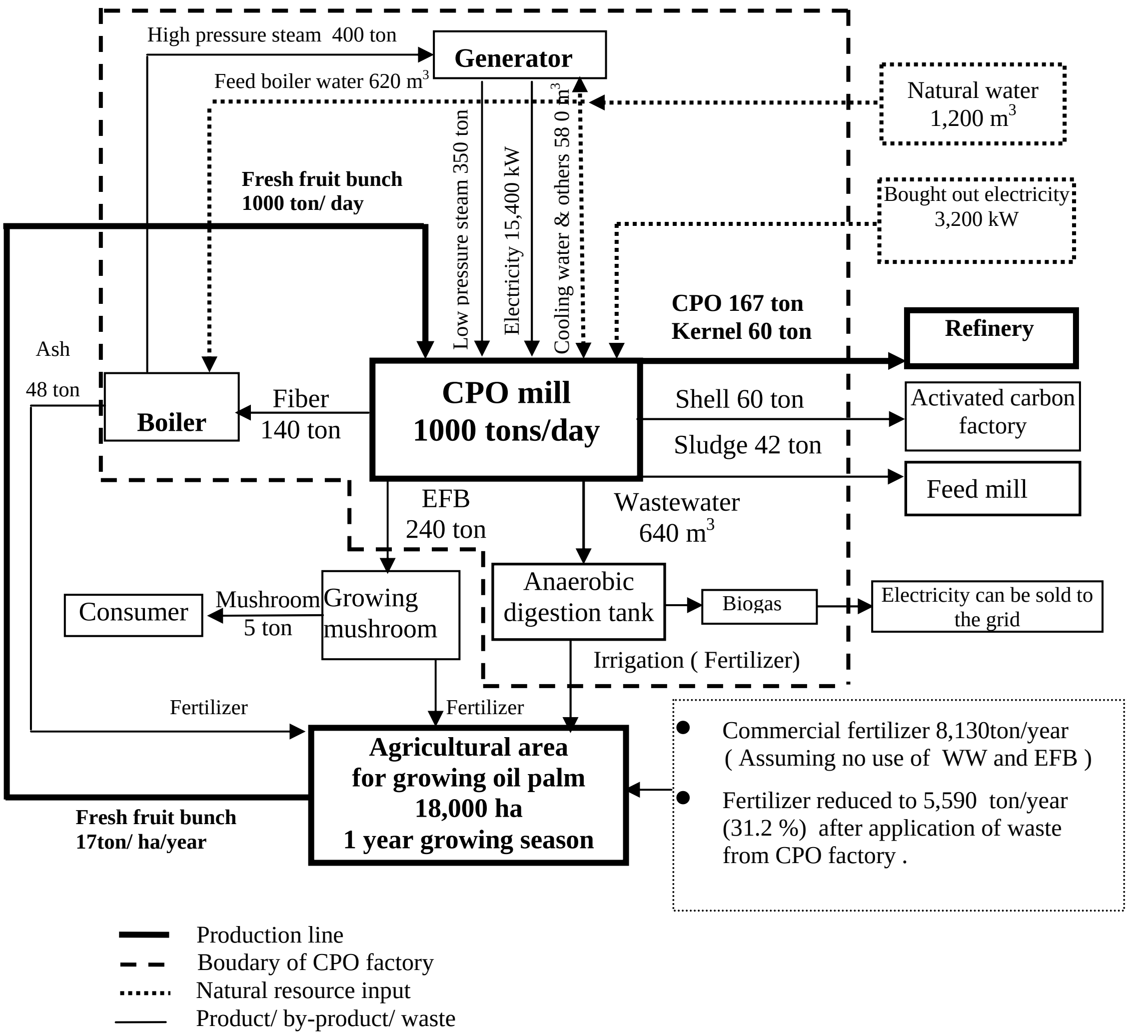


Figure 6.11 Material balance of the proposed physical-technological model of an almost zero waste industrial ecosystem of a mill in a plantation area

Table 6.18 Balance of fertilizer demand for oil palm plantation area

Fertilizer demand	N	P	K	Mg	B
Old palm tree, kg/ha/year	204	26.3	70	26.3	12.5
Oil palm tree, tons/18,000 ha/year	4,890	630	1680	630	300
Fertilizer from waste (EFB&WW), ton/ year	446	35	1268	458	-
Commercial fertilizer, ton/ year	4,424	595	412	162	300
Reduce commercial fertilizer (%)	9.5	5.6	75.4	74.3	0

The total amount of waste that can be used as fertilizer to replace commercial fertilizer is shown in Table 6.18. Since the EFB and wastewater may not contain all the requisite types and quantities of nutrients, an appropriate amount of commercial fertilizer should be applied to the palm oil plantation area to meet the necessary growth requirements, depending on the age of oil palm tree.

6.7 Conclusions

Crude palm oil mills generate large amounts of by-products and wastewater, which may have a significant impact on the environment if they are not managed properly. Each ton of fresh fruit bunch processing generates 240 kg of empty fruit bunch, 140 kg of fiber, 60 kg of shell, 42 kg of decanter sludge, 48 kg of fly ash and 640 kg of wastewater. From the results of five case studies can be concluded that mills that are situated close to a community have a better environmental performance than those that are located far from a community or in a plantation area. The reason being the application of more clean technology options such as in-plant reuse/recycle options, use of decanter and separator for recovery oil from wastewater. In addition, all crude palm oil mills in Thailand are developing a number industrial eco-system practices for waste recycling. Biomass, fiber and shell from crude palm oil processing, can be reused as solid fuel in boilers. Empty fruit bunch can be reused in the agricultural sector. However, there are several options that may have potential as more added value products, such as the reuse of shell as raw material for activated carbon production; reuse decanter sludge as animal feed; reuse fly ash for concrete block production. In addition, wastewater can be treated to produce biogas for generating electricity. The combination of clean technology, industrial ecology and appropriate waste treatment is a good approach in the improvement of environmental performance of the crude palm oil industry in Thailand. Such an approach can transform a palm oil mill in an environmental friendly industry. An industrial ecosystem approach for the crude palm oil industry, based on reuse, recycling, and utilization of solids and liquid waste, can achieve the goal of an almost zero discharge.

Chapter 7
Actors and institutions in crude palm oil industrial ecosystems

7.1 Introduction

To transfer the developed model for an eco-industrial system from the design table in the previous section to reality, it is essential that the complex social, economic and political relations and institutions governing the implementation of the industrial ecosystem are analysed in depth. As indicated in chapter 3, the triad network model (developed by Mol, 1995) is used for analysing these interactions among actors, who have or can have an influence on the application of the physical-technological model of the palm oil companies. Examination of the actor interactions in the policy, economic and societal arenas provides insight in the main push and pull (f)actors for enabling and constraining environmental reforms.

7.2 Economic network analysis

The crude palm oil industry is part of an economic network ranging from oil palm growers to downstream industries and a variety of other actors. Central characteristic of the economic network is that relations between these actors are predominantly of an economic and financial nature. The economic network of the crude palm oil industry is presented in Figure 7.1.

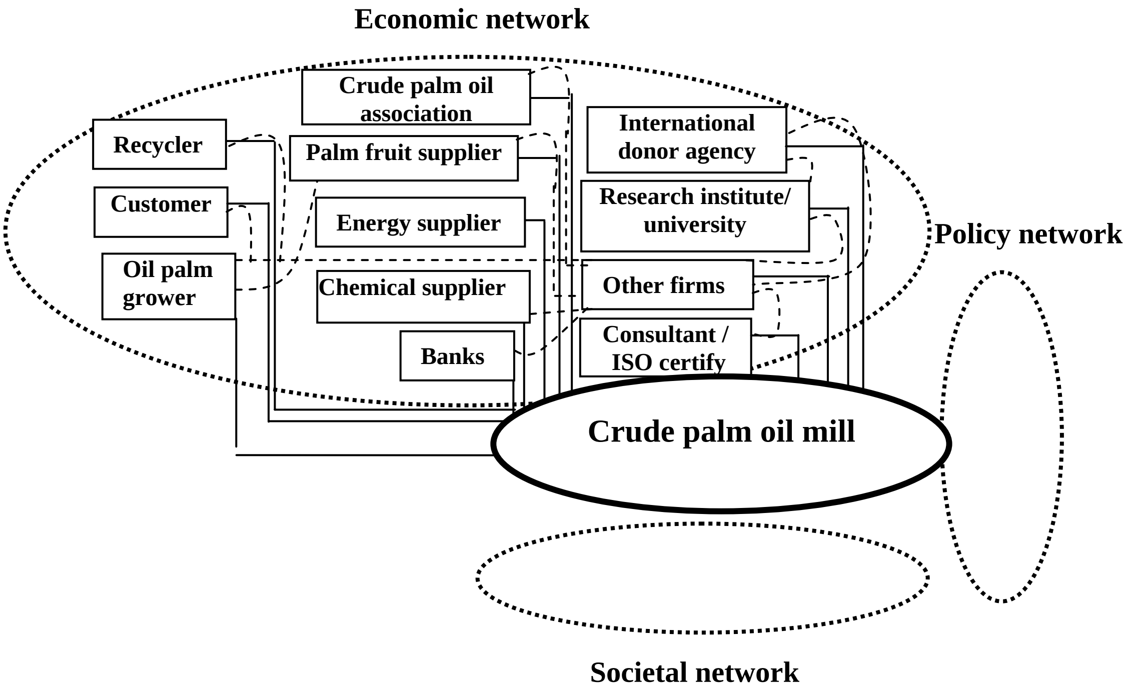


Figure 7.1 Economic networks relevant to the crude palm oil industry

The interactions of the economic network consist of two main parts: vertical interactions and horizontal interactions. The vertical network consists of a vertical connection and integration between them: from raw materials to products. The horizontal interactions are formed by the relationships between the mills and other crude palm oil mills inside the country.

7.2.1 Vertical interaction

The crude palm oil industry is a part of an economic network of oil palm growers and downstream industry. This network primarily consists of the oil palm planters, the palm oil refinery industry, the customers of palm oil products, and the consumers of palm oil and palm oil products, as is shown in Figure 7.2. The actors who have an influence on crude palm oil mills are oil palm planters, raw material suppliers (fresh fruit bunch supplier), customers, consumers, and recyclers (waste exchange aspect). Oil palm planters are divided into 3 main groups: the registered company (mill owner planter, independent company planter), the smallholding planter and the cooperative.

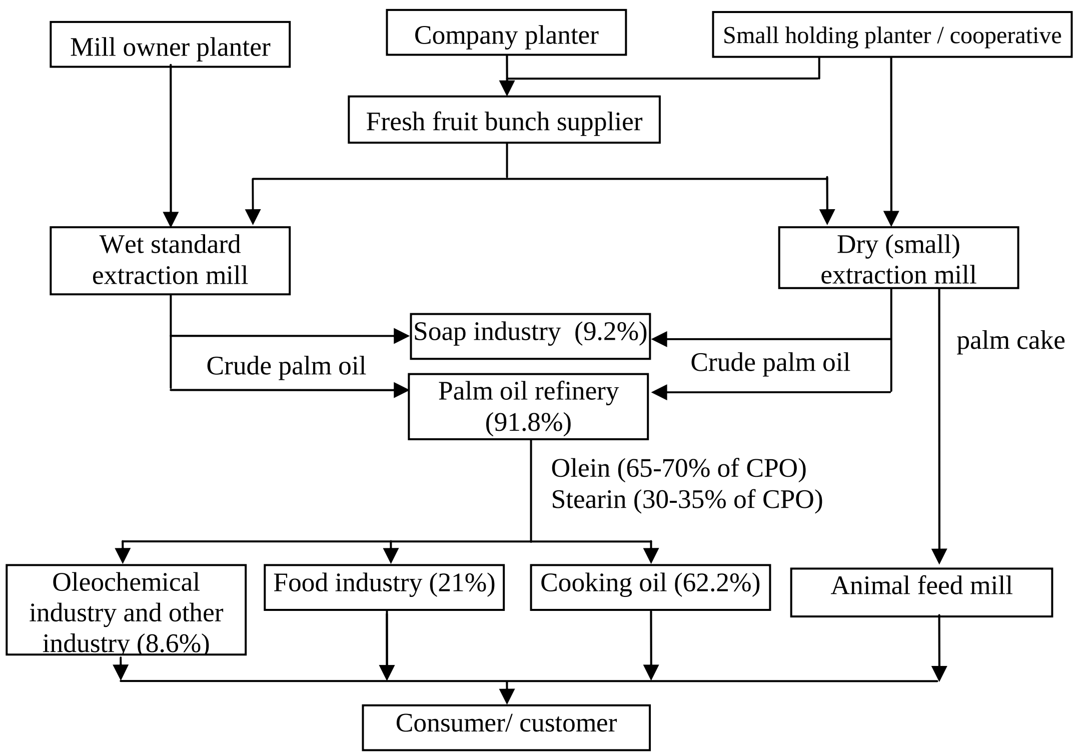


Figure 7.2 Marketing channels of oil palm and oil palm products (adapted from The Oil Palm News Letter, 2001)

1) Oil palm planter

Oil palm planters influence the application and introduction of cleaner production by millers via 2 aspects: the quality and quantity of raw materials (FFB) supply, and the reuse/recycling of wastes from production processes.

The production efficiency of FFB depends on the type of oil palm producers. They are divided into 3 groups as is shown in Table 7.1:

- Registered companies that need to have a plantation area of at least 160 hectares (36% of the total oil palm planting area belongs to registered companies).
- Small plantation owners (not registered) (48% of the total planting area).
- Cooperative members (16% of the total planting area, mainly in the Krabi province).

Table 7.1 Distribution of type of oil palm growers and plantation areas in 2002

Type	Oil palm owner		Plantation area		No. of Plantation (ha/planter)	FFB production (ton FFB/ha)	% of total FFB product	Production cost (Baht/kg)
	No.	%	hectare	%				
Registered Company	174	0.71	85,347	36	491	1,81.3	43.3	1.04
Smallholder	16,600	68.28	112,591	48	6.72	1,37.5	42.4	1.2
Cooperative	7,600	31.1	37,197	16	5	1,37.5	14.3	1.2
Total (average)	24,400	100	235,192	100	-	(16.7)	100	-

Source: Ministry of Agriculture and Cooperatives, 2002
1 EU = 40 Baht (year 2002)

The main type of oil palm producers in Thailand is a smallholding planter. Over 99.3 % of total planters are smallholders and cooperatives, their plantation areas cover around 6ก% of the total area. The commercial companies account only for 1% of the total number of planters and 36% of the total plantation area. Most of the commercial companies own a crude palm oil mill. The production efficiency of smallholders (13.7 ton FFB/ha) is lower than that of commercial companies (18.1 ton FFB/ha). The FFB produced from companies account for 43% of the total FFB production. Generally, oil palm planting by companies is known to be efficient, because they invest in all facilities and maintenance, including good irrigation systems. They also grow high quality and productive oil palm species. Accordingly, their yield is highest and they have good applications for recycling organic solid wastes from the mills into to plantations.

An improvement on oil palm species and FFB production per plantation area will reduce FFB production cost because the planter gets a higher yield of FFB with the same amount of production cost. At the same time, the high-yield FFB also increases the CPO production. On the one hand, a high oil content of FFB can result in relatively low amount of waste generation per ton oil production. This can be seen as an improvement for the environment. On the other hand, the cultivation of high oil content palm varieties requires generally more fertilizers and pesticides, contributing to economic dependencies and environmental pollution.

Factory A owns an oil palm plantation area of about 3,200 hectares, and grows a high quality oil palm variety. The FFB harvested from his plantation area is only 30% of FFB processed in the mill. The remaining 70% is purchased from FFB suppliers. In 2003, Surathani province had 66,220 hectares of palm oil plantation, 1.12 million tons FFB or 16.9 ton FFB/ha. This is quite high, due to the good soil conditions. The prices of FFB depend on the quality of the raw material i.e. oil content and ripeness of the harvested fruit. The price of FFB varies from 2.6 to 4.0 Baht/ton FFB, depending on season and quality of FFB. The survey confirmed that the production efficiency of this mill is among the highest in Thailand in 2002. The other 4 studied mills are located in Surathani province, Krabi province, Chumporn province and Trang province. They also buy palm fruits directly from FFB suppliers. Since the quality of FFB affects the production yield of the mill, factory A, B and D, which have their own plantation area, have better means to control production efficiency by controlling FFB quality input. The raw material for these factories is a mix of FFB from the factory's own plantation and purchased FFB. This advantage is confirmed by comparing production efficiency: Factory A, B and D achieve a higher production efficiency than factory C and E.

Currently, the oil content in FFB is on average 17% (Department of Agriculture Technology, 2002), while in Malaysia that is 22% (MPOB, 2003). The reason is the lack of good palm varieties. The agricultural research institute of Surajthani province researched oil palms for high quality species since 1985. The amount of high quality seeds was not enough for covering all planting areas. Oil palm planters buy seeds from a seed supplier nearby, and recommend by other oil palm growers. They have little knowledge and information about the varieties and the quality of FFB. Since the FFB supply is less than the demand, there is no incentive for oil palm growers to move to high yield and high quality oil palm seeds. Farmers also lack expertise in cultivation. There is limited research on oil palm trees and government officers cannot give good advice because they do not have enough expertise themselves.

Reuse/recycling of wastes form production process

Most smallholders sell their products to FFB suppliers, since transportation of FFB to a mill is costly and the amount is usually small. There is no direct contact between millers and smallholding planters in terms of FFB purchasing. This is one of the most crucial barriers for reuse/recycle of the waste/by-products in the agricultural sector. At present, little waste from palm oil factories is reused as fertilizer in palm plantations. Interviews with mill managers and planters indicated that only large plantations, in the vicinity of the mill and owned by factories, reduce cost of commercial fertilizer by recycling waste from the oil production processes (e.g. wastewater, ash, EFB and bottom sludge from wastewater treatment plant) to the plantation area. They save on fertilizers, chemicals and transportation. Major production costs for oil palm plantations are related to fertilizer and labour (including harvesting costs), accounting for 30.03 % and 32.7 % (23 %for harvesting costs) of total costs, respectively (Department of Agriculture Technology, 2002). The cost of production shows a rising trend due to increasing costs of fertilizer. If waste from factories can be used as fertilizer in the palm plantation, the costs for growing palms will be decreased.

Some cooperative planters reuse empty fruit brunch as substrate for mushroom cultivation in their plantation area. However, smallholders often do not recycle such wastes in the plantations, because they lack the required technical knowledge. They are often not aware that they can make use of such wastes from the factory. Table 7.2 summarizes the relationship between mills and different groups of oil palm planters.

Table 7.2 Relation between mills and different groups of oil palm planters

Oil palm planter	Relationship with mill	Distance from mill	Waste reuse/ recycle
Registered companies	Owned by palm oil mill	- Close to a mill	- Reuse /recycle of wastewater and solid waste in plantation area
		- Far from a mill	- No
Small holders	No relationship	- Close	- Reuse decanter sludge for feeding cows - Reuse of empty fruit brunch for mushroom cultivation
		- Far	- No
Cooperative members	Indirect relationship	- Far / close	- Reuse of empty fruit brunch for mushroom cultivation

2) Fresh fruit bunch supplier

In the past millers purchased FFB directly from oil palm planters. At present the millers purchase FFB from FFB suppliers, contractors who directly buy FFB from farmers and sell it to factories. Generally, crude palm oil mills will contact various suppliers for buying FFB, and vice versa, the supplier will contact various factories to sell FFB, without making fixed long-term agreements. Both sides will negotiate the price. The supplier contacts many smallholders. The supplier is responsible for purchasing and transporting the FFB to the factory. Some suppliers also harvest the FFB. Most smallholders sell FFB to a supplier because this reduces transportation and harvesting labour costs. Every day the purchasing manager of a mill contacts the various suppliers for the quantity of the material needed for the factory. The reason why mills do not want to make long-term agreements with suppliers is the constant changes in the palm oil price in Bangkok, which depends on the price of palm oil on the world market. Moreover, the price of FFB varies according to season, ripeness (% oil content) and size of FFB. Oil palm production peaks during the rainy season and is low in summer. The state of ripeness of the fruits at the time of harvesting will influence the yield and the quality of palm oil, as determined by the level of free fatty acids in the extracted oil. When the FFB is harvested, the free fatty acid content in oil will gradually increase, making FFB less wanted and thus lower priced.

Factory A distinguished the price setting via the quality of FFB, in 2 rates: one for FFB and one for fallen palm fruit:

- The FFB buying price will depend on oil content, which varies between 13-18%. The oil content in FFB is estimated based on the factory’s experience.
  - The price for FFB with a oil content>18% will be highest
  - The price for FFB with a oil content< 18% will decrease accordingly.
- Factory A will buy fallen palm fruits for prices 30% higher than FFB. The reason being that fallen fruit contains no stalks, which is 27% in weight of a fruit bunch. Fallen fruits can also yield more oil.

Some mills sell empty fruit brunch (EFB) at a low price to the suppliers from whom they bought FFB. The suppliers will then sell the EFB back to the smallholding planters/cooperatives. There is no direct relationship between farmers and factories, because all trade is between the crude palm oil factory and the supplier. This lack of a factory-farmer relationship forms a barrier for reuse/recycling of solid waste from the factory, such as decanter sludge, ashes and wastewater, at oil palm plantations. At present farmers use chemical fertilizer and they are not aware of the fertilizer value of the factory waste. To apply the industrial ecology concept in the crude palm oil industry, a reorganization of the relations between mills and farmers seems to be essential.

3) Consumers/Customers

The main buyers of crude palm oil are the local refinery factories that refine CPO to pure palm oil, suitable for consumption or for use as raw material for the downstream industry. Around 90% of all crude palm oil is sold to refineries; the remaining 10% goes to soap and detergent industries, as is shown in Figure 7.2. Millers generally sell their product to refineries on terms of a previously negotiated contract, which specifies volume, quality and price of the product. The contract period may be 12 months or 3-5 months depending on the amount and price of product. There are fixed relations and long-term agreements, but the price of crude palm oil is not included and fluctuates everyday. The quality of palm oil from the various millers does not differ significantly because they employ the same production technology, introduced from Malaysia. Oil refineries buy crude palm oil using the following quality standards:

- Free fatty acids <5%.
- Moisture content <0.5%.
- Purity grade A >50-52%.
- Colour bleaching ability by using cell 51/4 $<2x30^{y}$Red.

The refineries are mostly located in the Bangkok Metropolitan region, near the end-users. There are only 11 refineries in Thailand and some of them have expanded into crude palm oil production and palm cultivation to lower costs and reduce uncertainty in raw material supply. The use of refined palm oil in Thailand is for direct consumption as cooking oil and local industrial use. The price is controlled by the government (minimum price fixed) and the competition in the market is on both product differentiation and price. The price of pure palm oil is lower than other kinds of vegetable oil and palm oil is favoured among restaurants and consumers. Around 95% of refined palm oil is consumed locally. The remaining 5% is sold to neighbouring countries like Laos, Myanmar and Cambodia (MOAC, 2003).

The large refineries have to be certified for ISO 14000 and HACCP to create a good image in the consumer market. However, customers play at the moment a minor role in pushing the refineries to take both product quality and environmental performance into account via ISO certification. Currently the production capacity of refineries is higher than the crude palm oil supply and lower than market demand. The CPO case study factories show that local customers and consumers have minor influence on the environmental performance and ISO certification of extraction mills.

The Thai palm oil industry has to enhance the production efficiency to lower the higher production costs compared to Malaysia and Indonesia and to compete on the world market, in order to meet the increasing demand in the future. Thailand is a member of the Asian Free Trade Area (AFTA) and WTO. In the year 2004, Thailand had to reduce the import tax on palm oil from 20% to 0-5% following AFTA agreements. The Siam Commercial Bank Research Institute Report (2000) concluded that the impact on the palm oil complex could cause some planters and millers to go out of business because they cannot compete in the market. In 1999, the government introduced “A Development of Oil Palm and Palm Oil Plan 1999-2003” involving many stakeholders such as the Ministry of Agriculture and Cooperatives, the Ministry of Industry, the Ministry of Commercial and the Government bank. The objective of this plan was to promote production and marketing, to prepare the sector for international market competition and to improve the product quality and production efficiency continuously. Options to reduce oil loss in production wastes and recover oil from wastewater were among the first priorities. Another option was the application of the waste exchange concept. The reuse/recycling of waste and added value products was believed to bring significant benefits through selling by-products, saving disposal costs and improving the environmental performance of the industry. Since 2002, The price of CPO in Thailand was decrease to the same as in Malaysia. This is also due to devalue of Thai Baht.

4) Electricity suppliers

Electricity is the dominant energy source for the production process. The electricity generated by the company’s cogeneration plant is sufficient for the plant operation and other uses. Only during the shutdown and the start-up of the mills, millers use electricity from the Electricity Generation Authority of Thailand (EGAT). The electricity net is state-owned and the state has a monopoly position. Therefore, millers are unable to sell self-generated electricity to other local companies or communities. The electricity and fuel costs of palm oil mills are less than 1 % of the production costs. Consequently there is no incentive for millers to recover and reuse biogas from wastewater treatment systems. Only if they can sell additionally generated electricity to the EGAT, the investment of anaerobic digestion tanks to recover biogas for electricity generation will be economically attractive for these factories. Currently, 2 crude palm oil mills have registered with DIW for setting up a power generation plant using biogas. There are still under construction.

5) Chemical suppliers

The companies buy chemicals on the local market from different merchants. Buying is done on ‘on the spot’ purchase basis, depending on the price.

6) Recyclers

Recycling activities include cement and brick factories (factory that use solid fuel), activated carbon factories, livestock feed production mills, concrete block factories and oil palm growers. Most by-products and waste from the crude palm oil production can be sold to other industrial sectors or to the agricultural sector.

- ***Waste exchange in the industrial sector***

For waste reuse/recycling in other industries, the mills sell by-products to recyclers at a low price. If millers could produce products from such wastes, they would profit from these added value products, such as: activated carbon from palm shell, animal feed from decanter cake.

However, they lack technology and access to necessary knowledge and information. These are the important barriers for waste exchange in Thailand. The reason for this is that there is no cooperation between millers, governmental institutes and research institutes/universities.

The millers sell shells at the low price of 500 Baht/ton to various factories that use shells as solid fuel in burners. These factories include a cement factory, a brick factory and a charcoal factory. Since the price of shells per unit of caloric value is much cheaper than fuel oil, a cement factory located in the Nakornsrithamrat province has long-term agreements with some crude palm oil factories in the neighbourhood for buying shells. With the present reuse of shells, this is not an economically feasible option. Conversion of the shell to a higher added value product, like activated carbon, is another option for turning a by-product into a resource. Commercial palm kernel shell activated carbon, made in Nigeria (trade name MIDAC) sells in a price range of 1,000-1,526 US$/ton. It is applied for colour adsorption, particulate coagulation and dechlorination in distillers, by bottling companies, oil refineries, chemical industries, and used in water purification equipment and water filter cartridges. A study on Thai production of activated carbon from shell at lab-bench scale confirms that it is technically possible; the iodine adsorption meets the industrial product standard. However, there is a need for the study of cost-effective development of commercial scale production, and the most desirable method of producing activated carbon by adjusting process conditions to control precisely the properties of the end product. Thailand also lacks technology for the design and construction of the machines and equipment for activated carbon production. Moreover, at present there are many local brands of activated carbon from coconut shell, which are of higher quality than activated carbon from palm kernel shell.

The decanter cake generation from all crude palm oil mills is about 140,000 ton/year. At present, only a small amount of this waste is reused/recycled as animal feed, thus most is disposed as waste. Decanter cake has a high oil and protein content and can be reused as animal feed substitute. Recycling of decanter cake as animal feed for cows has been adopted only in the Chumporn province. Farmers in other provinces are afraid of negative effects from this by-product, because they lack experience in reuse of this waste as animal feed. To reuse the decanter cake as animal feed the moisture content of the sludge should be less than 10%. Otherwise, this waste will ferment and produce a bad smell, when kept longer than 24 hours. The mills could recover heat from the exhaust gas to dry decanter cake. This option is widely applied in Malaysian palm oil mills.

- ***Waste exchange in agricultural sector***

Interviews with mill managers and recyclers showed that off-site reuse and recycling of non-products is not practiced in the studied mills located far from plantations. At present, oil palm cultivation cooperatives in Krabi and Surathani province practice the growing of straw mushroom. Farmers in Chumporn Province practice the use of decanter cake as animal feed. Knowledge of these practices does not yet seem to have spread to other provinces. Cooperatives and smallholder plantation owners do not know that wastewater from CPO factories contains high levels of fertilizers and can be reused on the plantation area to reduce the cost of fertilizers. Cow farms, located close to mills, do not know that decanter sludge contains high concentrations of fat and minerals and can be reused as feed for livestock.

There are several kinds of institutional barriers: lack of research and development institutes, lack of direct government support and lack of cooperation between mills and planters. Moreover, most of present waste exchange recycler practices technology themselves is no available of technical data on the reuse and recycle of such waste. Conversion of the waste/by-product to added valued material, such as organic fertilizer, will directly solve part of the environmental problems and turn the by-product into a resource for another industry.

For recycling of wastewater in plantation areas, interviews with mill managers and planters indicate that only mills that are located in a plantation can recycle their wastewater for irrigation. The important barrier for mills located far from plantations is the transportation cost. Smallholding planters surrounding the mills do not recycle the wastewater in their plantations because they are not aware of the fertilizer value of this wastewater. They are also afraid of the side effects since the colour of palm oil wastewater is black.

The important barrier for waste exchange is lack of know-how and access to information. This is a major problem hampering reuse and recycling of waste in other industries and the agricultural sector. Using palm oil sludge as animal food, or wastewater for irrigation cannot be implemented due to farmers' lack of knowledge about the quality and amount of waste and the return profit. The factories also could not provide these data because there is often no direct relationship between millers and oil palm planters. Even when there is information on waste application in plantation areas, farmers have no incentive to apply these wastes/by-products in their plantation area. The case studies show that it is hard to find cooperation between research institutes/ universities and recyclers, especially planters. This limits opportunities of recyclers in accessing new techniques or options to reuse/recycle solid waste from the mills.

There are several incentives and opportunities to overcome these barriers to implement a zero waste industrial ecosystem and increase competition on the world market. Currently (2005), 34 CPO mills have a larger total production capacity of than FFB harvested: factories have to compete for raw material for production. This results in high production costs of the CPO product. Sale profits from producing and selling CPO product are therefore low. Especially in 2005, Thailand will have to reduce the import tax on CPO from Malaysia to 0%, according to the agreements of the AFTA. Factories could adapt themselves, to survive and compete with Malaysian palm oil, by increasing their production efficiency and selling more by-products for additional income.

7) Crude palm oil association

Crude Palm Oil Association (CPOA) plays minor role in environmental improvement of mill. There are 16 crude palm oil mills as its member. There is not authorized. It does not act as representative of the industry and link between government institutions and CPO mills. CPOA plays no role on planning of national crude palm oil policy and environmental improvement of mills.

Local institutions, such as universities/research institutes, local authorities and the Thai Palm Oil Association, can play a role in training, applying research, academic studies and dissemination of information on waste recycling. Successful utilization of by-product and waste demonstration projects will convince producers and waste recyclers of the significance using more by-products/wastes. In case of reuse/recycling waste in the agricultural sector, the Ministry of Agriculture and Cooperation should do more to provide knowledge and information to the planters on the use and benefit of waste. Especially the use of compost produced from palm oil sludge, ash and partially treated wastewater will reduce the use of fertilizers

7.2.2 Horizontal interaction between the producer and other crude palm oil companies

Competition between CPO mills in the same province is related to the fact that they have to buy materials from the same suppliers. Factory owners in the province have a meeting every month to exchange information and to agree on a set price and quality of fresh fruit bunch from the FFB suppliers. There is usually a standard price for FFB and an agreement between factory owners to buy FFB of good quality (not rotten). Consequently, the supplier must control the quality of FFB. However, in the area where many mills are located close to each other, these factories seriously compete on raw material supply for the production process, especially because the production of these mills is only at 67% of their production capacity. The Department of Industrial Work has set up rules for the registration of new factories, allowing factories to be located only in their own plantation areas.

At present, Thai millers have to improve their production process to be able to compete with other countries, such as Malaysia and Indonesia. Factories have to increase production effectiveness and at the same time improve their environmental performance. By implementing projects on reduction of oil loss in waste streams, selling waste to other industrial sectors, recovery of biogas from wastewater, and selling electricity to EGAT, they can increase their profit margin. Since there is little competition on selling by-products, and production technology does not differ among millers, they can and do share expertise on manufacturing technology and waste treatment. There is an informal network of managers and engineers, who collaborate on clean technology projects. In addition, there are personal contacts between millers. They share information on cleaner technology, especially on cost-benefits. In some cases, mill managers visit other mills to observe and collect data on clean technology options. Some networks were created when members participated in clean technology projects organized by DIW, university/research institutes and NGOs, supported by international donor agencies. These networks and relationships can be further used for environmental improvement within factories.

7.2.3 The interactions between mills and other economic actors

Relevant economic agents in the economic network include banks, research institutes, international donors and insurance companies. Banks and insurance companies have not provided any incentives for companies to apply clean technology and pollution prevention measures.

1) Research institutes

Research institutes/universities that conduct research and development on cleaner production are mostly financially supported by the government or by international donor agencies. Their main activities have been training, outreach projects and demonstrations. Most research involves several actors, such as government institutions, NGOs, consultants and millers. At present factory A collaborates with several academic agencies to conduct research within the factory. Academic agencies often take initiatives for such investigations by supporting it with technology and manpower. Meanwhile, the factory partially contributes to the budget for such research. These projects do not have financial support from the government. Most research emphasizes on waste treatment and waste recycling, which are the current environmental problems of this factory. This joint research helps company A to improve its environmental performance. This kind of collaboration does not take place in the other case-study industries yet.

For other waste reuse/recycling options, like biogas recovery systems, activated carbon from palm kernel shell and reuse of fly ash for concrete block, academic agencies can play important roles in conducting research and helping the companies to implement the proposed waste exchange measures. They can provide reliable technical information by demonstrating equipment or pilot systems and training government agencies, palm oil mill employees and palm growers for the application of by-products and wastes. However, at the moment no such initiatives are taking place. These activities need financial support from the government and companies, etc. and also financial support in terms of low interest loans to factories for the implementation of clean technology to improve their environmental performance.

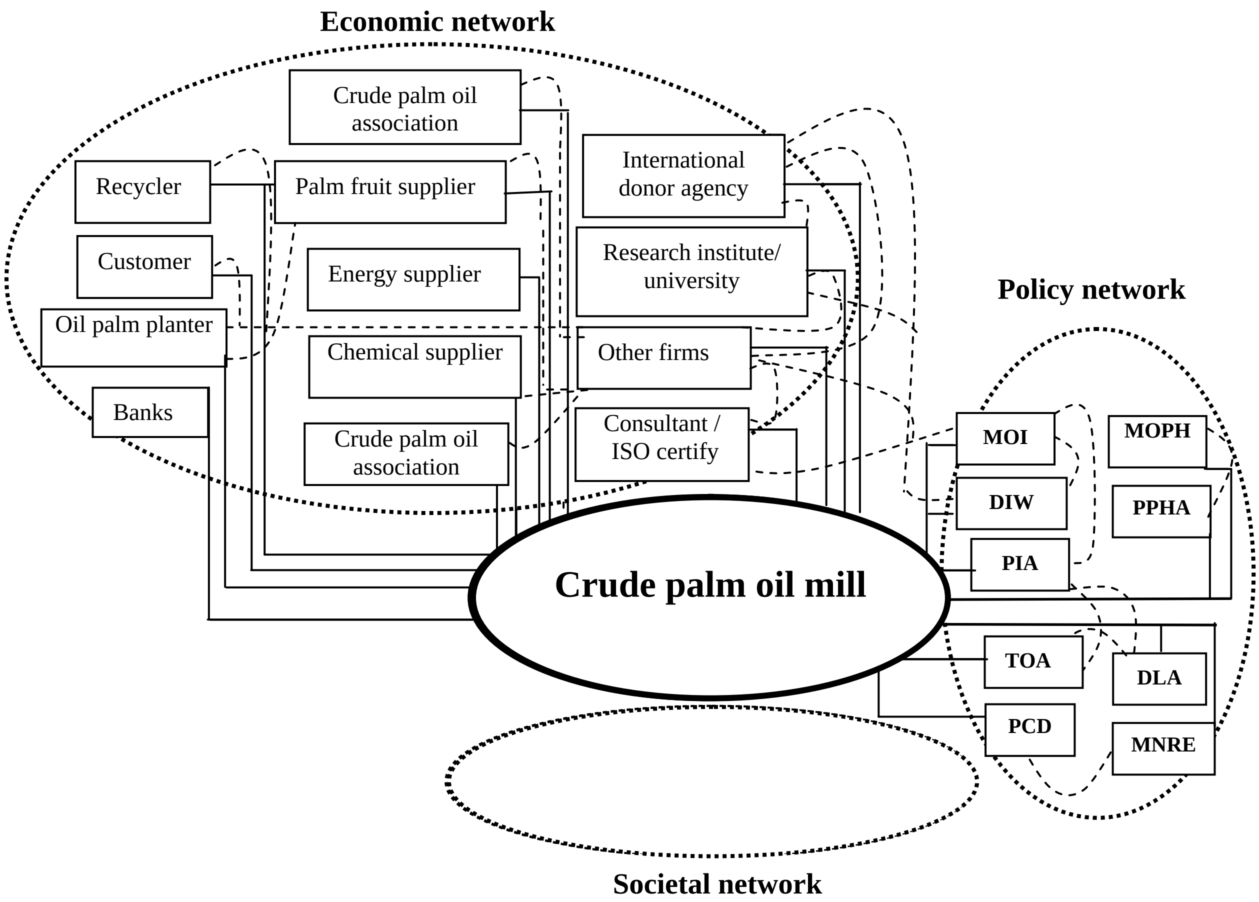
2) International donor agencies

In the past 8 years, several international donor agencies initiated activities in waste minimization, good housekeeping, source reduction, recycling, reuse etc. Examples of these international donor agencies are the GTZ (assisting the project on Environmental Advisory Assistance for the Agricultural Industry, together with the Industrial Work Department), the Carl Duisberg Gesellschaft South East Asia program Office, and the Danish Cooperation for Environment and Development (DANCED) (on establishing a national clean technology centre (MOSTE) that promotes clean technology in the Thai industry, including the CPO industry). These initiatives produced results in the CPO industry, leading to increased saving and additional profits, whilst substantially reducing wastes. The environmental performance of the crude palm oil industry improved due to the introduction of environmental management systems (EMS) by DIW. Results show that most mills know clean technology and implemented environmental management systems and cleaner production methods (DIW, 1997 and DIW, 1999).

7.3 Policy network

Palm oil is one of the 15 fast track industrial products with AFTA agreements in 1996. By 2003, the tariff rates have to be brought down to 0-5 percent in 5 years. When the Thai palm oil market has to open to foreign competition, the palm oil industry will be strongly affected because of the higher the production costs of Thai crude palm oil compared to Malaysia's. One of the tools that the government has used to support the domestic CPO producers is cleaner production. The implementation of cleaner production activities, supported by the government and involved stakeholders, on a voluntary basis in a bottom–up approach were often more successful (Visvanathan and Kumar, 1999). The main activities were training, outreach projects and demonstrations. Data from this study in 2002 showed that 75% of the factories are engaged in clean technology. Most clean technology applications are meant to increase production efficiency by reducing oil loss in wastes.

This section will analyse the current legislation and governmental authorities that are involved in environmental policy towards the industry. Policy institutions at different levels (central, provincial, and local) related to environmental management of the crude palm oil industry are presented in Figure 7.3.



MOI=Ministry of Industry; DIW= Department of Industrial Works; PIA=Provincial Industrial Office); DLA=Department of Local Administration; TAO=Tambol Administration Organization; MNRE= Ministry of Natural Resource and Environment; PCD= Pollution Control Department; MOPH= Ministry of Public Health; PPHA= Provincial Public Health Office.

Figure 7.3 Policy network involving to crude palm oil mill

The government institutes that have a relationship with crude palm oil millers and have direct/indirect impacts on environmental management of the millers can be divided into three levels:

- National level.
- Provincial level.
- Local level.

7.3.1 National level

The government institutions at the state level, which have either a direct or indirect effect on the environmental improvement of CPO mills, are summarized in Table 7.3:

Table 7.3 Government institutions related to environmental improvement of the crude palm oil industry (2004)

Level	Institutes	Responsible unit	Responsibility
Central	DIW (under MOInd)	- The Factory Environmental Technology Bureau	- Research and development of industrial production, including clean technology in CPO industry.
		- The Factory Control and Inspection Bureau 4	- Regulating industrial production including the pollution from CPO production
		- Factory Registration Bureau	- Responsible for issuing and revoking factory licenses
	PCD (under MNRE)	- Water Quality Management Bureau	- Setting emission/effluent standards from industry - Take actions on public complaints related to pollution from CPO production
Provincial	PIA (under MOInd and Provincial Governors)	- Industrial Work Section	- Regulating industrial production including the pollution from CPO production - Responsible for issuing, shutdown and revoking factory licenses
	PPHA (under MOPH and Provincial Governors)	- Representative of the DOH	- Provision of public health of both workers and community
	Provincial Governors	- Head of the Provincial Governors	- Regulating the activity of provincial governor and Local governor - Having authority for revoking factory licenses
Local	PAO/ municipality and TAO (under DLA)	- PAO and TAO council	- Protect and maintain the environmental quality of the provincial/ sub-district area - Take action on public complaints and responsible for primary inspection

MOInd has a direct relationship with millers in two aspects: (1) developing and introducing clean technology for the crude palm oil industries and (2) enforcement and monitoring of pollution from crude palm oil production. The Clean Technology Unit (CTU) under the

Factory Environmental Technology Bureau is responsible for the development and introduction of clean technology in the crude palm oil industry. For regulation of pollution from CPO production, the Factory Control and Inspection Bureau 4 has representatives at the provincial level (PIA). The PIA is responsible for regulating the discharge and other nuisances from the mills.

The Factory Environmental Technology Bureau of DIW is the most important actor that has direct influence on clean technology application by the crude palm oil industry. It established 3 programs to promote the adoption of concepts and practices of clean technology in the industry. The relationship of this governmental agency with the millers started in1994. The project "Environmental Advisory Assistance to the Industry" was implemented by the Department of Industrial Work (DIW) and supported within the framework of the Thai-German Technical Cooperation Program by the Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, which contracted academic agencies for carrying out research activities. GTZ supported all research grants and technical resources in this program during 1994-1997. Five mills joined this project. Another project is "Impact Assessment Guideline for the Palm Oil Industry" granted by the GTZ, implemented by a consultant company during 1998-1999. Eleven CPO mills joined this project. The output of these projects resulted in the development and implementation of cleaner production methods as well as the application of waste management in the palm oil industry (DIW, 1997; DIW, 1999). The last project is "Cleaner production for crude palm oil industry" granted by DIW, carried out by an NGO during 1999-2000. Five mills joined this project.

Research related to clean technology, granted by other governmental institution are:

- "Pollution prevention for Thai industry" granted by PCD to an academic agency during 2002-2003. Six CPO mills joined this project.
- "A feasibility study on co-generation from palm oil mill bio-mass"; granted by Ministry of Science, Technology and Environment; during 2001-2002. Five CPO mills joined this project
- "Developing environmental performance indicators for competitiveness for Thai industry": granted by Thailand Research Promotion Institution, studied by a NGO during 2000-2001. Ten CPO mills joined this project.
- "Cleaner production for CPO industry"; granted by Thailand Research Promotion Institution, carried out by academic agencies in 2003. One CPO mill joined this project.

Managers of factory A, B and C, who joined the Environmental Advisory Advice for Industry conducted project by DIW, said that they can establish a CT work group in the factory when they know the advantage of improving production efficiency by reducing waste, to gain more benefit. Therefore, the factory makes doing CT a target and task every year which really reduce in production expense.

The interviewed mill managers of 15 CPO factories all know clean technology from the DIW's projects, and all millers have applied good housekeeping to reduce oil loss in the wastewater. Factories A, B, C and D have cooperated in several clean technology projects to improve their environmental performance through many clean technology options. After benefiting from implementing the first clean technology project, they have continued to increase their production efficiency by reducing resources used, reuse/recycling of waste in the production process and trying to cooperate in other clean technology projects. Factory A, B and C have improved their production efficiency and at the same time improved their environmental performance by investment in clean technology equipment such as a decanter, automatic fuel feeder, boiler, buffer tank, etc. Factory E has never been involved in any of these projects. The manager has implemented good housekeeping by introduction of the Environmental Management for Crude Palm Oil Industry Guideline, prepared by DIW and PIA officers.

7.3.2 Provincial level.

At the provincial level, the Provincial Industrial Agency (PIA) is responsible for regulating the discharges and other nuisances from the crude palm oil factories. PIA plays an important role in environmental improvement of CPO mills. PIA has contacts with the mill owner or manager. The PIA inspects the company when the mill applies for a five-year license and takes action in public complaints. Since PIA officials inspect all activities of the factory operation (such as machine and equipment condition; mill operating; safety and waste treatment), the factory's environmental management is only one part of the inspection process. The PIA submits a report of the inspection of all factories in the province to the Factory Control and Inspection Bureau. The PIA also plays a role in environmental performance improvement of the mills by introducing good housekeeping and good maintenance practice at the factories. Besides the enforcement of pollution control, they create environmental awareness of the millers by giving out warnings to improve the wastewater treatment plant in the wet season to prevent pollution effects to the community. The effluent standard limit for BOD concentration in discharged wastewater is 20 mg O_2/L. This applies to the industry, but is too stringent. Most CPO mills are prohibited to discharge wastewater to the environment because they are unable to treat their wastewater to meet the standard. The factories surrounded by oil palm plantations can reuse their wastewater for irrigation. Factories located in communities have to collect their wastewater in ponds and when the production capacity increases, they will have to buy more land to expand the wastewater treatment plant to prevent overflow of wastewater in the rainy season. Regarding the pollution control aspect, the millers have to conduct environmental monitoring and measurements themselves and submit the environmental monitoring report to the PIA every 3 months.

Factory A and B are under regulation of the Surathani Provincial Industry Agency (PIA). Factory C, D and E are under regulation of the Krabi, Chumporn and Trang PIA respectively. The interviews of the PIA officials and factory managers showed that the enforcement mechanism is ineffective due to lack of manpower and capacity at the PIA. The number of officers working for the Industry Unit, responsible for environmental monitoring and control in the Surathani, Krabi, Chumporn and Trang provinces, are 2, 1, 2 and 1 persons, respectively. In the Surathani province, 207 of in total 884 factories cause environmental impacts. The enforcement mechanism suffers from inadequate staff and weak monitoring. PIA inspects a factory only when a mill submits a license or is facing complaints by citizens. PIA together with the factory owner inspects the factory. During inspection, PIA officials check overall factory operation, including safety and environmental aspects. They take wastewater samples from the wastewater treatment plant and compare to the factory data on wastewater analysis in the factory's environmental monitoring report. However, if there are any complaints on environmental performance of the mills, the PIA has to inspect more frequently until the problem is solved. The PIA official takes wastewater samples to analyse and decides on action in case of non-compliance. PIA can order mills to improve their environmental performance by constructing more ponds. PIA can also shut down the mill temporarily if the mill is unable to solve the complaint. In case of a mill unable to not reduce severe environmental impact, the PIA can revoke its license.

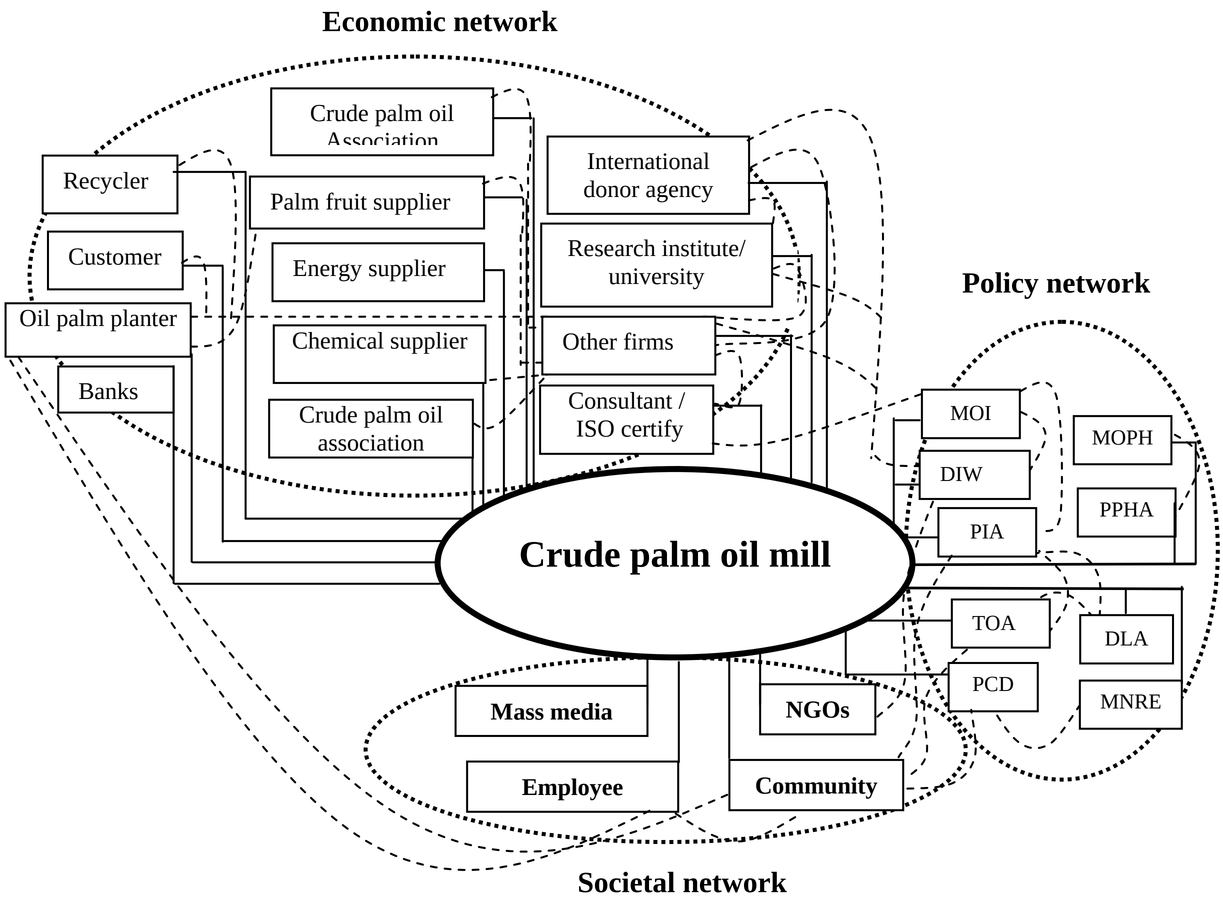
7.3.3 Local level

According to the new constitution, as specified in the TAO Act, TAOs have the authority to protect and maintain the environment. TAO collect land tax from the mills. When a mill applies for a license, the PIA has to ask permission from the TAO. The TAO is responsible for monitoring and can take action in case of pollution from the CPO production or public complaints. However, TAO suffers from a human resource shortage. At present, TAO plays a role in mill environmental improvement by acting as a formal representative for citizens. A serious problem at case study mill A: wastewater overflow from the treatment plant into a communal channel, caused citizens to complain to the TAO. TAO did a primary inspection by observing the wastewater treatment plant of the factory and sampled the water in the channel surrounding the factory. Subsequently, the TAO reported to PIA for further detailed inspection of the factory. Following complaints in the other case studies, primary inspection together with the factory manager improved the environmental performance. In the near future however, PIA has to transfer their responsibility on factory monitoring and control to the TAO. Their challenging task is to maintain good environmental resources and, at the same time, safeguard the factory’s economic growth without conflict with the surrounding community.

Results from interviews with factory managers led to the conclusion that the principal external actors who stimulate firms to improve the environmental performance are communities and government authorities. The industry has to comply with legislation such as effluent standards. If they discharge the wastewater to the waterways local communities affected by such waste complain directly to the PIA or the TOA. As a result PIA inspects and orders the mill to improve their performance. Following growing awareness of the impact of pollution on resident people, company A, B and C introduced appropriate waste management systems and also moved beyond control technology and considered clean technology. The promotion of cleaner production has been implemented in these factories through the support of the government and international donor agencies as described in previous sections.

7.4 Societal network analysis

The societal network of crude palm oil companies consists of surrounding communities, employees, NGOs and the mass media, as shown in Figure 7.4.



MOI=Ministry of Industry; DIW= Department of Industrial Works; PIA=Provincial Industrial Office); DLA=Department of Local Administration; TAO=Tambol Administration Organization; MNRE= Ministry of Natural Resource and Environment; PCD= Pollution Control Department; MOPH= Ministry of Public Health; PPHA= Provincial Public Health Office.

Figure 7.4 Societal network involving to crude palm oil mill

7.4.1 Community

The local communities play an important role in environmental improvement of companies. They are directly affected by pollution and they have rights to complain to the provincial governor or the central government. The World Bank (2000) stated that where formal regulators are absent or ineffective, informal regulation could be implemented through community groups or NGOs. The agents of informal regulation vary from country to country: local religious institutions, social organizations, community leaders, citizen movements or politicians, but the pattern is similar. Their effects on the environmental performance of the Thai palm oil industry are the same as on other polluting industries in other developing countries.

Factory A is located close to a small community, about 10 km. from the Surajthani municipality. Small household plantation areas, mainly coconut trees, surround the factory. There are about 4,000 people living in this sub-district, of which 50 people working in this mill. Four heads of villages surrounding the mill, the head of the sub-district, and the TAO's chairman were chosen for in depth interviews. All the interviewees reported that the pollution impact from the factory on the environment has decreased the last 10 years, because the factory improved the wastewater treatment plant and implemented measures to prevent the impact of wastewater on the community.

During the last decade, the water quality of the channel surrounding the mill deteriorated due to overflow of the wastewater treatment plant in the rainy season. Since palm fruit productivity is highest in the rainy season, the high production of the mill parallels a high quantity of wastewater accumulating in the pond system. Consequently, a pond overflow makes utilisation of channel water for consumption by the citizens impossible. The water has a black colour and also affects their health. The first complaint by community to the Provincial Industrial Agency was in 1993. The neighbouring community of the factory suggested to the village head to complain to the district head. Subsequently, the head of the district passed the complaint to the head of the provincial administration and then to the PIA (Figure 7.5). The PIA inspected the wastewater treatment plant and the channel near the factory and ordered the factory to improve its wastewater treatment plant and prohibited discharging wastewater into the watercourse. Complaints on pollution occurred again in 1997 (Table 7.4). Citizens complained of bad smell from the wastewater treatment plant and of solids waste accumulation in factory. Following these complaints, the PIA ordered the mill to improve its environmental performance. The mill constructed more ponds for treating wastewater and disposed solid wastes from the factory everyday. After the establishment of the TAO in 1999, the third complaint by the community on wastewater overflow to the channel in 2001 was reported to the TAO. The TAO has the authority to inspect at the impact area and reported to PIA for further inspection. At present, TAO puts pressure on the mill to increase the awareness of the environment by visiting the mill regularly.

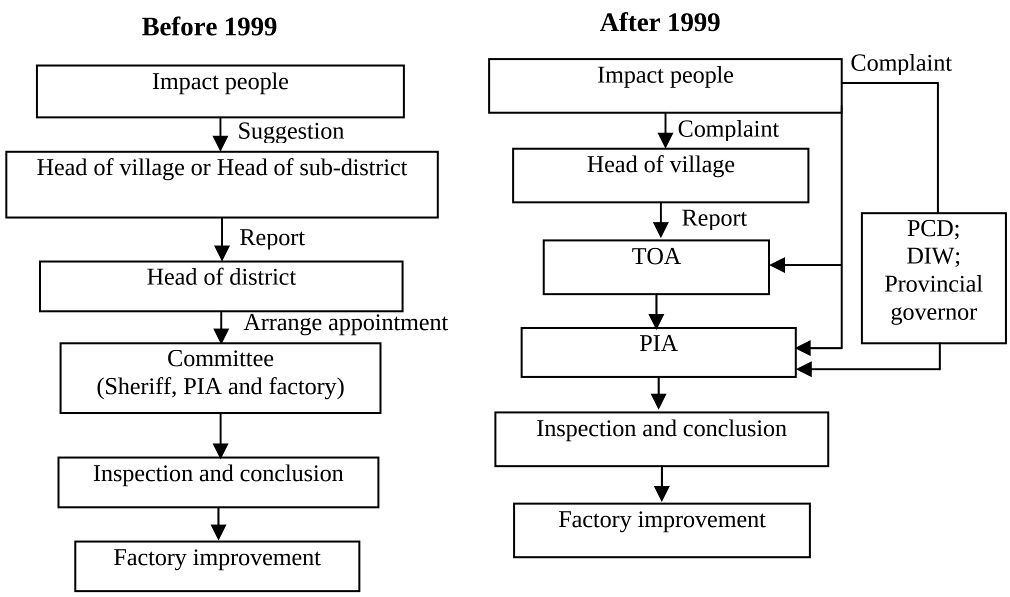


Figure 7.5 Chart of environmental regulations following environmental complaint

Table 7.4 Activity on environmental improvement of factory A (PIA, 2004)

Activity	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Official complaints by community	——				——				——		
Joined in CT project set up by government		······	······	······							
Joined in other CT projects							······	······	······	······	
Wastewater treatment plant construction		– – –				– – –					

The many years of community complaints resulted in environmental performance improvements of the factory. This is confirmed by the mill management, The improvement started by investments in the wastewater treatment plant, until the land became a limiting factor. Finally, the mill joined in a CT project set-up by the government and installed new machines and reuse/recycle wastewater in the production process. This is confirmed by the 2002 factory survey (of Chapter 5), which showed wastewater generation and BOD loading of the mill were equal to 0.5 m^3/ton FFB and 30.7 kg/ton FFB, respectively. The amount of wastewater generated decreased compared to that of the previous survey in 1994, which showed the wastewater generation was equal to 1 m^3/ton FFB (Kittikhun, 1999).

At present, the relation between factory A and the community is much better, as is expressed by the donation of public utilities like equipment and school accessories, by welcoming academic and research institutes for factory visits, and the fact that workers from the surrounding communities are increasingly employed.

The interviews with key persons in several other provinces with crude palm oil industry located close to communities, show the same results as found for factory A. The details of the complaint statistics of all case studies are shown in Table 7.5. Factory C, located in a densely populated area (5,000 people), showed not only a serious bad smell from wastewater treatment plant but also particulate emission from the chimneys. The local inhabitants suffering from these environmental pollutants made complaints to the head of sub-district/local authorities. Subsequently, the PIA investigated the factory and ordered it to improve its environmental performance. Acting on community complaints, Factory A and C implemented many CT options to improve the environmental performance of the mill. Since three years, no complaints have been received. Factory D is surrounded by oil palm plantations and had no complaints from communities until 2004. In 2003 the factory increased the production capacity with only small improvements to the wastewater treatment plant. As a consequence, bad smell from the wastewater treatment plant affected the surrounding community. In contrast, factory E did not apply any clean technology options. There are often complaints by communities located down-stream. Factory E received complaints on serious channel water contamination with wastewater due to wastewater overflow in the rainy season. The PIA stopped the mill's operation and ordered improvement of their wastewater treatment plant. The factory owner decided to construct more ponds for keeping the wastewater. However after 3 years, there were still complaints. This proves community complaints are not always successful in pushing for cleaner technology introduction. Factory A and C applied clean technology because the owners have a policy on environmental improvement, while the owner of factory E is not aware of the environment.

Table 7.5 Complaint statistics of 5 selected crude palm oil industry (PIA, 2004)

Activity	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Factory A: in community												
- Complaint on WW	———				———				———			
- Join in CT projects		....	....	....			....	....	....	....		
- WWTP construction		– – – –				– – – –						
Factory B: far from community												
- Complaint (no)												
- Joins in CT project		....	....	....			....	....	....	....		
Factory C: in community												
- Complaint on bad smell and particulates matter			——— 2			——— 3	——— 2					
- Joins in CT projects		....	....	....								
- WWTP construction						– – – – Change boiler			– – – – Biogas			
Factory D: plantation area												
- Complaint on bad smell												———
- Joins in CT projects											....	
Factory E: far from community												
- Complaint on WW overflow		———				———					———	
- Joins in CT projects												
- WWTP construction			– – – –				– – – –					

There is increasing public concern with- and participation in the management of environmental issues. In the past, the democracy in Thailand was not able to provide public participation. The 1997 Constitution represents a revolution in Thai politics. It is often referred to as a true people’s constitution (Jarusombat, 2002). On the issue of the environment, the 1997 Constitution supports, enables and stimulates public participation in environmental management and conservation. There are three clauses related to the rights of communities and individuals to co-manage natural resources and the environment.

7.4.2 NGOs

The environmental NGO community in Thailand is significant. There are over 70 NGOs registered with the DEQP. Environmental NGOs are involved in a variety of activities, varying from population and community development to natural resource protection and pollution control. At present the role of the NGOs in pollution from industries is very limited. Most NGOs in Thailand focus on natural resource issues rather than on industrial pollution. As in many developing countries, NGOs generally lack financial resources, manpower and research capacity. Most of them are poor and depend on external support; few have a long-term, professional staff. Most are poorly networked and spread their activities across a large array of environmental issues. And most have little access to the media (So and Lee, 1999). Those environmental NGOs that focus on industrial pollution, are virtually all heavily supported by the business community. This includes the Thailand Environmental Institute, the Thailand Environment and Development Network, Magic Eyes and the Thailand Business Council for Sustainable Development (Rock, 2001). This means that they have cooperative relations with industries, instead of adversarial and conflicting strategies.

NGOs individual companies, or get involved in policy-making and implementation. The Thailand concerned with environmental reforms of the crude palm oil industry are active in environmental training and dissemination of environmental information. They do not engage with Environment Institute (TEI) performs action-oriented research on cleaner production technologies in the crude palm oil industry, supported by the Thailand Research Fund. However, a study on waste exchange is not available.

7.4.3 Employees

At present most employees are local people. Mills located in communities use employees as an early warning system. If there is any environmental impact or complaint from the community, they have to report it to the manager. The manager aims to eliminate the pollution source before the situation becomes worse. However, most employees don’t have knowledge of environmental pollution, therefore they often do not take any action themselves to improve the environmental performance in the factory. The engineering and manager staffs are non-local residents and often reside far from the mill.

7.5 Major actors on environmental improvement of CPO mills

From the network analysis can be concluded that the actors which play an important role in clean technology implementation in the crude palm oil industry in Thailand are: DIW, PIA, communities, international donor agency, universities and other crude palm oil mills. These actors have a close relationship with decision makers within the company. Customers, palm fruit suppliers, banks, PCD, local authorities, NGOs and mass media have only a minor influence on clean technology adoption of the mill. Oil palm growers and consumers have no influence on clean technology application. Table 7.6 summarizes the actors that have an effect on clean technology application.

Table 7.6 Actors influence on clean technology application

Impact on CT application	Policy actors	Economic actors	Societal actors
Major actor	- DIW (Cental level) - PIA (Provincial level)	- Research institute/university - Other CPO firms - International donor agency,	- Community
Minor actor	- TAO (Local authority) - PCD	- Crude Palm Oil Association - Oil palm planter - Palm fruit supplier - Customer (refinery)	- Employee - NGOs - Mass media
No influence	- PPHA	- Bank - Consumer - Utility and chemical supplier	

Since 1974, the government has initiated promotion campaigns to substitute imported vegetable oil by locally produced palm oil. Current Thai governmental policies on palm oil development are: (1) Promotion scheme by supporting investment in CPO factories; and (2) Protection of the CPO industry by imposing a high tariff wall and restrictions control on imported palm oil product. The result is a gradual increase in crude palm oil production by on average 11% annually. With the increasing demand of CPO, most mills increased their production capacity and there are new CPO mills built. The expansion of CPO production results in increasing environmental impacts from the increase in palm oil mill effluent. The monitoring and enforcement mechanism suffers from inadequate staff of the PIA. PIA officers inspect a mill only when it applies for a license or complaints are received. In the later case, the PIA orders the mill to improve the environmental performance by constructing or installing (more) waste treatment capacity. It can be concluded that the principal actors that stimulate firms to improve their environmental performance are communities and government authorities (PIA). Communities surrounding factories play an important role in environmental improvement of mills through their influence on policy makers.

With the AFTA agreements in 1996, it was agreed that the protectionist measures for palm oil had to be removed. By the year 2003, the Thai palm oil market was to start opening up to foreign competition. Therefore, Thai CPO mills have to improve their production efficiency, since the cost of palm oil in Thailand is high and cannot compete on the world market. One of the tools used by the government to support the domestic CPO producer is cleaner production. In 1994, the GTZ (International Donor Agency) together with DIW and universities promoted clean technology in the crude palm oil mills. The results showed that most mills knew clean technology. Through a growing awareness of the pollution impact to surrounding people, some companies introduced appropriate waste management systems and also moved beyond control technology to clean technology. During the past 10 years, crude palm oil mills have improved their environmental performance gradually due to, among other, local community complaints about environmental deterioration. At present, the conflicts related to environmental pollution in the company's area are not severe. This is confirmed by the report of Sricharoen (2002), who concluded that the important factors influencing environmental management policy of factories are community and regulation by 53% and 40% respectively. It reflects the power of the public and communities on the environmental management. Factories surrounded with communities always have an acceptable level of environmental management according to studies and surveys and also confirmed by our case study. Moreover, these factories usually improve their environmental performance by implementing clean technology rather than by add-on technologies.

The crude palm oil case studies show that local customers and consumers have a minor influence on the extraction mills to take the environment into account and in triggering companies to certify in ISO 14000. Crude palm oil is a raw material for local palm oil refineries and soap manufacturing and their products are locally consumed. Moreover, palm oil is the cheapest cooking oil in the country, so there is no incentive for factories to get eco-labels or ISO 14000 certification to compete on other aspects than price.

The CPOA is not given permission to have a voice in governmental policy planning and has a small number of members. CPOA does not cooperate with other economic actors like universities or oil palm planters, and it plays a minor role in environmental improvements of CPO mills.

Most NGOs in Thailand focus on natural resource issues rather than on industrial pollution. NGOs dealing with environmental reforms of the crude palm oil industry are active in environmental training and dissemination on environmental information. This actor influences capacity of the company’s human resources.

7.6 Barriers to move the CPO industry to more sustainability

The principal actors in cleaner production are of course the companies, which control the production process. Their decisions and operations are influenced by politics, by economic actors that have market relations with these companies, and by societal actors. As a kind of conclusion from the network analyses this final section summarizes the barriers for cleaner production implementation and for approaching a zero waste industrial ecosystem of the crude palm oil industry in Thailand. Four types of barriers are distinguished: informational barriers, cooperation barriers, price barriers and human capacity barriers.

7.6.1 Informational barriers

The collection and dissemination of information plays a crucial role in cleaner production implementation. An important barrier in pushing the CPO industry to move to sustainability is the lack of any governmental unit strongly supporting research and technology development in the palm oil industrial complex. There is no central governmental institute that takes responsibility in generating and collecting relevant information on (cleaner production of) palm oil production. In addition, there is no advanced institutional arrangement to transfer information on palm oil production innovations systematically to the sector. Most mills lack the ability to change their technology and production processes because they have no technical information and knowledge to apply optimised clean technology options in their production process.

Lack of know-how and access to information is also an important problem in the reuse and recycling of CPO waste in other industries and in the agricultural sector. Since Thai oil palm producers are mostly smallholding planters, the use of palm oil sludge as manure or animal food, or the use of wastewater for irrigation is hardly implemented. The farmers lack knowledge of, information on, and practical experience in the quality and usefulness of waste, and the economics of waste reuse. Factories equally lack data and information on these topics, because no systematic information is returned to the factories from farmers reusing CPO waste**.** Thus what Thailand lacks is a central institution or arrangement, which carries out research on various cleaner production options, collects information and data nationally and internationally, and systematically disseminates these findings in a coordinated way to the relevant economic actors in the palm oil networks.

7.6.2 Cooperation barriers

Information exchange will not work when there is no systematic cooperation among the relevant actors. Lack of cooperation between mills and other actors, especially within the economic networks such as the crude palm oil association, research institutes/ universities and oil palm planters, is an important barrier for clean technology adoption and waste exchange in Thai CPO mills. The fact that the economic networks in palm oil production are hardly vertically integrated forms one explanation for this limited cooperation. But also without vertical integration, cooperation is possible in palm oil production.

Associations could play a role in such cooperative efforts, but this is hardly the case in Thailand. The Crude Palm Oil Association (CPOA) is meant as a cooperative that brings together 16 CPO mills. Since the CPOA is not an authorized association, it receives no financial support from the government. The CPOA plays hardly any role in planning the national crude palm oil policy and only a minor role in environmental improvements of mills. It does not act as a representative of the industry towards the policy networks and does not link the mills with government institutions or other economic actors such as oil palm planters and universities. The authorized Oil Palm and Palm Oil Association of Thailand (OPPOA), which members are oil palm planters and crude palm oil mills, plays a larger role in cooperation between the two groups. However, the OPPOA also plays a minor role in governmental policy-making and planning on oil palm development.

On an individual basis cooperation is limited. In general, there is no direct contact between the CPO mills and oil palm farmers. Farmers have no incentive to apply waste/by-products in their plantation areas, and most buying and selling of FFB goes via middlemen. The case studies revealed there is also no direct cooperation between research institutes/universities and (potential) recyclers, especially farmers. This limits opportunities of recyclers in accessing and applying new techniques or options to reuse/recycle solid waste from the mills.

7.6.3 Price barriers

A third category of barriers that hinders mills to implement clean technology options are to be found around pricing: the low, or lack of, prices on environmental pollution and natural resources (water and energy) and the lack of feed back prices for recovered energy (biogas and steam).

Thai environmental policies rely on command and control measures. These regulations give the mills (especially those that are situated far from communities) little incentive to change the production process or to reduce emissions below the official standards, because there is no (economic or societal) reward to do so. Currently, Thailand uses economic instruments according to 'the polluter pays' principle, focusing on user charges but not on emission charges. The emission charge gives more incentive for mills to adopt a cost-effective solution to pollution abatement to lower the charge they have to pay. Recently a feasibility study on emission charges for industrial factories has been carried out, but implementation is still under consideration (Srichareon, 2002).

Prices for natural resources, such as water and energy, are generally low and a very marginal part of production costs. CPO mills utilize primarily mechanical processing technology. They tend to be located near surface waters and they consume raw water from these watercourses free of charge. The production costs of CPOs consist mainly of FFB (85% of total production cost). The cost of electricity and chemicals for water treatment facilities are 0.5% and 0.4% of the production costs, respectively. The low overall costs for water use and water treatment form a constraint to conserve and reduce water usage, for instance via internal reuse/recycling in production processes. Another potential clean production measure, recovery of biogas from wastewater, is also subverted through prices. The use of methane for power generation could be considered, but most palm oil mills are self-sufficient in energy. An alternative would be recovery of methane as fuel in the boiler or for power generation and sell electricity back to the electricity generation authority of Thailand. However, the high investment cost and the long payback period make it not attractive for mills to invest in this option (Kochapansunthorn, 1998; Biomass One-stop Claring House, 2004).

7.6.4 Human capacity barriers

Finally, the shortage of human capacity (both quality and quantity) within both state authorities and companies are important barriers in clean technology adoption. Thai environmental policies rely heavily on command and control measures that are enforced on factories by governmental agencies. The most important state agency is the PIA, which has responsibility for regulating discharges and other nuisances from the factories. However, monitoring and enforcement capacities are weak due to inadequate staff numbers and low monitoring technology. Besides, local authorities are not authorized to monitor and enforce factories to improve their environmental performance, due to the political structure.

Within the CPO mills the factory's owner is the most important actor for taking decisions on clean technology. In general, the factory owner has a clear preference for making more profit with the existing production technologies instead of investing in new clean technology options. Most mills lack the human resources for cleaner production, especially the mills that employ only an engineer for operating the production process. In addition, due to lack of environmental knowledge and capacity, they face difficulties in identifying environmental problems, and solving these by implementing appropriate solutions through clean technology.

Chapter 8
A comparison of the palm oil industry in Thailand and Malaysia

8.1 Introduction

Malaysia has been the world's largest producer of palm oil since 1971. From 1989 onward, Malaysia is also the world's largest exporter of oil palm accounting for 68.3% of the world export. The palm oil industry maintains its position as the third largest export earner of the country. At the same time, the crude palm oil industry was the worst source of water pollution. This pollution was in 1975 equivalent to pollution generated by a population of more than 10 million people. Faced with this crisis, the government passed the Environmental Quality Act and established the Department of the Environment, which could adjudge licenses with stringent environmental regulations at severe polluters. The regulatory package was effective in reducing pollution and improving the quality of Malaysia's rivers (World Bank, 2001). Malaysian's experience with environmental regulation of the palm oil industry shows that pollution reduction and industrial expansion can occur simultaneously. The success in merging environmental and industry goals was the development of technological innovation in environmental reform and the industry's development of added-value products from waste.

The objective of this chapter is to generate ideas for improving the environmental reform of the crude palm oil industry in Thailand by learning from Malaysia's experiences with technologies, regulatory framework and economic structure on 'best environmental practices' in the crude palm oil industry. The technological and institutional arrangements of the crude palm oil industry of Malaysia will be analysed briefly with focus on the learning moment for Thailand.

8.2 Overview of palm oil industry in Malaysia

8.2.1 Development of the Malaysian palm oil industry

The oil palm has been introduced into Malaysia in 1917, as the prime crop for the diversification program. Palm oil production began in the 1960s through government encouragement, with very high growth rates. Malaysia soon became the world's largest producer of crude palm oil. The palm oil industry is an important component of the Malaysian economy and especially of the agriculture sector. Palm oil is currently the most important agricultural crop in Malaysia and has been providing the prime impetus for growth in the agricultural sector in the past four decades (Gopal, 2001). Oil palm plantations currently account for 58% of the total cultivated land in Malaysia. Of the 3.38 million hectares of oil palm area in 2000, about 60.0% was privately owned, and 40.0% by organized and independent smallholders (MPOB, 2002). Table 8.1 shows the introduction and development of the palm oil industry in Malaysia. The oil palm industry provides about half of the overall agricultural employment (1.4 million) in the country. This industry is an important contributor to the country's GDP. Malaysia exported a record of 9.2 million tons, or 65% of global palm oil exports. Export earnings from palm oil, palm kernel oil and its products in 1998 amounted to almost RM 14.42 billion, equivalent to 5.6% of the GDP (Yusoff, 2004). Export earnings from the industry reached RM 19.2 billion in 1999, but declined to RM 14.9 billion in 2000, due to lower prices in the world market. Palm oil export earnings accounted for 4.0% of the nation's total export of merchandise in the year 2000 (MPOB, 2001). Palm oil production is expected to grow 4.57% annually over the next five years to 26.2 million tons by 2005. Exports are expected to grow 5.6% to reach 18.1 million tons by 2005, capturing 41% of the global oils and fats market (Yusoff, 2004).

Table 8.1 Phases in the development of the Malaysian palm oil industry (Gopal, 2001)

Phase	Period	Development
First	1870 - 1916	Oil palm as an ornamental crop/commercial curiosity
Second	1917 - 1959	The first commercial planting and slow growth in planted area
Third	1960 -1969	Rapid growth of planted area as a consequence of crop diversification, competitiveness and demand
Fourth	1970 - 1979	Export-oriented refining industry established-rapid expansion in crude palm oil Processing and processed palm oil export
Fifth	1980 - 1990s	Market expansion and consolidation Establishment of oleo chemical industry and its rapid expansion

The Malaysian government wants to increase the added value of the industry through imposing high export tariffs on CPO. Malaysia now exports more than 99% of palm oil in processed form. At the same time, Malaysia embarked on further downstream production and export of oleochemicals, specialty oils and fat products, and consumer products using palm and palm kernel oil as the main raw material.

The Malaysian palm oil industrial complex refers to the various direct linkages, processing chains and products created as a consequence of the cultivation of oil palm and the production of the main product (palm oil) and secondary products (palm kernel oil and cake). The oil palm products are employed in numerous food and non-food applications. The network primarily consists of the oil palm growers, the palm oil refinery industry, the user, the customers of palm oil products and the consumers of palm oil and palm oil products (shown in Figure 8.1). In 2003, there were 352 crude palm oil mills, 47 refineries with a production capacity of 15.5 million ton, and 17 down stream industries with a production capacity of 1.96 million ton of oleochemical products (MPOB, 2004). The Malaysian Palm Oil Board's long-term programme is to establish a biodiesel plant that will produce methyl ester (biodiesel), which can be used to replace petroleum diesel (Yusof, 2001). Another potential revenue generator is to convert the large quantity of biomass (13.2 million ton dry weight) into added value products**.** At present, the commercial added value products from waste are pulp and paper, MDF and particleboard from EFB (Ming and Chandramohan, 2002).

8.2.2 The production efficiency

The average planting cycle of a palm tree is about 25 years for efficient productivity. The oil palm is planted at a density of about 148 palms per hectare (Gopal, 2001). Each palm yields about 120-150 kg of FFB/ year depending on the soil conditions, climate, species and other agronomic conditions (Agamuthu, 2001). Therefore, the average total production of FFB per palm tree for 23 productive years is 3.46 tons. Table 8.2 shows the various component of the oil palm.

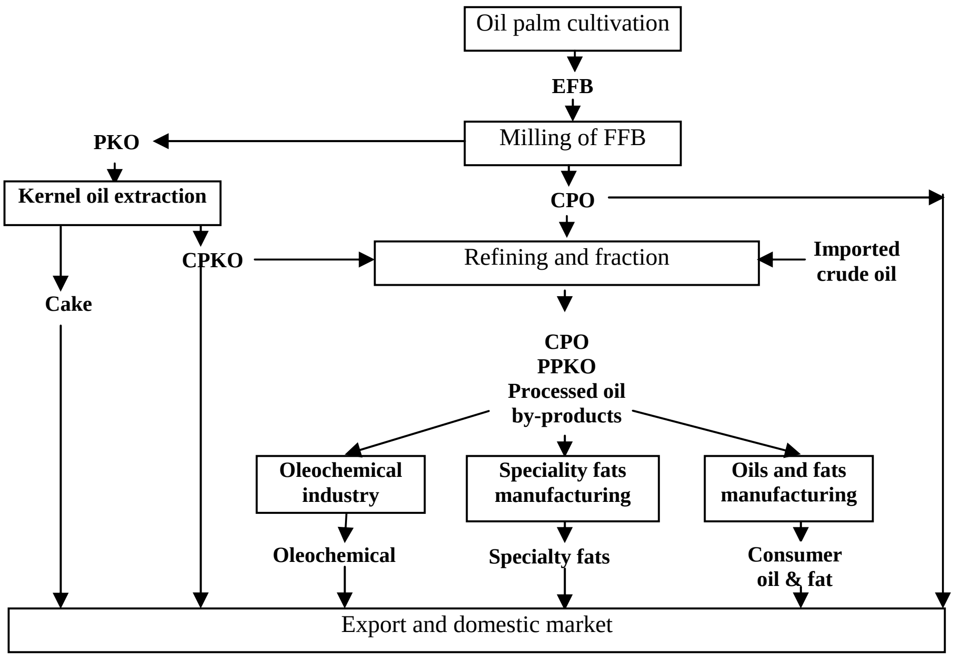


Figure 8.1 The structure of the Malaysian palm oil industrial complex (Gopal, 2001)

Table 8.2 Availability of fresh and dry weight of EFB, shell, fibre and effluent in tons per hectare per year (Yusoff, 2004)

	Fresh wt. (t/ha/year)	Dry wt. (t/ha/year)
Harvest yield of FFB	18.33	10.60
Oil yield	3.46	3.46
EFB at 22% of FFB	4.42	1.55
Fibre 11% of FFB	2.02	1.63
Shell 5.5% of FFB	1.10	1.10
• Sterilizer condensate 12% FFB	2.41	0.12
• Clarification sludge 50% of FFB	10.04	1.50
• Hydocyclone washing 5% of FFB	1.00	0.05
• Total POME	13.45	0.67

8.2.3 Comparison of production technology between Thailand and Malaysia

The current average yield of a plantation in Thailand is between 14-18 tons of FFB/ha/year (average 16.5 tons of FFB/ha/year). Each oil palm tree yields about 110 kg of FFB per year. The average total production of FFB is 2.75 ton per palm tree or 413 ton per hectare/ year. Compared to Malaysia, the efficiency of FFB production (ton/ year) is 10% higher in Thailand. But oil yield per ha/year in Malaysia is 20% higher than in Thailand (Table 8.3), which is caused by the lower average oil yield of Thai palm fruit (17%) compared to Malaysia (23%). The soil conditions and weather in Malaysia are more suitable for growing oil palms than in Thailand. Moreover, in order to increase the oil production efficiency in Malaysia, several government institutions focus on research and development to improve oil palm species (high oil content) and good management of the plantation system.

CPO production efficiency in Thailand is 16.8%. Compared to palm oil production in Malaysia, oil production efficiency in Thailand is 11 % lower than that in Malaysia. This is also due to the fact that the oil content in Thai oil palm fruit is 13% lower than in Malaysia. From these data, it can be concluded that the production efficiency of Thai crude palm oil mills are at the same level as Malaysian mills. This makes sense because most machines and technology are introduced from Malaysia.

Table 8.3 shows that solids waste generated from palm oil extraction in Thailand is higher than in Malaysia. Empty fruit bunch on dry weigh basis generated in Thai mills is 40% higher than in Malaysia. This means that palm fruits content in a bunch stalk in Thailand is much lower than in Malaysia. For other wastes such as fiber, shell, and for wastewater the amounts do not really differ between Thailand and Malaysia. The wastewater generated at Thai mills is less than in Malaysia, because the amount of FFB harvested per hectare and processed from Malaysian plantation area is higher than in Thailand.

Table 8.3 Comparison of palm oil production and waste generation between Thailand and Malaysia

	1 ha of mature palms			
	Fresh weight		Dry weight	
	Thailand[1)]	Malaysia[2)]	Thailand[1)]	Malaysia[2)]
No. of CPO mill	25	352	-	-
Total production capacity of CPO mills, million ton/year	0.8	17.4	-	-
FFB production, ton/ha/year	16.5	18.33	-	-
Oil yield, ton/ha/year	2.75	3.46	2.75	3.46
Oil content in oil palm fruit, %	17	23	-	-
Oil extraction, %	16.8	18.7	-	-
EFB, ton/ha/year	3.96	4.42	2.6	1.55
Fibre, ton/ha/year	2.31	2.71	1.6	1.63
Shell, ton/ha/year	1.0	1.1	0.9	1.10
Wastewater, ton/ha/year	10.56	13.45	0.64	0.67

Note; 1) Results from 5 selected factories in Thailand (2002); Office of Agricultural Economy (2003)
2) Yusoff, 2004

In 2001, Malaysia produced about 67,745,000 ton of CPO and 4,312,000 ton of palm kernel (MPOB, 2002). Malaysian palm oil accounted for about 52% of the world palm oil production. The production processes generate large amounts of solid waste/by-products and POME, as is shown in Table 8.4.

Table 8.4 Comparison of waste/by-product generated by palm oil mills

Waste/by-product	Quantity (million ton)		Moisture content (%)	Oil content (%)	Heat value (kcal/kg)
	Thailand	Malaysia			
Empty fruit bunch	0.9	14.9	65	5	3,700
Fibre	0.6	7.5	42	5	4,420
Shell	0.2	3.73	7	1	4,950
Wastewater	2.3	37.9	95	1	-

Note; 1) Results from 5 selected factories in Thailand (2002), Office of Agricultural Economy (2003)
2) Adapted from Yusoff, 2004.

8.2.4 Clean technology for the crude palm oil industry

In Malaysia, the palm oil industry is now at the stage of seeking more added value products, not only from the oil and kernel, but also from its biomass. In the case of biomass, there is the opportunity to convert the annual 13.2 million ton (dry weight) of biomass into pulp and paper, particleboard, medium density fibreboard, furniture etc. (Yusof, 2002). At present all the palm oil mills in Malaysia use the fiber and shell waste as boiler fuel for steam production, to generate electricity for the factory’s operation. These solid fuels can supply more than enough electricity for the mill, since only about 100 kWh of electrical energy is required to produce one ton of palm oil (Ma, 1999). In Malaysia an activated carbon plant was set up, which uses shells in the production line. Pulp& paper industry that uses EFB as raw material was also established recently. EFB is traditionally incinerated for its ash, which contains high concentrations of plant nutrients, in particular potassium. The ash is also high in alkalinity and useful for the oil palms on alluvial soils. The problem associated with incinerating EFB is the emission of white smoke, composed of water vapour with some fly ash. It is also a visual nuisance and the Department of Environment (DOE) discourages the practice and it is not allowed for new establishments. However, EFB is a good source of organic matter and plant nutrients, and it is increasingly recycled back into the plantation as mulch (Ma, 1999). The EFB also can be used to generate power. EFB has a caloric value of about 1950 kcal/kg at moisture content of 50% (Yusoff, 2004). To make it more easily combustible, EFB has to be shredded and dehydrated to a moisture content below 50%. However, this option is not often practiced because there is already enough energy from shell and fibre. From the viewpoint of logistics and cost, EFB offers the best prospects for commercial exploitation as raw material in the pulp and paper industry.

To further promote the “zero-waste’ concept in Malaysia, POME as a nutrient source in plantation areas, the recovery of POME solids for animal feed protein, the generation of biogas from the effluent ponds, and use of surplus boiler energy to generate electricity are implemented. The current effort of R&D at the Malaysian Palm Oil Broad is to minimize the production of greenhouse gasses (GHGs). The production of biogas from anaerobic digestion of POME has been explored in Malaysia. The biogas generated from 1 ton of FFB is estimated at 19.6m^3 with a caloric value of 22.9 MJ/m^3. Thus, the total biogas energy from 3.45 million tons of FFB is 1.55 GJ. Furthermore, the digested effluent also contains high nutrient concentrations and can be applied as fertilizer to the oil palm plantation (Yusoff, 2004). The comparison of clean technology (waste exchange) between Thailand and Malaysia is shown in Table 8.5

Table 8.5 Comparison of dominant clean technology and waste exchange between Thailand and Malaysia

Waste/ by-product	Thailand	Malaysia
Shell	- Reused as fuel in boiler, - Sold as solid fuel	- Reused as fuel in boiler, - Activated carbon
Fibre	- Reused as fuel in boiler	- Reused as fuel in boiler, pulp & paper, particleboard and medium density fibreboard.
Empty fruit bunch	- Mushroom cultivation & Fertilizer	- Production of pulp & paper, particleboard, PDF Board - Incinerated and ash sold as fertilizer, mulching material
Decanter cake	- Disposal	-Dried and reused as soil conditioner or animal feed
Wastewater		
- Wastewater recycle	- Irrigation in plantation area	- Irrigation in plantation areas
-Greenhouse gas from wastewater treatment plant	- Recovery biogas and utilized for electricity generation	-Recovery biogas and utilized for boiler and electricity generation
Excess steam from boiler	- Discharged as wastewater	-Recovery heat to the rotary drier for drying decanter sludge

8.2.5 Wastewater management of Malaysian crude palm oil mills

The crude palm oil industry in Malaysia used to be the worst source of water pollution. Palm oil mills discharged their wastewater directly into nearby waterways (World Bank, 2001). In 1975, organic loading from palm oil mills was equivalent to the pollution generated by 10 million people (PORIM, 1998). To solve the severe problem, Malaysian’s government established the Department of Environment and the Environmental Quality Regulations in 1977. The effluent control in the palm oil industry takes place through a system of licensing, application of effluent discharge standards, and a pollution charge system. This pressures millers to construct wastewater treatment plants, as the effluent-related license fees are levied on the BOD load discharged. DOE added a surcharge of 100M$ per ton BOD discharged beyond the allowed limits. The effluent-related fees are used for research on palm oil mill effluent treatment technology, which is operated under MPOB. Pollution control from palm oil mills is encouraged. Currently most mills can treat their effluent to meet the effluent standard of 100 mg/l BOD. In 1991, 75% of the monitored mills were found to comply with the discharge standards for BOD (Angel and Rock, 2000).

8.3 Comparison of the network between Thailand and Malaysia

A triad network scan was carried out for the CPO production in Malaysia, based on a literature review, secondary data analysis, and interviews, with the main aim to identify the similarities and differences with Thailand's CPO industry.

8.3.1 Economic network

There are three different main aspects of the economic network of Malaysia and Thailand: larger international integration; larger vertical integration; and better horizontal organization and coordination.

1) Larger international integration

In 2003, the Malaysian domestic market consumed only 8% of the total palm oil production and the remaining 92% was exported, mainly to China (21%), the European Union (14%), India (13%) and Pakistan (9%) (MPOB, 2004). At present, the palm oil mills do not have direct contacts with the foreign traders themselves, but only indirectly via the downstream refiners. International market customers, especially in the European Union, influence local downstream players, which in turn impact on palm oil mills. The food related sector, especially in the Western markets, needs various ISO 9000, ISO 14000 certification, and HACCP to meet their environmental, health and safety requirements. As the various ISO series are process-oriented, with one of the underlying themes being continuous improvement, the production process over time will attain better quality, better environmental management and also better occupational health and safety management. The various ISO, HACCP and Codex certification and audit programmes contributed to clean production (Choy, 2004), in the form of efficient utilization of resources, better housekeeping and maintenance, and better waste management practices.

Differently, the Thai domestic market consumes 95% of the total CPO production. Palm oil has now a share of 70% of the total cooking oil market in Thailand, due to its low price. There is no incentive for factories to get eco-labels or ISO 14000 certification to penetrate in the markets. The Thai crude palm oil case studies show that local customers and consumers have minor influence on the extraction mills in triggering companies to get ISO 14000 certification or to improve environmental performance.

2) Larger vertical integration

In Malaysia, the palm oil industry is a well-developed and diversified industry (Basiron, 2002). There is a well-established processing sector, which encompasses the milling, refining, crushing, up to the final oleochemical sub-sectors. In 2001, there were 352 mills, 46 refineries, 17 oleochemical plants and 38 palm kernel crushers, which operated at a capacity of 67.74, 15.48, 1.96 and 4.31 million ton per year, respectively (MPOB, 2001). The Malaysian government also encourages the industry to produce oleochemical derivatives and finished products.

Oil palm growers can be classified into 3 categories: private estates, public sector and state schemes, and independent smallholders. Data on palm area ownership show that the largest producers of palm fruit in Malaysia are private estates (big plantation areas), that own 58.9% of total plantation area in the country (MPOB, 2001). The owners of such private estates have mills in their plantation area to reduce transportation costs and to achieve a high production efficiency. Oil palm growers do not directly influence clean technology application, however their harvesting practices impact production efficiency of millers because the oil content in palm fruits depends on the ripeness of FFB. The smallholders always sell unripe fruits to millers during the low production season.

The Thai palm oil industry has had a relatively late start in 1968, some 50 years later then Malaysia. The Thai palm oil industrial complex is much smaller vertically integrated compared to Malaysia. Currently, there are altogether 25 crude palm oil mills and 11 refining factories in Thailand. The production capacity is 1 million tons of crude palm oil/year. Around 90% of all CPO is sold to refineries and 90% of CPO is for producing refined palm oil for local consumption. In the Thai palm oil industrial complex, participants at each level (e.g. planter, miller, refinery) are not linked through the same company. This hinders the controlling of the production process and increases capital costs. Planters and small holders have inadequate management practice in planting, due to lack of knowledge, information, and capital funds for irrigation. The production efficiency and the quality are low. Waste from CPO production is reused/recycled as solid fuel in cement factory and agriculture sectors.

3) Better horizontal organization and coordination

The other important actor that influences environmental performance of the CPO industry is the Malaysian Palm Oil Association (MPOA) and the Palm Oil Miller's Association (POMA). The MPOA represents the oil palm growers and CPO producers. The main task of MPOA is the long-term growth and development of the Malaysian palm oil industry (oil milling and plantation crop industry). The duty of the MPOA is to represent the industry with a single voice and meet the complex needs of the plantation industry more effectively. MPOA also works on environmental concerns and sustainable development. This association influences clean technology application in palm oil mills. POMA acts as a mediator in settling disputes among its members and between the millers and suppliers of FFBs. It makes common recommendations to the government, trade organizations and various others, it negotiates on various issues, provides information on palm oil R&D to members, and generally coordinates cooperation amongst its members (Agamuthu, 1995). The Malaysian Palm Oil Board (MPOB) and Malaysian Palm Oil Promotion Council (MPOPC) have a representative from the MPOA and POMA, either in the Board of Trustees or in the Executive Committee initiatives. By participating with these organizations, the government ensures that the interests of all parties are taken into account in policy making, providing for smoother functioning of activities related to production, processing, marketing, and the development of the industry.

The Oil Palm Fruit and Palm Oil Association of Thailand has the duty to represent the planters and the mills in communication, negotiation, participation and presentation with the governmental sector. Since this Association has no involvement in policymaking, R&D and information exchange between various actors, it has no influence on technology innovation in mills.

8.3.2 Policy network

The policy network of Malaysian palm oil sector is different from that in Thailand in three – for environmental innovations relevant- aspects.

1) More responsible government institution

Malaysia is now the largest producer and exporter of palm oil in the world. Due to the limitations of land and labour, the priority of the country is not to remain the largest producer but to become the most efficient, to focus on value addition, and to ensure the successful marketing of products (MPOB, 2001). To remain competitive, the Malaysian government set up a number of institutions to support the growth and development such as: the Malaysian Palm Oil Board (MPOB); the Ministry of International Trade and Industry (MITI); the Malaysian Palm Oil Promotion Council (MPOPC); the Ministry of Plantation Industries and Commodities (MPIC). Besides, the Environmental Quality Act (1974) authorized the Department of Environment to control the pollution impact from CPO industries. Malaysia's experience offers the lesson that pollution abatement and industrial expansion can occur simultaneously (Angel and Rock, 2000). The tasks of these institutions, as well as their equivalents in Thailand, are shown in Table 8.6. The details of Malaysian government institutes and their responsibilities in the palm oil industry development are elaborated below.

Table 8.6 Comparison of government agencies related to CPO mills Malaysia and Thailand

Governmental task related to CPO mills	Malaysian institutions	Thai institutions
R&D in new technologies (CT)	- Malaysian Palm Oil Board (MPOB)	- Does not exist
Registration and licensing	- MPOB	- Provincial Industrial Office, DIW
Trade and marketing promotion	- Ministry of International Trade and Industry (MITI) - Malaysian Palm Oil Promotion Council (MPOPC) - Ministry of Plantation Industries and Commodities (MPIC)	- Does not exist
Industrial regulation		
• National level	-Department of Environment in Ministry of Science, Technology and the Environment (MOSTE)	- Department of Industrial Works in Ministry of Industry
• State (provincial) level	- State Department of Environments	- Provincial Industrial Office
• Local level	- Does not exist	- Does not exist

Research and development institutions

The Malaysian Palm Oil Board (MPOB) was established in 2000, by Act of Parliament and under the ministry of Plantation Industries and Commodities, to enhance the well being of the Malaysian oil palm industry through research, development and ancillary services. MPOB has taken over the functions of the Palm Oil Research Institute of Malaysia (PORIM) and the Palm Oil Registration and Licensing Authority (PORLA) (MPOB, 2003). The current government agency conducts and promotes research and development activities related to the planting, extraction, use, consumption and marketing of palm oil and its products. It is responsible for providing the scientific and technological support to the Malaysian palm oil industry and also encompasses registration, licensing and enforcement activities, also with respect to the environment. The strategic plan of MPOB (2001-2005) summarizes its activities in three strategies: a high-income strategy, a biomass utilization (zero waste) strategy, and a down stream added value strategy. The details of the biomass utilization (zero waste) strategy are (MPOB, 2004):

- Optimising utilization of biomass
  - Use of biomass for pulp & paper, MDF, energy generation.
  - Extraction of valuable minor components from biomass
  - Use of EFB for soil conservation, nutrient balance
- Full utilization of mill effluent
  - Use of mill effluent as fertilizer and biogas for energy generation
  - Reuse wastewater for irrigation in plantation area
  - Recovery of valuable components from mill effluent
- Increasing efficiency of production
  - New machinery, processes and methods for increasing production efficiency

In contrast, Thailand has no specific governmental unit to support research and technology innovations to develop and improve palm oil production. The current government policy is to develop biodiesel from RDB palm stearin and fatty acid as an alternative fuel. However, the responsible agency is the Ministry of Energy. There is a research unit at Songklanakarin University supported by the Thailand Research Fund Office. This unit distributes *The Oil Palm Newsletter*, which aims to be a medium for information exchange and access on oil palm and palm oil industries. The Thailand Research Fund also supports funds for academic institutes to perform research on palm oil development. However, most emphasis is on oil palm plantations. Compared to MPOB, their activities are few, poorly funded and lack sufficient resources and manpower to really make a difference for further upgrading the Thai palm oil production, as well as its environmental performance.

Trade and marketing promotion institutes

Simeh and Ahmad (2001) state that the success of the Malaysian palm oil export diversification program was not just enhancing production but was also accompanied by initiatives for penetrating and deepening of markets. R&D and a regulatory framework were developed through strong institutional support of the Malaysian government. Three main institutes were involved to implement these policy objectives: MPOPC, PORIM and PORLA. PORLA’s general function was to ensure the orderly development of the palm oil industry. The regulatory action of PORLA aimed at quality control of palm oil and its products. PORLA’s functions were taken over by MPOB in 2000. MPOPC was to undertake public relations and to promote palm oil mainly in the export markets. Besides, two Ministries are related to the palm oil industries: the Ministry of International Trade and Industry (MITI) and the Ministry of Plantation Industries and Commodities (MPIC). The main tasks of these government institutes are:

- MPOB : Enhancing the well being of the Malaysian oil palm industry through research, development and ancillary services (ensure viability and sustainability of this sector).

- MPOPC : Promotion and marketing of Malaysian palm oil and removal of obstacles and creating opportunities in the market and image of Malaysian Palm oil

- MITI : Oversees the promotion of international trade and investment, and encouragement added value down-streaming of industries, including the palm oil industry.

- MPIC : Overseeing the development of the plantation and commodity sector covering research and development (R&D), production, processing, and marketing in respect to oil palms and other plants.

Thailand has no specific government unit to promote trade and marketing of palm oil products. The main target of the policy is to increase production capacity by expanding oil palm plantations.

Environmental management agencies and measures
In Malaysia, a different strategy has been followed in promoting a more environmentally sound crude palm oil production process. The system of licensing, and the application of emission charges and effluent discharge standards have been implemented in the crude palm oil production. To strengthen the regulatory mechanism, national standard and monitoring systems were developed to make enforcement more realistic. At present, inspectors have the power to close facilities. Meanwhile, the maximum fines for offences were increased to reflect a greater commitment to enforcement (Atkinson, 1999). Malaysia's Environmental Quality Act in 1996 raised the potential height of fines by ten times, up to 100,000 RM (± 20,000 EU), and more than doubled the maximum jail sentence to five years for violation of environmental regulations including water pollution. The fines for discharging oil into water bodies were increased 20-fold. This approach has been successful in controlling effluent discharges in these industries and 76% of the firms are reported to be in compliance with the BOD limit of 100 mg/L (PORIM, 2001). The industry's ability to reduce its BOD discharge to these levels was facilitated not only by improvements in treatment technology, but also by the development of various commercial by-products made from palm oil effluent (Angel and Rock, 2000). Although some of the waste effluents are converted into products, it entails high capital costs. Malaysian mills shifted the costs upstream to oil palm growers by reducing the price of FFB, rather than increasing consumer prices, to remain competitive in the world market.

The Thai environmental policy is mainly based on command and control. To strengthen the regulatory provisions, government subsidies are used to address industry complaints about the high costs of pollution control equipment. Environmental funds have been set-up to provide grants and loans to enterprises to cover (part of) the costs of pollution control. The main enforcement agency for industrial pollution, the Ministry of Industry (Provincial Industrial Office), has limited technical expertise and manpower to establish effective regulation. Moreover, the effluent standard is stringent (BOD limit 20 mg/L). Most mills cannot treat their wastewater to meet this effluent standard. In order to comply with the law, they keep their wastewater in ponds without any discharge. There is no incentive for treating their wastewater to below the standard and or for applying technological innovations. Thailand has a National Master plan on cleaner production supporting the use of economic instruments, but it focuses on subsidizing procedures, such as using tax incentives, soft-loans, and setting funding to support the implementation of clean production processes. While the institutional lay-out as well as the regulations and laws seem to differ significantly, this does not mean that easy conclusions can be reached on the environmental performances of any of the two models.

2) More active palm oil policies

Malaysia sets palm oil to be the main industry of the nation. There are several national plans to reduce capital costs and increase the production efficiency to the maximum (Gopal, 2001). The important national policies for the Malaysian palm oil miller, which is a major driver for environmental reform, are the Oil Extraction Rate (OER) policy and the zero waste policy. These policies have led to better environmental performance of the crude palm oil industry.

The OER was firstly developed jointly by the Johore state MPOB and the Southern Peninsura POMA. This was later made into a national policy (Tay, 2004; Yu, 2004). The program was held to resolve the problem of lower oil extraction rates (OER) and poorer quality of crude palm oil due to unripe FFB sold by the oil palm smallholdings to the millers. The measures led to the situation that the millers would not accept unripe FFBs. Meanwhile, the smallholders would also incur a penalty. This return penalty policy has led to better harvesting practices not only by the smallholdings but also in the plantations (Choy, 2004). As the licensing requirement for mill operation comes under its purview, the MPOB has imposed a minimum 18% OER Policy. Millers flouting this policy will have their license withdrawn. This policy has a positive effect as more oil is recovered and less waste is generated.

The Zero Waste policy advocated by the DOE and MPOB is also in line with the CPO mills interest as the wastes in the form of treated POME, shell, fibre, and EFB are reused/recycled into environmentally renewable resources.

The National policy on the Thai oil palm and palm oil development plans are implemented by the Ministry of Agriculture and Cooperative, such as the Oil Palm Development Plan (1984) and the Oil Palm and Palm Oil Development Plan of 2000-2006. The main objectives are increasing oil palm plantation area and yield improvement of both oil content and oil palm fruit. Within the Thai national policy on palm oil production neither production efficiency nor waste exchange are emphasized.

3) Closer industry-government relations

In Malaysia, there are closer industry-government relations. MPOB and MPOPC both have a representative from the MPOA and POMA. DOE has a representative in both MPOB and MPOPC. This allows for close collaboration between government and industry. With respect to research and development, the PORIM-Industry Forum and PORIM-Industry committees have been established to ensure that R&D in PORIM is in line with the industry needs and information is widely spread to the industry. The government-industry linkage shows that a sector-specific government institution, MPOB, together with the industry related associations have developed and implemented technologies and policies that meet the twin objectives of profitability and the improved environment for the palm oil mills. The waste treatment technologies developed jointly by MPOB and the palm oil mills have led to a drastic decline in water pollution. Also the department of Environment (DOE) is part of an important government-industry link. This government-industry synergistic relationship has led to better environmental performances. But there is also a drawback to too close relations between industry and the government, as it may entail less stringent enforcement by DOE.

In Thailand, the Ministry of Agriculture and Cooperative is the main government institute that is responsible for oil palm development, while the Ministry of Industry is responsible for efficiency improvement of the industry. The Clean Technology Unit in DIW also works on clean technology introduction in CPO mills. However, there is no relationship between these governmental agencies, or with the industry. Different institutes, such as universities, NGOs and research institutes, carry out research separately. They pursue their own interests and agendas and not necessarily those of the CPO industry.

8.3.3 Societal network

The difference in the societal network around CPO mills between Malaysia and Thailand focuses on the role international NGOs play and the pressures from local communities.

1) Larger role of international NGOs

Malaysia exports 9.2 million tons palm oil products. Safety and health concerns of consumers become apparent in today’s trade in the form of food standards and regulations, including labelling requirements. NGOs have a significant role in protecting consumers by advocating stringent standards that should be met by exporters. International NGOs increase their voice at various international forums on planting material, to plantation practices, and production processes in oils and fat. For example, the involvement of Greenpeace in food legislations and policies in Europe has significant bearings on the marketing of Malaysian oils and fats throughout the world (Yusoff, 2004). International environmental NGOs have also been active in contesting the establishments of large oil palm plantations in Malaysia, and the related loss of biodiversity. Domestic NGOs concerned with palm oil mills are the World Wide Fund for Nature Malaysia (WWFM) and the Round Table on Sustainability of Palm Oil. They strongly cooperate with the industry through dialogues and seminars and the development of Best Management Practices (Hai, 2002).

Since in Thailand most palm oil products are consumed locally, international NGOs play a minor role. Most domestic NGOs in Thailand focus on natural resource issues rather than on industrial pollution.

2) Less pressure from local community

In Malaysia, communities play a minor role in pressing for clean technology application in palm oil mills. Since most palm oil mills are situated in plantation areas and far from residential areas, the pollution impacts on surrounding people are low. Although the environmental awareness in Malaysia is quite high, there is no local community action against or involvement in palm oil affairs.

In Thailand, where weak monitoring and enforcement by government agencies occurs, growing community pressure has been more effective for enhancing industrial environmental management. Since most Thai CPO mills are situated close to communities and cannot reuse/recycle their wastes in adjacent agricultural areas, the environmental impacts from bad smell and wastewater overflow in the rainy season cause increasing numbers of complaints. Consequently, the government responded to growing complaints about pollution by decentralization of government agencies, and building and implementing more effective command and control measures.

8.4 Malaysian lesson for better environmental management in the Thai CPO industry

From this comparison the following lessons can be drawn for the CPO industry in Thailand.

8.4.1 Lesson for economic network

1) Strengthened palm oil association of Thailand

The Oil Palm and Palm Oil Association of Thailand should be strengthened and supported by the government. The government should support the association by having representatives from the Ministry of Industry (DIW, PIA), the Ministry of Agricultural and Cooperative and the Ministry of Energy in its committee. The association should also have representatives on the research advisory committees of these government agencies and should be involved in national palm oil policy planning. The association should be allowed to collect a small tax from the millers on the basis of tonnage of produced crude palm oil. This association could also function as the centre for cooperation between oil palm growers and millers, for instance to decrease raw material prices and fertilizer costs. It should cooperate with MOAC for promoting the widespread reuse/recycling of waste materials from mills as fertilizer to minimize the demand for inorganic fertilizers. The association becomes thus the centre of information and research on clean technology and waste exchange and also the centre of training and education on technology development for mills and oil palm planters.

2) Encourage investment in downstream industry

Vertical integration in the Thai industry is small, from the oil palm plantations to palm oil millers, refineries and oleochemical manufacturers. The Thai palm oil industry should focus on new product development and the government should encourage millers or planters to invest in downstream activities: refining, oleochemical production and other added value products. The government could do so by providing soft-loans and information on processing/production technology to investors. There is a high potential for the industry to widen the demand base for oil in the non-food sector such as cosmetics, oleochemical products, polyols, and biodiesel.

8.4.2 Policy network

1) Establishment of the palm oil research institute

To ensure sustainable development of the Thai CPO industry, there is a need to establish the Palm Oil Research Institute of Thailand (PORIT), in the same way as the Malaysian Palm Oil Broad, to generate information, increase production and processing efficiency, and expand use of palm oil products/by-products through R&D. Representatives from the industry and the government should form the Board of this governmental unit. It can be sustained by a tax collected from the palm oil industry for R&D, marketing, and promotion of oil palm planters. The institute must be established as a reliable provider of information and technology, especially to anticipate and solve industrial problems. Focal areas of research should be new planting materials for higher crop yields, and downstream activities, which emphasise on the development of high added value palm-based products. This all in line with the need to preserve a clean environment as well as to achieve a vision of an almost zero-waste strategy in the Thai palm oil industry

2) Encouragement of industry-government cooperation

The government must establish a close relationship between themselves and industry. The encouragement is on triangular linkage among government, industry and research institute/universities.

PORIT should set up close cooperation with MOInd (DIW) for providing firms with suggestions on technical and management solutions on waste treatment, reuse/recycling of waste, and promotion of a waste exchange centre. This waste exchange centre should function under DIW control and should be set-up as a demonstration project for recycling.

PORIT should cooperate with The Ministry of Agricultural and Cooperative for providing more research on waste recycling in plantation areas and provide the information on recycling these wastes to farmers. Especially the use of compost produced from palm oil sludge, ash and partially treated wastewater instead of chemical compost will reduce the latter, with economic and environmental benefits.

8.4.3 Policy on palm oil industry

1) Setting a long-term national policy on palm oil development

The formulation of a long-term national policy on palm oil development should be developed and implemented by PORIT. The government ensures sustainable development of palm oil industry through adequate legislation and implementation of research activities. PORIT, a centralized body, plans and implements R&D for the palm oil industry as a whole.

The Malaysian's National policy (the Oil Extraction Rate (OER) policy and the zero waste policy), which has worked successfully in environmental reform of mills, should be part of such a long-term policy for the Thai palm oil industry, in order to promote clean technology and waste exchange implementation.

2) Strengthening of policy on pollution control

Economic instruments used in Thailand do not stimulate firms to implement clean technology approaches to reduce industrial waste. The economic instruments should emphasise on emission charges on wastewater. Fees from such emission charges should fund R&D on clean technology, waste exchange and waste treatment technology investments. R&D is conducted by an Industry-MOI committee and is in line with the industrial needs. The fee will provide incentives to encourage mills to look beyond compliance and to investigate opportunities for reducing waste generation and for reuse/recycling wastes in other sectors. At the same time, the regulatory mechanisms should be strengthened by increasing the inspection and enforcement power of regulators.

Chapter 9
Conclusion

9.1 Introduction

The objective of this study has been to seek for possibilities and potentials to move the existing Thai crude palm oil industry to a more sustainable (or an almost zero waste) industrial ecosystem, by overcoming the implementation barriers of clean(er) technology and waste exchange and by learning from Malaysia's experiences with technologies, regulatory frameworks and 'best environmental practices' in crude palm oil industry. Three main research questions have been considered. First, how to apply clean technology and industrial ecology concepts at the factory level to ensure a more sustainable industrial development in the Thai crude palm oil industry? The second question has been: which actors, factors and barriers are crucial for introducing clean technology and waste exchange in Thai crude palm oil mills in practice? Finally, what lessons can be learned from Malaysia's experiences in crude palm oil industry with respect to clean technology and waste exchange in Thai CPO industry?

This final chapter answers these research questions. The second section explains the existing environmental performance of crude palm oil industry in Thailand. Subsequently, the possible technological and managerial options for improving the environmental performance of the Thai crude palm oil industry are presented. The third section discusses the main (f)actors in developing and applying the clean technology options and waste exchange, and elaborates on the barrier in implementing an almost zero waste industrial ecosystem. The forth and final section will conclude on opportunities for improving the environmental reform of crude palm oil industry in Thailand by drawing on experiences from Malaysia.

9.2 Technological improvement for environmental performance of crude palm oil industry

This research started with the description of the state-of-the art technology and the existing environmental performance of CPO production processes in Thailand and the South-East Asian region. The important locations of oil palm cultivation are in South East Asia, where about 80% of the world's palm oil production can be found. Malaysia is the world's largest producer of palm oil with 50% of the world's production, while Thailand ranges fourth with 5% of global production. Priority of Thai government to produce palm oil was related to import substitution. In Malaysia, oil palm is the most important agricultural crop that accounts for 58% of the total cultivated land (3.4 million hectare). The comparative advantage of the Malaysian palm oil sector is related to its suitable condition for oil palm cultivation and soil condition. As the main industry of the nation, Malaysia has intensive research and development to improve the production efficiency and industrial expansion of palm oil. Moreover, Malaysia's experience with the regulation of pollution control for CPO industry shows that pollution abatement and industrial expansion can occur simultaneously. Malaysia is seen as a major example for the technical and organisational development of the palm oil production in Thailand.

The existing environmental performance of Thai CPO production process

Result from five case studies in Thailand showed that only 22.8 % of raw materials are converted into valuable products (CPO and palm kernel); the rest is by-product and waste. Current industrial wastes and recoverable materials are empty fruit bunches, fibers, shells, decanter sludge and ash. It is estimated that in 2003, a total of 2.1 million ton of solid wastes/by- products and 2.5 million m^3 of wastewater was generated by the Thai CPO industry. Most of these by-products can be sold or reused in the production process or by other industries, such as fibers, shell and empty fruit bunches (EFB). However, significant amounts of waste have to be treated properly before disposal or discharge. These wastes include ash, decanter sludge and wastewater. To convert palm fruits into palm oil large amount of water and steam (1.2 and 0.6 ton/ ton FFB, respectively) are consumed in the production process. At the same time, mills generate 0.64 m^3 of effluent for every ton of fresh fruit bunch processed. The estimated total pollution load in term of BOD from the entire CPO production in Thailand in 2003 was equivalent to the amount of wastewater annually generated by 5 million citizens. Oil loss in wastewater was 10,400 ton/ year, with a value of 170 million Baht (EU 3.4 million). Most POME treatment plants have been constructed to meet a BOD concentration limit of 20 mg/L in the effluent. This effluent BOD limit is achievable if the treatment system is well designed and operated. Nevertheless, it is observed that most crude palm oil factories cannot treat their wastewater up to the level of the effluent standard at all time. Serious environmental impacts from POME usually occur in the rainy season, especially with mills located close to communities and / or mills that do not own an oil palm plantation. The overflow from wastewater treatment plants causes heavy surface water pollution. In addition, the anaerobic ponds produce methane and carbon dioxide. These gasses are released into the air. Carbon dioxide and methane are so called greenhouse gases (GHGs), which contribute to global warming. Thus, it can be concluded that such wastes pose a serious threat to the environment and the quality of life (both in rural areas and at the global level), unless proper pollution measures are taken. In practice, small and medium-sized crude palm oil industries have difficulties dealing with their environmental problems. Industries themselves recognize the problem and have expressed interest to seek appropriate solutions. Environmental authorities and local communities are equally concerned about the environmental effects of palm oil production.

The Thai government's response

In response to these and other environmental threats Thai authorities have developed a pollution control regime. The current regime of (water) pollution control in Thailand follows a command and control approach. The majority of legislation focuses on end-of-pipe approaches to pollution control. This approach has been successful in raising awareness on environmental issue among industrialists, but government is facing difficulties in law enforcement and compliance. Although the Ministry of Industry (the Provincial Industrial Agency) has the authority to control and enforce pollution policies on the palm oil industry, significant policy weaknesses and non-compliance by polluters is widespread. Because of the rapid growth of the palm oil producing industry, the economic importance of palm oil production, and the significant impact of palm oil production on the environment, it is essential to successfully implement minimum environmental requirements for this industry. Faced with the limited successes of a command and control approach Thai government has adopted some new approaches to reduce or eliminate the CPO industry's environmental impact. One of the strategies of the government has been to support the domestic CPO industry with clean technology. In 1994, GTZ (a German Donor Agency) together with DIW and university researchers have started to promote clean technology in crude palm oil mills.

Comparison of production technology between Thailand and Malaysia

Compared to palm oil production in Malaysia, oil production efficiency in Thailand is 11 % lower than that in Malaysia. This is mostly due to the fact that the oil content in Thai oil palm fruit is 13% lower than in Malaysia. From these data, it can be concluded that production efficiencies of Thai crude palm oil mills are at the same level as Malaysian mills. That makes sense as most production machines and technology are imported from Malaysia. Clean technology application in Thai CPO mill is also similar that in Malaysian mills. However, waste exchange practices in Malaysian CPO mills are more advanced. In Malaysia, the palm oil industry is now at the stage of seeking more value-added products, not only from the oil and kernel, but also from its by-product biomass. In the case of solid waste, Malaysian palm oil mills are on their way to convert the annual 13.2 million ton (dry weight) of available biomass from the oil palm sector into pulp and paper, particleboard, medium density fiberboard, furniture and other applications and products.

Technological improvement for environmental performance of Thai CPO industry

Thai crude palm oil industry has developed a number of industrial ecosystem practices for recycling waste. The nature of these industrial ecosystem practices can be divided in in-plant industrial ecosystem (clean technology) and external waste exchange, the latter including recycling of waste between the industrial sector and other sectors such as agriculture. The various technical options for an industrial ecosystem approach have been elaborated more in detail in chapter 6. Currently, resource recycling and recovery is among the highest concerns of the CPO industry. The crude palm oil industry is developing a number of industrial eco-system practices for waste recycling. The case studies in this research show that approaching a zero waste industrial ecosystem needs the combination and integration of various clean technologies and waste exchange options. Clean technology and waste exchange prove valuable elements for developing zero waste industrial ecosystem models for crude palm oil mill in two situations: situated closed to communities and sited in a plantation area. The physical-technological model consists of crude palm oil factory, other types of industries and the agricultural sector. Various technological options in this model are as follows:

- Fibers and shells are traditionally used as solid fuels for steam boilers for electricity generation and for heating the production line. However, the fibers alone are able to fulfill the energy requirements in a palm oil mill. There are other alternative options for re-using fibers and shells, which have a higher value added. Shell has high potential for producing activated carbon for water purification; fibers may be used for briquette production.

- Empty fruit bunch is effectively reused as a media for mushroom cultivation. After harvesting mushrooms it still contains a high nutrient value and can be use as fertilizer in oil palm plantation area. Other value added products from EFB waste can be obtained by using it in the production of pulp& paper, of MDF and by composting.
- Decanter sludge can be reuse as animal feed.
- Biogas recovered from the anaerobic treatment of palm oil mill effluent can be reused as fuel in boilers or used in gas turbines to generate electricity. The latter can either be used in the factory or sold to the national grid.
- Palm oil mill effluent is sometimes already being used as organic fertilizer. Treated wastewater and sediment from anaerobic ponds can be reused for irrigation.

These options should be combined in such a way to optimize the use of resources on a sustainable basis.

A Physical – technological model of industrial ecosystem with a minimum waste

Based on the analysis of the existing material and energy flows at the five selected crude palm oil mills, the model of an almost zero waste industrial ecosystem for crude palm oil industry can be designed. Figure 9.1 represents a schematic diagram of a crude palm oil mill in an industrial ecology complex. The estimated mass balances given in this figure are based on the extraction of 1000 tons of fresh fruit bunches, resulting in the generation of about 640 m^3 of wastewater, 240 tons of empty fruit bunches, 140 tons of fiber, 60 tons of shell and 42 tons of sludge from decanter.

9.3 Barriers in approaching an almost zero waste industrial ecosystem of Thai CPO mill

This section is the answer of the second question: which actors, factors and barriers are crucial for introducing clean technology and waste exchange in crude palm oil mill in practice? As a result from network analysis, it can be concluded that the actors which play an important role in clean technology implementation of crude palm oil industry in Thailand are DIW, PIA, communities, international donor agency, universities and other crude palm oil mills. In 1994, DIW together with GTZ (German Donor Agency) and university scholars started to promote clean technology in crude palm oil mills. Through a growing awareness of the pollution impact to surrounding people, some companies introduced appropriate waste management systems and also moved beyond control technology to consider clean technologies. During the past 10 year, crude palm oil mills have improved their environmental performance gradually, due to among other local community complaint about environmental deterioration.

In spite of these obvious advancements, many mills are faced with various constraints in implementing clean technology options and waste exchange. As a conclusion from the network analyses of chapter 7 this section summarizes the barriers for cleaner production implementation and for approaching a zero waste industrial ecosystem of crude palm oil industry in Thailand. Four types of barriers can be distinguished: informational barriers, cooperation barriers, price barriers and human capacity barriers.

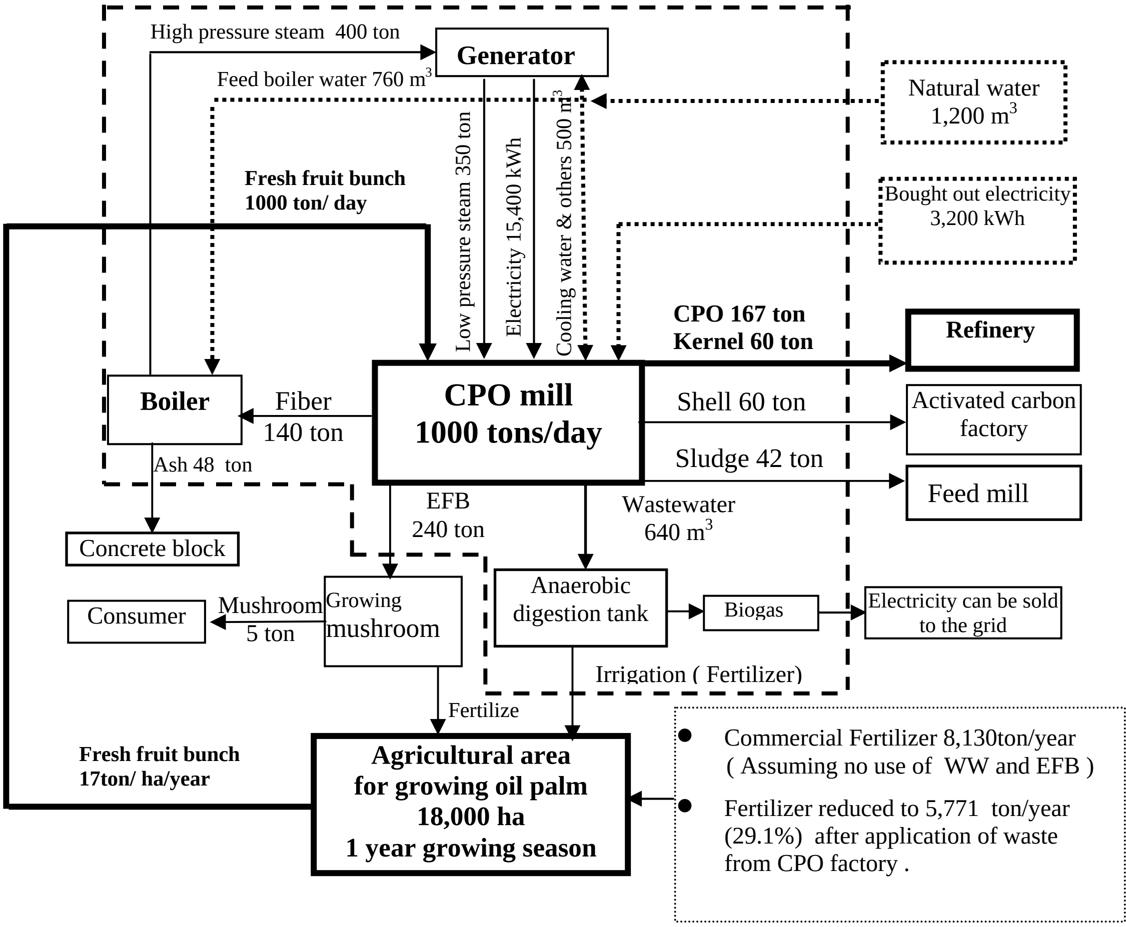


Figure 9.1 Material balance of an almost zero waste industrial ecosystem of mill

Informational barriers. Informational barriers are related to the lack of any governmental unit to strongly support research and technology development on the palm oil industrial complexes. The shortcomings in technical information and knowledge on cleaner production options and implementation trajectories form important barriers in pushing CPO industry towards sustainability. Lack of know-how and access to information is also an important problem in the reuse and recycling of CPO waste in other industries and in the agricultural sector.

Cooperation barriers. Lack of cooperation between mills and other actors in especially the economic networks (such as the crude palm oil association, research institutes/ universities and oil palm planters) forms a barrier for clean technology adoption and waste exchange in Thai CPO mills.

Price barriers. A third category of barriers that hinders mills to implement clean technology options are to be found around pricing: financial incentives are lacking due to the low - or non-existence of - prices of environmental pollution and natural resources (water and energy) and the shortage of feed back prices for recovered energy (biogas and steam).

Human capacity barriers. The shortage of human capacity (both quality and quantity) regarding environmental management within both state authorities and companies is an important barrier in clean technology adoption. The monitoring and enforcement capacities of local authority are weak due to inadequate staff numbers and low monitoring technology. Environmental experts in companies are often absent, even in the larger ones.

9.4 Strategy to move crude palm oil industry to more sustainability

Results from a triad network scan of CPO production in Malaysia are used to identify the differences with the economic, policy and societal network of Thailand's CPO industry. With respect to the economic network, there are three main differences between Malaysia and Thailand: Malaysia has a larger international orientation and integration; a larger vertical integration; and a better horizontal organization and coordination. The policy network of Malaysian palm oil sector differs in three ways from that in Thailand with respect to environmental innovations: there are more responsible government institutions, such as research and development institutions, trade and marketing promotion institutes, environmental management agencies; more active palm oil policies exist; and there are closer industry-government relations. The difference in the societal network around CPO mills between Malaysia and Thailand are not that large, and relate to the role of international NGOs and pressures from Local Communities. Compared to Thailand, Malaysia witnesses a larger role of international NGOs, but less pressure from local communities.

Malaysian lesson for better environmental management in the Thai CPO industry

To answer the final research question on what should be done to improve the environmental performance of Thai crude palm oil industry, the information from the former sections are combined to develop strategies for lifting barriers for adoption of cleaner production activities by industry. The strategies to move Thai crude palm oil industry more sustainable can be summarized under three headings and visualized in Figure 9.2.

Policy network

- Establishment of the Palm Oil Research Institute of Thailand. To ensure sustainable development of Thai CPO industry, there is a need to establish the Palm Oil Research Institute of Thailand (PORIT), similar to the Malaysian Palm Oil Broad, to generate information, increase production and processing efficiency and expand use of palm oil product/ by-products through R&D. This institute is also do research on clean technology and waste exchange for sustainable Thai CPO industry. The Board of this governmental unit is formed by representatives from the industry and the government.

- Encouragement of industry-government cooperation. The government must establish a close relationship between themselves and industry. The preference is on triangular linkage among government, industry and research institutes/universities.

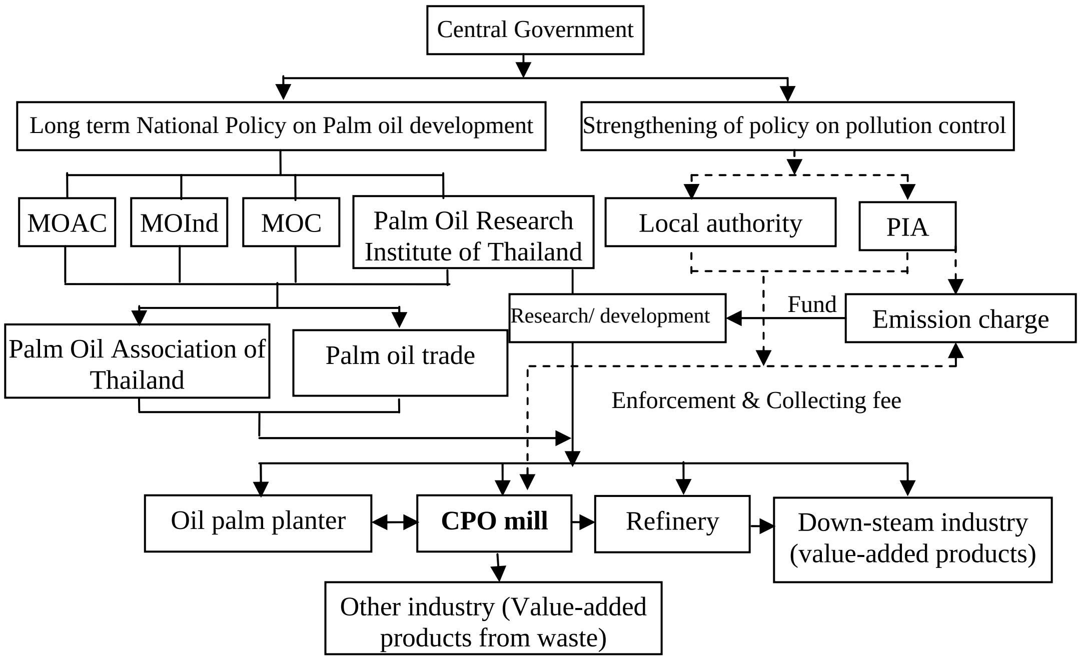


Figure 9.2 Schematic flow diagram of environmental reform of crude palm oil industry

Economic network

- Strengthen the Palm oil Association of Thailand. The Oil Palm and Palm Oil Association of Thailand should be strengthened and supported by government, among others by having representatives from the Ministry of Industry (DIW, PIA), the Ministry of Agricultural and Cooperative and the Ministry of Energy in its committees. The association becomes thus the center of information and research on clean technology and waste exchange and also the center of training and education on technology development for mills and oil palm planters.
- Encourage investment in downstream industry. The Thai palm oil industry should focus on new product development and the government should encourage millers and planters to invest in downstream activities: refining, oleochemical production and other value-added products.

Policy on palm oil industry

- Setting a long term National Policy on Palm Oil Development. The formulation of a long term national policy on palm oil development should be developed and implemented by PORIT. The government ensures sustainable development of palm oil industry through adequate legislation and implementation of research activities. PORIT, a centralized body, plans and implements R&D for the palm oil industry as a whole.

- Strengthening of policy on pollution control. The economic instruments should emphasize on emission charges on wastewater. Fees from such emission charges could fund for R&D on clean technology, waste exchange and waste treatment technology investments. R&D is conducted by a Industry-MOI committee and is in line with the industrial and societal needs.

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APPENDICES

Appendix A-1
Factory B

Introduction to the company

Factory B was established in 1993. Factory B is a medium sized CPO company with 70 employees. This factory covers an area of 160,000 m^2, and has no community in the vicinity. The maximum production capacity of the factory is 60 ton/hour (1,400 ton/day); the average production capacity is 960 ton/day. In 2002, the factory produced 42,500 tons crude palm oil and 8,000 tons palm kernel nut from 250,000 tons fresh fruit brunch.

Inputs

Only 5% of the fresh fruit bunches is from the factory's plantation area, the remaining 95% is purchased from palm fruit suppliers. The production process of factory B is not different from factory A. Raw water from the river Tapee, nearby the factory, is treated with alum and polymer before use in the production process. In 2002, the raw water consumed was 250,000 m^3; the energy used was 3,360,000 kW. The electricity used in this mill is obtained from 2 sources, a turbine generator in the factory and purchased from the government supplier. The electricity generated in the factory is about 80% of total electricity consumption.

Production technology

The crude palm oil production process of factory B is briefly described in Figure A1.1. The factory employs a modified oil clarification process, consisting of a settling tank followed by a decanter (three-phase centrifuge). A separator (two-phase centrifuge) is used to separate oil and suspended solids from the wastewater.

This factory has installed a water tube boiler with a capacity of 20 tons steam per hour. Steam from the boiler is sent to the turbine for electricity generation. After energy generation the steam from the turbine is used in various units of the production process. Autoclaves for sterilizing fresh fruit bunch are manually operated at a controlled temperature of 120-130 ^oC, at 3-3.5 bar and a settling time of 75 minutes. After oil extraction, raw crude oil flows to a vibrating screen to separate large particles from the crude oil. Subsequently sand is separated from the raw crude oil by a sand cyclone. After sand separation the raw crude oil flows to a buffer tank and a clarification tank used for the separation of sludge and wastewater from the crude oil,

Factory B has implemented many clean technology options. During the last seven years the following measures have been taken in that respect.

- Installation of a buffer tank to separate sludge from the crude palm oil before this palm oil flows to the settling tank to enhance oil separation.
- Installation of a 2^{nd} bunch stripper to enhance fruit separation from bunch stalk with the aim to reduce oil loss from the empty fruit bunch.
- Recycling sterilized condensate to the screw press and separator to reduce hot water use.

- Recycling sludge from vibrating screen to digestion tank.
- Recovery of oil from wastewater using a decanter and a separator. The recovered oil is pumped to settling tank.

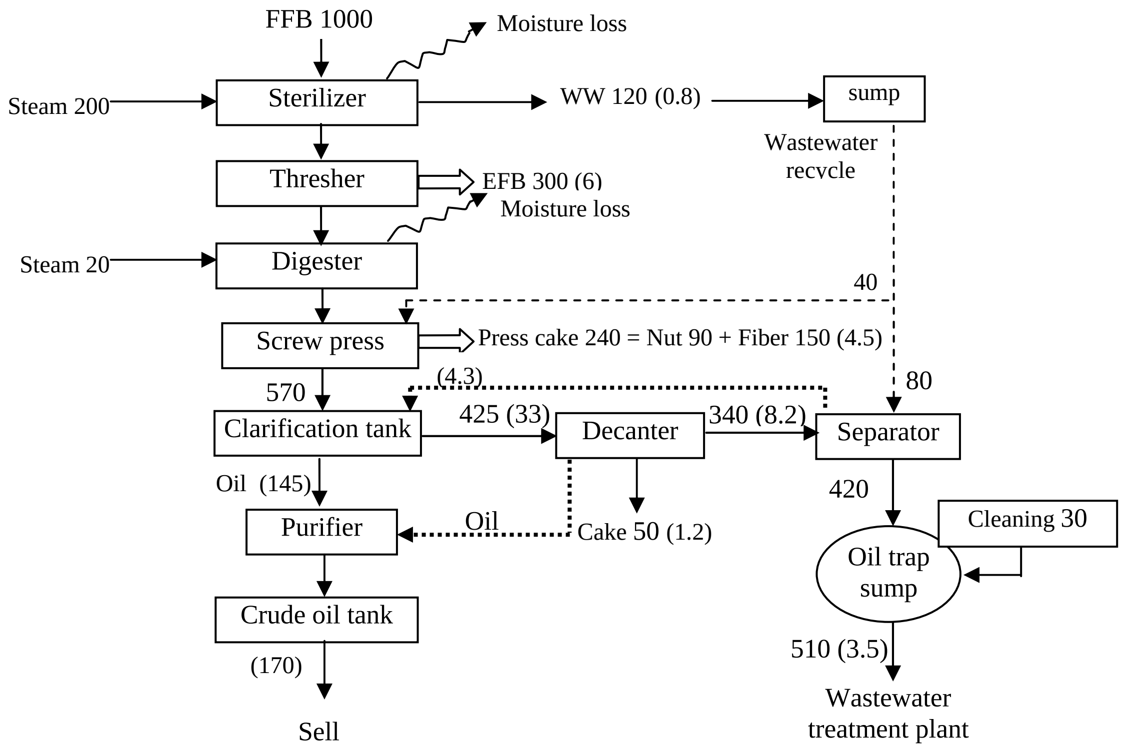

Figure A1.1 Schematic flow diagram of mill B, including mass balances
( ) Oil content

Mass balances in terms of dry weight, based on 1 ton of fresh fruit bunch (wet weight) flows are shown in Figure A1.2.

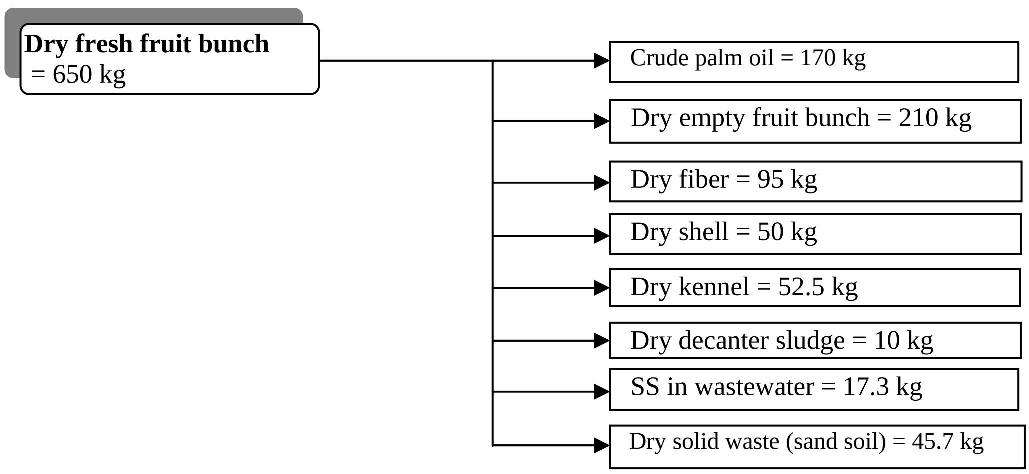

Figure A1.2 Mass balance in terms of dry weight per ton FFB

Liquid material and energy balance

Figure A1.3 shows the volume balance for the liquid material flows of the palm oil production of factory B. In this balance all liquid materials including supplied water and generated wastewater are considered. The water consumption of factory B is 1 m^3 per ton FFB, of which about 50% becomes wastewater. Wastewater from the sterilizer (0.12 m^3) is recycled in the production process.

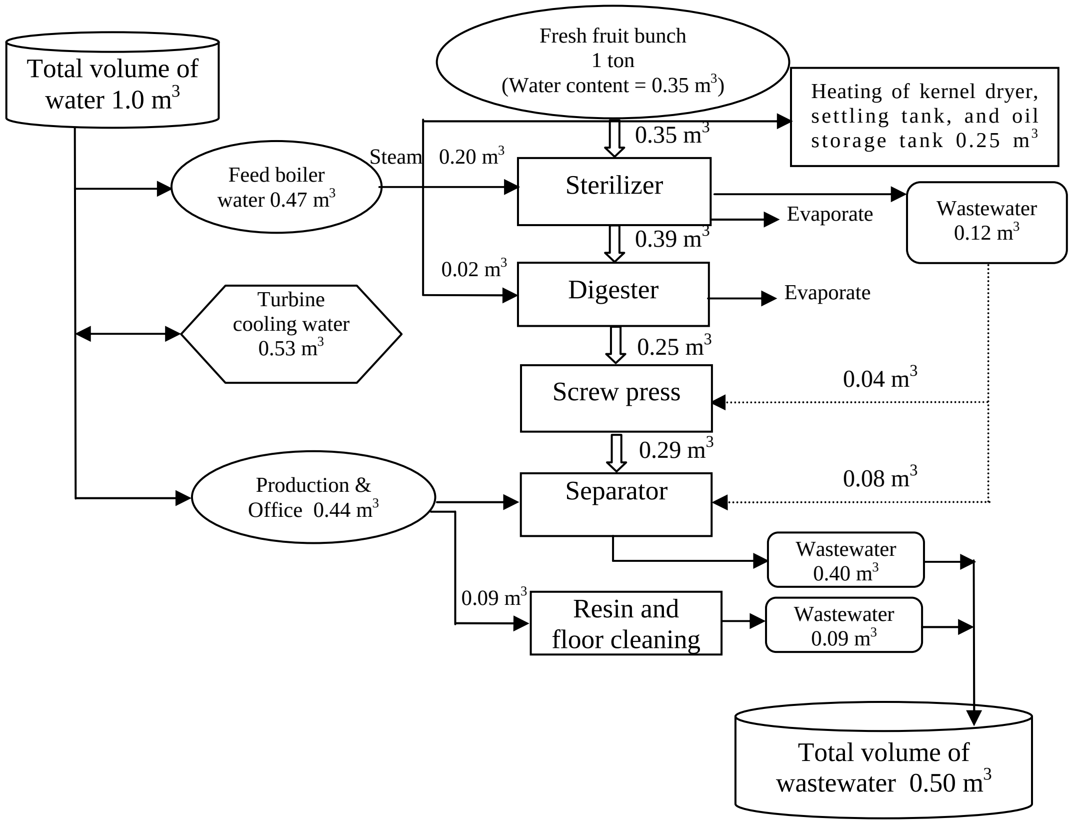

Figure A1.3 Liquid material balance of factory B

The energy required for the process is produced by a cogeneration system, which produces heat (steam) and electricity. The fiber and shell have a high caloric value and are used as fuel is the boiler. The fuel consists of fiber and shell in the ratio of 3:1, and is sent to the boiler in an amount of 113 kg/ton of fresh fruit bunch. The electricity generated is sufficient for plant operation and other uses. The electricity consumption of factory B is about 10.5 kWh/ton of fresh fruit brunch. During shutdown and start-up of the mill, electricity from Electricity Generation Authority of Thailand (EGAT) is used. It is estimated that 4.21 kWh/ton FFB is purchased from the EGAT. This mill has installed a boiler capacity of 20 ton/hr, which can produce 410 kg steam/ton FFB. The energy balance is presented in Figure A1.4. All supplied electricity and steam is consumed, no other energy was generated from the current production process. The total energy loss in the production process is high.

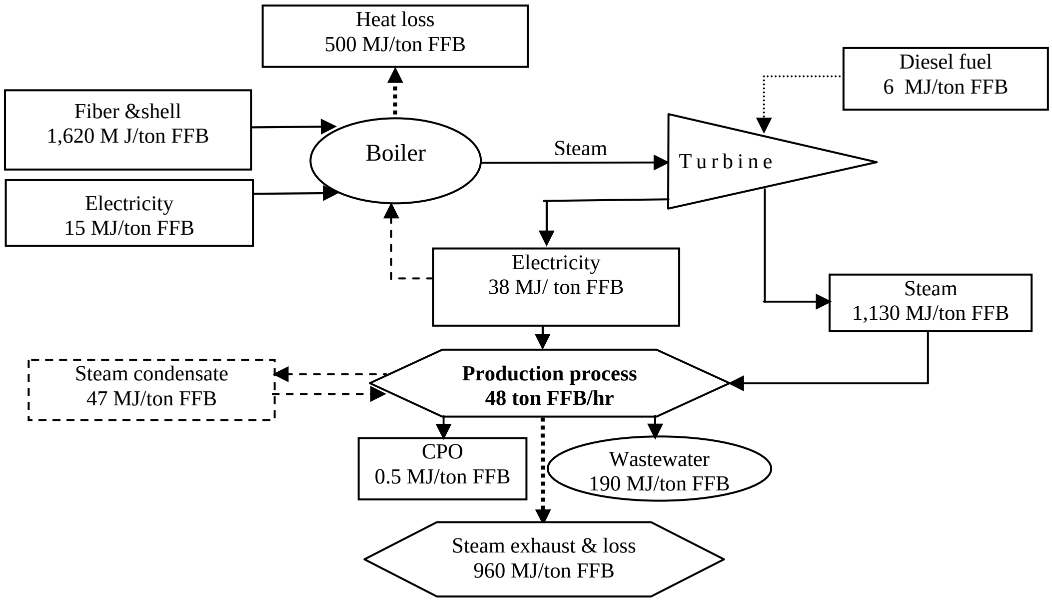

Figure A1.4 Energy balance of the production process of factory B

Cost benefit analysis

The cost structure of a large extraction plant shows that the fixed costs including fuel/energy, labour, maintenance, interest and others, is 2.3 bath/kg CPO. The total production cost per unit is 11.1 bath/kg CPO, which is 1.0 Baht/kg CPO higher than at factory A. This is due to production efficiency of factory A, which is 0.5% higher than at factory B. Factory A owns their oil palm plantation area and can get a higher yield of FFB. The high-yield oil palm species also increases the CPO production.

Wastewater treatment plant

Wastewater generated from the production process is cooled down and oil is separated from the wastewater in oil trap sumps before going to the WWTP, located at the factory. The treatment plant consists of 6 ponds with a total surface area of 63,000 m^2. The first 3 ponds are anaerobic ponds, pond 4 and 5 are oxidation ponds, and the final pond is a maturation pond. Wastewater is kept in the ponds without discharge. The characteristics of the wastewater in each pond are shown in table A1.1.

Table A1.1 Characteristics of wastewater from the production process and WWTP of factory B

Sampling point	pH	BOD_5 (mg/l)	COD (mg/l)	SS (mg/l)	TS (mg/l)	TKN (mg/l)	TP (mg/l)	O&G (mg/l)	Colour (pt.Co unit)
Influent	4.83	59,650	74,304	39,033	60,440	126	13	6,860	18,000
Pond 3	8.12	3,650	6,192	5,000	14,680	479	32	222	9,800
Pond 4	8.52	288	3,578	1,120	12,510	126	13	44	9,100
Pond 5	8.42	172	2,890	527	11,225	176	12	6	4,900
Pond 6	8.34	36	605	89	1,917	25	6	ND	750

Appendix A-2
Factory C

Introduction to the company

Company C is a medium size industry located in the Krabi province in Southern Thailand. The mill was established in1984 and it covers an area of 82 rai (131,200 m^2). The company has 90 employees. The mill has a production capacity of 40 ton FFB/hr. The maximum production capacity is 1,000 ton FFB/day. The amount of operation hours of the mill is not constant throughout the year due to the fluctuation in fruit availability. The mill is located very close (300 m) to a village. The mill does not own an oil palm plantation area, therefore it has to buy fresh fruit bunch from an oil palm grower. The final product from this mill is crude palm oil and palm kernel. The crude palm oil is sold to refineries and palm kernel to other crude palm oil mills for palm kernel oil production.

Input and products

The raw material needs for the production process are fresh fruit bunch, alum, clay, coagulant aid, diesel oil, salt and electricity. An overview of the raw material consumption and products is shown in table A2.1. The total electricity consumption is about 11 kWh/ ton FFB. About 93.1% of total electricity consumption in the factory is generated by a turbine generator. All generated fibbers are fed to the boiler (rate 10 ton/hr) to produce steam and electricity for use in the factory.

Table A2.1 Raw materials, products and by-products of factory C

Item	Quantity (per year)	Quantity (per ton FFB)
Raw material		
• Fresh fruit bunch	200,000 ton	-
• Clay	210 ton	1.1 kg
• Electricity demand	2,200,813 kWh	11.0 kWh
• Diesel oil	108,800 L	0.5 L
Product		
• Crude palm oil	34,000 ton	170 kg
• Palm kernel	12,500 ton	63 kg
By-product		
• Empty fruit bunch	46,000 ton	230 kg
• Fiber	28,000 ton	140 kg
• Shell	8,000 ton	40 kg

Production process

The production process of factory C is similar to factory A and B, except for the machine used for oil recovery from wastewater in the oil clarification step. This mill has installed an oil trap tank to remove oil from the wastewater before it goes to the anaerobic digestion tank, which is used to recover biogas. After the digestion tank it flows to the anaerobic ponds. The shift to clean technology during the last 5 years can be illustrated as follows:

- Installation of a 2nd bunch stripper to enhance fruit separation from bunch stalks and increase oil yield.
- Installation of a 30-ton water tube boiler with cyclone for control particulate matter.
- Construction of an anaerobic digester tank to recover biogas from the wastewater.

The flow diagram of the process with mass balances is shown in Figure A2.1

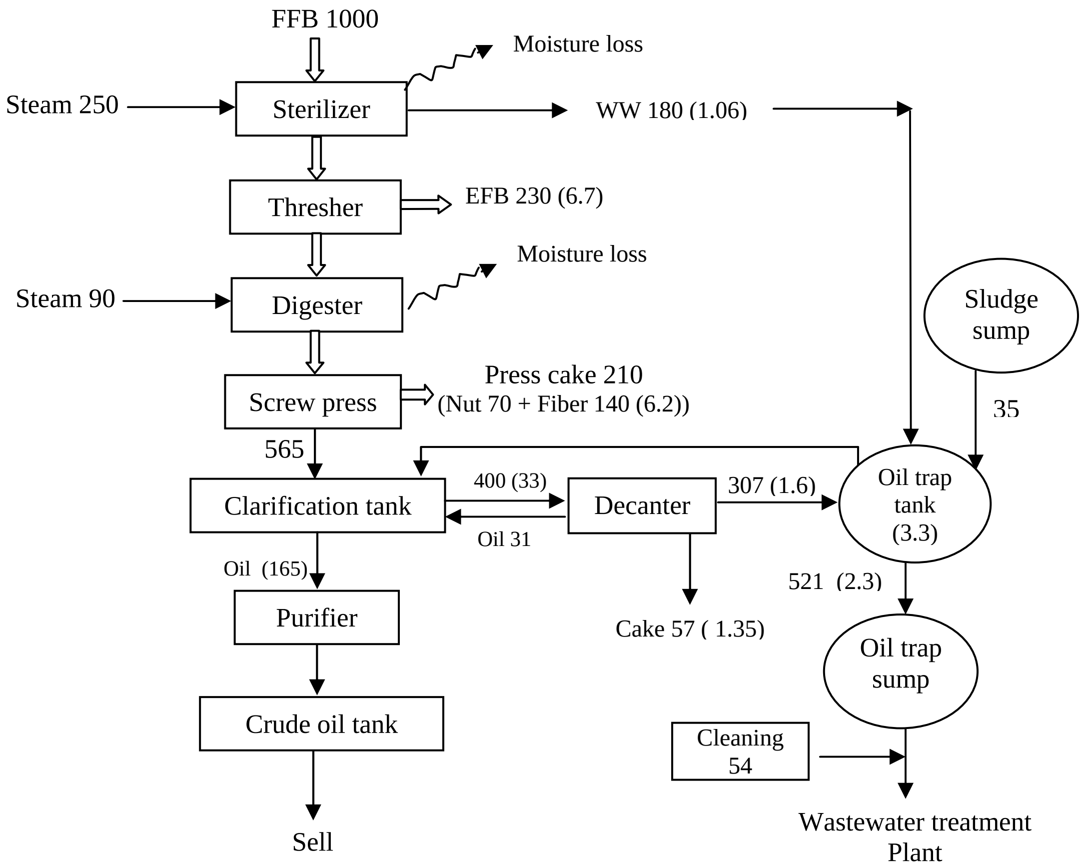

Figure A2.1 Schematic flow diagram of mill C, including mass balances
( ) Oil content

Water usage and wastewater generation

Channel water is the source of process water. Clarification and filtration is necessary to use this water in the process. Alum and polymer are used as coagulant and flocculant in the clarifier. The water consumption of the mill is about 28 m^3/hr or 1.1 m^3/ton FFB. Wastewater generation is about 52.7% of the water supplied (0.58 m^3/ton FFB). Table A2.2 shows the water usage in the production process of factory C. This mill has installed only a decanter to recover oil from wastewater, so the water consumption in the production process is lower compared to factory A and B. There is no wastewater reuse/recycling in the production process. Wastewater is pumped to an oil trap tank (retention time 3 days) to remove oil from the wastewater before it is sent to the treatment plant. Table A2.3 and A2.4 show the characteristics of the wastewater generated from the production steps and of the wastewater treatment plant.

Table A2.2 Water demand for the crude palm oil production process of factory C

Process stream	Flow rate of water consumption	
	m^3/ton FFB	m^3/day
Water for boiler (steam)	0.54	285
• Sterilizer	0.25	132
• Digester	0.09	48
• Other (nut dryer, crude oil storage tank, hot water tank)	0.20	105
Water from cooling system in turbine is reused in	0.56	306
• Screw press	-	-
• Vibrating screen	0.004	2
• Clay bath and machine cleaning	0.07	37
• Other.	0.49	262
Water use in production process	0.64	340
Total water consumption	1.10	614

Note: Production capacity is 530 ton/day

Table A2.3 Characteristics of the wastewater from the production process and the wastewater treatment plant of factory C

Source of wastewater	pH	BOD_5 (mg/l)	COD (mg/l)	SS (mg/l)	TS (mg/l)	O&G (mg/l)	Colour (pt.Co unit)
Sterilizer	5.26	46,350	66,048	20,067	55,300	5,910	7,400
Decanter	4.75	57,600	84,089	50,567	69,500	5,090	10,000
Sludge sump	4.85	8,262	30,270	5,840	119,890	16,270	3,500
Influent	4.76	52,300	79,808	38,833	63,930	3,600	8,500

Solid waste and by-product

One ton of fresh fruit bunch processing generates 230 kg empty fruit bunch, 140 kg fiber, 40 kg shell, 30 kg palm kernel, 57 kg decanter cake, and 17 kg ash. All fibres generated are used as fuel in the boiler. The solid waste handling methods in this factory are shown in Figure A2.2

Table A2.4 Characteristics of the wastewater from the wastewater treatment plant of factory C

Sampling point	pH	BOD_5 (mg/l)	COD (mg/l)	SS (mg/l)	TS (mg/l)	TKN (mg/l)	TP (mg/l)	O&G (mg/l)	Colour (pt.Co unit)
Influent	4.76	52,300	79,808	38,833	63,930	324	87	4,540	8,500
Pond 1	5.27	8,633	41,280	16,850	27,120	529	57	2,444	6,800
Pond 2	7.53	3,730	7,568	5,500	14,700	625	55	389	4,643
Pond 3	7.54	2,886	6,330	2,600	12,310	448	33	444	4,800
Pond 4	8.48	3,125	3,715	631	8,535	149	5	244	5,500
Pond 9	8.70	76	2,472	350	1,120	35	ND	101	890

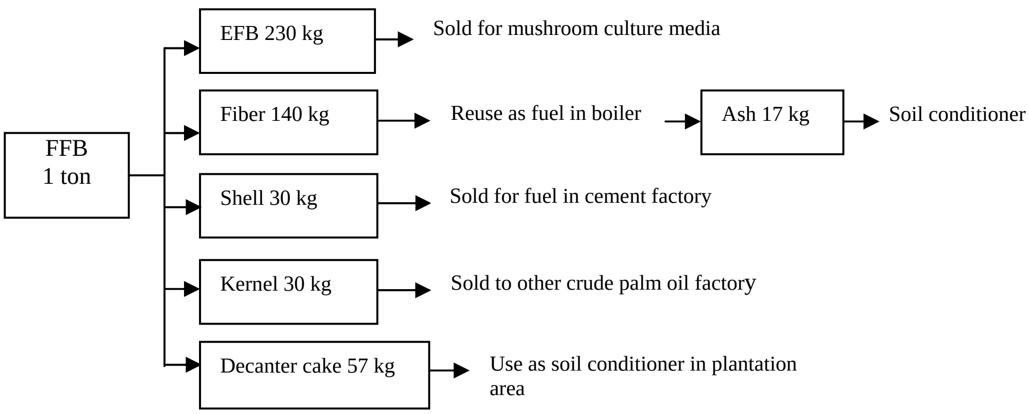

Figure A2.2 Solids waste management in mill C

Material and energy balances

Figure A2.3 and A2.4 show the water balance and energy balance in the production process of factory C. The mill does not apply wastewater recycling and energy conservation options. Fiber generated in the production process (140 kg/ton FFB) is reused as fuel in the boiler. For one ton of fresh fruit bunch processing, 540 kg feed water for the boiler is used to generate 450 kg of steam (215 ^{o}C). The steam is used in the turbine to generate 20 kWh electricity. The electricity used in the boiler and in the production process is about 5.8 and 10.6 kWh/ ton FFB respectively. About 18% of the electrical power generated by the turbine is lost during the production process.

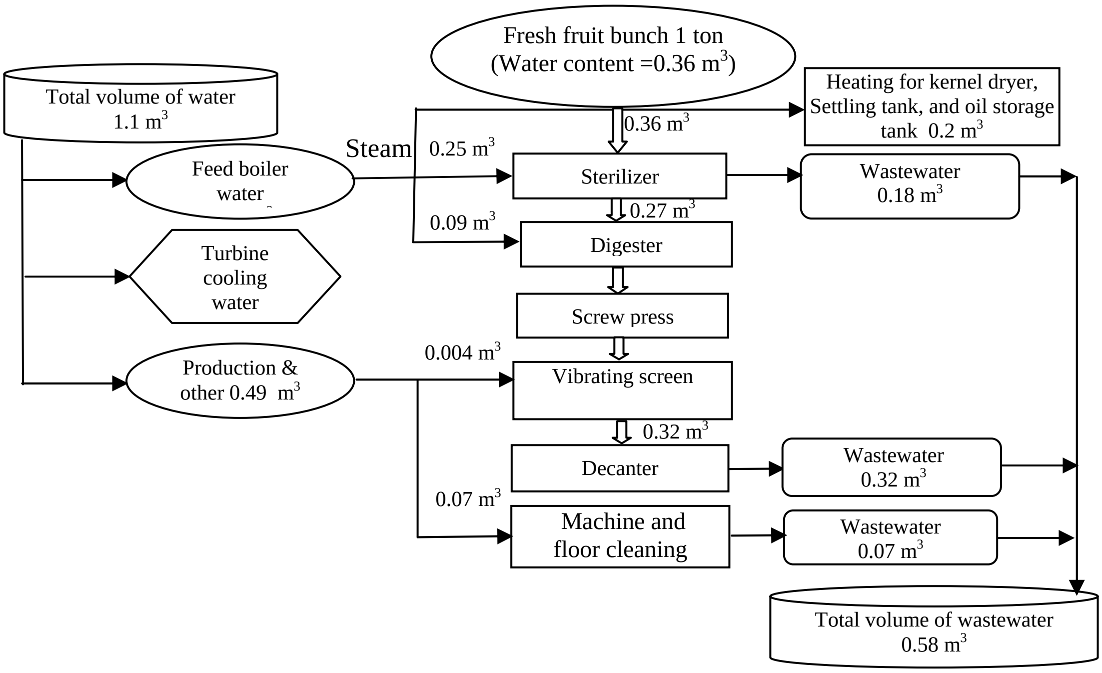

Figure A2.3 Water and wastewater balance of factory C

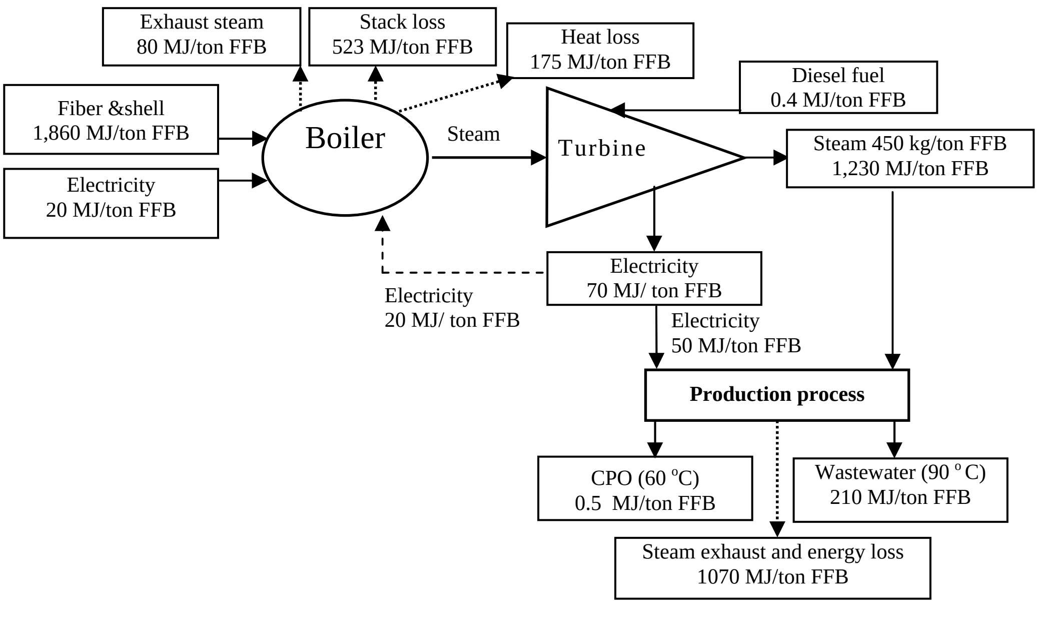

Figure A2.4 Energy balance of the production process of factory C

Appendix A-3
Factory D

Introduction to the company

Factory D has one of the highest CPO productions of the five cases studied. This mill is located in oil palm plantation area. The production process is operated continuously for 24 hours a day, 300 days per year. The average production capacity is about 41 tons of FFB per hour; the maximum production capacity is 60 tons FFB/hr. In 2002, the raw material (FFB) processed was about 269,760 ton, the CPO production was 46,852 ton. The efficiency of the production process was 16.5%.

The production activities of the company have not yet caused serious pollution to the environment because most wastes can be reused/recycled in the plantation area. The wastewater is reused for irrigation. Factory D owns an oil palm plantation area of 25,000 rai (40 km^2) and the mill is situated in the plantation area. About 40% of the FFB processed is from their plantation. The remaining 60% is purchased from fresh fruit bunch suppliers.

Production process

Factory D employs a standard decanter process, consisting of a settling tank followed by a decanter to recovery oil from the wastewater. The production process is similar to factory C. Factory D has good housekeeping practice illustrated by:

- A separation of fresh fruit bunches into 3 categories: ripe fruit, unripe fruit and medium ripe fruit. In this way they optimise the conditions for sterilization of fresh fruit bunch. The optimum time for sterilizing ripe fruit is shorter than that of unripe fruit. This approach saves energy and steam for the sterilization step.
- Construction of a sewer to collect oil contaminated water from loading ramp in order to recover oil before sending to wastewater treatment plant.

Clean technologies options applied in this mill are:

- Installation of decanter to recover oil from the wastewater.
- Installation of an automatic controller to optimise operation of the sterilizer (steam pressure, time).
- Collecting manually and re-sterilized unripe fresh fruit brunch
- Installation of a buffer tank to separate sludge from crude oil before this goes to the settling tank.
- Recycling wastewater from the sterilizer and sand cyclone to the screw press to reduce hot water use and to recover oil.
- Installation of an oil recovery sump and oil trap tank (HRT 1 day) to recover oil from the wastewater before discharging to the WWTP.

The schematic flow diagram with mass balances of the standard decanter process of factory D is shown in Figure A3.1.

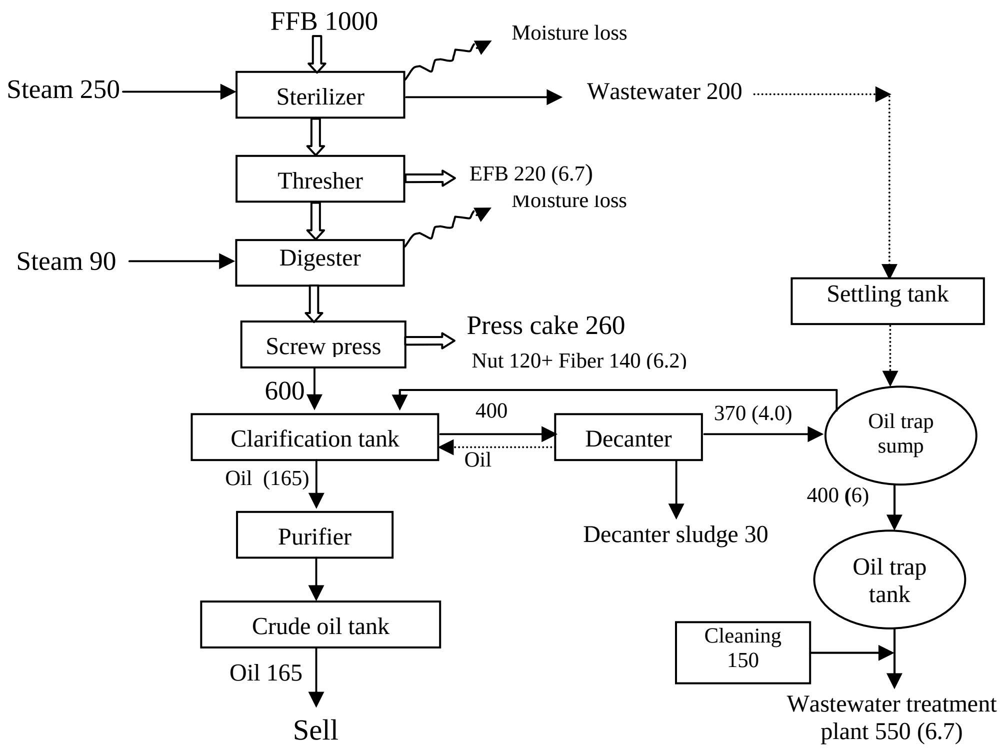

Figure A3.1 Schematic flow diagram of mill D, including mass balances
( ) Oil content, g/ kg FFB

Environmental aspects

The maximum production capacity of factory D is about 1,600 ton/day. The total water consumption is 341,080 m^3/year or 1.26 m^3/ton FFB. About 40% of the water consumption (0.51 m^3/ton FFB) is used as feed boiler water. Only the feed boiler water is treated with alum for coagulation, followed by ion exchange. The cost of chemicals used for treating the feed water is 1.45 Baht/per m^2. Turbine cooling water (0.75 m^3/ton FFB) is pumped from a reservoir without treatment and released back to the reservoir after it is used.

About 0.545 m^3 of wastewater is generated per ton of fresh fruit bunch processed and stored in a pond system consisting of 6 anaerobic ponds, 2 aeration ponds, 3 facultative ponds and the final pond. Wastewater in the final pond is aerated and allowed to settle before discharge to a channel. Since this mill owns an oil palm plantation area, the bottom sediment from the final treatment pond can reused as fertilizer in this plantation area. Also the wastewater from the clay bath can be recycled in the plantation area after partial evaporation in a sedimentation pond. Table A3.1 shows characteristics of the wastewater in the WWTP of factory D.

Table A3.1 Characteristic of the wastewater from the wastewater treatment plant of factory D

Sampling point	pH	BOD_5 (mg/l)	COD (mg/l)	SS (mg/l)	TKN (mg/l)	TP (mg/l)	O&G (mg/l)	Colour (pt.Co unit)
Influent	5.10	38,650	99,840	35,510	1,090	-	14,980	10,000
Anaerobic pond (pond 1)	4.62	46,500	79,870	27,880	1,008	117	12,240	15,000
Aerated pond (pond 7-8)	8.15	3,466	19,470	12,720	1,040	76	110	19,000
Oxidation pond (pond 9)	7.95	1,973	8,990	7,200	560	110	ND	12,000
Final pond (pond 12)	8.36	268	1,520	580	81	9	ND	5,000

Note: ND= not detect

Material and energy balances

Mass balances for solid material (wet weight) flows are shown in Figure A3.2. Processing 1 ton of fresh fruit bunch produces 165 kg crude palm oil and generates 220 kg EFB, 140 kg fibre, 60 kg shell, 50 kg kernel and 30 kg decanter cake.

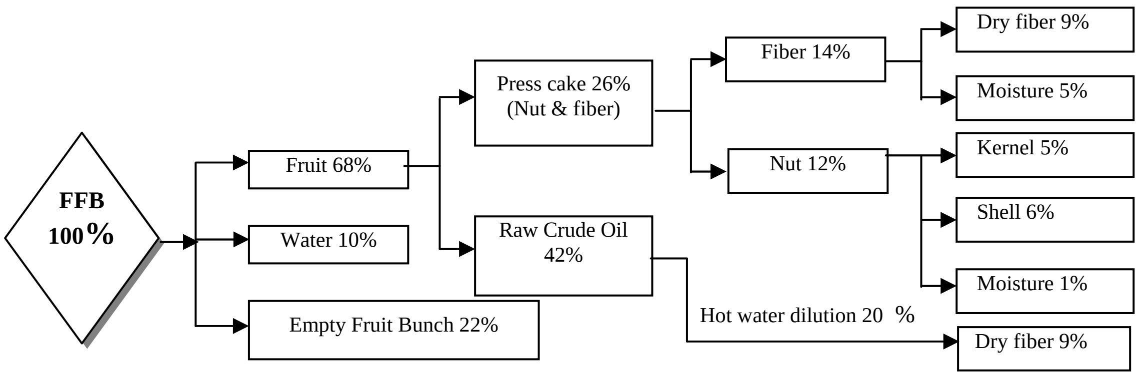

Figure A3.2 Material balances of palm oil mill D

Liquid material balances

The water consumption in the mill is 1.26 m^3/ton fresh fruit bunch. Steam, 30 ton/hr, is applied to a generator for generating electricity before it is supplied to the sterilizer, digester, kernel dryer tank, settling tank, and oil storage tank. About 50% of the stream is supplied to the sterilizer. Sterilizer condensate is sent to settling tank to remove settleable solids before recycling to the vibrating screen. The main source of wastewater in the process is generated from the decanter (0.4 m^3/ton FFB). Other sources of wastewater are from resin regeneration and cleaning water, which amounts to 0.15 m^3/ton FFB (Figure A3.3).

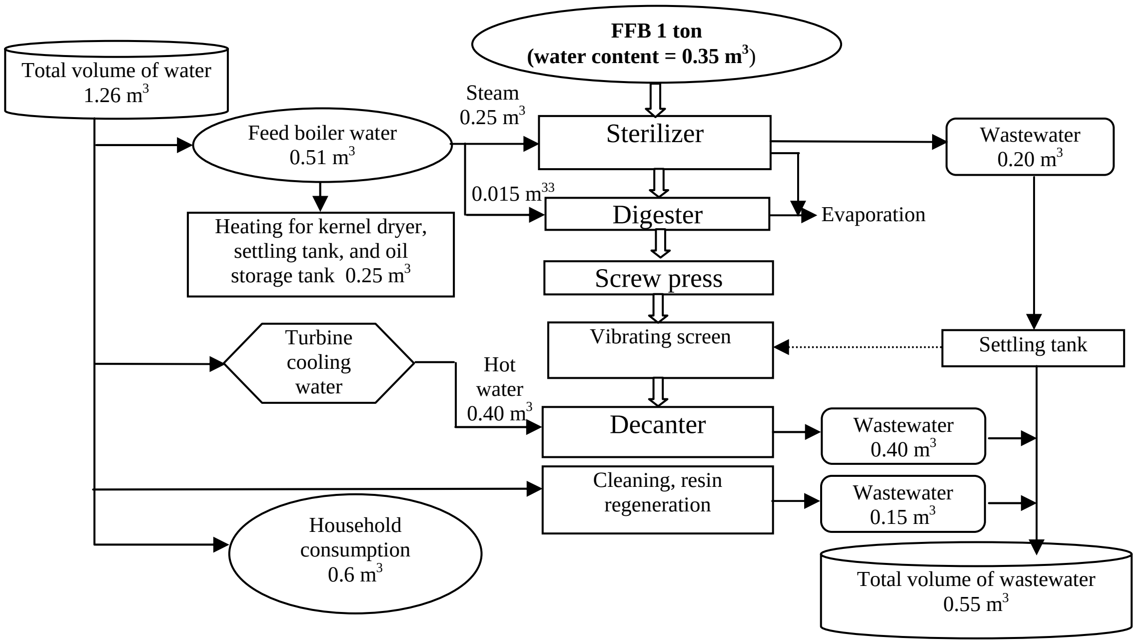

Figure A3.3 Water balance from 1 ton FFB processing in factory D

Energy balance

Factory D consumes electricity and diesel fuel at an amount of about 800 kW/d and 200 l/d, respectively. The turbine generator can generate 1200 kW/d, which is used in the production process, offices and households. Fibre and shell are fed to the boiler (4 ton/hr). The energy balance is presented in Figure A3.4.

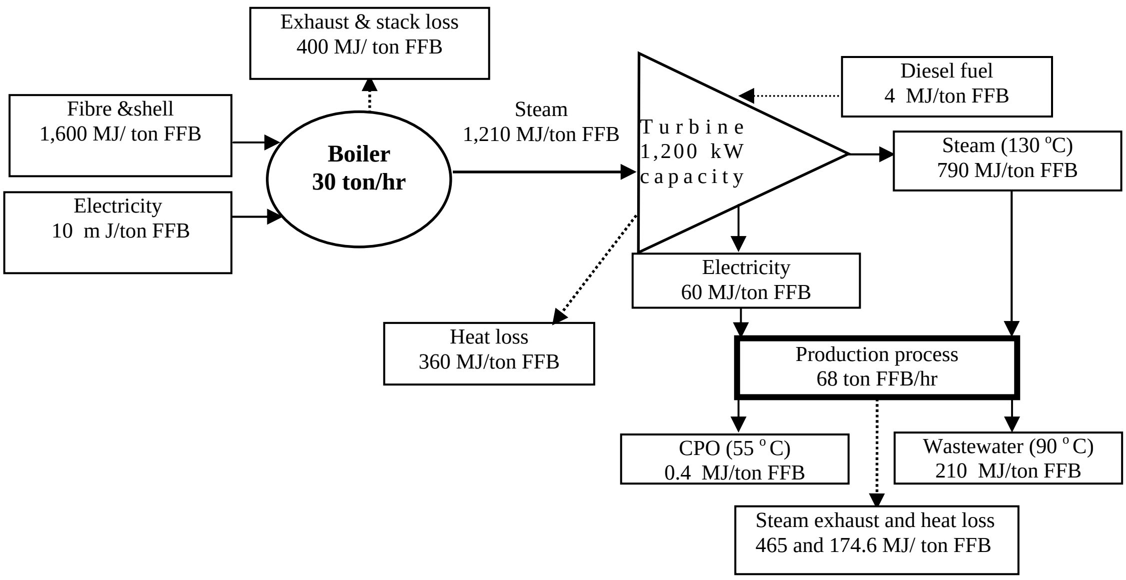

Figure A3.4 Energy balance in the production process of factory D

Appendix A-4
Factory E

Introduction to the company

Factory E is one of the smallest companies involved in crude palm oil production. This factory was established in 1993 on an area of 160,000 m^2. It has approximately 50 employees. The production capacity is 30 ton FFB/hr; the average production capacity is 400 ton FFB/day. Total production of the company is 10,000 ton CPO/year and 3,400 ton palm kernel/year.

Input

The amount of FFB processed is 100,000 tons/year. Water consumption amounts to156,000 m^3/year and is pumped from a deep well at the factory. Water is treated by coagulation to remove suspended solids from the water. Factory E employs a standard wet process. A settling tank followed by a separator is used to extract palm oil. A schematic flow diagram of the standard wet process, including mass balances, is shown in Figure A4.1. This factory applies a few clean technology options and good housekeeping, e.g. processing fresh fruit bunches within 24 hours after harvesting, reuse of the cooling water from turbine for cleaning and domestic purposes. Within the last 2 years a 2nd bunch stripper was installed to enhance fruit separation from bunch stalk to reduce oil loss from FFB.

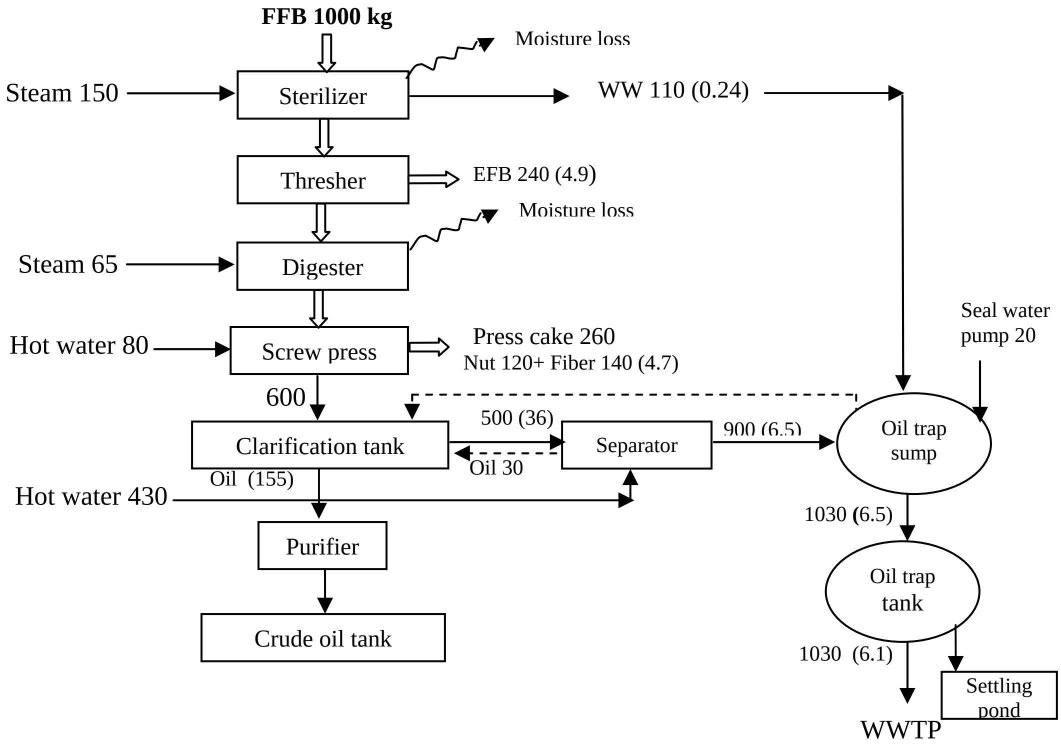

Figure A4.1 Schematic flow diagram of mill E, including mass balances

( ) Oil content

Material and energy balance

Solid material balance

Factory E uses a separator for oil recovery from the wastewater. Therefore there is no sludge from a decanter generated in production process. The mass balance, based on 1 ton of fresh fruit bunch (wet weight), is shown in Figure A4.2

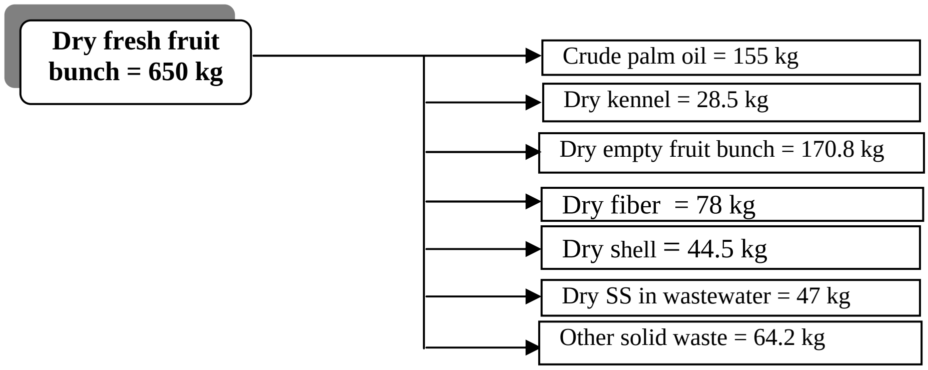

Figure A4.2 Mass balance for material flows in terms of dry weight of mill E

Liquid material balance

One ton of FFB consumes 1.3 m^3 of fresh water. The liquid materials including water consumed in each production step and wastewater generation are shown in Figure A4.3. This factory uses only a separator for oil recovery from the wastewater and uses neither hot water nor recycled wastewater in production process. Therefore all generated wastewater goes directly to the WWTP. The total wastewater generation in the production process is 1.0 m^3/ton FFB. This is the highest volume of wastewater per ton FFB processed compared to other factories, which use a decanter (factory A-D) in the production process. Wastewater generated from the separator is about 0.9 m^3/ton FFB, which is higher when a decanter is used. A factory that uses a decanter can reduce the amount of wastewater with 43-54%. Since the SS concentration limited at 4% in the feed separator wastewater so wastewater have to be diluted by hot water before feeding to the separator.

Cost benefit analysis

The raw material cost is 9.7 Baht/kg CPO. Fixed production costs of this mill are equal to 0.9 Baht/kg CPO, which is higher than at other factories. This is due to the low production efficiency (15.5%) of this mill compared to others. The total cost of production is 10.6 Baht/kg CPO. It is estimated that 91.5% of the production costs is for raw material purchasing. The profit from selling CPO for this factory is 1.4 Baht/kg CPO.

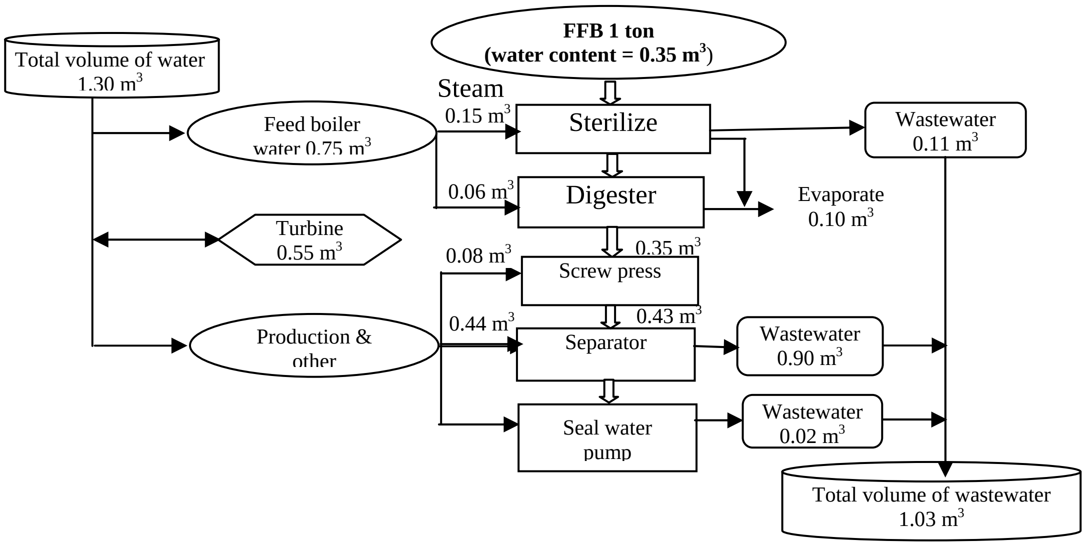

Figure A4.3 Volume balance for liquid material flows in factory E

Energy balance

The energy balance of this mill is presented in Figure A4.4. The turbine and boiler capacity are higher than the consumption, resulting in a high energy loss. The turbine capacity is 900 kW/d, but only 61% of the power generated is used in the production process. Also at the steam exhaust the heat loss is very high. The energy loss in the production process is about 73%.

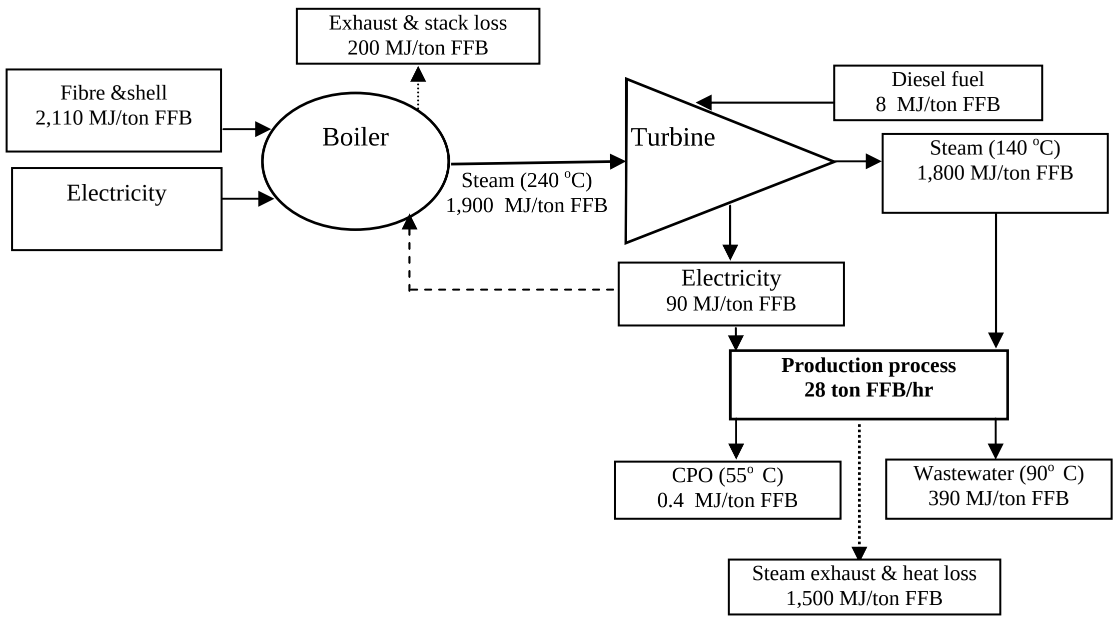

Figure A 4.4 Energy balance of factory E

Appendix B

Table B.1 General data of preliminary survey of 15 crude palm oil mills in year 2002

Factory	Production capacity (ton FFB/hr)	Actual raw material consumption (ton FFB/year)	CPO production (ton FFB/year)	Extraction efficiency (%)	ISO certification	Oil recovery technique	Location	Own oil palm plantation
A	45	173,000	29,410	17.0	ISO 9001	Decanter and separator	Close to community	Yes
B	60	250,000	42,500	17.0	ISO 9001	Decanter and separator	Far from community	No
C	45	200,000	34,000	17.0	ISO 9002	Decanter	Close to community	No
D	60	250,000	40,000	16.0	-	Decanter	Far from community	Yes
E	30	120,000	19,000	16.0	-	Separator	Far from community	No
F	45	576,000	103,680	18.0	-	Decanter and separator	Far from community	No
G	45	207,000	36,000	17.4	ISO 9002	Decanter and separator	Far from community	No
H	50	200,400	25,880	16.0	-	Decanter and separator	Far from community	No
I	45	168,000	28,600	17.0	ISO 9002	Decanter	Close to community	Yes
J	25	153,000	26,500	17.3	-	Decanter	Close to community	Yes
K	35	90,000	16,000	16.7	-	Decanter	Close to community	Yes
L	15	36,000	6,000	16.7	-	Decanter	Close to community	No
M	60	305,000	54,900	18.0	-	Separator	Far from community	Yes
N	60	315,000	56,760	18.0	-	Separator	Far from community	Yes
O	30	100,000	15,700	16.5	-	Separator	Far from community	Yes
Range	15-60	36,000-576,000	6,000-103,000	16.0-18.0				
Average	46.3	207,560	35,662	17.0				

Table B.2 Data of preliminary survey of 15 crude palm oil mills on environmental problems and waste treatment in year 2002

Factory	Wastewater treatment plant				Environmental problem			Improvement	
	Wastewater treatment plant	Influent BOD (mg/L)	BOD in final pond (mg/L)	Wastewater reuse	Wastewater	Air pollution	Smell	Wastewater treatment plant	Boiler
A	Anaerobic pond, polishing pond	56,000	35	No	√			√	√
B	Anaerobic pond, polishing pond	43,700	200	No					
C	Anaerobic digestion tank (biogas), Anaerobic pond, polishing pond	41,600	46	No	√	√	√	√	√
D	Anaerobic pond, aeration pond	-	-	Irrigation			√	√	
E	Anaerobic pond, polishing pond	42,000	22	Irrigation	√		√		
F	Anaerobic pond, aeration pond	56,500	80	No					
G	Anaerobic pond, oxidation pond, coagulation system	60,400	20	No	√	√		√	√
H	Anaerobic pond, polishing pond	30,500	40	No	√			√	
I	Anaerobic pond, polishing pond	29,600	22	Irrigation	√	√	√	√	√
J	Anaerobic pond, polishing pond	27,200	11	No	√	√	√	√	
K	Anaerobic pond, polishing pond	36,000	200	Irrigation	√			√	√
L	Anaerobic pond, polishing pond	36,000	86	No	√		√	√	
M	Anaerobic pond, polishing pond	24,000	37	Irrigation	√			√	
N	Anaerobic pond, polishing pond	50,700	500	Irrigation					√
O	Anaerobic pond, polishing pond	40,000	200	Irrigation					

Table B.3 Data of preliminary survey of 15 crude palm oil mills on incentives and barriers for environmental performance

Factory	Incentive to improve environmental performance					Barrier for improving environmental performance				
	Increase production capacity	Increase production efficiency	Management's policy	Community complaint	Comply with the law	Support from government	Technology	Building capacity	Access to information	No incentive
A		√	√	√		√		√		
B		√	√			√		√		
C	√		√	√	√	√				
D	√	√	√			√		√	√	√
E				√	√		√	√	√	√
F	√	√			√			√	√	√
G	√	√	√	√	√					
H		√			√		√	√	√	√
I	√	√	√	√			√	√		√
J		√	√	√	√					
K	√	√	√	√	√					
L				√	√		√	√	√	
M	√	√	√		√					
N					√	√				√
O	√	√	√		√			√		√
total	8	11	10	8	11	5	4	8	5	7
%	53.3	73.3	66.7	53.3	73.3	33.3	26.7	53.3	33.3	46.7

Appendix C

Appendix C-1
General survey: crude palm oil industry

<u>Part 1</u> General data

Date .... / .... / ....

Factory name .... Registered number ....

Location ....

....

Telephone number .... Fax ....

Total employees .... Male .... Female ....

Working day per year ....

Year established .... Investment cost .... Baht

Owner ....

Customer ....

Palm supplier ....

Location map of factory

<u>Part 2</u> Production process data

1. Raw material

Material type	Quantity (ton)/year	Price/unit (Baht)
For production process 1) Fresh fruit bunch 2) :	: 	: :
For wastewater treatment plant 1) : 2) : 3) :	: : :	: : :

2. Product

Products	Quantity (ton)/year
1) Palm oil 2) Palm kernel oil	: :
By-product	**Quantity (ton)/year**
1) Kernels 2) Fibers 3) Shell 4) Empty fruit bunches 5) Ash from boiler 6) Wastewater	: : : : :

3. Energy use

Energy Use	Energy use/month		
	Production process	Wastewater treatment	Total
1) Electricity (Unit) 2) Diesel (Unit) 2) Fibre or shell (Unit)	: :	: :	: :

4. Water use

Production process	Water used (m^3/month)
1) Boiler 2) Cooling water 3) Sterilization 4) Oil Extraction • Digester • Screw Press • Separator • Vibrating screen • Sand cyclone 5) Cleaning machine 6) Clay bath 7) Domestic	
Total	

Schematic diagram: Palm oil mill process ....

Working Hour .... per day, ... shifts / day
Average production capacity .... (unit: .... per month)
Maximum production capacity .... (unit: .... per month)

<u>Part 4</u> Waste management

1. Wastewater treatment schematic diagram

2. Wastewater characteristics

Parameter	Influent	Effluent
1) pH 2) SS (mg/l) 3) BOD (mg/l) 4) COD (mg/l) 5) Oil (mg/l)		

3. Effluence management

O Agriculture O Channel, river O Other ....

4. Solid waste management

Waste	In plant reuse/recycle	External reuse/recycle			Disposal
		Sell to	Price	Other	
1) Fiber 2) Shell 3) Empty fruit bunches 4) Sludge cake 5) Ash from Boiler					

5. Air pollution c ontrol

O Air pollution control equipment ....

O No

6. What is the environmental problem of the factory?
O Wastewater O Solid waste O Noise
O Air pollution O Smell from .... O Dust from ....

7. What have been the biggest obstacles to improve the environmental performance?
O Technology
O Financial
O Knowledge
O Other ....

8. Do you think that Thai industrial emission/ effluent standard are appropriate?
O Yes.
O No. Reason ....

Part 5 Clean technology

I. General

1. What is the concept of the word clean technology?

....
....
....

2. Has the company adopted the Cleaner Production?

O Yes from when .... O No

3. Why does the company apply cleaner production?
O Reduce oil loss O Increase production efficiency
O Enhance product quality O Reduce cost of production
O Increase competitiveness O Comply with the effluent standard

4. What is the incentive for company to apply the clean technologies?
....
....

5. What have been the changes adopted in last 10 years?

O Clean technology
O Good housekeeping ....
....
O In-plant reuse/recycle ....
....
O Process modification ....
....

O **Waste exchange**

□ Reuse/recycle of waste --

□ Wastewater water treatment plant---

----

6. Who have introduced clean technology to the factory?

O Government agency O International donor agency
O NGOs O University
O Other mills O Supplier

7. What are the major barriers of clean technology application within the mill?

O Lack of the personal resource O Lack of know-how
O Lack of information O Lack of incentive from government institute
O Lack of competitiveness O Lack of money
O Other ------------------------------------

8. What the government agencies should do for better industrial environmental management?

Π. Clean technology application

1. What kind of improvements has been done?

1.1 Wastewater

- Control system of sterilizer
  O Automatic O Manual

- Management of wastewater from sterilization
  O Go to Wastewater Treatment plant
  O Separate and recycle to --
  O Other ------------

- Oil-water separation equipment
  O Separator O Decanter O Decanter & Separator
  O Settling tank O buffer tank
  O Other --------------------------------

- Management of steam condensate
  O Drain to sewer
  O Separate and recycle to --

- Oil separation from wastewater before pumped to wastewater treatment
  O Oil trap tank O Oil skimmer O Other ------------------

1.2 Solid waste management

- EFB disposal
  O Mushroom O Fertilizer O Landfill O Burning

- Fibre disposal
  O Fuel in factory O Sell to other factories O Other

- Shell disposal
  O Fuel in factory O Sell to other factories O Other

- Floating scum
  O Soap O Fuel O Other

2. After cleaner production application, any change?

O Increase production yield O Enhance product quality
O Reduce water consumption O Reduce wastewater flow
O Reduce oil loss in wastewater O Reduce energy consumption
O Reduce operation cost O Other

3. What is done in order to introduce continuously improvement and how is this done?

----

4. What will be done, in the future, related to improving the technology management in the company?

III. Knowledge

1. What is your source of knowledge in relation to improvement of the environmental performance?

O Consultancy O Supplier O University/Research institute
O Government agency O NGOs O International donor agency
O Other ---------------------------

2. What kind of knowledge do the company need in order to improve more?

O Technical assistance
  O Consultancy O Training O Demonstration
  O Manual O Pilot plant O Other -------------------

O Financial assistance
  O Low interest loan O Grant O Other -------------------

IV. Regulation

1. Which environmental laws must the company comply with?

----

2. Who enforces the law and how is this done?
   O Control of emission
   O Self–control
   O Visual inspections
   O Reaction when problem occur
   O Other ----------------------------

3. What is the conception of the regulation authority?
   O Enemy
   O Partner
   O Co–operation
   O Control and enforcement

4. Do the company think that the regulations need to be improved?
   O Yes ---
   O No

V. Market

1. Who is the competitive of palm oil?

----

2. What are the competitive advantages of the company today/in the future?

----

3. Does the company see opportunities in the market in the field of green products?

----

4. How big is the capacity to investigate the opportunities in new markets and create new market potentials?

----

5. What need to be done to improve this?

Appendix C-2
Questionnaire for 5 selected factories
(Clean technology approach)

1. What is the conception of the world clean technology?

----

2. What are the environmental problems of the factory?

----

3. Project concern in environmental improvement of the factory (Actors involving, how, when and the outcome)

    1) --

    ----

    2) --

    ----

    3) --

    ----

    4) --

    ----

    5) --

    ----

    6) --

    ----

    7) --

    ----

4. What have been done in process to improve environmental performance or reduce environmental impact in company?

    1) --

    ----

    2) --

    ----

    3) --

    ----

    4) --

    ----

    5) --

    ----

5. Details of clean technology introduction within a mill.

Project	Motivation	Incentive	Information	From whom	Barrier	Problem

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6. What relationship do you have with the following actors?

Actor	Relationship	Contact Frequency	Report	Report frequency	Type of resource	Type of exchange
Policy Actors • TOA/ POA • DIW/ PIA • PCD • PPHA • Municipality/ District • Others **Economic Actors** • Other mill • Other downstream factory • Suppliers • Customer/ consumer • Bank • International donor agency • Oil palm planters • Recycler • University/research institute • Crude palm oil association • Other **Societal Actor** • Community • NGO • Mass media • Employee • Other						

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7. Do you have to deal with any pressure from environmental agencies, the surrounding community, or other actors on environmental issues?

-

8. What is the improvement of the business in the future?

- Hardware --

- Software ---

Summary

The crude palm oil industry plays an important role in the economic development of Thailand and in enhancing the economic welfare of the population. Despite obvious benefits of this industrial development, it also significantly contributes to environmental degradation, both at the input and the output sides of its activities. The sector generates solid waste and wastewater, which may have a significant impact on the environment if they are not managed properly. Fortunately, there is much room for improving the environmental performance of Thai crude palm oil industry. Environmental friendly approaches, such as clean technology and industrial ecology, can remedy and minimize environmental problems caused by oil palm production. In spite of these obvious potentials, many mills are faced with various constraints in implementing clean technology options and waste exchange. To improve the environmental performance of Thai crude palm oil industry, we have to assess the theoretical and practical potentials of these clean technology and industrial ecology approaches. Three main research questions are dealt with in this study. First, how to apply clean technology and industrial ecology concepts at the factory level to ensure a more sustainable industrial development in the Thai crude palm oil industry? Secondly, which actors, factors and barriers are crucial or potentially crucial for introducing clean technology and waste exchange in crude palm oil mill in practice? Finally, what lessons can be learnt from Malaysia in improving the environmental reform of Thai crude palm oil industry?

In order to answer these research questions a case study research offers the most relevant methodology. Detailed case studies are carried out on two different variables of palm oil enterprises in Thailand. The differences in production processes and locations are taken as core selection criteria. Factories are classified into 3 groups depending on their production technologies: improved processes, such as the use of modified decanter (decanter and separator in series) in oil recovery process; standard processes where a decanter is only used in oil recovery process; and standard processes where a separator is only used in oil recovery process. Further case selection takes the location factor into account.

Based on five extensive case studies, conclusions can be drawn for improving the existing environmental performance of Thai crude palm oil production. Firstly, cleaner production and industrial ecosystem approaches for crude palm oil industry - based on reuse, recycling, and utilization of solids and liquid waste and appropriate energy management - can achieve the goal of almost zero discharge of pollutants (against acceptable costs). Such an approach can transform palm oil mills in an environmental friendly industry. Clean technology and waste exchange prove valuable elements for developing zero waste industrial ecosystem models for crude palm oil mills that situated both close to communities and in a plantation area. To move Thai crude palm oil industry towards larger sustainability, the following options can be introduced:

- Shell has a high potential to produce activated carbon for water purification; fibers can be used for briquette production.
- Empty fruit bunch can effectively be reused as mushroom cultivation media. After harvesting it still contains high fertility value and can be use as fertilizer in oil palm plantation area. Another value added products from such waste can be

reached via recycling to raw material for production of pulp& paper and MDF, or via composting.

- Decanter sludge can be used as animal feed.
- Biogas recovered from palm oil mill effluent can be reused as fuel in boiler or gas turbines to generate electricity, which can be used in the factory or sold to the grid.
- Palm oil mill effluent is reusable as organic fertilizer in oil palm plantations or as enriched fertilizers for other crops.
- Treated wastewater and bottom sediment from anaerobic ponds can be reused for irrigation and as soil conditioner in plantation areas.

Secondly, the network analysis has provided clear understanding of the various barriers to implement the proposed model of an almost zero waste industrial ecosystem of crude palm oil industry in Thailand. The network analysis identified the principal actors who stimulate firms to improve their environmental performance, which are mainly located in the policy and societal networks, while actors in the economic network play minor role in environmental reform. The main crucial actors in clean technology implementation of crude palm oil industry in Thailand are the Department of Industrial Works, the Provincial Industrial Agencies, communities, international donor agencies, universities and other crude palm oil mills. Communities surrounding the factory strongly influence policy makers and implementers. Provincial Industrial Agencies are crucial in monitoring and enforcing regulation, especially following complaints of communities. The government has supported domestic CPO producers with cleaner production via collaboration with GTZ (German Donor Agency), DIW and universities. The results show that most mills are now aware of clean technology, and some companies have introduced appropriate waste management systems and moved beyond mere control technology towards clean technology. Thai CPO mills are also developing and introducing a number of industrial eco-system practices for waste recycling, although they are not often converted into high value products.

As a kind of conclusion from the network analyses the barriers are summarized for cleaner production implementation and for approaching a zero waste industrial ecosystem of crude palm oil industry in Thailand. Four types of barriers are distinguished: informational barriers, cooperation barriers, price barriers and human capacity barriers. Following these barriers strategies are developed to cope with them.

To make crude palm oil industry in Thailand more sustainable, the national policy frameworks and strategies for achieving clean technology and waste exchange should be reformed. A new governmental unit (Palm Oil Research Institute of Thailand) should be formed by representatives from the industries and government agencies, supporting research and development capacity throughout the palm oil complex (from supplying seed with high oil content all the way down the vertical chain of palm oil industry). This government unit should encourage industry-government cooperation and also provide firms with suggestions for technical and management solutions on waste treatment, reuse/recycling of waste and waste exchange. Moreover The Oil Palm and Palm Oil Association of Thailand should be strengthened and supported by government to be the center of information on clean technology and waste exchange and also the center of training and education on technology development for mills and oil palm planters. Finally, government should formulate a long term National policy on palm oil development and strengthen the Policy on Pollution control.

The Thai palm oil industry should focus on new product development and the government should encourage millers and planters to invest in downstream activities: refining, oleochemical production and other value-added products. Meanwhile, the legislative developments to facilitate cleaner production practices include emission charges and strengthened regulatory mechanisms. The mechanisms available will provide an incentive to encourage the adoption of cleaner production practice through information and education campaigns.

Samenvatting

De palmolie industrie speelt een belangrijke rol in de economische ontwikkeling van Thailand. Ondanks de duidelijke voordelen van deze industriële ontwikkeling levert deze sector ook een significante bijdrage aan de vervuiling van het leefmilieu, zowel aan de input- als aan de outputzijde van deze industrietak. De sector genereert vast afval en afvalwater, welke grote invloed op het milieu kunnen hebben indien de verwerking hiervan niet adequaat plaatsvindt. Daarnaast kan het gebruik van water, energie en natuurlijke grondstoffen gepaard gaan met inefficiënties en milieudegradaties. Gelukkig is er voldoende ruimte voor verbetering in de Thaise palmolie industrie. Een milieuvriendelijke aanpak, via de concepten van schone technologie en industriële ecologie, kunnen de problemen van afval en hulpbronnengebruik reduceren of verhelpen. Ondanks deze mogelijkheden worden veel bedrijven geconfronteerd met verschillende belemmeringen voor de toepassing van schone technologie en afvaluitwisseling. Om de milieuvriendelijkheid van de Thaise palmolie industrie te verbeteren moeten de theoretische en praktische mogelijkheden van schone technologie en industriële ecologie worden onderzocht. Drie hoofdvragen worden in dit proefschrift behandeld. Ten eerste: hoe dienen schone technologie en industriële ecologische concepten te worden toegepast op bedrijfsniveau, voor een meer duurzame ontwikkeling van de Thaise palmolie industrie? Ten tweede: welke actoren, factoren en belemmeringen zijn van belang bij de introductie van schone technologie en afvaluitwisseling in palmoliebedrijven? Ten slotte: welke lessen kunnen worden geleerd van Maleisië met betrekking tot de verbetering van de milieuhervormingen in de Thaise palmolie industrie?

De meest relevante methode om deze vragen te kunnen beantwoorden is casestudie onderzoek. Gedetailleerde casestudies zijn uitgevoerd op verschillende palmoliebedrijven in Thailand, geselecteerd op twee variabelen. De verschillen in productietechnologie en bedrijfslocatie vormden de belangrijkste selectie criteria. Palmolie bedrijven kunnen worden onderverdeeld in 3 categorieën afhankelijk van de toegepast procestechnologie: bedrijven met verbeterde technologie, zoals het gebruik van een aangepaste decanteer olie afscheider (decanteerapparaat en olie fasescheider in serie); bedrijven met standaard technologie, waarbij alleen een decanteerapparaat wordt gebruikt; en bedrijven met standaard technologie, waarbij een olie fasescheider wordt gebruikt bij de oliewinning. Het criterium bedrijfslocatie betreft de locatie van het bedrijf, waarbij de nabijheid van locale woongemeenschappen of vestiging in een oliepalmplantage relevant waren.

Op basis van vijf uitgebreide casestudies kunnen ten aanzien van de verbetering van het huidige milieuperformance in de Thaise palmolie industrie de volgende conclusies worden getrokken.
Een schone technologie en industriële ecologische aanpak, gebaseerd op hergebruik, recycling en utilisatie van vastafval en afvalwater, benevens adequaat energie beheer, biedt de mogelijkheid een nagenoeg afvalloze bedrijfsvoering te behalen tegen acceptabele kosten. Een dergelijke benadering kan de palmolie industrie in een milieuvriendelijk bedrijfstak veranderen. Schone technologie en afvaluitwisseling zijn belangrijke elementen voor de ontwikkeling van een model voor afvalloze bedrijfsvoering, zowel voor bedrijven in de nabijheid van dorpen en steden als bedrijven gevestigd in plantages. Om in de Thaise

palmolie industrie een grotere duurzaamheid te bewerkstelligen kunnen de volgende opties worden geïntroduceerd:

- Palmnotendoppen bieden een goede mogelijkheid voor de productie van actief kool voor waterzuivering; vezels kunnen worden gebruikt voor briketproductie.
- Lege palmnoottrossen kunnen effectief worden hergebruikt als voedingsbodem voor champignon cultivatie. Na de champignonoogst kan de voedingsbodem als bemesting in de oliepalmplantages worden hergebruikt. Andere producten met toegevoegde waarde kunnen worden verkregen van gerecycleerd ruw materiaal in de pulp en papier fabricage, via de productie van MDF of door compostering.
- Slib uit de decanteerapparatuur kan als veevoer worden gebruikt.
- Biogas, gewonnen uit afvalwater van de palmolieproductie, kan worden gebruikt als brandstof in boilers of gasturbines voor elektriciteitsproductie. De elektriciteit kan in het bedrijf worden gebruikt of worden verkocht aan het elektriciteitsnet.
- Palmolieproductie afvalwater is bruikbaar als organische bemesting in oliepalmplantages of voor andere gewassen.
- Gezuiverd palmolieproductie afvalwater is bruikbaar als irrigatiewater en het sediment uit anaërobe vijvers kan worden gebruikt als bodemverbeteraar.

Om de praktische haalbaarheid van deze opties te analyseren is een netwerkanalyse uitgevoerd. De netwerkanalyse gaf duidelijk inzicht in de belemmeringen voor de toepassing van het voorgestelde model van afvalloze bedrijfsvoering, inclusief de verschillende opties, in de Thaise palmolie industrie. De netwerkanalyse identificeerde welke actoren en instituties bedrijven stimuleren milieuvriendelijker te werken. Deze zijn voornamelijk te vinden in het beleidsnetwerk en sociale/civil society netwerk. Actoren in het economische netwerk spelen een ondergeschikte rol in milieuhervormingen en de doorvoering van de verschillende verbeteropties. De hoofdrolspelers in de toepassing van schone technologie zijn het Ministerie van Industrie, de Provinciale Industriële Organisaties, lokale gemeenschappen, internationale donor organisaties, universiteiten en andere palmoliebedrijven. Lokale gemeenschappen in de nabijheid van palmolieproducenten hebben een grote invloed op beleidsmakers en –uitvoerders door hun reacties en klachten over milieu-incidenten. Provinciale Industriële Organisaties zijn cruciaal in de toepassing en controle van beleid, vooral wanneer er sprake is van klachten vanuit de bevolking. De nationale palmolieproducenten worden door de regering ondersteund in samenwerking met GTZ (een Duitse donor organisatie), het Departement of Industriële Werken van het Ministerie van Industrie en universiteiten. De resultaten laten zien dat schone technologie bij de meeste bedrijven bekend is. Sommige bedrijven zijn verder gegaan dan corrigerende technologie en hebben afvalmanagement systemen geïntroduceerd. Tevens ontwikkelen en introduceren Thaise palmolieproducenten verschillende industriële ecosysteem toepassingen voor afvalrecycling, echter zelden resulterend in producten met een hoge toegevoegde waarde.

Samengevat komen uit de netwerkanalyse vier typen van barrières voor de invoering van schonere productie methoden en de benadering van een afvalloos industrieel ecosysteem: informatiebarrières, samenwerkingsbarrières, prijsbarrières en personeelscapaciteit barrières. Voor elke barrière kunnen strategieën worden ontwikkeld om deze barrières te slechten. Deze strategieën zijn deels gebaseerd op ervaringen uit Maleisië.

Om de duurzaamheid van de Thaise palmolie industrie te vergroten dienen de nationale beleidsraamwerken en -strategieën voor schonere productie en afvaluitwisseling hervormd te worden. Een nieuwe overheidsinstelling (het Palm Olie Research Instituut van Thailand) zou moeten worden opgericht, met vertegenwoordigers uit de industrie en staatsorganisaties als deelnemers, ter ondersteuning van onderzoeks- en ontwikkelingscapaciteit in het industrieel palmoliecomplex, beginnend bij het oliepalmzaaigoed tot en met de eindproducten. Deze nieuwe instelling dient samenwerking tussen industrie en overheid aan te moedigen en tevens bedrijven te voorzien van suggesties betreffende technische en management oplossingen voor afvalbehandeling, hergebruik, recycling en uitwisseling van afval. Bovendien zou de Oliepalm en Palmolie Associatie van staatswege ondersteund moeten worden, teneinde het centrum te worden voor informatie en informatie-uitwisseling over schone technologie en afvalhergebruik en voor training, educatie en technologieontwikkeling voor bedrijven en oliepalmproducenten. Tenslotte zou de staat een lange termijn planning moeten formuleren voor de ontwikkeling van de palmoliesector en daarmee het milieubeleid betreffende palmolie productie versterken. Die planning zou gericht moeten zijn op de ontwikkeling door de palmolie producenten van nieuwe producten. De overheid zou bedrijven en planters vooral moeten aanmoedigen te investeren in '*downstream*' activiteiten: raffinage, oleochemische productie en andere hoogwaardige producten. Tegelijkertijd dienen wetgevende ontwikkelingen ter ondersteuning van schonere productie te worden gemoderniseerd, bijvoorbeeld via een grotere nadruk op emissieheffingen.

About the author

Orathai Chavalparit was born on 3 January 1960 in Bangkok, Thailand. Since 1986, after received her M.Sc. Degree in Environmental Biology from Mahidol University, she worked in Office of Natinal Environmental Board. From 1987 till 1988 she worked as a lecturer at the Faculty of Science of Rangsit University. In 1990 she came to work with Faculty of Engineering, Chulalongkorn University. She was promoted to Associated Professor from 1997 up till now. She came to Wageningen University at 2001 to start her PhD study.