CHAPTER 6

CRUDE PALM OIL INDUSTRY IN THAILAND : EXISTING TECHNOLOGY AND 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 are selected for a more a detailed analyses on 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 following:

- Factories using improved processes: characterized by the use of a decanter and separator in oil recovery process. These will represent currently the best practice in clean technology in Thailand.
- Factories using standard processes: characterized by the use of a decanter in oil recovery process. This will present good improvement in clean technology.
- Factory using standard process, a separator is used in the oil recovery process. This will represent the only a small improvement technology 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 a introduction of 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 described the environmental performance of crude palm oil production processes in Thailand in more detail, material inputs, products, byproducts and wastes of individual companies and its 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 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 to Studied Factories

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

- Factory A and B recover extra oil from wastewater by using a decanter and separator. Mill A is situated closed to community, while Mill B is located far from community. However they have implemented many clean technology options as already 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 oil palm plantation area and far from community. They have good housekeeping and good maintenance practice. The environmental management tries to prevent environmental problems by reduction 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 poor environmental policy. There is not very much concern on source reduction techniques or investment in high technology machine such as a decanter. The factory is situated far from community (not in an 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 five selected factories.

	Factory A	Factory B	Factory C	Factory D	Factory E
Location	Close to communit	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 ad.option	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	-
Oil recovery from wastewater	Decanter & separator	Decanter & separato	Decanter	Decanter	Separator
ISO certification	ISO 9000 certification	ISO 9000 certificatio	ISO 9000 certificatio	-	-
Wastewater treatment plant	Anaerobic pond & oxidation pond	Anaerobic pond & oxidation pond	Anaerobic digestion tank & anaerobic pon	Anaerobic pond & aeration pond	Anaerobic pon & oxidation pond

Note: 1 hectare = 6.26 rai

6.3 Environmental Performance of 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 (sterilizing) 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. This oil water-mixture then 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 also the different sub-process of crude palm oil production of five case study factories.

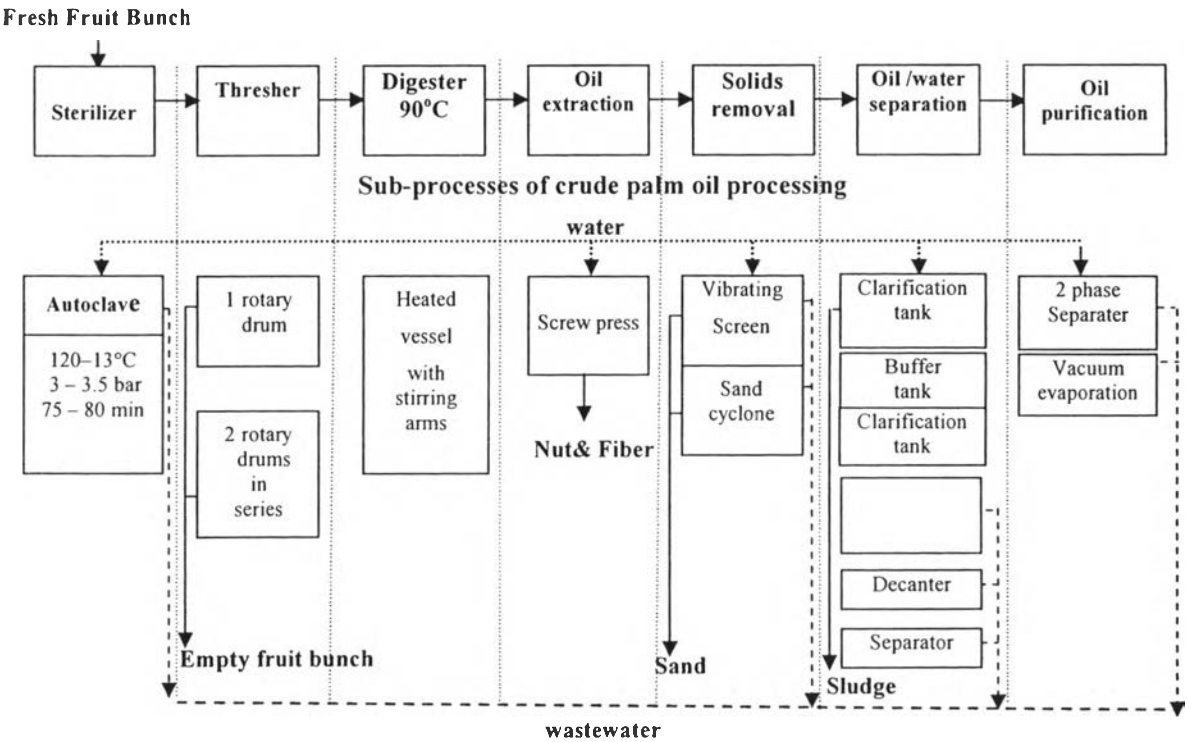


Figure 6.1 Schematic diagram of alternative or sub process of 5 selected factories
······· Water consumption
- - - Wastewater generation
—— Solid waste generation

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

Table 6.2 Oil loss in 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 machine	Oil trap tank	Wastewater recycle in production process	Sterilizer	Decanter	Separator	Combined wastewater	Oil trap Tank (1)	Oil trap pond (2)
A	Decanter-Separator	-	Sterizer 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 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 oil 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 in 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 operation days/ year and 24 hour/ day). Therefore the factories currently operate at an average 75% of their full design capacity because FFB production in Thailand is less than the demand of millers. 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.

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 CPKO), the rest is by-product and waste. Even most of these by-products can be reused in the production process or by other industries such as: fibers (10% as dry weight) reuse as fuel in boiler. Shell (5% as dry weight) and empty fruit bunch (24% as dry weiht) sell to use in other industry. However, there is a lot of waste that has to be treated properly before disposal or discharge. These wastes include ash, 5%, decanter sludge, 3.2%, and wastewater.

Table 6.3 The average oil yield and waste generation from five selected factories in Thailand (2002).

	Wet weight (ton/ha/year)	Dry weight (ton/ha/year)
FFB	16.5	10.6
Oil yield	2.75	2.75
Oil content in oil palm fruit, %	17*	-
Oil extraction, %	16.8	-
Mpty fruit bunch	3.96	2.6
Fiber	2.31	1.6
Shell	1.0	0.9
Wastewater	10.56	0.64

Note * Data from Ministry of Agriculture and cooperative, 2002

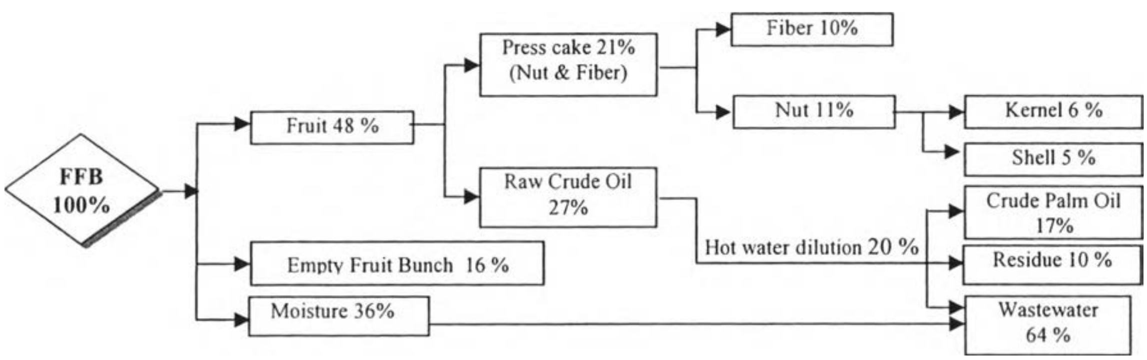


Figure 6.2 Composition of fresh fruit bunch (%)-dry weight average of five in Thailand

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 kWh/ ton FFB (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 84 % (72-95%) of the total electricity consumption. The small power plant in the mill incorporates also a water tube boiler with a steam capacity of up to 20-30 ton of steam/ 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 diesel generator to start up boiler.

Water consumption

A crude palm oil mill uses much water in the production process. Canal water is the source of water supply. The average water consumption is equal to 1.26 m^3/ton FFB. A detailed overview of water usage in the five selected factories is shown in Table 6.4. The quantity of water consumption per ton FFB is not very different among the five crude palm oil factories due to the fact that most of water is used for feed boiler water and turbine cooling water. Cooling water for turbine is recycled in the production process, cleaning machine and domestic purposes. It has been estimated that in the year 2003 the crude palm oil industry in Thailand consumed about 5 million m^3 of water .

Table 6.4 Water usage 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 need only very small amounts of chemical as a processing aid. Therefore, all substances found in the products, by–products and residues are originated from the fresh fruit bunch. However, there are a number of pollution problems at the factories, such as high water consumption, generation of a high organic content of the wastewater, 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.

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

Process	Air emission	Wastewater (WW)	Solid waste
Loading ramp	-	Oil contaminated WW	-
Sterilization	Steam blowdown	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

Wastewater generation

In wet process operation, high quantities of water are utilized during the process of extraction of crude palm oil. Results from survey show that the amount of water consumption in the production process for such an industry is in the range of 1.0-1.3 m^3 / ton FFB. About 53-79 % of the water used results in palm oil mill effluents (POME). The other part is lost as steam, mainly through exhaust gases from the sterilizer. The total pollution loads of BOD, SS, Oil, TKN and TP in the process wastewater for five selected factories discussed previously are shown in Table 6.6.

It can be estimate the total pollution load of wastewater from palm oil mills in Thailand in 2003 is equal to 2.6 million ton/ year. Comparing this with that of domestic sewage in terms of BOD this is equivalent to the amount of waste water annually generated by 5 millions 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.

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	1.26	0.54	25.1	15.1	6.6	0.5	-
E	1.3	1.03	43.1	30.3	6.5	0.2	-

The average BOD load and SS load in wastewater are equal to 30.8 and 22.5 kg/ ton FFB, respectively. BOD load varies with SS contamination in wastewater. Factory A, B, C and D employ decanter in order to separate oil and SS from wastewater. These machine reduce organic load in the wastewater, so wastewater from these factories contain lower organic load compared to Factory E that does not employs such decanter. Oil loss in wastewater varies from 2.5-6.5 kg/ton FFB. Factory A achieves lowest oil loss in wastewater. TKN and P loading varies between factory.

There are two main sources of wastewater generated from crude palm oil processing. Table 6.7 shows the characteristics of wastewater composition from various sources of factory A. And Table 6.8 shows the total pollutant load from different sources. It is clear that the main source of pollutants is generated from the decanter & separator step.

Table 6.7 Characteristics of wastewater from various process steps of factory A (year 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
Influent*	4.83	56,050	79,360	30,933	57,650	7,250	10,000

Note:* wastewater from production process combined with wastewater from factory cleaning.

Table 6.8 Total pollution from various process steps of factory A (year 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	0.73
Decanter & separator	0.49	33.2	49.35	28.17	36.67	2.04
Influent	0.59	33.2	46.79	18.24	33.99	4.28

Note:* wastewater from production process combined with wastewater from factory cleaning

Wastewater from sterilizer contains a high oil concentration (6.2.g/L or 0.73 kg/ton FFB). Such wastewater can be recycling in the production process in order to recover oil. Factory A and B recycle wastewater from sterilizer.

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

Air pollution. Air pollution (particulates and smoke also some CO_2) is generated from 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 (range of 590-890 mg/ m^3).

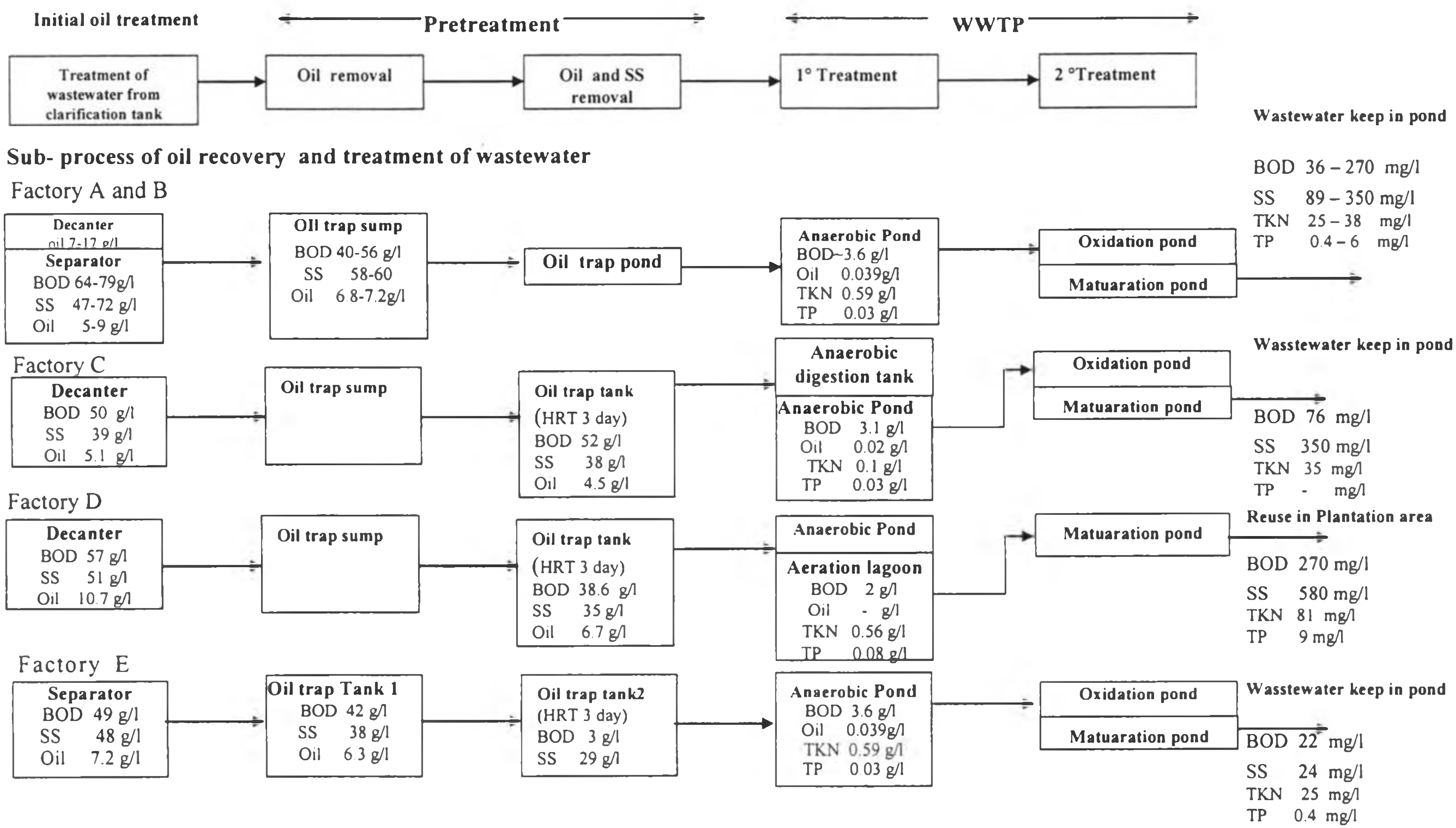
Green house gases. The anaerobic ponds produce methane and carbon dioxide. These are released as gases into the air. Carbon dioxide and certainly methane are so called green house gases (GHGs) which effect in global warming potential. Results from sampling and analyzing quantity of GHGs produced from 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 produce 20 m^3 biogas.
- Biogas contains 70% CH_4 and 29% CO_2.

Total wastewater generation from CPO industry in Thailand is 2,560,000 m3/ year, so methane and carbon dioxide release to atmosphere is about 36 and 15 million m3/ 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 boiler. The quantities of these materials are summarized in Table 6.9. In 2003 palm oil production generated



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

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

amounts of process residues were produced fiber: (0.6 million ton), shell (0.2 million ton), and empty fruit bunches EFB (0.9 million ton). This residues such as EFB and shells are already reused/ recycled as solid fuel. The other alternative potential options as a more value product will be discussed in the next section. For wastes which have to be disposed such as decanter sludge and ash, possible more environmentally sustainable solutions, based on recent research, will be proposed.

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 palm oil waste generation (per ton FFB production) from crude palm oil industry in Thailand. In 2003, Thai crude palm oil industry produced 0.7 million tons palm oil. Crude palm oil production generates large amounts of process residues such as fibers (0.6 million ton per year), shell (0.2 million ton per year), and empty fruit bunches, EFB, (0.9 million ton per year). Residues such as EFB and shells are already reused/ recycled as solid fuel. However, there are also other potential options to use these residues as a more valuable product. These options will be reviewed in the next section. For wastes which are currently disposed such as decanter sludge and ash, other more sustainable solutions for these wastes will also be discussed based on recent research in Thailand.

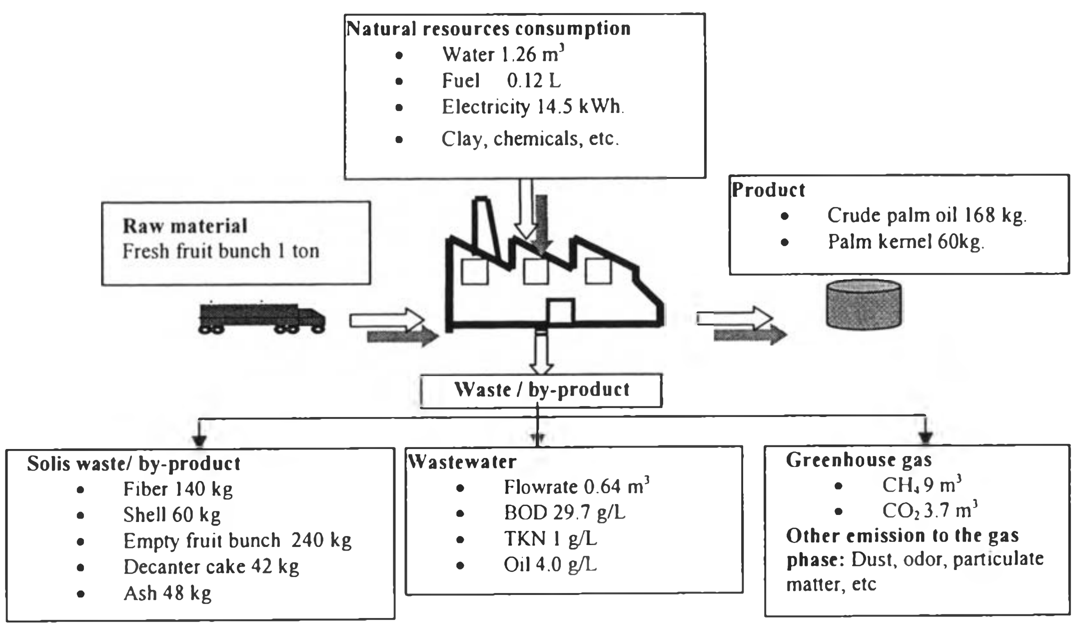


Figure 6.4 Average amount of waste generation rate (per ton FFB) from 5 studied crude palm oil mills.

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 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
Steam consumption, ton/ ton FFB	0.60	0.4	0.76	0.47	0.54	0.51	0.75
Water consumption, ton/ ton FFB	1.2	-	1.2	1.0	1.1	1.3	1.3
Electricity consumption, kWh/ ton FFB	23.4	-	15.2	10.5	19.9	16.6	5.5
Wastewater generation,m^3 / ton FFB	0.64	0.67	0.59	0.50	0.58	0.55	1.03
Oil loss in WW, kg / ton FFB	3.38	-	4.0	3.5	2.6	6.7	6.1
BOD loading in WW, ton/ ton FFB	29.8	-	30.7	25.0	29.1	21.3	43.1
SS loading in WW, ton/ ton FFB	22.0	-	18.2	24.6	21.6	15.3	30.3

Note: Average from the 5 selected factories.

* 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 in the company have influence on 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 type of machines employ 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 technology is divided into 3 categories such as; modified decanter (decanter and separator in series); decanter; separator. In Table 6.11 the production efficiency and waste generation from arious techniques are given.

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. Since decanter is used to separate suspended solids from wastewater, so it can clearly reduce the pollution load from wastewater.

Table 6.11 Comparison of environmental performance of CPO industry.

Indicator	Oil recovery technique		
	Decanter & separator	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

Management aspecs. From the result of a factory survey combined with data from managment interviewing on environmental performance of the five selected factories it can be summarized that:

- Factory A and B have the best environmental management performance compared to factory C,D and E because they want to reduce environmental impact to the community by reduction of waste, reduce cost and they also believe that it is right thing to do. The existing environmental performance of these factories regarding resources consumption and pollution load is better than other factory. They cooperate with several university to conduct the research about waste reduction and production efficiency improvement. The companies have environmental policy and forces the management their to achieve the policy targets. Source reduction is the primary waste reduction technique.

- Factory C and D have good environmental performance. Management tries to prevent environmental problem by reduction of waste both by source reduction and end of pipe treatment. The planning time frame is a long term. They engage in environmental management system. Laws and environmental regulations are still the most important factors for improving the waste treatment technique.

- Factory D has a poor environmental performance although even his waste is comply the law. This factory does not have a clear environmental policy. Top manager don't concern on source reduction technique or investment in high technology machine such as decanter. Data from natural resource consumption and pollution loading also show that factory C has a poor environmental performance.

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

6.4.2 Community level

Since the environmental impact from the crude palm oil production technology is affected mainly to the surrounded community, so this section will be focus on the effect of community on the environmental performance of crude palm oil industry in Thailand. The location of CPO mill such as; closed to community far from community and in plantation areas see table 6.17 will be discussed. The results could be used to find ways to improve the environmental performance of CPO industry in Thailand. For 5 selected factories, Factory A and C is represented as factory situated closed to community and factory B and E are represented as factory situated far from community. Factory D is represented as factory situated in oil palm plantation area.

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 tem	Short term
Top management involvement	Long term involvement	Long term involvement	Nonexistent
Organization	Company wide	Plant	Unit operation
Manager responsible for environment	Production engineer	Environmental sector	Nonexistent
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	Nonexistent
Research & development	Focus on new opportunity	Compliance-oriented	Nonexistent
Use of resource	Effective	Effective	Ineffective
Communication	Mostly top-down	Mostly top-down	Top-down
Technology	Continuous integration	Continuous integration	Compliance-oriented
Green performance	Audit, Benchmarking	Audit, Benchmarking	Solid waste reduction

1) Oil production efficiency

The percentage oil production is the relative quantity of crude palm oil (ton) production from of fresh fruit brunches, The percentage oil production in the five selected mills various from 15.5 to 17.8 (average 16.4%). The percentage oil production varies by factory, depended on the oil recovery technologies used. Factory A and C are situated closed to community and can achieve 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 process.

Location / Machine	Closed to community	Far from community	In plantation area
Modified decanter	17.8	17.0	-
Decanter	16.5	-	16.4
Separator	-	15.5	-
Average	17.15	16.25	16.4

2) Natural resources use

Water consumption. Table 6.14 shows the typical amount of water used for the 5 selected factories. It is clear from this table that their overall usage is not very different between these three groups due to the fact that the main water consumption in the production process is for boiler water did the which such mills employ the same boiler capacity. However, factory D those located in the plantation area, shows the highest water consumption compared with the other factories.

Table 6.14 Comparison of water consumption of five CPO mills using different technologies and at different location.

Location / Machine	Closed to community	Far from community	In plantation area
Modified decanter	1.2	1.0	-
Decanter	1.1	-	1.3
Separator	-	1.3	-
Average	1.15	1.15	1.3

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. Shown in Table 6.15.

Table 6.15 Comparison of electricity consumption of CPO mills at different technology and location.

Location / Machine	Closed to community	Far from community	In plantation area
Modified decanter	15.2	10.5	-
Decanter	19.9	-	16.6
Separator	-	55	-
Average	17.6	32.7	16.6

3) 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 production process is 4.16 kg / ton FFB. Quantity of oil loss in wastewater is depending mainly on the oil recovery technique from wastewater. Factories that are situated close to community have a lower oil loss in wastewater than those factories that are situated far from community. The details of oil loss in each category are shown in Table 6.16.

Table 6.16 Comparison of oil loss in wastewater from CPO mills.

Location / Machine	Closed to community	Far from community	In plantation area
Modified decanter	2.5	3.5	-
Decanter	3.7	-	4.7
Separator	-	6.7	-
Average	3.3	5.1	4.7

It can be concluded that communities have a positive effect on environmental performance of crude palm oil industry by stimulating the reduction of pollutant loading from the production process of crude palm oil mills. And this also result in an increasing production efficiency of the millers. However such communities do not have effect on raw material consumption of those millers. Table 6.17 shows the environmental performance indicators of 3 different location categories of crude palm oil mills. Factory A and factory C which are located closed to community can reduce oil loss and pollutant load in wastewater to a lower level than factory B, D and E …are located far from community. Factory D, which is located in oil palm plantation area has the highest BOD concentration in final pond because t reuse their wastewater in plantation area.

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

Indicator	Close to community	Far from community	In oil palm plantation area
% Oil production	17.15	16..3	16.4
Water consumption, ton/ ton FFB	1.1.5	1.15	1.3
Electricity consumption, kWh/ton FFB	17.6	32.7	16.6
Wastewater generation,m^3/ton FFB	0.57	0.77	0.55
Oil loss in WW, kg / ton FFB	3.3	4.8	6.7
BOD loading in WW, ton/ ton FFB	29.9	34	21.3
SS loading in WW, ton/ ton FFB	19.9	27.5	15.3
BOD concentration in final pond, mg/ L	56	29	268

6.5 Improving Environmental Performance of 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):

- Cleaner production/ 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.

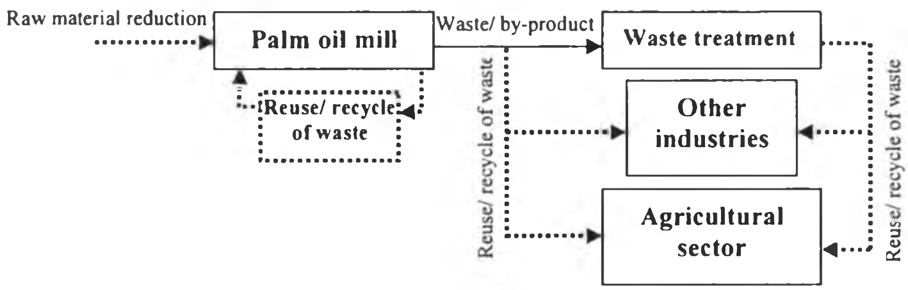


Figure 6.5 In-plant and cross industry waste reuse/ recycle.

An overview of the technical options for improving the environmental performance of crude palm oil mill is briefly summarized in Figure 6.6.

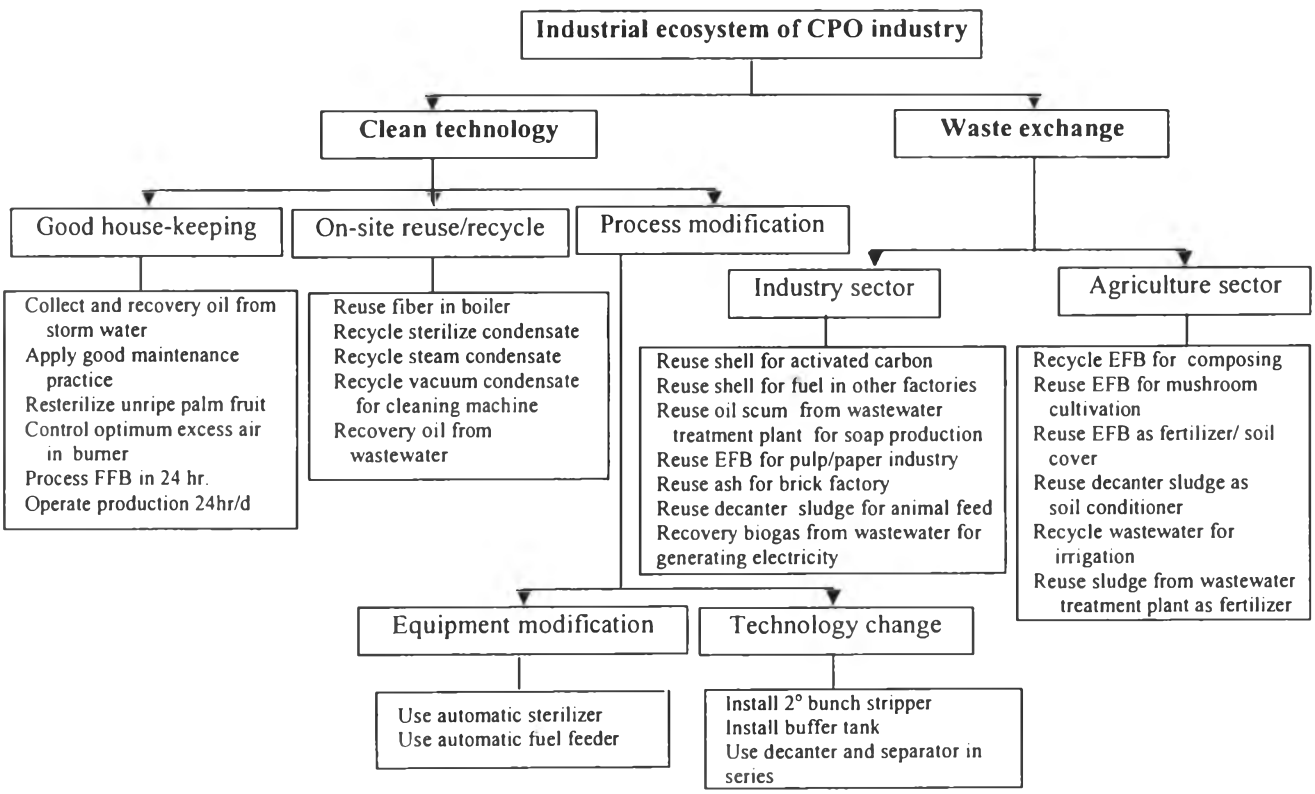


Figure 6.6 Waste management options for improving environmental performance of crude palm oil mill.

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 modified decanter for recovery oil from wastewater because use of a modified decanter can reduce oil loss in wastewater, reduce hot water consumption and remove suspended solids from wastewater.

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, ash that can be reused, a possible solution to reduced an 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 the "good housekeeping" and "good maintenance practice". The second one is on-site reuse/recycle of waste. The third one is process modification. Process modification comprises technical optimization of a production line, or recycling, reuse or recovery of waste/by-product in the production process. A process modification is an installation of equipment in order to reduce loss or enhance production efficiency. In practice, clean technology available in crude palm oil is emerging from good housekeeping and reuse and recycle of waste. Various measures can be taken to address the environmental problem found in crude palm oil industry. Following clean technologies have been adopted to minimize the level of pollution, as well as increase the efficiency of CPO production.

a) Good housekeeping

- Process fresh fruit bunch within 24 hour after harvested in order 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 from rain water and prevent oil contaminated on land and surface water.
- Apply good practice in solid waste handling such as solid waste segregation and application of certain fraction as soil cover material or reuse/ recycle in palm oil plantation area as soon as possible in order to reduce dust and bad smell in the mill area.
- Separate fresh fruit bunch into 2 categories: ripe fruit and unripe fruit in order to control optimal condition for sterilization. Since time for sterilization of ripe fruit is shorter than those for unripe fruit.
- Apply good maintenance practice.
- Control excess air /fuel ratio at 0.4 in burner in order to reduce energy consumption.

b) On-site reuse/recycle

- 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 in order to reduce hot water use and to improve the recovery of oil from wastewater.
- Recycle hot water from vacuum tank for cleaning decanter and separators.
- Recycle steam condensate (temp 100 C) from kernel dryer tank for reuse as

boiler feed water in order to reduce water use and energy used for heating water.

*c) **Process modification***

- Employ automatic sterilizer to control optimal conditions for sterilization.
- Collect remaining unripe palm fruit to resterilize manually in order to reduce oil loss.
- Install 2^0 bunch stripper to enhance fruit separation from bunch stalk in order to reduce oil loss from EFB .
- Install buffer tank to separate sludge from crude oil before flow to settling tank in order to enhance oil separation, and remove sand from sludge.
- Employ decanter for recovery oil from wastewater and construct oil trap sump to remove oil from wastewater before it goes to wastewater treatment plant.
- Reuse excess steam from 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.

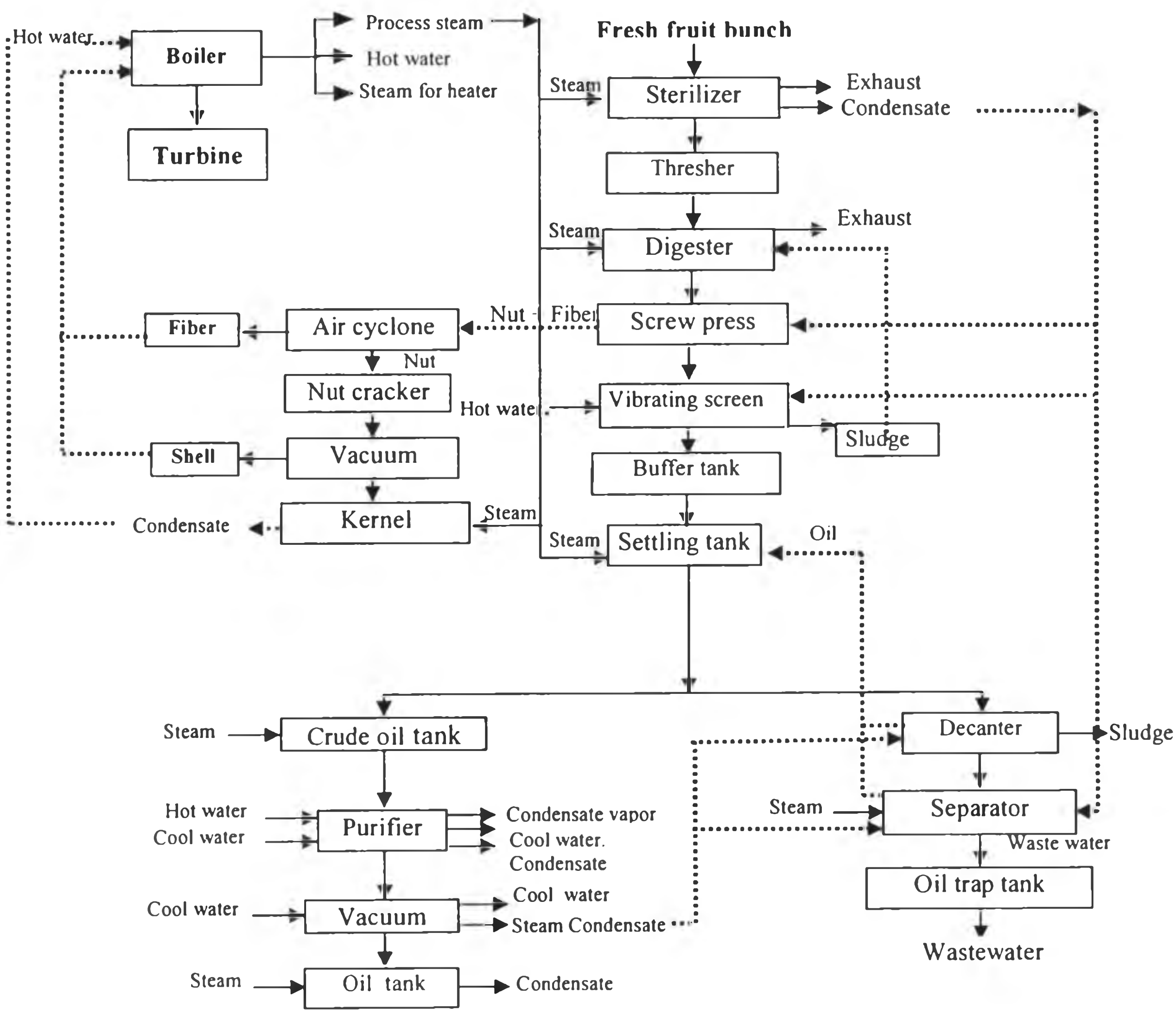


Figure 6.7 On-site reuse/ recycle in crude palm oil factory.

...... In-plant reuse/recycle
—— Production line

6.5.3 Waste exchange

Waste exchange is popular in the crude palm oil industry and is already applied at 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/recycle of by-product/ waste from crude palm oil industry to other type of industries are previous mentioned in section 5.3 and 5.4. These options can be briefly summarized :

- Reuse shell as fuel in cement factory
- Reuse shell as raw material for activated carbon production
- Recycle of empty fruit bunch as fiber for making pulp and paper
- Recycle of empty fruit bunch as medium density fiber broad
- Recycle decanter sludge as animal feed
- Recycle fly ash for substitute of cement for concrete block production
- Recovery biogas for generating electricity and sale 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 for organic compost
- 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

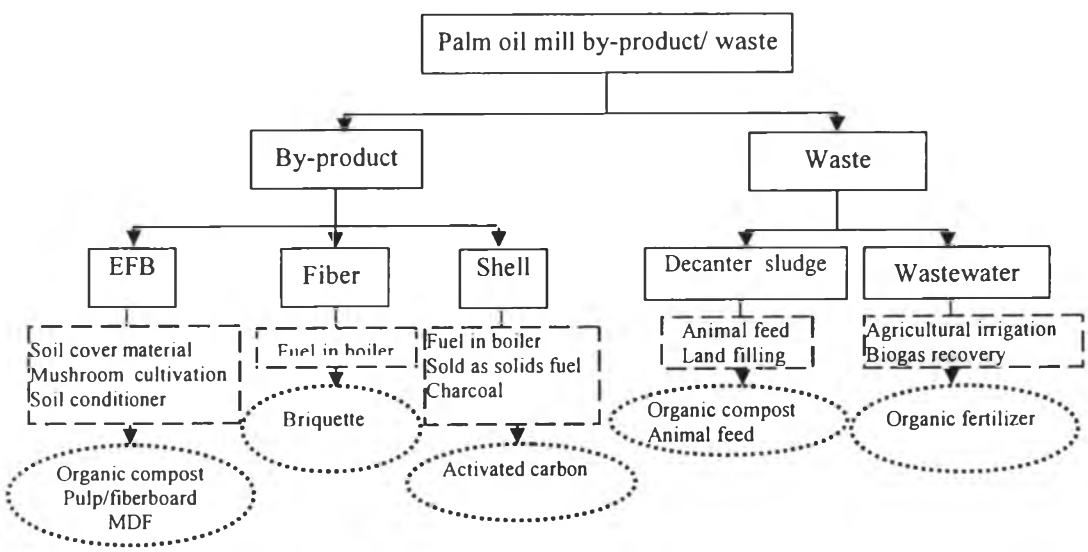


Figure 6.8 By-product/ waste application

Existing options   Purposed options

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/ recycle 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 five selected crude palm oil mills, this section continues to develop an intergraded model of an almost zero waste industrial Ecosystem for crude palm oil industry. First, however we will discuss the existing industrial ecosystem in the crude palm oil industry.

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, where we have to deal 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, harvesting from 18,000 hectares oil palm plantation area and producing 168 ton of crude palm oil and 60 ton palm kernel for selling to an oil refinery industry. The production process results in the generation of about 640 m^3 of wastewater, 240 tons of empty fruit bunch, 140 tons of fiber, 60 tons of shell and 42 tons of sludge from decanter. Even most of these by-products can be sold or reused in production or sell to other industry. However there is a lot of waste that has to be treated properly before disposal. For a crude palm oil mill that is situated closed to community, these wastes include 640 m^3 of wastewater, ash and decanter sludge. Since the transportation costs are high, they cannot reuse these wastes in oil palm plantation area. For decanter sludge and ash, the mill pay for truck transport to disposal these solids waste everyday because these waste cause bad smell and dust which nuisance to people surround the factory. Wastewater is treated and keeps in ponds without discharge because the composition of the wastewater does not satisfy the effluent standard. Differently, for crude palm oil mill located in plantation area, such wastes can be reused as fertilizer in 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 crude palm oil industry. As described in previous chapter crude palm oil mills in Thailand are standing scattered and most of them are located on the main roads closed to community. Only 17% of mills is located in plantation area. The selected technical options integrated to develop an almost zero waste industrial ecosystem model differ from each other for the two different type of oil mill location. The first scenario deals with the almost zero waste industrial ecosystem model for crude palm oil mill that is located closed to the community and in the second scenario is discussed the zero waste industrial ecosystem model for crude palm oil mill that located in oil palm plantation area. For both scenario an almost zero waste industrial ecosystem is discussed.

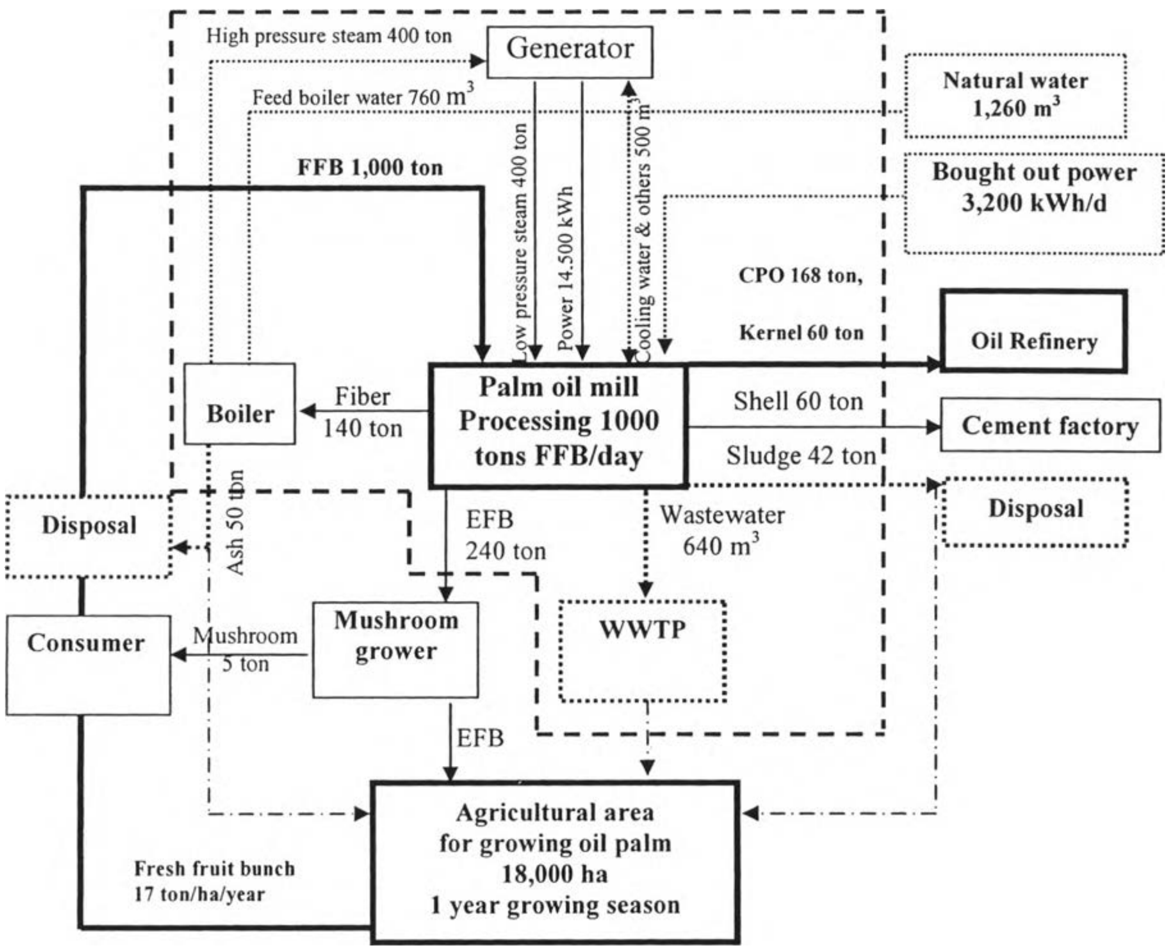


Figure 6.9 The existing industrial ecosystem model of five case study factories both situated closed to community and in plantation area.

.... For mills that are situated in community, wastes have to dispose.
— . — . For mill that is situaed in plantation area, wastes can be reused in plantation area
——— Production line
— — — Boudary of CPO factory
.... Natural resource input
——— Product/ by-product

The proposed physical-technological model of an almost zero waste industrial ecosystem of mill located closed to community

The crude palm oil factory that is located closely to community can not 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 simulated in Figure 6.10. In this model, 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 an this gas as fuel for boiler, construct of activated carbon plant are all designed to reach a model of an almost zero waste industrial ecosystem

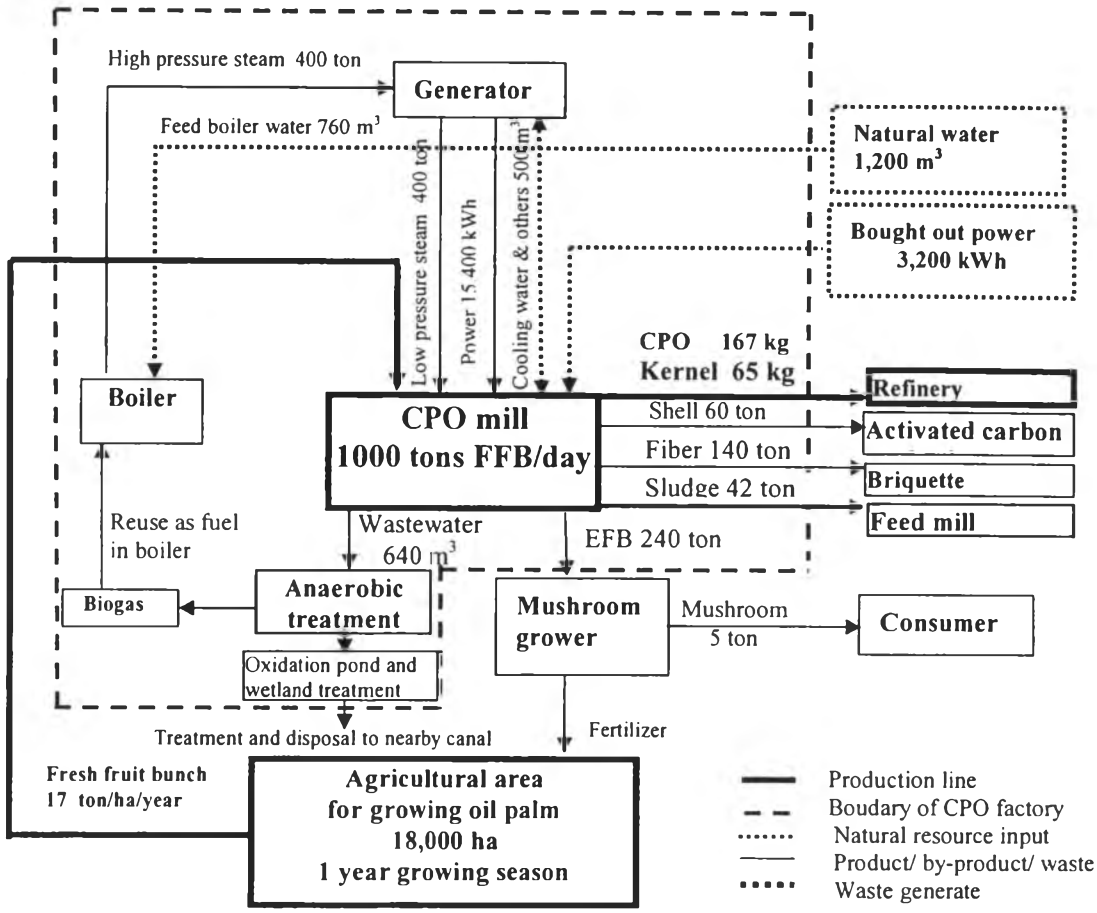


Figure 6.10 Material balance of the proposed physical-technological model of an almost zero waste industrial ecosystem of mill located closed to community.

The proposed physical-technological model of an almost zero waste industrial ecosystem of mill located in plantation area.

Figure 6.11 presents a schematic diagram of an almost zero waste industrial ecosytem of is a crude palm oil mill that located in plantation area. It is clear that EFB, decanter cake and wastewater from the crude palm oil mill contain high K, N, P and Mg content and can be used as fertilizer in oil palm plantation area. From calculations based on the extraction of 1,000 tons of FFB/ day or 300,000 tons/ year, the amount of the nutrients content in 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 59.7, 4.9, 35.1, and 35.1 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 palm.

The total amount of waste that can be used as fertilizer to replace a portion of the commercial fertilizer needed in the plantation is shown in Table 6.18. Since the EFB and wastewater may not contain all the requisite type and quantities of nutrients of a commercial fertilizer, 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. 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.

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	461	35	1265	125	-
Commercial fertilizer, ton/ year	4,429	595	415	505	300
Reduce commercial fertilizer (%)	9.5	5.6	75.4	19.8	0

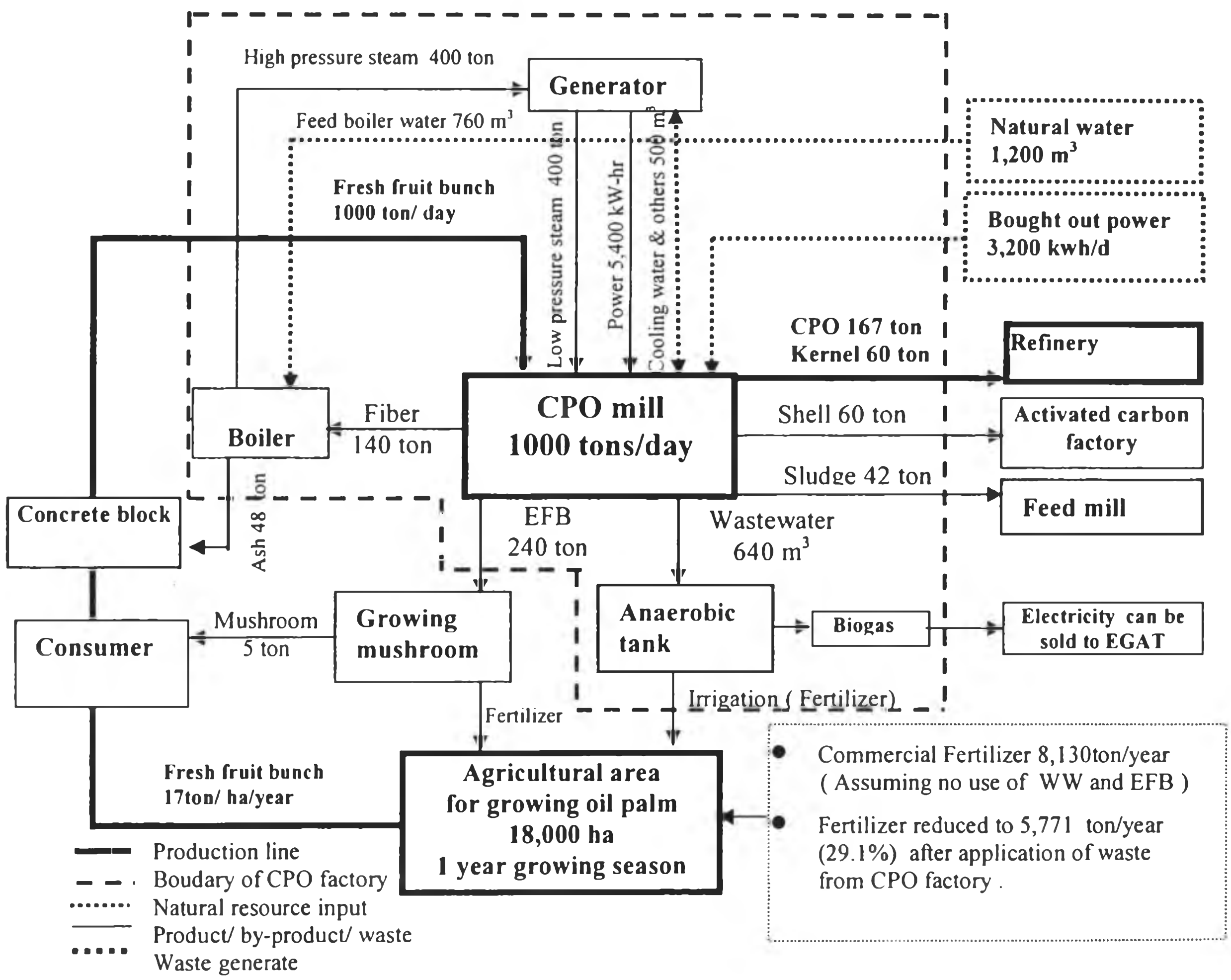


Figure 6.11 Material balance of the proposed physical-technological model of an almost zero waste industrial ecosystem.

6.7 Conclusion

Crude palm oil mills generate large amount 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 generated 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 it can be concluded that mills that are situated close to community have better environmental performance than those that are located far from community or in plantation area. The reason is they apply 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 of its industrial eco-system practices for waste recycling. Biomass, fiber and shell from crude palm oil processing, can be reused as solid fuel in boiler. Empty fruit bunch can be reused in agricultural sector. However, there are several options that may have potential as a more value added 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 improvement environmental performance from crude palm oil industry in Thailand. Such an approach can transform the 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.