CHAPTER IV
RESULT AND DISCUSSION

4.1 Description of Diary Manure Management Scenarios

Earthen holding ponds (Scenario 1) are earth-walled structures at or below ground that provide long-term storage of manure at a low cost (OSU, 2006). The holding pond is simply a manure storage system and includes no forms of treatment. The primary function of the holding pond is to store the manure for a period of up to 6 months (Tao *et al.*, 2008) while preventing ground and surface water contamination. To aid in the prevention of contamination, a liner for the holding pond may be installed. The open air holding pond is typically a source of odor. However, holding ponds that contain dairy manure typically form a floating crust that controls odor problems until the pond is agitated for liquid removal. During agitation the separated solids and liquids are mixed into slurry so that they may be pumped out of the holding pond into a distribution tank truck to be used for land application as a fertilizer.

The system boundary for Scenario 1A is shown in Figure 4.1. This Scenario begins with the manure being flushed from the free stall barn. The manure is then transported through a gutter into a chopper pump that creates evenly distributed slurry of manure. Following the chopper pump, the slurry is transported through a pipe into a holding pond using an electric pump. Once the manure reaches the holding pond it is stored for a maximum period of 180 days (Tao *et al.*, 2008) and then the manure is pumped out of the holding pond for land application (Lyngso, 2012; Harrigan, 2010). The frequency for manure land application depends on the season. It will be shown in Table 4.1.

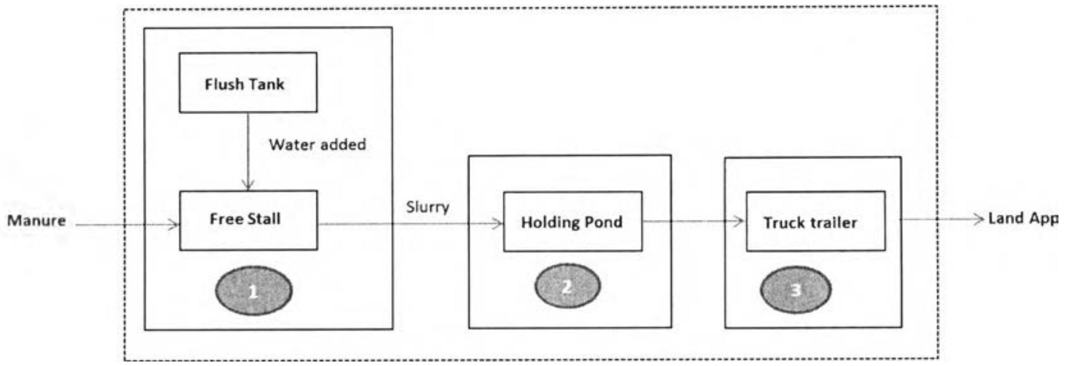


Figure 4.1 System boundary for Scenario 1A modeled for a holding pond.

Table 4.1 Time table for manure land application.

Season	Month	Frequency	Total
Spring	March, April, May	every week	12
Summer	June, July, August	every two months	1.5
Autumn	September, November, October	every two months	1.5
Winter	December, January, February	depended on weather	1
Total transfer/year			16

The system boundary for Scenario-Scenario 1B is shown in Figure 4.2. This Scenario has only one difference from Scenario-Scenario 1A. Here, the manure is collected by the use of mechanical scrapers instead of gravity flush (Chang *et al.*, 2005). The semi-solid manure is still run through each of the same processes as in Scenario-Scenario 1A. The manure solids content is higher than that in Scenario-Scenario 1A when it reaches the holding pond. Figure 4.2 shows the diagram for the system boundary of Scenario 1B.

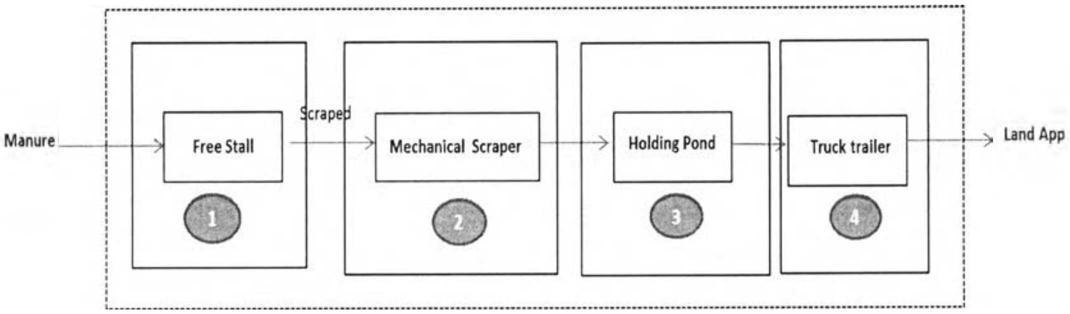


Figure 4.2 System boundary for Scenario 1B modeled for a holding pond.

The system boundary for Scenario 2 is shown in Figure 4.3. Similar to Scenario 1A and 1B, the manure is mixed into a uniform slurry after the manure is flushed. The manure is then pumped through a pipeline into an anaerobic digester that uses 20 days retention time, the average time period for the manure between the time of entering and leaving an anaerobic digester (Peter, 2001). The methane and carbon dioxide generated by the digestion process are captured at the top of the digester. After the manure is digested, it is pumped out of the digester into an effluent storage tank. The effluent manure goes through a process of solid-liquid separation in a detention basin. The liquid effluent is used for controlled irrigation, while the solids are used as bedding for the barns, potting soil, or can be spread as a land application.

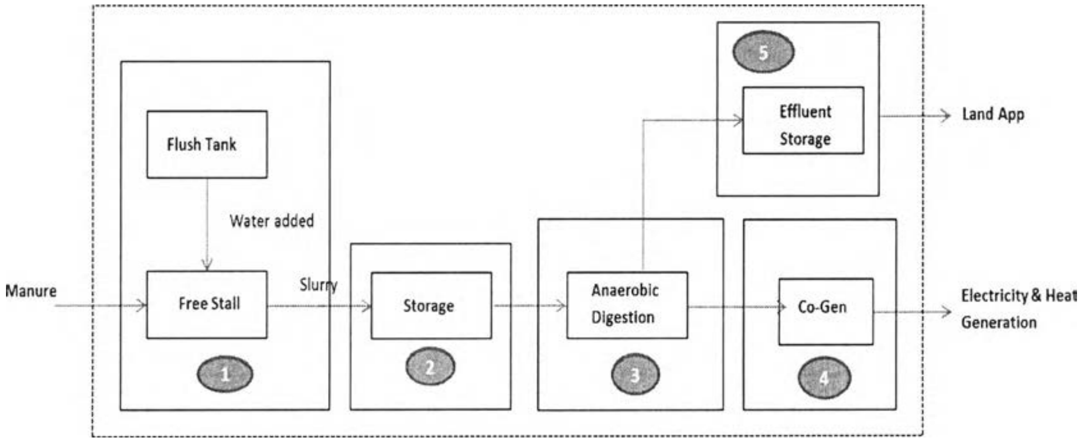


Figure 4.3 System boundary for Scenario 2 modeled for anaerobic digestion.

The system boundary for Scenario 3A is shown in Figure 4.4. The proposed process design combines advantages of highly energy-efficient superheated steam drying (SSD) technology and the heat generated from a reaction between cow manure moisture and fly ash. Fly ash also acts as coagulant that enhances the drying rate and helps breaking manure into small particles. In this scenario, the raw manure is pumped through a heat exchanger to pre-heat the cow manure by the residual steam from the turbine. Then, it was estimated 30 minutes to dry 6.25 tons of wet cow manure using a superheated steam drier (750 °F, 73.5 psi). The residual steam can be used to operate a turbine to generate electricity that offsets the electrical usage of the system. The effluent steam from the turbine is contacted with the raw manure feed through the heat exchanger and further preceded to a scrubber to remove VOCs and finally released as waste water. The biosolids produced from the drier has about 8,000 BTU/lb on a dry weight basis (2.3 kWh/lb), which is similar to the energy content of low-grade coal. So, it can be used for generating superheated steam for the process and also can be sold to a coal-fired power plant. Therefore it may be economically and environmentally beneficial to convert agricultural animal wastes to biofuel instead of land application. For Scenario 3B, the only difference from Scenario 3A, is that the manure is collected by the use of mechanical scrapers instead of gravity flush. The system boundary for Scenario 3B is shown in Figure 4.5.

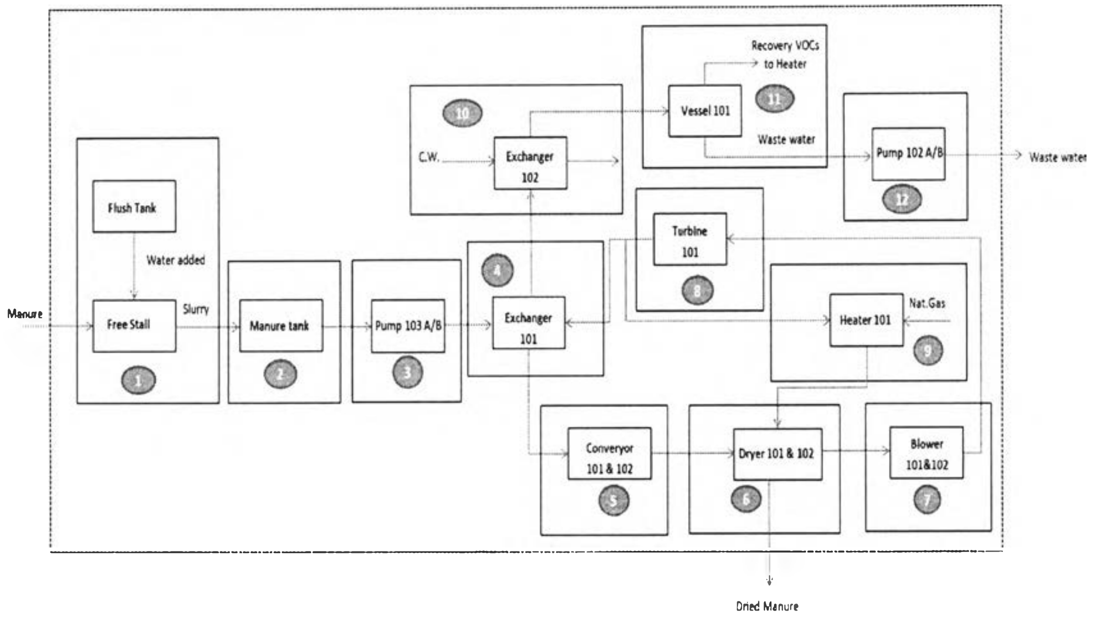


Figure 4.4 System boundary for Scenario 3A modeled for the proposed drying process with water flush.

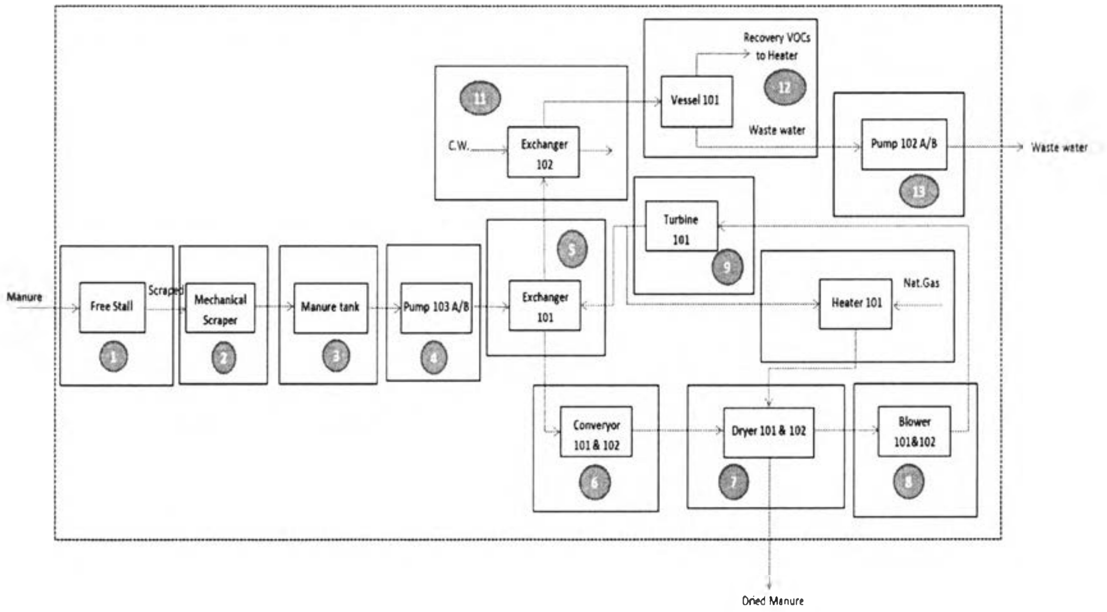


Figure 4.5 System boundary for Scenario 3B modeled for the proposed drying process with a scraper.

4.2 Life Cycle Inventory

LCA started with the cow manure as a waste from a dairy farm and ended with the product of cow manure after passing through the manure management. It included all the activities in the each manure management scenario. LCA also included transportations.

LCA considered only for the treatment operations. Emissions from material acquisition, construction and disposal were not included in LCA. The operation phase considered materials, energy, greenhouse gas (GHG), and acidification potential (AP) for all the activities involved in operating the systems, and also all the transportation in the processes. It was assumed that the machine, such as pump, turbine, exchanger were present in the processes. Creating an inventory of all the materials and energy consumption for the processes of the each system made it possible to estimate GHG emissions and AP using known values of emission factors.

Inventory for the operation phase all five Scenarios required the energy to supply for the pump in manure treatment process. The energy requirement for the pumps was estimated using the standard pump power equation (Anand *et al.*, 2011) as shown in Equation 1.

$$P = (Q \cdot \gamma \cdot (he+hp) \cdot (1+a))/\eta \qquad (1)$$

Where, P = energy delivered to pump [W], Q = flow rate [m^3/s], γ = specific weight of water [N/m^3], he = elevation head provided by pump [m], hp = pressure head provided by pump [m], a = percentage of energy lost to friction [e], η = combined mechanical and hydraulic efficiency of the pump [e].

The life cycle inventory for all five scenarios is given in Table 4.2. Calculations for GHG and AP of all the scenarios were based on three data sets: 1) Emissions from animal feeding operation (US.EPA, 2001). 2) Life Cycle Assessment of Biogas Production from Different Substrates (BFE, 2011). 3) IPCC 2006 method.

Table 4.2 Amount of gaseous emissions (kg) from five scenarios (i.e. life cycle inventory of manure utilization for five scenarios based on annual manure from 347 cows)

Stage	Item	Scenario					Source
		1A	1B	2	3A	3B	
Free stall barn	CH_4	67.46	67.46	67.46	67.46	67.46	(US.EPA, 2001)
	NH_3	13.31	7.61	13.31	13.31	7.61	
Conveyor	NH_3	-	4.11	-	-	4.11	(US.EPA, 2001)
Anaerobic lagoon	NH_3	19.01	19.01	19.01	19.01	19.01	
	N_2O	0.19	0.19	0.19	0.19	0.19	(US.EPA, 2001)
	H_2S	1.90	1.90	1.90	1.90	1.90	
	VOCs	2.09	2.09	2.09	2.09	2.09	
Combustion of co-generation system	CH_4	-	-	0.07	-	-	
	CO	-	-	0.20	-	-	
	CO_2	-	-	52.50	-	-	(BFE, 2011)
	N_2O	-	-	0.00*	-	-	
	SO_2	-	-	0.01	-	-	
	NM VOCs	-	-	0.00**	-	-	
Liquid manure land application	CH_4	7.76	7.76	4.56	-	-	(IPCC, 2006)
	NH_3	8.94	8.94	8.94	-	-	(US.EPA, 2001)
	N_2O	0.09	0.09	-	-	-	(IPCC, 2006)

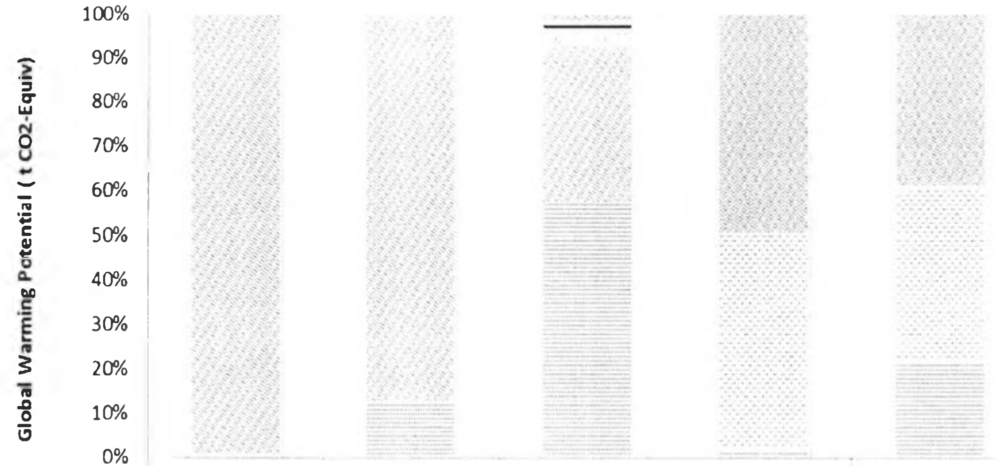
* N_2O from combustion of co-generation system is 0.000324.

** NM VOCs from combustion of co-generation system is 0.009086.

4.3 Life Cycle Impact Assessment

4.3.1 Global Warming Potential for Each Scenario

Figure 4.6 shows the distribution of global warming potential (GWP) of manure management of the five scenarios. The total amount of GHG emissions calculated by LCA were 36,400,121.05 kg CO_2-Equiv for Scenario 1A, 4,752,005.99 kg CO_2-Equiv for Scenario 1B, 535,687.30 kg CO_2-Equiv for Scenario 2, 404,917.98 kg CO_2-Equiv for Scenario 3A, and 322,079.19 kg CO_2-Equiv for Scenario 3B.



	Scenario 1A	Scenario 1B	Scenario 2	Scenario 3A	Scenario 3B
Scrubber	0	0	0	8833.67	549.77
Heater	0	0	0	8745.33	544.29
Co-generation	0	0	9.76582	0	0
⁚ Land app	3.51764	3.51764	1.82533	0	0
■ Electricty	9.36832	0.98649	6.53697	0	0
Storage	0	0	20.3981	13.02	13.02
Truck trailer	33739.60723	2099.87397	187.95505	0	0
Free stall	303.5587	303.55871	303.5587	303.5587	303.5587

Figure 4.6 Relative and absolute contribution of GWP comparison for all five scenarios.

In Scenario 1A (an open-pond with flush), the total amount of GHG was estimated 36,400.12 ton CO_2-Equiv, of which 303.56 ton CO_2-Equiv were emitted from a free stall, 33,739.61 ton CO_2-Equiv from a truck trailer, 2,344.07 from holding pond, 9.37 ton CO_2-Equiv from electricity, and 3.52 ton CO_2-Equiv from manure land application. Therefore, a truck trailer had the largest effect of GHG for this scenario. Almost 93% of the total GHG emissions are released from a truck. The result from Gabi software simulation showed carbon dioxide, carbon dioxide (biotic), and carbon monoxide, which are the major sources of GHG effect from a truck trailer. Hauling of manure from the pond to the field occurs 16 times a year in average, and each time 50,000 m^3 of manure slurry have to be pumped into the tank in the back of the truck. The truck drives 5 miles to the field in average, and drives another 70 miles in average to spread the manure in the field. Consequently the transportation and application of manure generated more GHG emissions from pump operation and truck engine combustion than the open pond.

Another manure management in USA is the untreated holding pond, the same manure management in Scenario 1A but the method of collected manure is different. Scenario 1B uses a manure scraper to collect manure instead of water flush. The total amount of GHG was estimated 4,752.01 ton CO_2-Equiv, of which 303.56 ton CO_2-Equiv were emitted from a free stall, 2,099.87 ton CO_2-Equiv from a truck trailer, 2,344.07 from holding pond, 0.98 ton CO_2-Equiv from electricity, and 3.52 ton CO_2-Equiv from manure land application. Holding pond and truck trailer are two major sources of GHG effect of Scenario 1B, which account for 49% and 44%, respectively. Because the collected manure by a scraper is a semi-solid manure, the solid content's of manure is higher than in Scenario 1A when it reaches a holding pond. However, the total GWP of Scenario 1B is about 9 times lower than Scenario 1A. Moreover, its GWP accounts for 49% from the open pond and 44% from truck operation, respectively. The huge reductions in the total GWP and the contribution of truck operation to GWP is due to the less amount of manure slurry to handle (38,500 lb/day) than Scenario 1A (600,000 lb/day), because Scenario 1B uses less water (2000 gal/day) than Scenario 1A (70,000 gal/day). It is interesting that the CO_2 emissions (2,099 ton CO_2 Equivalent) from the truck operation decreased more than 16 times in Scenario 1B from 330,000 kg CO_2 Equivalent in Scenario 1A. Consequently, a reduction in flush water can tremendously decrease total GHG emissions, especially in truck operation, and the emission from an open-pond slightly increases.

Scenario 2 (anaerobic digester), utilizing anaerobic digestion with biogas recovery for the purpose of supplementing the energy use. The need of purchasing electricity and gas for heat is becoming more common in the United States. In addition to the advantages of waste volume reduction and odor, the anaerobic digestion process produces a biogas mixture that contains primarily methane and carbon dioxide. This biogas can then be utilized as energy for process heating, steam generation, and electrical generation. Greenhouse gas emission from Scenario 2 was investigated by using LCA method. The total amount of GHG was estimated 535.69 ton CO_2-Equiv, of which 9.77 ton CO_2-Equiv was emitted from a co-generation system, 20.40 ton CO_2-Equiv from an effluent storage, 303.56 from a free stall, 187.96 ton CO_2-Equiv from a truck trailer, 1.83 ton CO_2-Equiv from land application, and 6.54 t CO_2-Equiv from electricity. The largest contributors towards the impact categories were the free stall and truck trailer, 57% and 36%, respectively. Biogas produced from the digester is used to generate electricity by a co-generation system (D Cuellar *et al.,* 2008), which, in turn, is used to operate machine, such as a centrifugal pump and a chopper pump in this scenario. Another product from a co-generation system is heat, and it can be used for maintaining the anaerobic digester temperature (Cavinato *et al.*, 2010; Hamed *et al.*, 2010). Therefore, this process were released the lower of GWP than the previous scenarios.

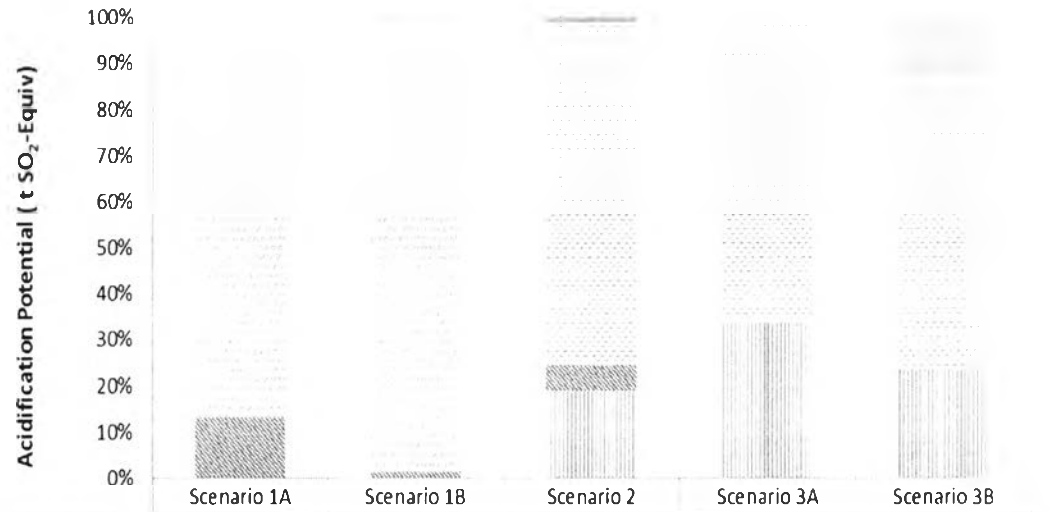
Scenario 3 is the process design combining advantages of highly energy-efficient superheated steam drying (SSD) technology and the heat generated from a reaction between cow manure moisture and fly ash. The residual steam after drying is used to operate an electric turbine to produce electricity. The dried cow manure can either be used for the fire heater to generate the steam, or sold to a coal-fired power plant. Greenhouse gas emissions from Scenario 3A was investigated by using LCA method. The total amount of GHG was estimated 404.92 ton CO_2-Equiv, of which 303.5587 ton CO_2-Equiv were emitted from a free stall, 13.02 ton CO_2-Equiv from a manure tank, 8,833.67 from a scrubber and 8,745.33 ton CO_2-Equiv from a heater was used to generate heat. The largest contributor to the impact category was the free stall. VOCs from effluent steam can be removed in the scrubber and 99% of VOCs can return back to the heater to burn and generate heat. So that can reduce the amount of natural gas and also the GHG effect. Overall, the net GHG emissions from Scenario 3A can decrease significantly. It meets the EPA requirement that water discharged must have below 150 ppm soluble VOC of the characterization of industrial wastewater.

The level of GWP of Scenario 3B turned out to be less than that of Scenario 3A, because 3B process released less VOC from effluent steam than Scenario 3A, and furthermore it used less water to evaporate than Scenario 3A. In addition, Scenario 3B uses less energy to dry the manure because the manure contains less water than Scenario 3A. The total amount of GHG is 322.08 ton CO_2-Equiv, of which 303.5587 ton CO_2-Equiv were emitted from a free stall, 13.02 ton CO_2-Equiv from a manure tank, 549.77 from a scrubber and 544.29 ton CO_2-Equiv from a heater was used to generate heat.

Product from Scenario 3 is dried cow manure (biosolids). It can be either sold to a coal-fired power plant or used for generating heat to produce superheated steam. That is the main reason for Scenario 3 to emit GHG less than Scenario 2. The results suggest that the superheated steam drying process (SSD) had a lower GWP when compare to the existing methods. Scenario 3B is regarded the best manure management method when it comes to GHG and GWP.

4.3.2 Acidification Potential for Each Scenario

Acidification Potential (AP) indicates the impact of the scenarios on ecosystems. High AP may cause an increase of acidity in water and soil. Gas emissions from a system with a high AP can also lead to acid rain which may have harmful impacts on environments, especially on trees (US.EPA, 2001). LCA results show that AP of Scenario 1A is 1,579.61 ton SO_2-Equiv, 1,100.64 ton SO_2-Equiv for Scenario 1B, 20.46 ton SO_2-Equiv for Scenario 2, 11.44 ton SO_2-Equiv for Scenario 3A and 9.40 ton SO_2-Equiv for Scenario 3B. Figure 4.7 shows the distribution of AP of the each manure management for the five scenarios.



	Scenario 1A	Scenario 1B	Scenario 2	Scenario 3A	Scenario 3B
= Co-generation	0	0	0.002944	0	0
Scraper	0	1.183573	0	0	1.183573
▨ Land app	0.228775	0.22875	0.22875	0	0
■ Electricty	0.046055	0.00485	0.032138	0	0
Storage	0	0	15.22328	7.611642	6.023601
Holding pond	1370.095505	1084.248202	0	0	0
▨ Truck trailer	205.408187	12.784124	1.144278	0	0
Free stall	3.833201	2.1904	3.833201	3.833201	2.1904

Figure 4.7 Relative and absolute contribution of AP comparison for all five scenarios.

AP of the existing manure managements (Scenarios 1 and 2) turned out to be much higher than the new process design (Scenario 3) because of NH_3, and NO_2 were released at high levels from these methods. The holding pond and truck operation were the two major contributors. They accounted for 87% and 13% of the total AP in Scenario 1A, respectively. In Scenario 1B, by using a scraper to collecting manure instead of using gravity flush, the total volume of manure entered into the holding pond reduced. As a result, the AP of the holding pond in 1B was lower (1,100 ton SO_2-Equiv) than in 1A (1,600 ton SO_2-Equiv). Furthermore, because of the very low AP of truck operation, the AP of the hold pond has the largest effect on the total AP, 99%. The result shows that raw manure colleting method has significant effects on AP of emissions.

AP of Scenario 2 was 20.46 ton SO_2-Equiv, which is a lower than the AP of Scenario 1A & 1B. Distribution of the AP of this scenario is estimated 74% from the storage, 19% from a free stall, and the rest from land application, and truck operation. The process that burns methane to generate electricity released a very low of AP, 2.94 kg SO_2-Equiv.

For the proposed process of Scenario 3A, a free stall and manure storage are a two major source of AP although they are very low compared to Scenarios 1 and 2. The total AP emission was estimated 11.44 ton SO_2-Equiv. The AP of Scenario 3B was not very much different from that of Scenario 3A (9.40 ton SO_2-Equiv). Other than the minor emissions from the manure storage, free stall, and scraper, AP from the rest of the system was insignificant. As a result, AP emissions of Scenario 3B is the lowest of all the manure managements investigated in this study. Because Scenario 3B used less water in the manure collecting stage, the emission in a free stall is lower than Scenario 3A. Because Scenarios 3A and 3B are closed loop processes, NH_3 emissions to environments are negligible. This result strongly supports the argument that reduction or removal of storages and transport operations can significantly decrease AP as well as GWP. Because the proposed process uses a rapid drying system, it can eliminate open pond or storages. It also achieves a closed-loop system that utilizes residual steam to generate electricity and uses dried manure to produce heat, which reduce gas emissions.