CHAPTER II
LITERATURE REVIEW

2.1 Background and Problem Definition

There are approximately 37,000 dairy cows in Northwest Ohio (9 million in U.S.) that produce 370 million pounds of manure per year. Many dairies spread manure on fields to avoid overflow from storage. The Ohio Department of Agriculture discourages, but does not ban, manure spreading, while many other states prohibit winter manure applications (Henry, 2004). When applied to land, nutrients, pathogens, and other contaminants in the manure seep into the soil and infiltrate drinking water sources threatening the public health and the environment.

Run-off and seep-through water of agricultural and dairy animal wastes from lagoons and fields poses serious impacts on drinking water sources. Field application of cow manure should be reduced or should use treated (sterilized) manures to reduce the serious health hazard. Furthermore, accumulation of animal wastes in lagoons and open ponds should be reduced or even eliminated to prevent run-off water from contaminating water sources. Existing manure treatment processes such as anaerobic digesters require storages or lagoons due to the long processing time and during this storage time, up to 50 % of the nutrients can be leached to nearby water bodies. A low cost and rapid conversion process that can more comprehensively address social, economic, and environmental sustainability is needed to improve the management of manure and increase the utilization of animal wastes, for example, for biofuel generation.

One of the ways to reduce the water and soil pollution impacts of direct field application of animal manures is to treat it to a less harmful manure-based product before application. A good example can be found in biosolids production. Biosolids are stabilized solids from municipal wastewater treatment that meet federal criteria for land application. Biosolids management already incorporates many beneficial reuses and incineration. According to a report issued by the North East Biosolids and Residuals Association, there were 8 million dry tons (MDT) of sewage sludge based biosolids used or disposed of in the United States in 2009 (Kirk, 2010). Approximately 45% of the total processed biosolids were categorized as having beneficial use, 46% was incinerated or landfilled, and 9% was listed as "other". Biosolids process can be applied to agricultural animal wastes. Value can be added to manure by properly converting it to biosolids.

Once properly converted to biosolids, animal manure can be used as fertilizer just like sewage sludge biosolids. The manure biosolids can also be used as biofuel. The use of manure to create biofuel especially seems a viable management alternative. Yet, lack of process design and optimization is a barrier to mass-manufacture of manure-based biosolids fuel. In addition, a sustainability analysis of this approach has not been conducted. Costs to treat animal manure are kept low, given the small profit margins in agriculture, but environmental impacts of recycling excess manure have led to increased environmental regulatory controls that increase the costs. For those dairies located in those states that ban land application, conversion of agricultural manure to biosolids fuel resolves the waste disposal problems.

When it comes to biofuel generation from agricultural manure, anaerobic digestion may be the most common method. However, there are several hindrances to wide-spread use of anaerobic digesters in the United States: One of them is the size of the dairy farms in the U.S. Unlike Europe, the dairy farms in the U.S. are very large. The sheer volume of agricultural animal wastes produced requires large-scale anaerobic digesters resulting in high capital and operating costs. The long residence times of anaerobic digesters (several days to months) result in large amounts of accumulating wastes that require large storage silos that often end up in a compost or lagoon. A low cost and rapid conversion process is needed to increase the utilization of animal wastes for biofuel generation.

2.2 Green House Gas Emissions in U.S.

Greenhouse gas is a gas in an atmosphere that can absorb and emit infrared radiation, but not radiation in or near the visible spectrum. Greenhouse gases (GHG) trap heat and make the planet warmer. Human activities are responsible for almost all of the increase in GHG in the atmosphere over the last 150 years (Solomon *et al.*, 2007). GHG consists of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). In the United States, total GHG emissions in 2011 amounted to 6,702 million metric tons (MMT) of carbon dioxide equivalent (US.EPA, 2011). The primary sources of greenhouse gas emissions are:

- Electricity production (33%). Electricity production generates the largest share of greenhouse gas emissions. Over 70% of our electricity comes from burning fossil fuels, mostly coal and natural gas (US.EIA, 2011).
- Transportation (28%). GHG emissions from transportation primarily come from burning fossil fuel for cars, trucks, ships, trains, and planes. Over 90% of the fuel used for transportation is petroleum based, which includes gasoline and diesel (Kahn, 2007).
- Industry (20%). GHG emissions from industry primarily come from burning fossil fuels for energy as well as greenhouse gas emissions from certain chemical reactions necessary to produce goods from raw materials (US.EPA, 2011).
- Commercial and Residential (11%). Greenhouse gas emissions from businesses and homes arise primarily from fossil fuels burned for heat, the use of certain products that contain greenhouse gases, and the handling of waste (US.EPA, 2011).
- Agriculture (8%). Greenhouse gas emissions from agriculture come from livestock such as cows, agricultural soils, and rice production (US.EPA, 2011).

Figure 2.1 shows the total greenhouse gases emissions in US in 2011 and its sources.

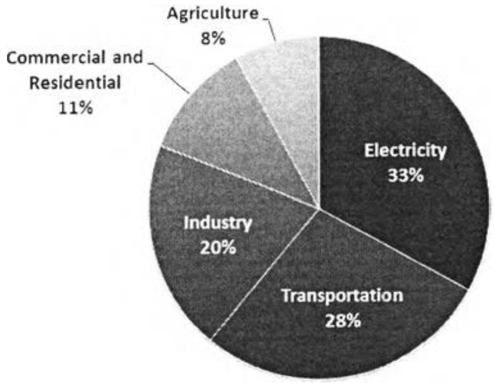

Figure 2.1 Total U.S. greenhouse gases emission 2011. (http://www.epa.gov/climatechange/ghgemissions/sources.html)

2.3 Manure Characteristics and Collections

2.3.1 Manure Characteristics

Manure is a valuable source of nutrients for crops, and it can improve soil productivity. The amount of manure produced, the composition of dairy manure, and its characteristics by livestock types, weights, and production levels are shown in Table 2.1. Thus, the quantity and properties of manure depend on:

- Animal species, age, and productivity.
- Levels of nutrients fed and ration digestibility

Table 2.1 Fresh manure Production and Characteristics per Animal Type (OSU Extension *et al.*, 2006)

Animal Type	**Animal Size (lb)**	**Nutrient content**				**Daily Manure**	
		Ratio (Wm/Wa)	**Water (%wb)**	**TS* (%db)**	**VS** (%db)**	**Weight (lb/day)**	**Volume (ft^3/day)**
Calf	150		88	12	85.7	13	0.200
Heifer	750	0.087	88	12	85.3	65	1.000
Dry Cow	1000	0.082	88	12	85.3	82	1.320
Lactating Cow	1400	0.110	88	12	85.0	153	2.480

*TS = Total solids

**VS = Volatile solids

For fresh manure, water content is consistent at 88 to 92% for non-poultry species and 73 to 75% moisture ranges can be expected for poultry manure. Manure with moisture content in the 88 to 92% range should be handled as a liquid, while manure in the 73 to 75% range should be handled as a solid. Density of fresh manure is similar for all species at 62 to 65 lb/ft^3 (water has a density of 62.4 lb/ft^3). At these densities, a gallon of manure would weigh approximately 8.3 lb. Therefore, to convert fresh manure weights to gallons, weights are divided by 8.3. (Donald *et al.*, 2006).

2.3.2 Type of Manure

2.3.2.1 Liquid Manure

Liquid manure can be stored in underground tanks either under or separate from the building, earthen storage, or above-ground tanks. It's planed for pumping liquid manure up to 12 months storage capacity and provided sufficient capacity for dilution water, rain, snow, and wash water. Manure with up to 4% solids content can be handled as a liquid with irrigation equipment (Delaval, 2013). Liquids that have had the larger solids removed, or manure with dilution water added may contain 4% or less solids (Lorimor, 2000).

2.3.2.2 Semi-solid Manure

Manure can be stored and handled as a semisolid or solid. Semi-solid manure has excess liquids drained off and some bedding added to increase solids content (Lorimor, 2000). In the 10 to 20% solids content range (Delaval, 2013), handling characteristics vary by the type of solids present. In this range, the percent solids content does not have as much effect on handling characteristics as does the type of manure and the amount of bedding present (OSU, 2006).

2.3.2.3 Solid Manure

Manure with 20% solids content (80% moisture content) does not use sand bedding (Delaval, 2013). To handle manure with a solids content of less than 15 to 20%, liquids need to be drained, and the manure must be dried, or bedding must be added. At 20% solids or slightly less, liquid may seep from the manure stack, so a tall stack is not feasible (Lorimor, 2000). Solid manure can be stored on an open or covered stacking slab with or without retaining walls.

2.3.3 Diary Collections

Dairy operations are affected by the quantity and quality of manure that may be delivered to the manure management system. For the housing system, free stall barns are currently the most popular method for large dairy herds. Corral systems with paved feed lanes are also commonly used. Also, in open lot systems, the manure is deposited on the ground and scraped into piles. This method significantly amounts to manure degradation resulting in greenhouse gas emissions.

The transport system of manure to an anaerobic lagoon or a holding ponds generally use a flush system and scrape system. Gravity flushing is performed by releasing water from a gravity tank to flush through the gutter system of a free stall barn or milk parlor to a small storage tank. Flush systems can reduce the concentration of manure less than one percent solids in the flush water. Manure can also be mechanically scraped from any of the housing systems using a metal scraper operated manually or by a motor that runs along the gutter in the barn. Scrape systems are simply systems that collect the manure by scraping it to a pond (Dennis, 2001).

2.4 Dairy Manure Management

2.4.1 Earthen Storage (holding Pond)

Earthen storages can be used for storing liquid manure. This type of storages needs low capital costs and keeps manure under anaerobic conditions. Also, the large exposed surface area permits large quantities of odorous gases to be released into the air. The odors are generally the worst when the manure begins to warm up in the spring. Storage facilities have been accepted as environmentally safe as long as the soil used to build them contains at least 15% clay content. Coarse sands and gravels are not considered environmentally safe and must be lined with an artificial seal (Natural Resource, Canada).

2.4.2 Anaerobic Digestions

The methane produced from the anaerobic digestion of organic wastes and energy crops represents an elegant and economical means of generating renewable biofuel. Anaerobic digestion is a mature technology and is already used for the conversion of the organic fraction of municipal solid wastes and excess primary and secondary sludge from waste-water treatment plants (Jean-Claude *et al.*, 2010).

Dairy manure is evaluated in batch digesters under mesophilic conditions (35 ^{o}C), and the biogas production is affected by manure screening. The methane yields of fine and coarse fractions of screened manure and unscreened manure, reported in term of Litter per Kilogram volatile Solids (L/Kg Vs) after 30 days, were 302, 228, and 241 L/ kgVS, respectively (Hamed *et al.*, 2010). It was found that about 90% of the final biogas yield from dairy manure could be obtained after 20 days of digestion. Average methane content of the biogas was 69% (Hamed *et al.*, 2010). Many researchers try to use thermophilic conditions in order to improve biogas yield from dairy manure, Also, under a proper thermophilic condition (47 ^{o}C), biogas can be produced 0.62 m^3/kg VS (Cavinato *et al.*, 2010). In this case, methane content was higher at 61%. A general improvement in digester behavior was clear when considering the stability parameters such as pH, ammonia, and VFA (Cavinato *et al.*, 2010).

The combustible component of biogas is methane. Equation (1) shows the methane combustion reaction for stoichiometric conditions:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \qquad (1)$$

This equation shows that the combustion of one mole of methane produces one mole of carbon dioxide. Changing this conversion to a mass basis using molecular weights shows that 16 g of methane produce 44 g of CO_2. In other words, 2.75 kg of CO_2 is produced from the complete combustion of 1 kg of methane (D Cuellar *et.al.*, 2008).

Biogas is mainly used for three purposes: 1) to be converted to electricity, 2) to produce heat, and 3) to be used in the transportation.

2.4.2.1 Anaerobic Lagoons

Anaerobic lagoons are covered ponds. Manure enters at one end and the effluent is removed at the other (Dennis, 2001). In an anaerobic lagoon, bacteria break down the manure in a two-step process that shows in Figure 2.2 One group of bacteria converts the manure to organic acids. The second group converts the organic acids to methane gas and carbon dioxide gas (Donald *et al.*, 2006).

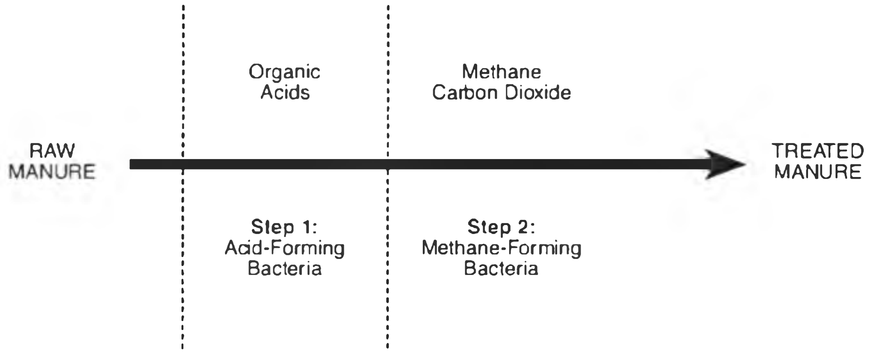

Figure 2.2 Anaerobic digestion process (Source: Ohio State University Extension Bulletin 604, 1992 Editions)

2.4.2.2 Complete Mixed Digester

A complete mixed digester is called a continuously stirred tank (CSTR). Mixing can be occurred with mechanical agitation, effluent recirculation or biogas recirculation. Digester tanks have been constructed of coated steel or concrete (Ann, 2005). Most of complete mixed reactors are operated in mesophilic range. All of the initial anaerobic digesters used to treat dairy manure were completely mixed mesophilic digesters. The advantage of these reactors is the rapid conversion of solids to gas and biomass (Ratkowsky *et al.*, 1981). The Hydraulic Retention Time (HRT) equals the volume of a tank divided by a daily flow (HRT=V/Q) and HRT is vary from 20 to 25 days (Dennis, 2001). Figure 2.3 shows a schematic of completed mixed digester.

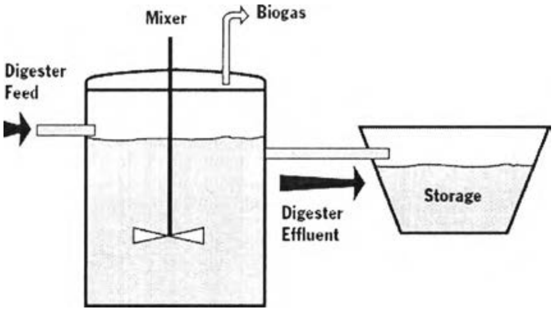

Figure 2.3 Complete mixed digester (Ogejo *et al.*, 2007)

2.4.2.3 Plug-flow Digesters

Plug-flow digesters are linear (horizontal or vertical) shaped reactors. They are essentially not mixed; substrate moves through the reactor in a "slug" and HRT = SRT (solid retention time). Manure is added daily to one side of the digester and an equal volume of digested manure is forced out at the other side. For continuous operation, some of the digested effluent flowing from the end of the tube is separated and returned to the influent substrate (Nallathambi, 1997). Plug-flow digesters work the best condition for dairy manure 11 percent to 14 percent of total solids (Ogejo *et.al*, 2007). HRT is expected to 20-30 days (Volbeda, 2009). Figure 2.4 shows a schematic of plug-flow digester.

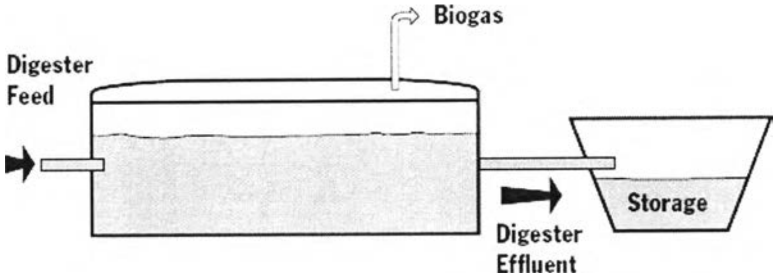

Figure 2.4 Plug flow digester (Ogejo *et.al*, 2007)

2.4.2.4 Fixed-film Digester

Fixed film digesters contain a packing material or media within the reactor vessel that serves as a structure on which bacteria attach, grow, and create a biofilm. Manure is subjected to dilution water for transport or processing. The biofilm serves as a medium to encourage and keep the methane-generating bacteria in the system while processing a high volume of liquid manure. This design, as shown in Figure 2.5, can operate at ambient temperature or higher temperature. HRT is in order of 2-4 days (Ann, 2005). Table 2 shows digester operation parameter for each digester type.

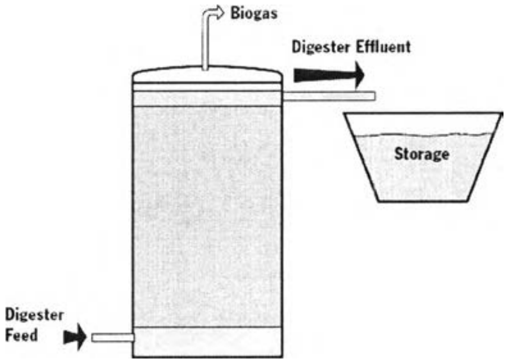

Figure 2.5 Fixed film digester (Ogejo *et.al*, 2007)

Table 2.2 Digester operating parameters (Ann, 2005)

Digester type	Total Solids	HRT (days)	Temperature
Covered lagoon	< 2 %	35-60	Ambient
Fixed-film	< 2 %	2-4	Ambient/Mesophilic
Complete-mix	3-10 %	20-25	Mesophilic
Plug-flow	10-14 %	20-30	Mesophilic

2.4.3 Superheated Steam Drying

A superheated steam dryer is a closed loop pneumatic conveying type. The wet solids are fed into the flow of pressurized superheated steam by pressure rotary valve. Superheated steam drying (SSD) is a process that uses steam heated beyond its boiling point, in a direct contact dryer to remove moisture from the wet material (Annex, 2010). Moisture removed in the form of superheated steam. Also, steam and the dry material are separated in a high efficiency cyclone. From the cyclone, steam is recycled by a centrifugal fan to the inlet of the first heat exchanger. The excess steam generated is continuously bled off. Figure 2.6 showed the schematic of superheated steam dryer.

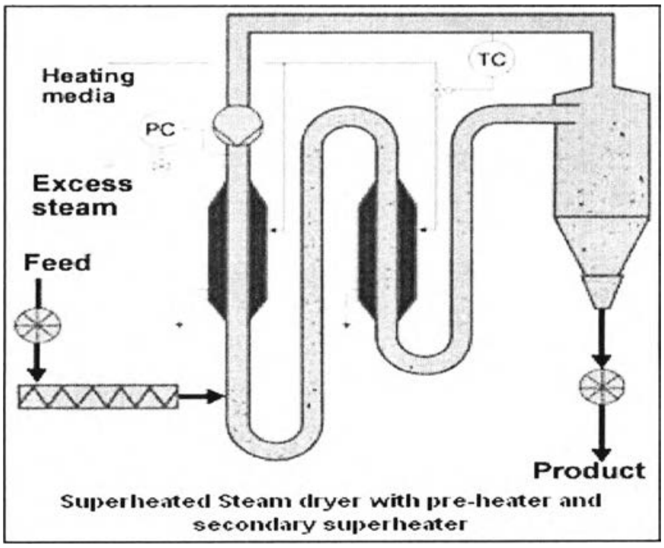

Figure 2.6 Superheated steam dryer (GEA, 2005)

Superheat steam dryers comply with the new trends on energy efficiency and low environmental impact, and thereby, they have a high potential for industrial application in the near future. Some potential materials for superheat steam drying are sludge and similar porous solids. Numerous dryer types currently employed in industry are very developed technologies. A common drying technique is to use hot combustion gas or hot air as the drying medium. Recent research has been done in the utility of superheated steam in the drying process. A benefit of using superheated steam dryers (SSDs) is that it is easy to recover the energy required to vaporize the water and dry the solid stream by condensing the steam stream with another process stream. "With efficient heat recovery, SSDs have net heating requirements as low as 20% that of conventional air drying" (Mujumdar, 2007). In conventional air dryers, the water content must be removed from the air stream, which results in a decreased energy recovery of the system.

On the other hand, steam can be condensed and be used as demineralized water. In some cases, other volatile compounds such as aromatic substances or volatile organic compounds (VOCs) are evaporated together with the steam. Standard processes permit condensing them separately and recovering them as a valuable product as, for example, VOC recovery from various agricultural fruits. Due to the internal circulation of the steam as a drying medium and the sealed housing, no waste air treatment is required. The pure steam with no oxygen present provides an inert process atmosphere in the dryer, which prevents oxidation of the product.

2.5 Life Cycle Assessment

2.5.1 The History and Definition of LCA

The first study on the idea of comprehensive environmental Life Cycle Assessments (LCA) was occurred on 1969 by Coca-Cola Company (Jensen *et al.*, 1997). This study was compared the beverage containers and showed that all container materials had a real environmental impact. In 1979, the Society of Environmental Toxicology and Chemistry (SETAC) (Robert *et al.*, 1996) was found to promote multi-disciplinary approaches to the study of environmental issues. In the late 1980s, life-cycle assessment emerged as a tool to better understand the risks, opportunities and trade-offs of product systems as well as the nature of environmental impacts. Beginning in 1993, the International Organization for Standardization (ISO) tasked a small group of SETAC LCA experts with making a recommendation regarding the need to standardize LCA. The group's recommendation was to proceed with standardization, as ISO14040 (ISO, 1997), ISO 14044 (ISO, 2006). In 2002, the United Nations Environment Programmer (UNEP), SETAC and partners from government, academia, civil society, business and industry joined forces to promote life cycle approaches worldwide (PE International, 2010).

Definition of LCA by SETAC (1993).

"Life Cycle Assessment is a process to evaluate the environmental burden associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal."

Definition of LCA by ISO 14040 (1997).

"LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by

- compiling an inventory of relevant inputs and outputs,
- evaluating the potential environmental impacts associated with those inputs and outputs,
- interpreting the results of the inventory and impact phases in relation to the objectives of the study.

LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle to grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health and ecological consequences."

2.5.2 Overview of LCA

Life cycle assessment (LCA) method has been adopted because it can evaluate and analyze the environmental impacts of product, process, services, or systems from cradle to grave, and it can be used to define and quantify GHG emissions (Miettinen *et.al,* 1997). LCA is an approach to assessing industrial systems. "Cradle-to-grave" begins with the gathering of raw materials from the earth to create products and ends at the point when all materials are returned to the earth. LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next (SAIC, 2006). Figure 2.7 is shown the overview of Life Cycle Assessment.

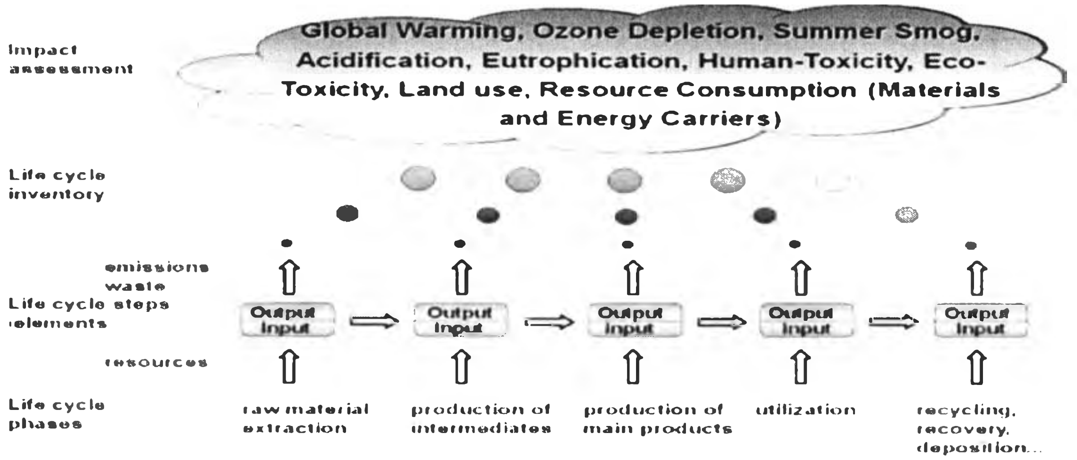

Figure 2.7 Overview of Life Cycle Assessment (Gabi handbook, 2010)

There are four main options to define the system boundaries used from cradle to grave that shows in Figure 2.8.

- Cradle to Grave: includes the material and energy production chain and all processes from the raw material extraction through the production, transportation and use phase up to the product's end of life treatment.

- Cradle to Gate: includes all processes from the raw material extraction through the production phase (gate of the factory) used to determine the environmental impact of the production of a product.
- Gate to Grave: includes the processes from the use and end-of-life phases (everything post production) used to determine the environmental impacts of a product once it leaves the factory.
- Gate to Gate: includes the processes from the production phase only; used to determine the environmental impacts of a single production step or process

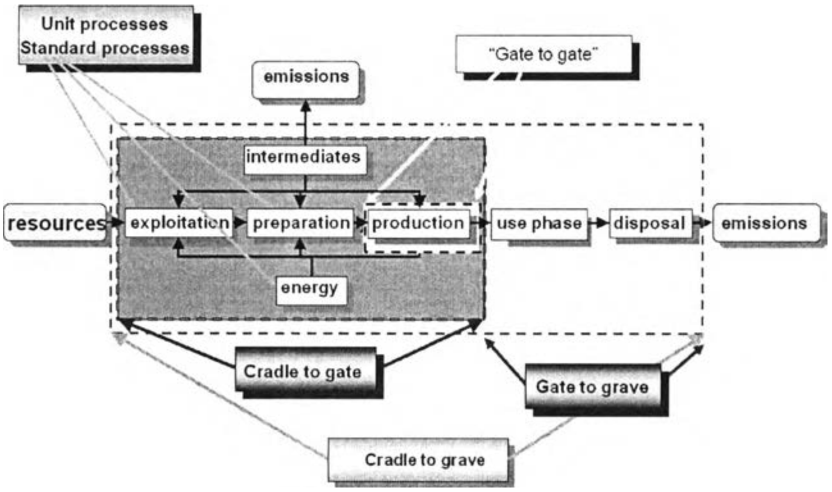

Figure 2.8 System boundaries from cradle to grave (ISO 14044, 2006)

The LCA process is a systematic, phased approach and consists of four stages as illustrated in Figure 2.9.

1. Goal Definition and Scoping

Define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment. During the scope, all assumptions are detailed and the methodology used to set up the product system is defined. The following factors require definition before the LCA is done and a detailed description of each factor is provided in the following functional units: reference flow, description of the system, system boundaries, allocation procedures, impact categories and the impact assessment method.

2. Inventory Analysis

A life cycle inventory (LCI) includes information on all of the environmental inputs and outputs associated with a product or service Identify and quantify energy, water and material usage and environmental releases (e.g., air emissions, solid waste disposal, waste water discharges)

3. Impact Assessment

The inventory list is the result of all input and output environmental flows of a product system. Assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.

4. Interpretation

Evaluate the results of inventory analysis and impact assessment to select a preferred product, process or service with a clear understanding of uncertainty and assumptions used to generate the results.

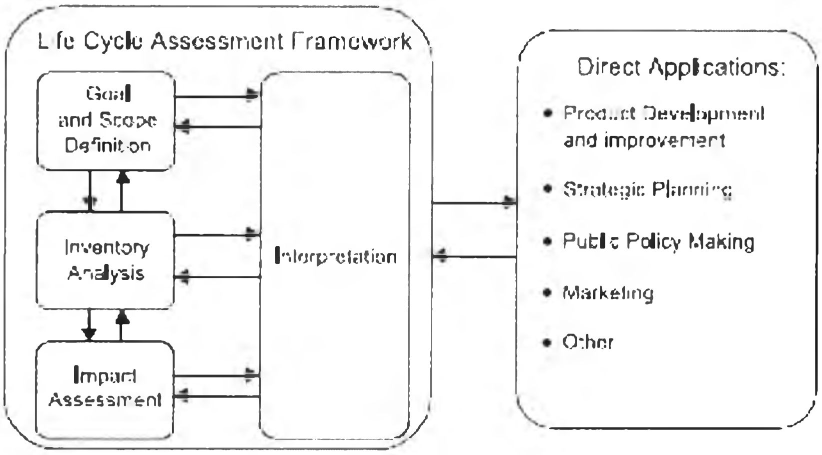

Figure 2.9 Phase and application of life cycle assessment (ISO 14040, 1997)

2.6 Gabi Overview

Professional Engineering (PE) International's consulting program, GaBi 5, supports every stage of an LCA, from data collection and organization to presentation of results and stakeholder engagement. GaBi automatically tracks all material, energy, and emissions flows, as well as giving instant performance of environmental impact categories.

The GaBi 5 platform is complemented by the most comprehensive, up-to-date Life Cycle Inventory database available. The databases maintained by PE International provide over 2,000 cradle-to-gate material data sets, 8,000 intermediary chemical process models, and thousands of LCA projects from quality-controlled industry projects (PE International, 2010)

With several thousands of LCI datasets in the areas of agriculture, energy supply, transport, biofuels and biomaterials, bulk and speciality chemicals, construction materials, packaging materials, basic and precious metals, metals processing, ICT and electronics as well as waste treatment, one of the most comprehensive international LCI databases is Ecoinvent Database that it supports to use in Gabi software.

2.7 Literature Review

The effect of greenhouse gas emissions from animal waste and run-off and seep-through-water of agricultural and dairy animal wastes from lagoons and fields poses serious impacts on drinking water sources. Furthermore, the management of cow manure waste has become the new challenge on the global warming concern. Due to these reasons, many research teams have conducted the LCA on cow manure. De Vries *et al.* (2010) studied the general farm scale situation where manure is applied without treatment, digested or co-digested. They used a LCA tool to focus on environmental analysis. In the case of untreated manure without any form of digestion (Senario 1) a high emission of CO_2-equivelants (CO_2-eq), around 149 kg CO_2-eq per FU was resulted, compared to another case with digestion of only manure

(Senario 2), that resulted in around 101 kg CO_2-eq. For the co-digestion of manure and silage maize (Scenario 3), which led to the lowest emission, even a negative net emission of greenhouse gases, around -3.9 kg CO_2-eq per ton applied product was resulted. Also, N_2O emissions in the first and second scenarios were slightly higher than the third case, at 102, 90.8 and 67.5 kg CO_2-eq, respectively. In scenarios 1 and 2, the high N_2O emissions were due to the intermediate storage of untreated manure, from which N_2O was assumed to emit with a rate of 0.5% of total N in the manure according to IPCC (2006). Moreover, N_2O emissions were reduced in scenario 2 and 3 because of the replaced amount of fertilizer. The comparison suggested that the co-digestion of manure and silage maize be the better method to management of cow manure waste than the other choices.

Hishinuma (2008) used LCA methods to determine the environmental impacts of manure utilization by a biogas plant and by a typical manure composting system. The researchers focused on environmental impacts of manure utilization for 100 cows, in terms of Greenhouse Gases (GHG) and Acidification Gases (AG). They categorized the manure utilization process into three cases: The first case is composting in a compost depot and then application to the field by a manure spreader. Second case is a solid and liquid composting in a compost depot and slurry store and then application by a manure spreader and slurry spreader with a splash plate. The last case is a biogas plant for slurry treatment and then application by a slurry tanker. The results showed that the biogas plant system produces lower GHG emissions than the land application, but it released higher ammonia emission that caused high acidification than (AG) emissions with land application.

Yoo-Sung (2011) estimated the environmental impact of dairy cow manure in Korea by LCA method. They found that manure management and breeding have significant environmental impacts from dairy cow. Improving digestion efficiency, preventing enteric fermentation process and developing manure management system are the ways to reduce environmental impact of methane and nitrous oxide that are related to greenhouse effect.

Turnbull (2002) were concerned of CO_2, CH_4 and NO_2 associated with installing, operating and ultimately closing down of each waste management system.

But their research avoided decomposition of the manure in open storage ponds and eliminated combustion of fossil fuels to heat water. Using anaerobic digestion (AD) technology with 400-cow dairy farm in California, they found that AD systems can reduce the Global Warming Potential (GWP) by almost 80% than a reference system without anaerobic digestion, over 50-year life cycle.

Mezzullo (2013) studied anaerobic digestion (AD) of cattle waste. The AD plant created emissions that appeared to have significant impacts into human respiratory systems and acidification/eutrophication issues within ecosystems. The emission included ammonia from storage, sulphur dioxide, nitrous oxide and particulate from the combustion of biogas, kerosene or diesel. Also, the results show the production and use of biogas is beneficial in terms of greenhouse gases and fossil fuel use.

Cu´ellar (2008) studied different scenarios to compare the change in GHG emissions. In the first scenario, animal manure is collected either in a lagoon or left in the open, and coal is burned to produce electricity for displaces coal-fired generation. The second scenario included the treatment of livestock manure in an anaerobic digester which converted the waste to biogas. The resulting biogas is burned to generate electricity and offset coal fired power. The results showed potential for anaerobic digestion of animal manure to both decrease GHG emissions and provide a renewable energy source. In that case animal waste can make electricity that displaces coal-fired generation (first scenario). The net GHG emissions from electricity production can decrease by 3.9 ± 2.3% (second scenario).