CHAPTER IV
RESULTS AND DISCUSSION

Municipal Solid waste in Thailand is defined as solid waste generated from community activities, e.g. residential (household), commercial and business establishments, fresh market, institutional facilities, construction and demolition waste, excluding hazardous and infectious wastes (PCD, 2010). Local governments are responsible for solid waste collection and disposal. Each local government may adopt solid waste disposal method appropriate for its waste collected in the area. The different methods of solid waste disposal such as incineration, composting, sanitary landfill, open burning and dump on open ground, impose different costs on the solid waste management and carbon emission per unit mass of waste collected, as well.

The amount of solid waste in Thailand continued to increase. In 2008, the amount of solid wastes around the country was approximately 15.03 million tons or 41,064 tons per day (excluding the pre-dumped solid waste). Collected solid waste in the Bangkok Metropolitan area amounted 8,780 tons per day or 21% while solid waste in the municipal and the city of Pattaya amounted 14,915 tons per day or 36%. The solid waste around all of the local administration areas amounted 17,369 tons per day or 43% of the total amount of solid waste collectible all over the country. Comparing the previous year, the amount of solid waste had been increased by 0.27 million tons or 1.81%, in correlation to the expansion of urban community and population growth. Solid waste in the municipal areas had peaked at 9.67% while the solid waste outside the municipal areas had decreased by 4.57%. This was a result from upgrading 343 local administrative governments to municipal status. The average solid waste generation rate in 2008 was at 0.64 kilograms per person per day (PCD, 2010).

Waste generation in this study came from secondary data collection from each municipalities. The amount of the total weight of the municipal solid waste was resulting from the weighing at solid waste transfer station or at the disposal site. Thus, the weight of waste recycled at home, or separated by tricycle scavenger, or separate

by waste collectors had not been included in the total weight of all solid waste. Therefore, the total weight of all waste should be the sum of the weight of solid waste from transfer station or at the disposal site and weight of recyclable materials and % of solid waste that cannot be collected.

The Per-Capita Generation Rates of solid waste calculate from total collected solid waste divided by registered population of that municipal area which might be effected by some factors such as unregistered population and tourists.

The recycling data sources from each municipality were difference. The weight of waste recycled, some municipalities are not collected. Therefore, field survey to estimate the weight of recycled waste have to be conducted.

4.1 Nonthaburi City Municipality

4.1.1 General Data

The municipality of Nonthaburi was established by Royal Decree on February 14, 1953. At the beginning the area was only 2.5 square km, but it expanded to encompass 38.9 square km by 1988. Nonthaburi is located on the east side of the Chao-Pha-ya River. In the year 2008 the total population was 264,485 including 107,451 households. Land in this municipality is mainly distributed among residential, commercial, and agricultural areas.

4.1.2 Solid Waste Management in Nonthaburi Municipality

In Nonthaburi Municipality, solid waste collecting trucks collect waste generated from households and haul to landfill disposal site. The waste is collected twice a week. The landfill location is 38 kilometers away from Nonthaburi Municipality. It belongs to the Nonthaburi Provincial Administration Organization. The municipality impose a strategy necessary to reduce the quantity of waste from households with the 3R concept and to monitor waste handling during its transport. (Fig 4.1)

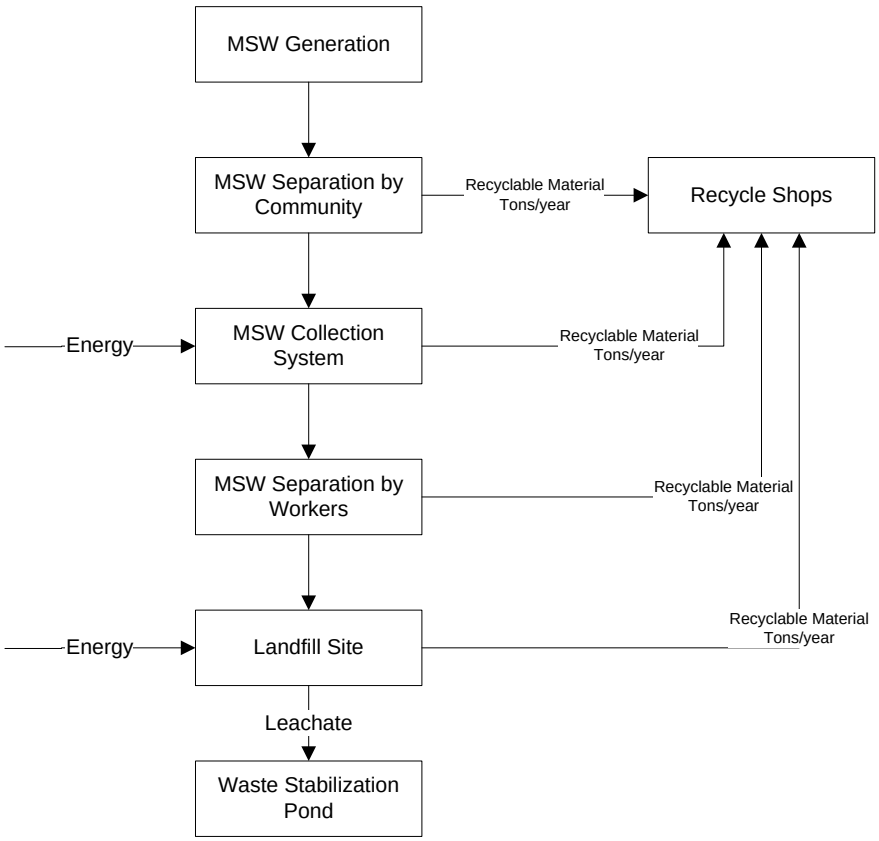

Figure 4.1 Flow diagram of solid waste management in Nonthaburi Municipality.

4.1.3 Solid Waste Generation and Composition

The rate of solid waste generation in Nonthaburi Municipality in 2008 was found to be 1.0±0.05 kg/capita/day, calculated from the urban population figure 264,485 with the average density of 6,799 person/sq.km. and the collected waste quantity as 96,610.40 tons. (see Appendix A Table A-1)

Waste composition is one of the main factors influencing emissions from solid waste treatment, as different waste types contain different amount of degradable organic carbon (DOC) and fossil carbon. Waste compositions, as well as the classifications used to collect data on waste composition in MSW vary widely in different regions and countries. (IPCC, 1996)

Identification of waste composition is crucial for selection of the most appropriate technology for treatment. Table 4.1 indicates the MSW composition of Nonthaburi Municipality, in which food waste was the major portion of the waste, about 63.55%. Whereas plastic, glass, paper and metals waste constitute 14.92%,

10.21%, 4.86%, and 1.12%, respectively. The remaining portions of waste were yard waste, rubber and leather and cloth.

Table 4.1 Nonthaburi Municipality solid waste composition (PCD, 2003)

Solid Waste Composition	% by Weight
Food Waste	63.55
Paper	4.86
Plastic	14.92
Glass	10.21
Metal	1.12
Rubber/Leather	0.32
Cloth	2.07
Yard	0.84
Others	2.11
Total	100.00

4.1.4 Solid Waste Collection and Transportation of Nonthaburi MSW

In Nonthaburi Municipality, 45 waste collecting trucks serve 264,485 population and 107,451 households that carry 96,610 tons/year and 264.00±12.89 tons/day of waste into landfill disposal sites. The waste is collected twice a week. The landfill location is 38 kilometers away from Nonthaburi Municipality. There is no transfer station the collecting trucks go directly to the landfill site after collection. (see Appendix A Table A-1)

Collection and transportation of solid waste generated from household to the landfill site was carried out, using 45 waste collecting trucks. The total distances was 1,317,600 kilometers in the inventory year (2008). The total diesel consumption were 785,049 liters/year. The diesel fuel consumption rate were 1.68±0.03 kilometers/liter of diesel, 8.15±0.50 liters of diesel/ton of solid waste and 7.4E-08 liters of diesel/kg of solid waste/kilometer. (see Appendix A Table A-2)

Carbon emissions from the waste collection mainly came from the CO_2 generated by the use of fuel for collection and transportation of waste. The actual

emissions varied with the type of truck, fuel type (diesel), size and distances. The total emissions could also be derived from the total distances or fuel usage. As the uncertainty with using distance was higher and collecting trucks also used their engines to power the hopper compactor during solid waste collection and transportation, this study therefore used the fuel consumption of the collection and transportation as the basis for the calculations. The total amount of carbon emission from the operation of Nonthaburi MSW collection and transportation was found to be equal to 627,254 kgCE/year and the average carbon emission was 6.51±0.40 kgCE/ton of solid waste. (see Appendix A Table A-3)

4.1.5 Energy Consumption and Carbon Emission from the Landfill of Nonthaburi MSW

The equipment use in Nonthaburi MSW landfilling consist of Dozer, Landfill Compactor, Track Loader, Backhoe/Hydraulic Excavator, Motor Grader, Steel Wheel Roller, Water Tank and Truck. Diesel consumption of Nonthaburi MSW landfilling was 195,164 liters/year. The diesel fuel consumption rate were 2.02±0.09 liters of diesel /ton of solid waste. (see Appendix A Table A-4)

The total amount of carbon emission from diesel fuel consumption in the operation of Nonthaburi MSW landfilling was found to be equal to 155,936 kgCE/year and the average carbon emission was 1.62±0.08 kg CE/ton of solid waste. (see Appendix A Table A-5)

Carbon emission of Methane gas from MSW degradation is calculated by using conversion factors reported in Appendix E. Table E-1.The amount of solid waste from each composition multiplied by the conversion factor for food waste, paper, plastic, glass, wood and cloths which were 99.40, 234.75, 6.57, 3.30 99.40 and 159 respectively, and convert from methane to carbon equivalent(*12/16: C/CH_4). The total amount of carbon emission was 5,794.186 MTCE/year and 0.05997 MTCE/ton of solid waste. (see Appendix A Table A-6)

Methane emitted from landfill is calculated by using emission factor. All carbon has its origin from biogenic carbon and is therefore not accounted for carbon emission as it return to the atmosphere.

To estimate the final carbon fixation (storage) in landfill, using factor from EPA's Waste Reduction Model (WARM) for mixed MSW which equal to 0.22 metric tons of CO_2 per wet short ton of MSW multiplied by the amount of wet solid waste in landfill. (see Appendix E Table E-2) The total amount of carbon fixation (storage) in landfill was 6,389.62 MTCE/year and 0.066138 MTCE/ton of solid waste.

The quantities of the four types of recyclable material in Nonthaburi MSWM consist of paper, plastic, glass and metal were 661.78, 94.39, 207.40 and 1,896.39 tons/year respectively. To estimate the final carbon reduction from recyclable material use emission factors for recycling in EPA's Waste Reduction Model (WARM) for mixed paper, plastic, glass, and metal which equal to 3.51, 1.5, 0.28 and 5.4 metric tons of CO_2 per wet short ton of recyclable material respectively(see Appendix E Table E-3), multiplied by the amount of wet solid waste in landfill and convert to carbon equivalent by multiplying with 12/44. The total amount of carbon reduction from recyclable material was 3,157.77 MTCE/year. (see Appendix A Table A-6)

4.1.6 Carbon Balance in Nonthaburi MSWM

After compiling all inputs and outputs of solid waste, energy and carbon emissions, storage, and reduction in the system boundaries, the next step is carbon investigation of the system. The result of this phase showed the contribution of carbon potentials of each processes of Nonthaburi MSWM.

From the model total carbon emission came from energy use in the collection transportation and landfill. The net carbon emission value was 783.21 MTCE/year. The methane emission from the landfill was 5,794.19 MTCE/year. This amount of carbon did not count in the carbon balance model because came from biogenic waste. If methane was collected and used as sources of energy it would be count as carbon reduction.. The carbon storage in the landfill 6,389.62 MTCE/ Year was count as carbon fixation(Appendix F (F.2)). The carbon reduction came from recyclable material as a sources reduction 3,157.77 MTCE/ Year. The net carbon balance was -2,374.56 MTCE/ Year. The negative sign means carbon reduction. The carbon balance in Nonthaburi MSWM present in Table. 4.2.

Table 4.2 Carbon balance of Nonthaburi MSWM

Inventory/ Categories	Carbon MTCE/ Year			Balance
	Emission	Fixation	Reduction	
Collection				
Diesel consumption	627.25	-	-	+627.25
Landfill				
Diesel consumption	155.94	-	-	+155.94
C /CH_4 Production	-	-	5,794.19*	-
C/Storage	-	6,389.62**	-	-
Recycle				
Paper	-	-	574.71	-574.71
Plastic	-	-	35.03	-35.03
Glass	-	-	14.37	-14.37
Metal	-	-	2,533.66	-2,533.66
Total Carbon	783.21	-	3,157.77	-2,374.56

* not accounted for carbon emission, if collect and use as fuel it means reduction

** not accounted for carbon emission

4.2 Khon Kaen City Municipality

Khon Kaen is one of the major provinces in North-eastern Region of Thailand. The city has been also known for the famous university town. The growing number of population from both locals and in-coming students had resulted in the increase of solid waste volume especially in the municipality area. The prediction of solid waste volume collected by 2025 would be 182-256 tons per day. Khon Kaen Municipality saw the need to have new disposal facilities constructed on its existing disposal site, 39 acres of land. Half of the land was used for managing 800,000 tons of solid waste accumulated in the site; the rest was for landfill system.

4.2.1 General Data

Khon Kaen Municipality is located in Muang District, Khon Kaen Province. The Province is centrally located in the North-East Region of Thailand. The Khon Kaen Municipality is located on the plain at an altitude of between 150-200 m.

The areas surrounding the plain to the north, west and south reaches 215 m. The total area of the Khon Kaen Municipality is 46 sq. km. The average annual temperature is around 27^{o}C and the average annual rainfall 1,244 mm. Both the geography and climate of the Region make it suitable for a wide range of crops, although it is occasionally susceptible to periods of both drought and flooding.

4.2.2 Solid Waste Management in Khon Kaen Municipality

In Khon Kaen Municipality, 29 waste collecting trucks serve 53,498 households that carry 152.48 ± 6.98 tons/day of waste into landfill disposal sites. The landfill location is 17 kilometers away from Khon Kaen Municipality. (see Appendix B Table B-1) (Fig 4.2)

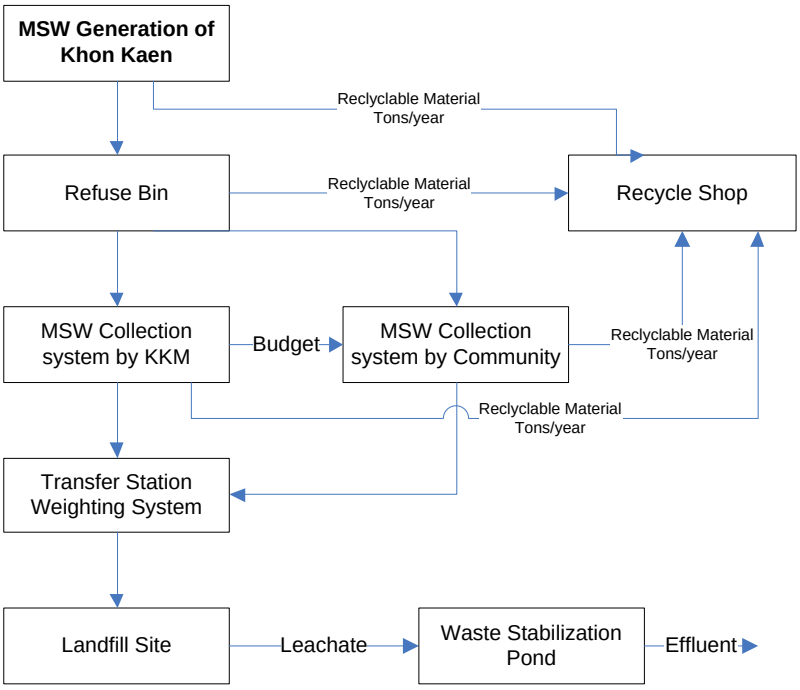

Figure 4.2 Flow diagram of solid waste management in Khon Kaen Municipality

4.2.3 Solid Waste Generation and Composition

The rate of solid waste generation in Khon Kaen Municipality for 2008 reported as 1.28±0.05 kg/capita/day. Given the urban population figure of Khon Kaen

Municipality as 118,203 for 2008 and the collected waste quantity as 55,795.37 tons for the same year. (see Appendix B Table B-1)

Identification of waste composition was crucial for selection of the most appropriate technology for treatment. Table 4.3 indicates the MSW composition of Khon Kaen where food waste, as the major portion of the waste, was about 73.66% whereas plastic, paper, glass and metals waste constitute 14.29%, 7.17% 2.05%, and 0.62% respectively. The remaining portions of waste were yard waste, rubber and leather and cloth.

Table 4.3 Khon Kaen Municipality solid waste composition (PCD, 2003)

Solid Waste Composition	% by Weight
Food Waste	73.66
Paper	7.17
Plastic	14.29
Glass	2.05
Metal	0.62
Rubber/Leather	0.34
Cloth	0.71
Yard	0.30
Others	0.86
Total	100.00

4.2.4 Solid Waste Collection and Transportation of Khon Kaen MSW

In Khon Kaen Municipality, 27 waste collecting trucks serve 118,203 population and 53,498 households that carry 55,795.37 tons/year and 152.48±6.98 tons/day of waste. The collecting trucks go directly to transfer station and then transport to landfill disposal sites. The landfill location is 17 kilometers away from Khon Kaen Municipality.

Collection and transportation of solid waste generated from household to the transfer station was carried out, using 27 waste collecting trucks. The total distances was 490,094.8 kilometers in the inventory year (2008). The total diesel

consumption were 91,682.93 liters/year. The diesel fuel consumption rate were 5.38±0.45 kilometers/liter of diesel, 1.65±0.17 liters of diesel/ton of solid waste and 1.23E-06 liters of diesel/kg of solid waste/kilometer. (see Appendix B Table B-2)

Carbon emissions from the waste collection mainly came from the CO_2 generated by the use of fuel. The total emissions could also be derived from the total fuel usage during solid waste collection and transportation. In this study therefore used the fuel consumption of the collection and transportation as the basis for the calculations. The total amount of carbon emission from the operation of Khon Kaen MSW collection and transportation was found to be equal to 73,254.66 kg CE/year and the average carbon emission was 1.32±0.14 kg CE/ton of solid waste. (see Appendix B Table B-5)

4.2.5 Solid Waste Transfer Station and Transportation of Khon Kaen MSW

Transfer station and transportation of solid waste generated from household to the landfill site was carried out, using 5 waste container trucks. The total distances was 149,328 kilometers in the inventory year (2008). The total diesel consumption were 144,570 liters/year. The diesel fuel consumption rate were 1.03±0.02 kilometers/liter of diesel and 2.60±0.12 liters of diesel/ton of solid waste. (see Appendix B Table B-3)

Carbon emissions from the waste transfer station and transportation mainly came from the CO_2 generated by the transport vehicles' use of fuel. The actual emissions varied with the vehicles' engine model, fuel type (diesel), size and load. The total emissions could also be derived from the total mileage or fuel usage. As the uncertainty with using mileage was higher during solid waste was transported from transfer station to landfill site, this part of this study therefore used the fuel consumption of the transport vehicles as the basis for the calculations. The total amount of carbon emission from the transportation of solid waste from transfer station to landfill site of Khon Kaen MSW was found to be equal to 115,511.43 kg CE/year and the average carbon emission was 2.07±0.10 kg CE/ton of solid waste. (see Appendix B Table B-6)

4.2.6 Energy Consumption and Carbon Emission from the Landfill of Khon Kaen MSW

The equipment use in Khon Kaen MSW landfilling consist of Dozer, Landfill Compactor, Track Loader, Backhoe/Hydraulic Excavator, Motor Grader, Steel Wheel Roller, Water Tank and Truck. Diesel consumption of Khon Kaen MSW landfilling was 48,849.05 liters/year The diesel fuel consumption rate were 0.88±0.25 liters of diesel /ton of solid waste. (see Appendix B Table B-4)

The total amount of carbon emission from diesel fuel consumption in the operation of Khon Kaen MSW landfilling was found to be equal to 39,033.39 kgCE/year and the average carbon emission was 0.70±0.20 kg CE/ton of solid waste. (see Appendix B Table B-7)

Carbon emission of Methane gas from MSW degradation is calculated by using conversion factors reported in Appendix E. Table E-1.The amount of solid waste from each composition multiplied by the conversion factor for food waste, paper, plastic, glass, wood and cloths which were 99.40, 234.75, 6.57, 3.30, 99.40 and 159 kg CH_4/ton, respectively, and convert from methane to carbon equivalent by multiplying with 12/16 as C/CH_4. The total amount of carbon emission was 3,870.1 MTCE/year and 0.069 MTCE/ton of solid waste. (see Appendix B Table B-8)

Methane emitted from landfill is calculated by using the emission factor. All carbon has its origin from biogenic carbon and is therefore not accounted for carbon emission that causes the increase of atmospheric CO_2 concentration.

To estimate the final carbon storage in landfill, was calculated by using factor from EPA's Waste Reduction Model (WARM) for mixed MSW which equal to 0.22 metric tons of CO_2 per wet short ton of MSW multiplied by the amount of wet solid waste in landfill. (see Appendix E Table E-2) The total amount of carbon storage in landfill was 3,690.19 MTCE/year and 0.0066 MTCE/ ton of solid waste (see Appendix F (F.2)).

The quantities of the four types of recyclable material in Khon Kaen MSWM consist of paper, plastic, glass and metal were 154.82, 144.94, 37.70 and 119.32 tons/year respectively. To estimate the final carbon reduction from recyclable material use emission factors for recycling in EPA's Waste Reduction Model (WARM) for mixed paper, plastic, glass, and metal which equal to 3.50, 1.5, 0.28 and 5.4 metric

tons of CO_2 per wet short ton of recyclable material respectively, multiplied by the amount of wet solid waste in landfill and convert to carbon equivalent by multiplying with 12/44 as C/CO_2. (see Appendix E Table E-2) The total amount of carbon reduction from recyclable material was 350.26 MTCE/year. (see Appendix B Table B-8)

4.2.7 Carbon Balance in Khon Kaen MSWM

After compiling all inputs and outputs of solid waste, energy and carbon emissions, storage, and reduction in the system boundaries, the next step is carbon investigation of the system. The result of this phase shows the contribution of carbon potentials of each processes of Khon Kaen MSWM.

From the model total carbon emission came from energy use in the collection, transfer station and transportation of SWM. The net carbon emission value was 227.8 MTCE/year. The methane emission from the landfill was 3,870.1 MTCE/year. This amount of carbon did not count in the carbon balance model because it came from biogenic waste. If methane was collected and used as sources of energy it would be count as carbon reduction. The carbon storage in the landfill 3,690.19 MTCE/year was count as a carbon fixation(see Appendix F (F.2)). The carbon reduction came from recyclable material as a sources reduction 350.26 MTCE/ Year. The net carbon balance was -122.46 MTCE/ Year. The carbon balance in Khon Kaen MSWM present in Table. 4.4.

4.3 Phitsanulok City Municipality

4.3.1 General Data

MBT is a waste pre-treatment technology whereby waste in its total as delivered at the landfill site is subject for an extended period of time (about 9 months) to an aerobic decomposition and transformation of the organic waste to an inert, “compost” like material. This material is then either build-in at a landfill site or the material is sieved and the “compost” part is utilized. This utilization should be restricted to landfill sites since the material may be polluted from parts of the waste (e.g. heavy metals from toxic / hazardous waste components). It has suitable properties for use as bio-filter layer in the final cover of the landfill or even as temporary cover during the MBT process.

Table 4.4 Carbon balance of Khon Kaen MSWM

Inventory/ Categories	Carbon MTCE/ Year			Balance
	Emission	Storage	Reduction	
Collection				
Diesel consumption	73.25	-	-	+73.25
Transfer station				
Diesel consumption	115.51	-	-	+115.51
Landfill				
Diesel consumption	39.03	-	-	+39.03
C /CH_4 Production	-	-	3,870.1*	-
C/Storage	-	3,690.19 **	-	-
Recycle				
Paper	-	-	134.45	-134.45
Plastic	-	-	53.79	-53.79
Glass	-	-	2.61	-2.61
Metal	-	-	159.41	-159.41
Total Carbon	227.8	-	350.26	-122.46

* not accounted for carbon emission, if collect and use as fuel it means reduction

** not accounted for carbon emission

The process used in Phitsanulok is from Faber Company and is patented also in Thailand. They have in common a first mechanical treatment stage and a second biological treatment stage.

The mechanical stage is needed dominantly to homogenize the waste in order to facilitate the later biological decomposition. In a first step hindering parts of waste, such as bulky pieces or very heavy pieces are sorted out. This is done here in Thailand by manual labor, if needed assisted by machines. Then the material is transferred to a homogenization drum or alternatively in other processes to a shredder or a ball mill. Here the waste is thoroughly mixed. In the experimental stage in Phitsanulok, the drum has inside attached a series of sharp blades, which rip open the plastic bags. This is essential to allow access of air to all parts of the waste in the

biological stage. The material is then transferred to the area where the biological process takes place.

For the biological the homogenized waste is built in trapezoid windrows upon a ventilation layer. In the case of the FABER AMBRA process, palettes and ventilation pipes are utilized. The windrow is covered with a biofilter to minimize any eventual smell and to avoid access of birds, flies or rodents. In Phitsanulok, coconut husk is utilized since this material is easily available and shows excellent filter properties. On top of the windrows, sprinklers are installed to provide for the necessary moisture for the biological decomposition. Regularly, the temperature and the moisture content are measured in the windrow to control the process. Additionally, the process is con-trolled through gas measurements (oxygen, carbon dioxide and methane concentrations) within the windrows. The waste stays for nine months in the windrows and is then transferred to the active cell area for disposal.

4.3.2 Solid Waste Management in Phitsanulok Municipality

In Phitsanulok municipality, 16 waste collecting trucks serve 32,459 households that carry 75.17±4.91 tons/day of waste into transfer station and then compress and transport to Mechanical Biological (MBT) landfill disposal sites. The landfill location is 29 km. away from Phitsanulok municipality. The MBT landfilled belong to Phitsanulok municipality. (Figure. 4.3)

4.3.3 Solid Waste Generation and Composition

The rate of solid waste generation in Phitsanulok Municipality for 2008 reported as 0.97±0.06 kg/capita/day. The population of Phitsanulok Municipality was 74,848 for 2008 and the collected waste quantity was 27,509.48 tons for the inventory year. (see Appendix C Table C-1)

Identification of waste composition is important for selection of the appropriate technology for treatment. Table 4.5 indicates the MSW composition of Phitsanulok where food waste, as the major portion of the waste, is about 68.59% whereas plastic, paper, glass and metal waste constitute 20.59%, 2.53% 1.61%, and 1.45% respectively. The remaining portions of waste are yard waste, metals, rubber and leather and cloth.

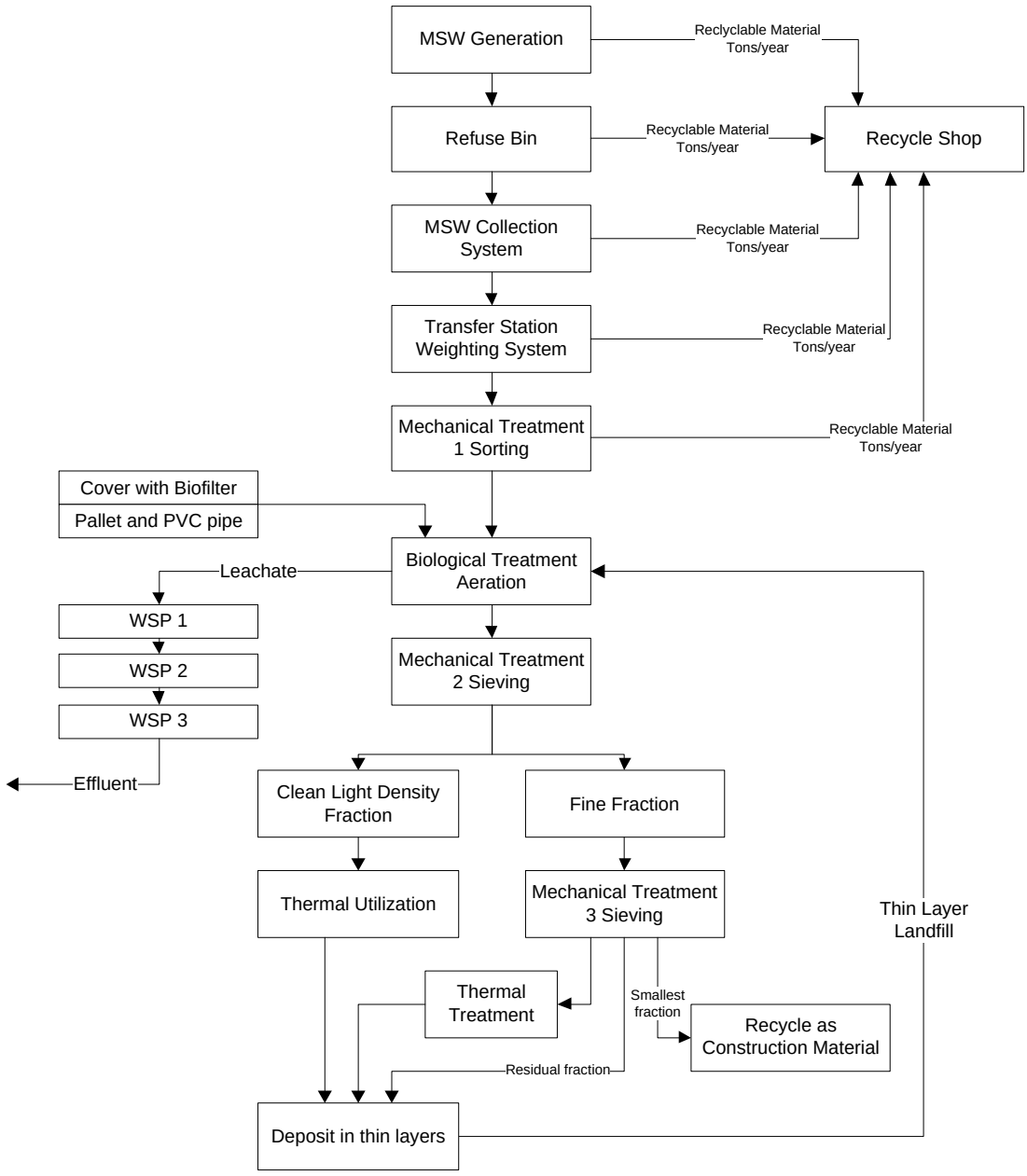

Figure 4.3 Flow diagram of solid waste management in Phitsanulok Municipality.

Table 4.5 Phitsanulok Municipality solid waste composition (PCD, 2003)

Solid Waste Composition	% by Weight
Food Waste	68.59
Paper	2.53
Plastic	20.59
Glass	1.61
Metal	1.45
Rubber/Leather	0.29
Cloth	1.51
Yard	0.89
Others	2.54
Total	100.00

4.3.4 Solid Waste Collection and Transportation of Phitsanulok MSW

In Phitsanulok Municipality, 16 waste collecting trucks serve 77,340 population and 32,459 households that carry 27,509.48 tons/year and 75.17±4.91 tons/day of waste into landfill disposal sites. The landfill location is 29 kilometers away from Phitsanulok Municipality. There is a transfer station before the collecting trucks go to the landfill site. (see Appendix C Table C-1)

Collection and transportation of solid waste generated from household to the landfill site was carried out, using 16 waste collecting trucks. The total distances was 444,800.77 kilometers in the inventory year(2008). The total diesel consumption were 146,722.21 liters/year. The diesel fuel consumption rate were 3.04±0.19 kilometers/liter of diesel, 5.35±0.34 liters of diesel /ton of solid waste and 1.45E-07 liters of diesel/kg of solid waste/kilometer. (see Appendix C Table C-2)

Carbon emissions from the waste collection mainly came from the CO_2 generated by the transport vehicles' use of fuel. The actual emissions varied with the vehicles' engine model, fuel type (diesel), size and load. The total emissions could also be derived from the total mileage or fuel usage. As the uncertainty with using mileage was higher and garbage trucks also used their engines to power the hopper compactor during solid waste collection and transportation, this study therefore used

the fuel consumption of the transport vehicles as the basis for the calculations. The total amount of carbon emission from the operation of Phitsanulok MSW collection and transportation was found to be equal to 117,231.05 kg CE/year and the average carbon emission was 4.271±0.27 kg CE/ton of solid waste. (see Appendix C Table C-5)

4.3.5 Energy Consumption and Carbon Emission from the Transfer Station.

At the transfer station of Phitsanulok MSW there are two activities. The first is compaction of solid waste into container the density after compaction is 480-570 kg/cubic meter and one container has capacity of 24.5 cubic meters so for one trip. Another activity is to transport solid waste after compaction from transfer station to MBT site which can carry 12-14 tons of solid waste per trip.

The energy consumption at the transfer station consist of electricity use for compaction and diesel fuel use for transport container from transfer station to MBT site.

From the data collection and field survey, the total electricity consumption were found to be 80,996.44 kWh/year, and 2.84±1.87 kWh/ton of solid waste.

The total diesel consumption were 37,149 liters/year. The diesel fuel consumption rate were 4.03±0.31 kilometers/liter of diesel and 1.35±0.05 liters of diesel /ton of solid waste. (see Appendix C Table C-6, C-7)

Carbon emissions from the waste transfer station and transportation to landfill site mainly came from carbon equivalent that calculate from electricity consumption and the CO_2 generated by the transport vehicles' use of fuel.

The total carbon equivalent from diesel consumption were 29,682.05 kgCE/year and 1.08±0.04 kgCE/ton of solid waste. (see Appendix C Table C-6)

The total carbon equivalent from electricity consumption were 12,392.46 kgCE/year and 0.434±0.29 kgCE/ton of solid waste. (see Appendix C Table C-7)

4.3.6 Energy consumption and carbon emission from the MBT of Phitsanulok MSW

The equipment use in MBT landfill site of Phitsanulok MSW consist of Shredding, homogenizing, Track Loader, Backhoe/Hydraulic Excavator, Motor Grader, Water Tank and Truck.

Diesel fuel consumption of Phitsanulok MSW MBT landfilling was 121,825.28 liters/year. The diesel fuel consumption rate were 4.43±0.39 liters of diesel /ton of solid waste. (see Appendix Table C-8)

The electricity consumption at MBT landfill site were 34,221.83 kWh/year, and 2.837±1.87 kWh/ton of solid waste. (see Appendix Table C-7)

The total carbon equivalent from electricity consumption at MBT landfill site were 5,235.94 kgCE/year and 0.19±0.05 kgCE/ton of solid waste. (see Appendix Table C-7)

The total amount of carbon emission from diesel fuel consumption in the operation of Phitsanulok MSW landfilling was found to be equal to 97,338.48 kgCE/year and the average carbon emission was 3.54±0.31 kg CE/ton of solid waste. (see Appendix C Table C-8)

The decomposition process in MBT is aerobic. There is no methane emission, and the CO_2 emission which came from biogenic waste and return back to carbon pool in the atmosphere are not accounted in carbon balance model.

To estimate the final carbon storage in landfill, using factor from EPA's Waste Reduction Model (WARM) for mixed MSW which equal to 0.22 metric tons of CO_2 per wet short ton of MSW multiplied by the amount of wet solid waste in landfill. (see Appendix E Table E-2) The total amount of carbon storage in landfill was 1,819.42 MTCE/year and 0.06 MTCE/tonSW(see Appendix F (F.2)).

The quantities of the four types of recyclable material in Phitsanulok MSWM consist of paper, plastic, glass and metal were 187.44, 311.65,42.25 and 228.09 tons/year respectively. To estimate the final carbon reduction from recyclable material use emission factors for recycling in EPA's Waste Reduction Model (WARM) for mixed paper, plastic, glass, and metal which equal to 3.50, 1.5, 0.28 and 5.4 metric tons of CO_2 per wet short ton of recyclable material respectively, multiplied by the amount of wet solid waste in landfill and convert to carbon equivalent. (see Appendix E

Table E-3) The total amount of carbon reduction from recyclable material was 712.17 MTCE/year. (see Appendix C Table C-9)

4.3.7 Carbon Balance in Phitsanulok MSWM

After compiling all inputs and outputs of solid waste, energy and carbon emissions, storage, and reduction in the system boundaries, the next step is carbon investigation of the system. The result of this phase shows the contribution of carbon potentials of each processes of Phitsanulok MSWM.

From the model total carbon emission came from energy use in the collection, transfer station, transportation and MBT site. The net carbon emission value was 261.88 MTCE/year. The carbondioxide emission from the landfill was not count in the carbon balance model because came from biogenic waste. The carbon storage in the landfill 1,819.42 MTCE/year was count as a carbon fixation(see Appendix F (F.2)). The carbon reduction came from recyclable material as a sources reduction 712.18 MTCE/ Year. The net carbon balance was -450.37 MTCE/ Year. The carbon balance in Phitsanulok MSWM present in Table. 4.6.

Table 4.6 Carbon balance of Phitsanulok MSWM.

Inventory/ Categories	Carbon MTCE/ Year			Balance
	Emission	Storage	Reduction	
Collection				
Diesel consumption	117.23	-	-	+117.23
Transfer Station				
Electricity Use	12.39	-	-	+12.39
Diesel consumption	29.68	-	-	+29.68
MBT Landfill/				
Electricity Use	5.24	-	-	+5.24
Diesel consumption	97.34	-	-	+97.34
C /CH_4 Production	-	-	-*	-
C/Storage	-	1,819.42**	-	-
Recycle				
Paper	-	-	197.79	-197.79
Plastic	-	-	140.54	-140.54
Glass	-	-	3.56	-3.56
Metal	-	-	370.29	-370.29
Total Carbon	261.88	-	712.18	-450.37

* not accounted for carbon emission, if collect and use as fuel it means reduction

** not accounted for Carbon emission

4.4 Phuket City Municipality

Phuket is an island province in the south of Thailand stretching 49 km from north to south and 19 km from east to west with a total area of 570 sq.km.

4.4.1 General Data

Due to high income and urbanization, like other big cities, Phuket is inevitably confronted with environmental problems especially regarding solid waste management. The increasing amount of MSW in Phuket conforms to the increasing number of tourists.

4.4.2 Solid Waste Management in Phuket Municipality

Phuket comprises of 3 districts which are Muang district, Thalang district, and Kathu district. Local authority administration of Phuket is separated into 6 municipalities, 13 tambon administration organizations, and 1 provincial authority organization. MSW from these areas is collected for treatment and disposal, under the responsibility of Phuket Municipality. Incineration is used as the main process to treat MSW which also provides electricity as a supplementary function. Other MSW management practices are separation of useful materials for utilization and landfilling for disposal of the remaining wastes which can not be incinerated.

MSW in Phuket is collected and transported to the treatment and disposal center where it is weighed and separated based on source and characteristics of the waste, to be managed by three methods – incineration, recycling and landfilling.

In Phuket Municipality, 25 waste collecting trucks serve 20,877 households that carry 97.80±3.59 tons/day of waste into Phuket Municipality Incineration. MSW collected from urban area of Phuket was about 522 tons/day where the maximum capacity of incinerator is 250 tons/day. Some of the remaining waste which could not be treated in the incinerator was sent for disposal in a landfill.

In 1993, Pal Consultants was hired by the Department of Public Works to study the garbage problem. Their study included consideration of landfill, composting and incineration but did not look at waste segregation or recycling. It recommended the construction of a 250 ton per day waste-to-energy incinerator. In 1995, the national government provided 788 million Baht to construct such an incinerator, and requested the Department of Forestry to allocate mangrove lands for the site.

The Phuket incineration plant site, located in central urban area of Phuket municipality, covers an area of approximately 43,000 sq.m. It started the operation in 1998. A moving grate type incinerator (Mitsubishi-Martin) operating at a combustion temperature of 800-950 ^{o}C is used here. The main components of the incinerator consist of waste storage pit, automatic feeding system (pit and crane), combustion unit (auto-reversing type stoker), ash removal system, gas cooling and cleaning system and heat utilization system.

The pollution control system of this incinerator includes air pollution control system, wastewater treatment unit, odor and noise control system and ash

management system. The flue gas treatment system is dry type equipped with bag filter. The emission of air pollutants is continuously monitored. The plant wastewater is pre-treated and sent to Phuket municipality central sewage treatment plant.

Heat generated from the incinerator is utilized for electricity generation. The energy recovery system consists of steam turbine and generator producing 2,500 kW of electricity. This electricity is sufficient for in-plant use and the remaining unused electricity can be sold out to the national grid.

The cost of incineration is 54 and 38 million THB per year when operated by private and governmental sector respectively. The cost includes 22 million THB of materials and equipment and the rest is allocated for personnel cost. Unit operating cost for waste incineration is therefore ranging from 420 to 590 THB per ton of MSW. (Chiemchaisri, 2008)

The solid waste management flow chart of Phuket is shown in Figure 4.4.

4.4.3 Solid Waste Generation and Composition

The situation of MSW Phuket management tends to be more serious because of the increasing amount of MSW whereas the capacity of incineration system is limited at 250 tons/day along with an ineffective operation of the sorting plant and limited area of landfill site. MSW collected in Phuket province in the fiscal year 1997 was 196 tons/day and increased to 522 tons/day in the fiscal year 2008.In the inventory year (2008) the solid waste generation in Phuket City Municipality was 35,792.77 tons and average 97.80±3.59 tons/day. The rate of solid waste generation in Phuket Municipality for 2008 reported as 1.28±0.05 kg/capita/day. Given the urban population figure of Phuket Municipality as 76,276 with the average density of population 6,356 person/sq.km. (see Appendix D Table D-1)

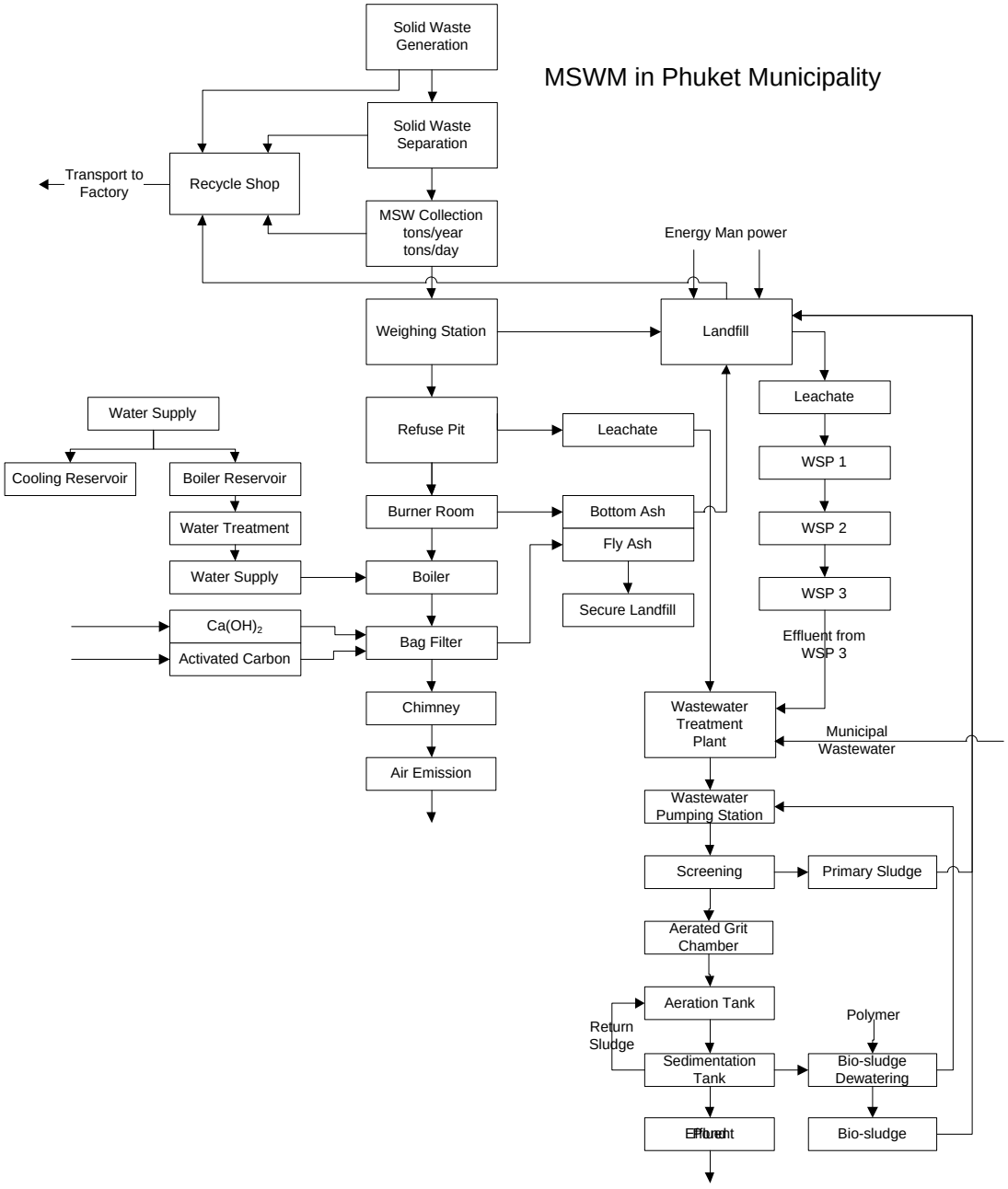

Figure 4.4 Flow diagram of solid waste management in Phuket Municipality

Table 4.7 indicates the MSW composition of Phuket where food waste, as the major portion of the waste, is about 65.64 % whereas plastic, paper, glass and metal waste constitute 19.28%, 6.56% 4.09% and 0.35% respectively. The remaining portions of waste are yard waste, rubber and leather, cloth, stone and ceramic.

Table 4.7 Phuket MSW composition (PCD, 2003)

Solid Waste Composition	% by Weight
Food Waste	65.64
Paper	6.56
Plastic	19.28
Glass	4.09
Metal	0.35
Rubber/Leather	0.03
Cloth	0.64
Yard	-
Others	3.41
Total	100.00

4.4.4 Solid Waste Collection and transportation of Phuket MSW

In Phuket Municipality, 25 waste collecting trucks serve 76,276 population and 20,877 households that carry 35,792.77 tons/year and 97.80±3.59 tons/day of waste into treatment site which consist of incineration and landfill. The treatment site located in the area of Phuket Municipality. There is no transfer station, the collecting trucks go directly to the treatment site after collection. (see Appendix D Table D-2)

Collection and transportation of solid waste generated from household to the landfill site was carried out, using 25 waste collecting trucks. The total distances was 330,359.92 kilometers in the inventory year(2008). The total diesel consumption were 126,075 liters/year. The diesel fuel consumption rate were 2.62±0.11 kilometers/liter of diesel, 3.53±0.18 liters of diesel /ton of solid waste and 1.29E-07 liters of diesel/kg of solid waste/kilometer. (see Appendix D Table D-2)

Carbon emissions from the waste collection and transportation came from the CO_2 generated by the use of fuel of collecting truck. The actual emissions varied with the vehicles' engine model, fuel type (diesel), size and load. The total emissions could also be derived from the total distance or fuel usage. As the uncertainty with using distance was higher and collecting trucks also used their engines to power the hopper compactor during solid waste collection and transportation, this study therefore

used the fuel consumption of the vehicles as the basis for the calculations. The total amount of carbon emission from the operation of Phuket MSW collection and transportation was found to be equal to 100,733.93 kgCE/year and the average carbon emission was 2.82±0.15 kgCE/ton of solid waste. (see Appendix D Table D-5)

4.4.5 Energy Consumption and Carbon Emission from the Landfill of Phuket MSW

The equipment use in Phuket MSW landfilling consist of Backhoe Loader, Dovetail truck, Dump Truck, Water Tank and Truck. Diesel consumption of Phuket MSW landfilling was 5,284.9 liters/year The diesel fuel consumption rate were 0.44±0.11 liters of diesel /ton of solid waste. (see Appendix D Table D-3)

The total amount of carbon emission from diesel fuel consumption in the operation of Phuket MSW landfilling was found to be equal to 4,222.84 kgCE/year and the average carbon emission was 0.35±0.09 kg CE/ton of solid waste. (see Appendix D Table D-6)

Carbon emission of Methane gas from MSW degradation is calculated by using conversion factors reported in Appendix E. Table E-1.The amount of solid waste from each composition multiplied by the conversion factor for food waste, paper, plastic, glass, wood and cloths which were 99.40, 234.75, 6.57, 3.30, 99.40 and 159 respectively, and convert from methane to carbon equivalent(*12/16: C/CH_4).The total amount of carbon emission was 764.04 MTCE/year and 0.063 MTCE/ton of solid waste. (see Appendix D Table D-7)

To estimate the final carbon fixation (storage) in landfill calculate by using factor from EPA's Waste Reduction Model (WARM) for mixed MSW which equal to 0.22 metric tons of CO_2 per wet short ton of MSW multiplied by the amount of wet solid waste in landfill. (see Appendix E Table E-2) The total amount of carbon fixation (storage) in landfill was 804.51 MTCE/year and 0.06 MTCE/ton of solid waste.

The quantities of the four types of recyclable material in Phuket MSWM consist of paper, plastic, glass and metal were 168.58, 199.37, 501.46 and 4.65 tons/year respectively. To estimate the final carbon reduction from recyclable material use emission factors for recycling in EPA's Waste Reduction Model (WARM) for

mixed paper, plastic, glass, and metal which equal to 3.50, 1.5, 0.28 and 5.4 metric tons of CO_2 per wet short ton of recyclable material respectively, multiplied by the amount of wet solid waste in landfill and convert to carbon equivalent. (see Appendix E Table E-3) The total amount of carbon reduction from recyclable material was 317.56 MTCE/year. (see Appendix D Table D-7)

4.4.6 Energy Consumption and Carbon Emission from Incineration of Phuket MSW

Diesel fuel consumption in the incineration use for startup incinerator and others activities such as transport bottom ash and fly ash to the landfill. Total consumption of Diesel at Phuket MSW incineration in 2008 was 6,853.44 liters/year The diesel fuel consumption rate were 0.29±0.24 liters of diesel /ton of solid waste. (see Appendix D Table D-4.7)

The total amount of carbon emission from diesel fuel consumption in the operation of Phuket MSW incineration was found to be equal to 5,475.90 kgCE/year and the average carbon emission was 0.24±0.19 kg CE/ton of solid waste. (see Appendix D Table D-4.7)

The total electricity production by the incineration plant (proportional of solid waste from Phuket municipality) was 2,833,455 kWh/year and 119.74±12.82 kWh/ton of solid waste. The carbon equivalent was 433,519 kgCE/year and 18.32± 1.96 kgCE/ton solid waste. The electricity use in the incineration plant was 1,754,346.49 kWh/year and 74.16±18.78 kWh/ton of solid waste. The carbon equivalent was 268,415 kgCE/year and 11.35± 2.87 kgCE/ton of solid waste. Electricity sold to the Provincial Electricity Authority (PEA) was 1,079,109 kWh/year and 54.53±9.61 kWh/ton of solid waste. The carbon equivalent was 165,104 kgCE/year and 8.34±1.47 kgCE/Ton of solid waste(see Appendix D Table D-4.2- D-4.6)

The total carbon emission from combustion of solid waste divide into two types the calculation showed in Appendix F

- Biomass C generated from organic waste combustion, the carbon equivalent was 272.53 kgCE/ton of MSW and Total Carbon emitted from Biomass combustion in the inventory year was 6,442 MTCE/year (see Appendix F)

- Fossil C generated from plastic waste combustion the carbon equivalent was 139.83 kgCE/ton of MSW and Total Carbon emitted from Fossil C combustion in the inventory year was 3,305 MTCE/year (see Appendix F)

4.4.7 Carbon Balance in Phuket MSWM

After compiling all inputs and outputs of solid waste, energy and carbon emissions, storage, and reduction in the system boundaries, the next step is carbon investigation of the system. The result of this phase shows the contribution of carbon potentials of each processes of Phuket MSWM. From the model total carbon emission came from energy use in the collection, transportation and carbon from fossil burning in incineration. The net carbon emission value was 3,433.97 MTCE/year. The methane emission from the landfill was 764.04 MTCE/year. This amount of carbon did not count in the carbon balance model because it came from biogenic waste. If methane was collected and used as sources of energy it would be count as carbon reduction. The carbon storage in the landfill 804.51 MTCE/year was count as a carbon fixation(see Appendix F (F.2)). The carbon reduction were 177.89, 89.90, 42.21 and 7.55 MTCE/year came from plastic, paper, glass and metal respectively and electricity that sale to PEA which was 165.10 MTCE/ Year. The net carbon balance of Phuket Municipality was +2,932.78 MTCE/ Year. The carbon balance in Phuket MSWM present in Table. 4.8.

Table 4.8 Carbon balance of Phuket MSWM.

Inventory/ Categories	Carbon MTCE/ Year			Balance
	Emission	Fixation	Reduction	
Collection				
Diesel consumption	100.73	-	-	+100.73
Landfill				
Diesel consumption	4.22	-	-	+4.22
C /CH_4 Production	-	-	764.04*	-
C/Storage	-	804.51**	-	-
Recycle				
Paper	-	-	177.89	-177.89
Plastic	-	-	89.90	-89.90
Glass	-	-	42.21	-42.21
Metal	-	-	7.55	-7.55
Incineration				
Diesel consumption	5.48	-	-	+5.48
Electricity Sale	-	-	165.10	-165.10
Combustion				
C from Biomass	6,442***	-	-	-
C from Fossil	3,305	-	-	+3,305
Total Carbon	3,418.22	-	482.65	+2,932.78

* not accounted for carbon emission, if collect and use as fuel it means reduction

** not accounted for carbon emission

***Carbon from biomass emission not accounted for carbon emission

4.5 Model Development and Evaluation

The total amount of greenhouse gases produced to directly and indirectly support human activities, usually expressed in equivalent tons of carbon dioxide (CO2) and converse to carbon by multiply with C/CO_2 conversion factor (12/44)

$$\text{Net CE} = \sum C_{ec} + \sum C_{lf} + \sum C_r + \sum C_{inc} + \sum C_{mbt} \quad (4.1)$$

Where ;

CE is Carbon balance of the system MTCE/year

$\sum C_{ec}$ is Total carbon equivalent from energy consumption in collection, transfer and transportation of the system. MTCE/ Year

Which calculated from total Energy (Diesel, Gasoline, NGV and Others) consumption in collection (unit/year) x Carbon Equivalent of each energy use (MTCE/unit of Energy) MTCE/ Year

Carbon from energy consumption

= Total Liters of Diesel x (0.94 kgCE/kgDiesel) x 0.85(Density of Diesel) = kgCE (4.2)

(Lal,2004)

= kWh of Electricity x 0.153 kgCE/kWh = kgCE/year (4.3)

(Hinchiranan, 2009)

$\sum C_{lf}$ is Total carbon equivalent from landfilling

Which calculated from $\sum C_{elf} - \sum C_m - \sum C_s$

$\sum C_{elf}$ = Total Energy (Diesel, Gasoline, NGV, Electricity and Others) consumption in landfill (unit/year) x Carbon Equivalent of energy use (MTCE/unit of Energy) MTCE/ Year using

$\sum C_m$ = Carbon from methane production from biodegradable from solid waste in landfill site MTCE/year

= Total mass of biodegradable solid waste composition x CH_4 production rate from landfill for each composition of solid waste (Food waste, paper, some type of plastic, wood and yard waste) x Carbon/Methane conversion factor (12/16)

$\sum C_m$ Carbon from methane production from biodegradable from solid waste in landfill site MTCE/year

= Tons of food wastex99.4 CH_4 (kg/tonSW) x 12/16 = kgCE

= Tons of mixed paper x 234.75 CH_4 (kg/tonSW) x 12/16 = kgCE

= Tons of mixed plastic x 6.57 CH_4 (kg/tonSW) x 12/16 = kgCE

= Tons of mixed cloths x 159 CH_4 (kg/tonSW) x 12/16 = kgCE

= Tons of mixed glass x 3.3 CH_4 (kg/tonSW) x 12/16 = kgCE

(Sandgren et. al., 1996.)

$\sum C_s$ = Total carbon fixation in the landfill that are store in the landfill. MTCE/year

= Total mass for each of solid waste composition from the landfilled that are not fully decompose by anaerobic bacteria x The final storage factor of carbon for the biodegradable solid waste components MTCE of CO_2E/Wet Short Ton x C/CO_2 conversion factor (12/44)

$\sum C_s$ Total carbon fixation in the landfill that are store in the landfill. MTCE/year

= Tons of mixed MSW x 0.22 MTCO2E/Short Ton x (1/1.1023short ton/MT) x (12/44:C/CO_2) = MTCE (EPA, 2010)

$\sum C_r$ is Total carbon reduction from recyclable material MTCE/year

Which calculated from total mass of each recyclable material x Emissions factor for Recycling ($MTCO_2E$/Short Ton of Material Recovered) x 1.1023 Short Ton /MT x C/CO_2 conversion factor (12/44)

$\sum C_r$ Total carbon reduction from recyclable material MTCE/year

= Tons of mixed paper x -3.51 $MTCO_2E$/Wet Short Ton x (1/1.1023short ton/MT) x (12/44:C/CO_2) =MTCE

= Tons of mixed plastic x -1.5 $MTCO_2E$/Wet Short Ton x (1/1.1023short ton/MT) x (12/44:C/CO_2) = MTCE

= Tons of mixed glass x -0.28 $MTCO_2E$/Wet Short Ton x (1/1.1023short ton/MT) x (12/44:C/CO_2) =MTCE

= Tons of mixed metal x -5.4 $MTCO_2E$/Wet Short Ton x ((1/1.1023short ton/MT) x (12/44:C/CO_2) = MTCE

(EPA, 2010)

$\sum C_{inc}$ is Total carbon equivalent from incineration (see Appendix F)

Which calculated from $\sum C_{inc} = \sum C_{ec} + \sum C_{elec} + \sum C_{cf}$

$\sum C_{elec}$ = Total carbon equivalent from Electricity production, use and sale

= Net Electricity x CE conversion factor (1 kWh = 0.153 kgCE)

$\sum C_{cf}$ = Total carbon emission from fossil

= Mass of Plastic x CO_2 Emission factor from incineration kg/kg waste plastic x C/CO_2 conversion factor (12/44)

= Mass of Plastic x 0.967 kg x 0.75 kg C/kg plastic waste x (12/44) = kgCE (Sundqvist et. al.,1997)

Carbon from biomass and fossil (see Appendix F)

$\sum C_{mbt}$ is Total carbon equivalent from Mechanical Biological Treatment (MBT)

Which calculated from $\sum C_{mbt} = \sum C_{ec} + \sum C_{elec} + \sum C_s$

$\sum C_{elec}$ = Total carbon equivalent from Electricity use in site

= Net Electricity x CE conversion factor (1 kWh = 0.153 kgCE)

4.6 Comparison of carbon balance in 4 municipalities

From the study of MSWM in the four municipalities, the comparison of carbon balance showed in Table 4.9.

The data from Table 4.9 showed the potential of emission when the consumption energy present. CH_4 production from landfill came from biogenic waste was not account in carbon balance model because its emission go back to the carbon pool in the atmosphere but in the case of CH_4 capturing and using as energy source these are account as carbon reduction . From the data the portion of the carbon in organic materials in landfill does not decompose so these carbon stored in landfill as carbon fixation.

The carbon from fossil such as many type of plastic when burn in incineration these amount of carbon defined as carbon emission, but carbon from biogenic waste after burning and convert to CO_2 will return to carbon pool in the atmosphere are not account in carbon balance model.

The most effective in carbon reduction was recycling of recyclable material in the MSWM because of sources reduction and using methane as a source of energy.

Table 4.9 Comparison of carbon balance from four municipality.

MSWM Activities	Municipality (MTCE/ Year)			
	Nonthaburi	Khon Kaen	Phitsanulok	Phuket
Collection				
-Diesel	+627.25	+73.26	+117.23	+100.73
Transfer				
-Diesel		+115.51	+29.68	-
-Electricity			+12.39	-
Landfill				
-Diesel	+155.94	+39.03	-	+4.22
-CH_4 Production	5,794.19*	3,870.1*	-	764.04*
-C Fixation	6,389.62 **	3,690.19 **	1,819.42**	804.51**
MBT				
-Diesel	-	-	+97.34	-
-Electricity	-	-	+5.24	-
Incineration				
-Diesel	-	-	-	+5.48
-Electricity sale	-	-	-	-165.10
-C-Biomass	-	-	-	6,442***
-C-fossil	-	-	-	+3,305
Recycle	-3,157.77	-350.26	-712.18	-317.55
Carbon Balance	-2,374.56	-122.46	-450.37	+2,932.78

* not accounted for carbon emission, if collect and use as fuel it means reduction.

** not accounted for carbon emission.

***Carbon from biomass emission not accounted for carbon emission.

4.7 Unit Measurement of Carbon Equivalent of MSWM

The carbon equivalent per 1 ton of solid waste in each activities of municipal solid waste management for four municipalities showed in Table 4.10. From the data found that carbon emission came from energy use in collection, transportation, landfilling, MBT and burning of carbon from fossil (waste plastic). The major sources of carbon emission come from burning of carbon from fossil in incineration. The two major sources of carbon reduction were the recycle of recyclable material and capturing of methane generation to use as energy.

Table 4.10 Carbon Equivalent of activities in MSWM

MSWM Activities	Municipality (KgCE/ Ton of Solid Waste)				
	Nonthaburi	Khon Kaen	Phitsanulok		Phuket
			Fuel	Electricity	
Collection	+6.51±0.40	+1.32±0.14	+4.27±0.27	-	+2.82±0.15
Transfer	-	+2.07±0.10	+1.08±0.04	+0.434±0.29	-
Landfill	+1.62±0.08	+0.70±0.20	-	-	+0.35±0.09
CH_4 Production	59.97*	69.36*	-		21.35*
C-storage	66.14**	66.14**	66.14**		66.14**
MBT	-	-	+3.54±0.31	+0.19±0.05	-
Incineration	-	-	-	-	+0.24±0.19
Electricity	-	-	-	-	-4.61
C-Biomass	-	-	-	-	272.75***
C-fossil	-	-	-	-	+139.61
Recycle	-31.11	-6.22	-26.81		-0.03
Carbon Balance	-22.98	-2.13	-17.30		+138.38

* not accounted for carbon emission, if collect and use as fuel it means reduction.

** not accounted for carbon emission.

***Carbon from biomass emission not accounted for carbon emission.

4.8 Waste Recycling Scenarios

4.8.1 The Scenarios of Nonthaburi Municipality

From the model when the recyclable material increased to 10%, 25% and 35% resulting in the quantity of solid waste and carbon emission from energy consumption in collection transportation and landfilling decreased. The total carbon balance increase in reduction from -2,374.56 MTCE/year in base-line scenario to -4,000.04, -4,608.64, and -8,110.91MTCE/year of 10%, 25% and 35% recycle, respectively. CH_4 production in landfill reduce from 5,794.19 MTCE/year in base scenario to 5,697.96, 5,553.61, and 5,475.38 MTCE/year of 10%, 25% and 35%, respectively. If the methane is used as fuel, the carbon emission decreases. (Table 4.11) (see Appendix A Table A-7)

Table 4.11 Carbon balance (MTCE) of Nonthaburi MSWM at 10% 25% and 35% recycle

Inventory/ Categories	Base-line scenario	Scenarios (% Recycle)		
		10%	25%	35%
Collection				
Diesel consumption	+627.25	+622.43	+592.67	+572.83
Landfill				
Diesel consumption	+155.94	+154.89	+147.48	+142.55
C /CH_4 Production	5,794.19*	5,697.96*	5,553.61*	5,475.38*
C/Storage	6,389.62**	6,323.52**	6,021.18**	5,819.62**
Recycle				
Paper	-574.71	-1,088.00	-1,857.92	-2,371.21
Plastic	-35.03	-876.94	-2,139.79	-2,981.70
Glass	-14.37	-61.54	-132.29	-179.45
Metal	-2,533.66	-2,750.88	-3,076.71	-3,293.93
Total Carbon	-2,374.56	-4,000.04	-4,608.64	-8,110.91

* not accounted for carbon emission, if collect and use as fuel it means reduction

** not accounted for carbon emission

4.8.2 The Scenarios of Khon Kaen Municipality

From the model when the recyclable material increased to 10%, 25% and 35% resulting in the quantity of solid waste and carbon emission from energy consumption in collection transportation and landfilling decreased. The total carbon balance increase in reduction from -122.46 MTCE/year in base scenario to -975.04, -2,255.49, and -3,107.47 MTCE/year of 10%, 25% and 35%, respectively. CH_4 production in landfill reduce from 3,870.1 MTCE/year in base scenario to 3,795.46, 3,683.49, and 3,608.84 MTCE/year of 10%, 25% and 35%, respectively. If the methane is used as fuel, the carbon emission decreases. (Table 4.12) (see Appendix B Table B-9)

Table 4.12 Carbon balance (MTCE) of Khon Kaen MSWM at 10% 25% and 35% recycle

Inventory/ Categories	Base-line scenario	Scenarios (% Recycle)		
		10%	25%	35%
Collection				
Diesel consumption	+73.25	+71.87	+69.21	+67.43
Transfer station				
Diesel consumption	+115.51	+112.71	+108.53	+105.74
Landfill				
Diesel consumption	+39.03	+38.11	+36.70	+35.76
C /CH_4 Production	3,870.10*	3,795.46*	3,683.49*	3,608.84*
C/Storage	3690.19**	3,601.15**	3,467.58**	3,378.54**
Recycle				
Paper	-134.45	-556.59	-1,189.79	-1,611.93
Plastic	-53.79	-413.33	-952.65	-1,312.19
Glass	-2.61	-12.24	-26.68	-36.31
Metal	-159.41	-215.57	-299.81	-355.97
Total Carbon	-122.46	-975.04	-2,255.49	-3,107.47

* not accounted for carbon emission, if collect and use as fuel it means reduction

** not accounted for carbon emission

4.8.3 The Scenarios of Phitsanulok Municipality

From the model when the recyclable material increased to 10%, 25% and 35% resulting in the quantity of solid waste and carbon emission from energy consumption in collection transportation and landfilling decreased. The total carbon balance increase in reduction from -450.37 MTCE/year in base scenario to -854.61, -1,460.91, and -1,865.10 MTCE/year of 10%, 25% and 35%, respectively. (Table 4.13) (see Appendix C Table C-10)

Table 4.13 Carbon balance (MTCE) of Phitsanulok MSWM at 10% 25% and 35% recycle

Inventory/ Categories	Base-line scenario	Scenarios (% Recycle)		
		10%	25%	35%
Collection/				
Diesel consumption	+117.23	+114.42	+109.80	+106.73
Transfer Station/				
Electricity Use	+12.39	+11.63	+11.16	+10.85
Diesel consumption	+29.68	+28.93	+27.77	+26.99
MBT Landfill/				
Electricity Use	+5.24	+5.09	+4.88	+4.75
Diesel consumption	+97.34	+94.83	+91.01	+88.46
C/Storage	1819.42**	1,771.79**	1,700.34**	1,652.71**
Recycle				
Paper	-197.79	-271.23	-381.39	-454.83
Plastic	-140.54	-395.96	-779.09	-1,034.51
Glass	-3.56	-7.28	-12.88	-16.61
Metal	-370.29	-435.04	-532.17	-596.93
Total Carbon	-450.37	-854.61	-1,460.91	-1,865.10

* not accounted for carbon emission, if collect and use as fuel it means reduction

** not accounted for carbon emission

4.8.4 The Scenarios of Phuket Municipality

From the model when the recyclable material increased to 10%, 25% and 35% resulting in the quantity of solid waste and carbon emission from energy consumption in collection transportation and landfilling decreased. The total carbon balance increase in reduction from +2,932.78 MTCE/year in base-line scenario to -+1,932.44, +445.69, and -519.76 MTCE/year of 10%, 25% and 35%, respectively. CH_4 production in landfill reduce from 764.04 MTCE/year in base-line scenario to 748.59, 725.41, and 709.95 MTCE/year of 10%, 25% and 35%, respectively. If the methane is used as fuel, the carbon emission decreases. When increased recycle resulting in the amount of carbon from fossil fuels of furnace down from +2,932.78

MTCE/year in base-line scenario to +1,932.44, +445.69, and -519.76 MTCE/year of 10%, 25% and 35%, respectively. (Table 4.14) (see Appendix D Table D-8)

Table 4.14 Carbon balance (MTCE) of Phuket MSWM at 10% 25% and 35% recycle

Inventory/ Categories	Base-line scenario	Scenarios (% Recycle)		
		10%	25%	35%
Collection				
Diesel consumption	+100.73	+98.64	+93.85	+90.77
Landfill				
Diesel consumption	+4.22	+4.16	+3.97	3.84
C /CH_4 Production	764.04*	748.59*	725.41*	709.95*
C/Storage	804.51**	786.57**	749.73**	725.16**
Recycle				
Paper	-177.89	-427.11	-800.93	-1,050.14
Plastic	-89.90	-402.92	-872.43	-1,185.45
Glass	-42.21	-54.61	-73.20	-85.59
Metal	-7.55	-28.01	-58.69	-79.15
Incineration				
Diesel consumption	+5.48	+5.29	+5.05	+4.88
Electricity Sale	-165.10	-160.45	-152.93	-147.92
Combustion				
C from Biomass	6,442***	6,595***	6,747***	6,823***
C from Fossil	+3,305	+2,897	+2,301	+1,929
Total Carbon	+2,932.78	+1,932.44	+445.69	-519.76

* not accounted for carbon emission, if collect and use as fuel it means reduction

** not accounted for carbon emission

***Carbon biomass emission not accounted for carbon emission