Methane to Markets

Resource Assessment Report for Livestock and Agro-Industrial Wastes – Thailand

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EXECUTIVE SUMMARY

The Methane to Markets Partnership is a collaborative effort between national governments and others to capture methane emissions and use them as a clean energy source. The Partnership was launched in 2004 to minimize methane emissions from key sources including agriculture, coal mining, landfills, and oil and gas systems. The role of the Partnership is to bring diverse organizations together with international governments to catalyze the development of methane projects in developing countries and countries with economies in transition. These include the private sector, the research community, development banks, and other governmental and non-governmental organizations. Facilitating the development of methane projects will decrease greenhouse gas (GHG) methane emissions, increase energy security, enhance economic growth, improve local air quality, and improve industrial safety.

Thailand is a lower-middle-income economy and agriculture is very important as it employs more than 50 percent of the active population. Although the relative contribution of agriculture to the gross domestic product (GDP) has declined as exports of goods and services have increased, it still contributes about 10 percent to the total GDP. Thailand is one of the leading producers and exporters of rice, tapioca,[1] and sugar. Energy related crops such as sugar cane, tapioca, and oil palm have become the main focus in the Thai agricultural sector as a result of government's policy on biofuel promotion.

In 1994, Thailand reported that methane accounts for 23.3 percent of the country's GHG emissions, which was estimated to be 66.6 million tonnes of carbon dioxide equivalent (CO_2e) per year, of which the energy sector contributed 45.3 percent, followed by 27 percent from the agriculture sector and 0.3 percent from waste. In 2003, methane emissions in Thailand increased its share to 27.7 percent of the total country's GHG emissions.

Methane capture from livestock and agro-industry wastes is a proven effective GHG abatement initiative. Utilization of anaerobic digestion (AD) systems for wastewater treatment and methane capture for energy use has been known in Thailand for more than 40 years; however, the number of AD systems, or biogas systems (as commonly called in Thailand), has only significantly increased during the last 10 years as a results of more stringent pollution control regulations and serious renewable energy policy and programs from the Thai government. The latter has not just increased the number of AD systems but has also strengthened domestic the AD industry in terms of research and development (R&D), system designs, construction, and maintenance.

This assessment reviews livestock and agro-industrial sub-sectors in Thailand deemed to have the greatest potential for methane emission capture, the status of AD implementation to date, and the remaining methane emission potential. Major agro-industry sectors that have significant wastewater generation, high organic concentration, and identifiable industry geographical concentration are the criteria used in determining the focus of the assessment. In Thailand, these sectors include swine farming, tapioca, palm oil, and ethanol. The food processing and slaughterhouse sectors are important, but their contribution to the total methane emissions in Thailand appears to be less than 5 percent. The report includes brief discussion on the slaughterhouse sector, however, to enable comparison with other countries.

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[1] Tapioca has different meanings across different continents. In this report, the term tapioca will be used to reference the starch extracted from the root of the cassava plant.

Swine farming is the major sub-sector in the livestock industry. As of December 2008, the country had about 8.5 million pigs and hogs to mainly meet domestic demand. The swine farms in Thailand are a combination of “standard” commercial farms being registered with Department of Livestock Development (DLD), Ministry of Agriculture and Cooperatives (MOAC), as well as non-registered commercial farms and backyard farms. In 2008, there were about 3,400 standard swine farms and more than 200,000 backyard farms throughout the country. Standard farms account for about 60 percent of the total swine population in the country. Average wastewater generated per 60-kilogram (kg)-pig confined on farms in Thailand is about 27 liters per day, and the typical biological oxygen demand (BOD) of effluent wastewater from swine farms is about 8,000 to 10,000 milligrams (mg) per liter, and chemical oxygen demand (COD) is about 18,000 mg/liter. As of 2008, it is estimated that most of medium to large commercial farms have biogas systems accounting for about 50 percent of swine population in the country.

Thailand was the world's largest tapioca products exporter in 2005, with 72 percent of the market share. The main concentration of production is found in the northeastern, northern and central region of Thailand of the country with the total production over 25 million tonnes of cassava roots per year. There are approximately 70 tapioca factories consuming about 60 percent of total cassava root production. The combined total production capacity of these factories is around 3.5 million to 4 million tonnes of tapioca per year. Each tonne of tapioca produced generates approximately 11 to 33 cubic meters (m^3) of wastewater, with organic concentration in the form of COD as high as 13,000 to 20,000 mg/liter. It is estimated that about 40 tapioca factories in Thailand are now either operating or constructing wastewater treatment systems with biogas generation, accounting for about 60 percent of the total starch production capacity.

Thailand is the third world largest palm oil producer; however, it accounts for only about 3 percent of the world production. Total production was around 8.68 million tonnes of fresh fruit bunches (FFB) in 2008, and 80 percent oil palm plantations are in Suratthani, Krabi, and Chumphon provinces in the southern part of Thailand. Palm oil mills in these three major plantation provinces also account for about 80 percent of total crude palm oil (CPO) production in Thailand (1.56 million tonnes in 2008). The current milling processes generates only about 0.4 to 0.5 m^3 of wastewater per tonne of FFB, with COD and BOD ranging from 21,560 to 98,484 and 10,475 to 56,900 mg/liter, respectively. There are 29 palm oil mills in Thailand, which are either operating or constructing biogas systems, accounting for about 69 percent of total palm oil production capacity in the country.

The ethanol industry is an emerging industry in Thailand, in response to the national biofuel policy and programs and rising crude oil price. The first ethanol factory in Thailand began its operation in 2003, and currently there are 11 ethanol factories in operation with the total output of about 1.7 million liters per day. Main feedstocks of the Thai ethanol industry are sugar cane molasses and tapioca. Although the ethanol industry in Thailand has had an impressive growth rate of about 50 percent over the past two years, overall plant utilization capacities are still relatively low, and a surplus of approximately 1 million liters per day is expected by the end of 2009. Production of 1 liter of ethanol generates 12 to 20 liters of wastewater with 100,000 mg/liter COD. Five of 11 existing ethanol plants have biogas systems in place, capable of capturing 42 percent of total methane emissions.

The amount of potential methane emission reductions in each sector, estimated based on the IPCC methodology, as well as the remaining reduction potential considering biogas systems having been implemented to date in Thailand are summarized below:

Priority Sub-Sector	**Methane Emission Potential – 2008 (million tonnes CO_2e/ year)**	**Captured to Date (2008, percent)**	**Remaining Reduction Potential (million tonnes CO_2e/ year)**
Swine Farm	2.6	50%	1.3
Tapioca Starch	2.8	60%	1.12
Palm Oil	1.07	69%	0.33
Ethanol	2.5	42%	1.45
Total	**8.97**		**4.2**

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We would like to acknowledge the significant contributions of key officials from the Department of Livestock Development (DLD) and the Office of Agricultural Economics (OAE) under the Ministry of Agriculture and Cooperative, as well as the Energy Policy and Planning Office (EPPO) and the Department of Alternative Energy Development and Efficiency (DEDE) under the Ministry of Energy.

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ABBREVIATIONS AND ACRONYMS

ABR	Anaerobic Baffle Reactor
AD	Anaerobic Digestion
AFF	Anaerobic Fixed Film
BOD	Biochemical Oxygen Demand
CD	Channel Digester
CDM	Clean Development Mechanism
CH_4	Methane
CMU	Chiang Mai University
CovAL	Covered Anaerobic Lagoon
ConAL	Conventional Anaerobic Lagoon
CO_2e	Carbon Dioxide Equivalent
COD	Chemical Oxygen Demand
CPO	Crude Palm Oil
CSTR	Continually Stirred Tank Reactor
DEDE	Department of Alternative Energy Development and Efficiency
DIW	Department of Industrial Works
DLD	Department of Livestock Development
DOAE	Department of Agriculture Extension
DOH	Department of Health
EfE	Energy for Environment Foundation
ENCON	Energy Conservation Fund
EPPO	Energy Policy and Planning Office
ERDI	Energy Research and Development Institute, Chiangmai University
FAO	Food and Agriculture Organization
FFB	Fresh Fruit Bunch
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GTZ	German Technical Cooperation
HRT	Hydraulic Retention Time
H-UASB	High Suspended Solids – Up-flow Anaerobic Sludge Blanket
IPCC	Intergovernmental Panel on Climate Change

kg	Kilogram
KMUTT	King Mongkut's University of Technology Thonburi
LU	Livestock Unit
LWK	Live Weight Killed
mg	Milligram
MOAC	Ministry of Agriculture and Cooperatives
MONRE	Ministry of Natural Resources and Environment
MW	Megawatt
NEPO	National Energy Policy Office
OAE	Office of Agricultural Economics
PCC	Pollution Control Committee
PCD	Pollution Control Department
PDTI	Pilot Plant Development and Training Institute, King Mongkut’s University of Technology Thonburi
POME	Palm Oil Mill Effluent
SS	Suspended Solids
TDS	Total Dissolved Solids
TGO	Thai Greenhouse Gas Management Organization
TKN	Total Kjeldahl Nitrogen
TRF	Thai Research Fund
TS	Total Solids
TVS	Total Volatile Solids
UASB	Up-flow Anaerobic Sludge Blanket
VSPP	Very Small Power Producer

1. INTRODUCTION

The Methane to Markets Partnership is a collaborative effort between national governments and others to capture methane emissions and use them as a clean energy source. The Partnership was launched in 2004, and the partners made formal declarations to minimize methane emissions from key sources, stressing the importance of implementing methane capture and use projects in developing countries and countries with economies in transition. The Partnership is focusing on the a few key sources of methane, including agriculture, coal mining, landfills, and oil and gas systems.

The role of the Partnership is to bring diverse organizations together with international governments to catalyze the development of methane projects. Organizations include the private sector, the research community, development banks, and other governmental and nongovernmental organizations. Facilitating the development of methane projects will decrease greenhouse gas (GHG) methane emissions, increase energy security, enhance economic growth, improve local air quality, and improve industrial safety.

Thailand is a lower-middle-income economy with an emerging financial market. With a well-developed infrastructure, a free-enterprise economy, and generally pro-investment policies, Thailand has fully recovered from the 1997–1998 Asian financial crisis. The country is one of East Asia's best performers. Thailand is an economy based on food production, exports, tourism, and production of automotive and electronic goods. Export-oriented manufacturing—in particular, automobile and other manufacturing goods production—and farm output are driving export gains.

Thai agriculture employs more than 50 percent of the active population. The relative contribution of agriculture to the gross domestic product (GDP), however, has declined, while exports of goods and services have increased and contribute about 10 percent to the total GDP. Thailand is one of the leading producers and exporters of rice. Other major crops include rubber, sugar, corn, jute, cotton, and tobacco. Fishing is also an important activity, and Thailand is a major exporter of farmed shrimp.[2]

The Ministry of Natural Resources and Environment reported that, as of 1994, Thailand had an annual emission level of 286 million tonnes of carbon dioxide equivalent (CO_2e), and methane accounts for 23.26 percent of total emissions. The energy sector emits 45.3 percent of total GHG emissions, followed by 27 percent from the agriculture sector and 0.3 percent from waste. In 2003, the Department of Alternative Energy Development and Efficiency (DEDE), under the Ministry of Energy, conducted additional assessments of Thailand GHG emissions and reported an annual emission level of 344.2 million tonnes of CO_2e; methane increased its share to 27.7 percent. Thailand's GHG emissions by gas and by sector are shown in Figures 1-1 and 1-2, respectively.

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[2] The Federation of International Trade Associations. Thailand. www.fita.org/countries/thailand.html.

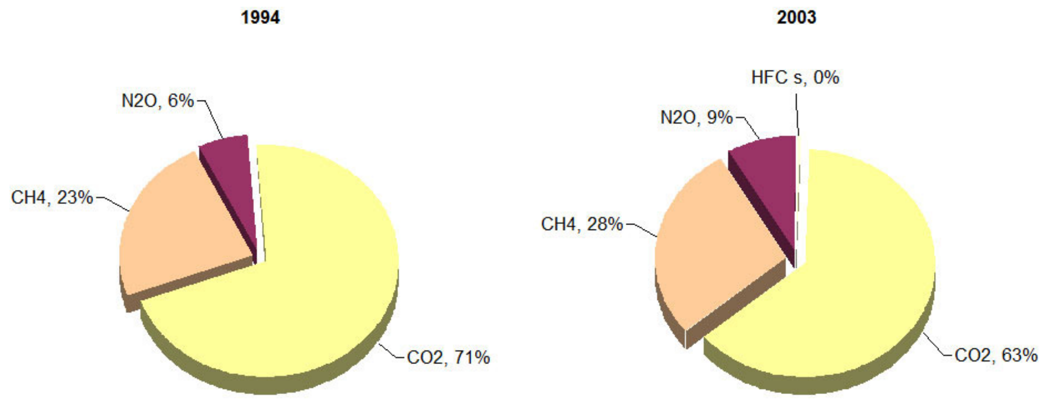


Figure 1-1: Thailand's GHG Emissions by Gas

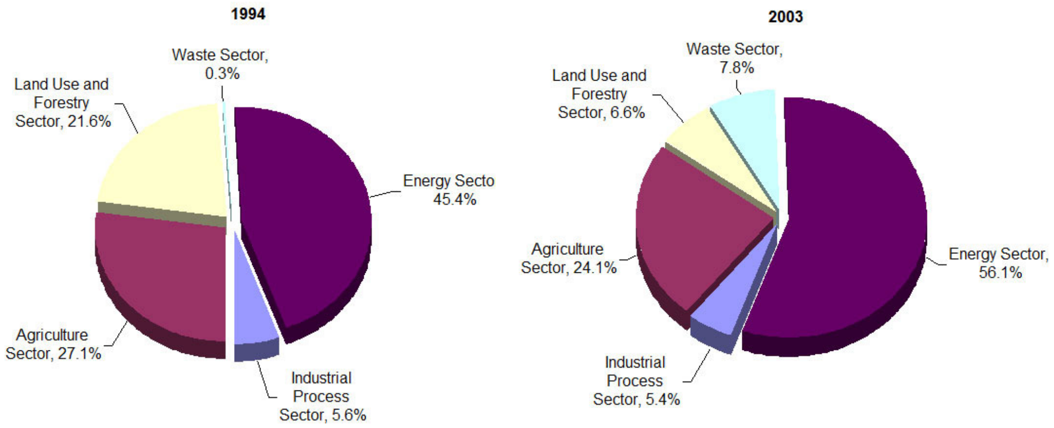
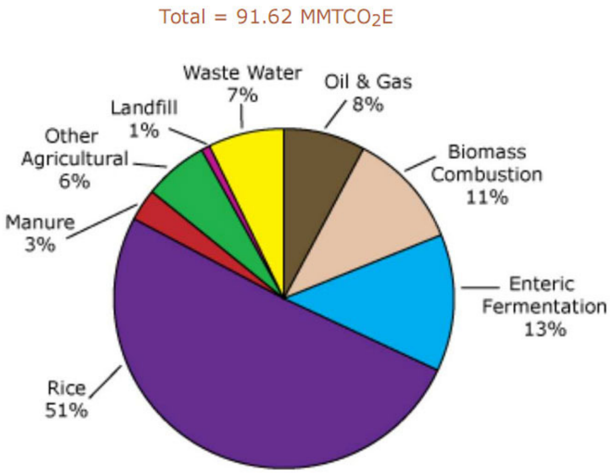


Figure 1-2: Thailand's GHG Emissions by Sector

Based on data in EPA's *Global Anthropogenic Emissions of Non-CO_2 Greenhouse Gases* report, in 2005, Thailand's estimated anthropogenic methane emissions ranked 16th in the world. Approximately 12 percent of its anthropogenic methane emissions—11.3 million metric tonnes of CO_2e—come from agriculture (manure management), landfills, and natural oil and gas systems, as shown in Figure 1-3.



Source: 2006 USEPA Report: Global Anthropogenic Non-CO2 Greenhouse Gas Emissions:1990-2020
http://www.epa.gov/nonco2/econ-inv/international.html

Figure 1-3: Thailand's Estimated Anthropogenic Methane Emissions by Source, 2005

In 2007, the Royal Thai Government established a Thai Greenhouse Gas Management Organization (TGO) to advise the government on matters relating to climate change and to develop national policy to mitigate GHG emissions. Following the establishment of TGO, a number of agro-waste methane capture projects have been evaluated and approved to date. Thailand has also been involved in the “Livestock Waste Management in East Asia” project (funded by the Global Environment Facility [GEF]), which aims to reduce the major negative environmental and health impacts of rapidly increasing concentrated livestock production. A key part of this project is to develop capacity and policies to deploy pollution reduction technologies appropriate for swine waste management using anaerobic digesters as the primary treatment.

2. BACKGROUND AND CRITERIA FOR SELECTION

This report documents the resource assessment of methane emissions of wastes coming from Thailand's livestock and agro-industrial sectors. It focuses on the livestock and agro-industry sub-sectors deemed to have the greatest potential for methane emission reduction or methane capture.

2.1 METHODOLOGY USED

The team used a variety of data sources for conducting the resource assessment including:

- **Field visits** to local sites in various sectors and scales of operations to characterize the waste management systems used and to verify the information collected through other sources.

- **Interviews** with local experts from pertinent ministries (e.g., ministries of agriculture, environment, and energy), local NGOs and engineering/consulting companies working on agriculture and rural development, current users of AD technologies, and other stakeholders.

- **Secondary data** including national and international data (e.g., United Nations Food and Agriculture Organization animal production data sets), specific sub-sector information from business and technical journals, and other documents, reports and statistics.

The team employed the following approach, which will be replicated in future resource assessments in this series:

Step 1: The first step in the development of the Argentina livestock and agro-industry resource assessment was the construction of general profiles of the individual sub-sectors (or commodity groups, e.g., dairies, swine, fruit processing). Each profile includes a list of operations used within the sub-sector and the distribution of facilities by size and geographical location. For the various commodity groups in the livestock sector, the appropriate metric for delineating distribution by size is average annual standing population, (e.g. number of lactating dairy cows, beef cattle, pigs). For the various commodity groups in the agro-industry sector, the metric is the mass or volume of annual processing capacity or the mass or volume of the commodity processed annually.

Step 2: Based on available data, the team then tried to determine the composition of the livestock production and agro-industry sectors at the national level, as well as the relative significance of each of them geographically.

Step 3: With this information, the team focused initially on those commodity groups in each sector with the greatest potential to emit methane from waste management activities. For example, a country's livestock sector may include dairy, beef, swine, and poultry operations but poultry production might be insignificant due to lack of demand or considerable import of poultry products, with correspondingly low methane emissions. We initially focused on those commodity groups with higher emissions to most effectively utilize available resources. Ideally, these livestock production and agro-industry sector profiles can be assembled from statistical information published by a government agency. If such information was unavailable or inadequate, a credible secondary source, such as the United Nations Food and Agriculture Organization (FAO), was used.

Step 4: The team characterized the waste management practices utilized by the largest operations in each sector. Typically, only a small percentage of the total number of operations in each commodity group will be responsible for the majority of production, and thus methane emissions. Additionally, the waste management practices employed by the largest producers in each commodity group should be relatively uniform. Unfortunately, the information about waste management practices is not always collected and compiled, is incomplete, or not readily accessible. Thus, it was necessary to identify and directly contact producer associations, local consultants and business advisors and visit individual operations to obtain this information.

Step 5: The team then assessed the magnitudes of current methane emissions to identify those commodity groups that should initially receive further analysis. For example, large operations in a livestock commodity group, such as beef or dairy, that relies primarily on a pasture-based production system, where manure is distributed continuously by the grazing animals, will have only nominal methane emissions because manure decomposition will be primarily by aerobic microbial activity. Similarly, an agro-industry sub-sector with large operations that utilize direct discharge of untreated wastewater to a river, lake, or ocean will not be the source of significant methane emissions. Thus, the process of estimating current methane emissions will be sharply focused to most effectively utilize available resources. This profiling exercise will aid in identifying the more promising candidate sectors and/or operations for technology demonstration.

2.2 ESTIMATION OF METHANE EMISSIONS IN THE LIVESTOCK AND AGRO-INDUSTRIAL SECTORS

This section describes the generally accepted methods for estimating methane emissions from livestock manure and agricultural commodity processing wastes, along with the modification of these methods to estimate the methane production potential with the addition of anaerobic digestion as a waste management system component.

2.2.1 Manure Related Emissions

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories Tier 2 method were used for estimating methane emissions from each commodity group in the livestock production sector. Using the Tier 2 method, methane emissions for each livestock commodity group (M) and existing manure management system (S) and climate (k) combination are estimated as follows using Equation 2.1:

$$\mathrm{CH}_{4\,(M)} = \left(\mathrm{VS}_{(M)} \times \mathrm{H}_{(M)} \times 365\ \mathrm{days/yr}\right) \times \left[\mathrm{B}_{o(M)} \times 0.67\ \mathrm{kg\ CH_4/m^3\ CH_4} \times \mathrm{MCF}_{S,k}\right] \quad (2.1)$$

where: $CH_{4\,(M)}$ = estimated methane emissions from manure for livestock category M, kg CH_4 per year

$VS_{(M)}$ = average daily volatile solids excretion rate for livestock category M, kg volatile solids per animal-day

$H_{(M)}$ = average number of animals in livestock category M

$B_{o(M)}$ = maximum methane production capacity for manure produced by livestock category M, m^3 CH_4 per kg volatile solids excreted

$MCF_{(S,k)}$ = methane conversion factor for manure management system S for climate k, decimal

As shown, Equation 2.1 requires an estimate of the average daily volatile solids excretion rate for the livestock category under consideration. The default values for dairy cows, breeding swine, and market swine are listed in Table 2.1. Default values for other types of livestock can be found in Tables 10A-4 through 10A-9 in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Table 2.1 – 2006 IPCC Volatile Solids Excretion Rate Default Values for Dairy Cows, Breeding Swine, and Market Swine (kg/swine-day)

Region	Dairy Cows	Breeding Swine	Market Swine
North America	5.4	0.5	0.27
Western Europe	5.1	0.46	0.3
Eastern Europe	4.5	0.5	0.3
Oceania	3.5	0.5	0.28
Latin America	2.9	0.3	0.3
Middle East	1.9	0.3	0.3
Asia	2.8	0.3	0.3
Indian Subcontinent	2.6	0.3	0.3

Realistic estimates of methane emissions using Equation 2.1, also requires identification of the appropriate MCF, which is a function of the current manure management system and climate. MCFs for various types of manure management systems for average annual ambient temperatures ranging from ≤ 10 to ≥ 28 °C are summarized in Table 2.2, and can be found in Table 10.17 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Table 2.2 – Default MCF values for Various Livestock Manure Management Systems

Climate	Manure Management System Default Methane Emission Factor, Percent								
	Conventional Anaerobic Lagoons	Storage Tanks & Ponds	Solid Storage	Dry Lots	Pit <1 Month	Pit >1 Month	Daily Spreading	Anaerobic Digestion	Pasture
Cool	66-73	17-25	2	1	3	17-25	0.1	0-100	1
Temperate	74-79	27-65	4	1.5	3	27-65	0.5	0-100	1.5
Warm	79-80	71-80	6	5	30	71-80	1	0-100	2

Finally, use of Equation 2.1 requires specification of the methane production potential (B_o) for the type of manure under consideration. Default values listed in Tables 10A-4 through 10A-9 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories can be used. The default values for dairy cows, breeding swine, and market swine are listed in Table 2.3.

Table 2.3 – 2006 IPCC Methane Production Potential Default Values for Dairy Cows, Breeding Swine, and Market Swine, m^3 CH_4/kg VS.

Region	Dairy Cows	Breeding Swine	Market Swine
North America	0.24	0.48	0.48
Western Europe	0.24	0.45	0.45
Eastern Europe	0.24	0.45	0.45
Oceania	0.24	0.45	0.45
Latin America	0.13	0.29	0.29
Middle East	0.13	0.29	0.29
Asia	0.13	0.29	0.29
Indian Subcontinent	0.13	0.29	0.29

2.2.2 Agricultural Commodity Processing Waste Related Emissions

Agricultural commodity processing can generate two sources of methane emissions, wastewater and solid organic wastes. The latter can include raw material not processed or discarded after processing due to spoilage, poor quality, etc. One example is the combination of wastewater and the solids removed by screening before wastewater treatment or direct disposal. These solid organic wastes may have relatively high moisture content and are commonly referred to as wet wastes. Appendix A illustrates a typical wastewater treatment unit process sequence. The methods for estimating methane emissions from both are presented below.

2.2.3 Wastewater

For agricultural commodity processing wastewaters, such as meat and poultry processing wastewaters, the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Tier 2 method (Section 6.2.3.1), which utilizes chemical oxygen demand (COD) and wastewater flow data, is an acceptable methodology for estimating methane emissions. Using the Tier 2 method, the gross methane emissions for each waste category (W) and prior treatment system and discharge pathway (S) combination should be estimated using Equation 2.2:

$$CH_{4\,(W)} = [(TOW_{(W)} - S_{(W)}) \times EF_{(W,\,S)}] - R_{(W)})] \qquad (2.2)$$

where: $CH_{4\,(W)}$ = annual methane emissions from agricultural commodity processing waste W, kg CH_4 per year

$TOW_{(W)}$ = annual mass of waste W COD generated, kg per year

$S_{(W)}$ = annual mass of waste W COD removed as settled solids (sludge), kg per year

$EF_{(W,\,S)}$ = emission factor for waste W and existing treatment system and discharge pathway S, kg CH_4 per kg COD

$R_{(W)}$ = mass of CH_4 recovered, kg per year

As indicated above, the methane emission factor in Equation 2.2 is a function of the type of waste and the existing treatment system and discharge pathway and is estimated using Equation 2.3:

$$EF_{(W,\,S)} = B_{o\,(W)} \times MCF_{(S)} \qquad (2.3)$$

where: $B_{o\,(W)}$ = maximum CH_4 production capacity, kg CH_4 per kg COD

$MCF_{(S)}$ = methane conversion factor for the existing treatment system and discharge pathway, decimal

If country and waste sector specific values for B_o are not available, the 2006 IPCC Guidelines for National Greenhouse Gas Inventories default value of 0.25 kg CH_4 per kg COD, based on stoichiometry, should be used. In the absence of more specific information, the appropriate MCF default value selected from Table 2.4 also should be used.

Table 2.4 – Default MCF Values for Industrial Wastewaters, decimal

Existing Treatment System and Discharge Pathway	Comments	MCF[1]	Range
Untreated			
Sea, river, or lake discharge	Rivers with high organic loadings my turn anaerobic, which is not considered here	0.1	0—0.2

Existing Treatment System and Discharge Pathway	Comments	MCF[1]	Range
Treated			
Aerobic treatment plant	Well managed	0	0—0.1
Aerobic treatment plant	Not well managed or overloaded	0.3	0.2—0.4
Anaerobic reactor (e.g. UASB, fixed film)	No methane capture and combustion	0.8	0.8—1.0
Shallow conventional anaerobic lagoon	Less than 2 meters deep	0.2	0—0.3
Deep conventional anaerobic lagoon	More than 2 meters deep	0.8	0.8—1.0

[1] Based on IPCC expert judgment

If the annual mass of COD generated per year (TOW) is not known and the collection of the necessary data is not possible, the remaining option is estimation using Equation 2.4 with country specific wastewater generation rate and COD concentration data obtained from the literature. In the absence of country specific data, values listed in Table 2.5 can be used as default values to obtain first order estimates of methane emissions.

$$TOW_{(W)} = P_{(W)} \times W_{(W)} \times COD_{(W)} \qquad (2.4)$$

where: $P_{(W)}$ = product production rate, metric tons per year

$W_{(W)}$ = wastewater generation rate, m^3 per tonne of product

$COD_{(W)}$ = wastewater COD concentration, kg per m^3

Table 2.5 – Examples of Industrial Wastewater Data, Doorn et al. (1997)

Industry	Typical Wastewater Generation Rate, m^3/ tonne	Range of Wastewater Generation Rates, m^3/ tonne	Typical COD Concentration, kg/m^3	Range of COD Concentrations, kg/m^3
Alcohol	24	16—32	11	5—22
Beer	6.3	5.0—9.0	2.9	2—7
Coffee	NA	NA	9	3—15
Dairy products	7	3—10	2.7	1.5—5.2
Fish Processing	NA	8—18	2.5	—
Meat and Poultry Processing	13	8—18	4.1	2—7
Starch Production	9	4—18	10	1.5—42

Industry	Typical Wastewater Generation Rate, m³/ tonne	Range of Wastewater Generation Rates, m³/ tonne	Typical COD Concentration, kg/m³	Range of COD Concentrations, kg/m³
Sugar Refining	NA	4—18	3.2	1—6
Vegetable Oils	3.1	1.0—5.0	NA	0.5—1.2
Vegetables, Fruits, and Juices	20	7—35	5.0	2—10
Wine and Vinegar	23	11—46	1.5	0.7—3.0

2.2.4 Solid Wastes

A variety of methods are possible for the disposal of solids wastes generated during the processing of agricultural commodities. Included are: 1) land application, 2) composting, 3) placement in a landfill, and 4) open burning. In addition, disposal of solid wastes from meat and poultry processing, such as solids separated from wastewater by screening and dissolved air flotation, may be disposed of by rendering.

If country and waste sector specific values for B_o are not available, the 2006 IPCC Guidelines for National Greenhouse Gas Inventories default value of 0.25 kg CH_4 per kg COD for wastewater, based on stoichiometry, should be used. The use of this default value for the solid wastes from agricultural commodity processing is based in the assumption that the organic compounds in these wastes will degrade as rapidly as the wastewater organic fraction.

Because the mechanisms responsible for the degradation of these wastes are similar to those of livestock manure following land application, the appropriate MCF value for manure disposal by daily spreading listed in Table 10.17 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories should be used. For composting, the IPCC default value of 4 g CH_4 per kg of wet waste, should be used. When agricultural commodity processing wastes are disposed of in landfills, the applicable MCF depends on the type of landfill as shown in Table 2.6.

Table 2.6 – Types of Solid Waste Landfills and Methane Conversion Factors

Type of Site	Methane Conversion Factor Default Value
Managed—anaerobic[1]	1.0
Managed—semi-anaerobic[2]	0.5
Unmanaged[3]—deep (>5m waste) and/or high water table	0.8
Unmanaged[4]—shallow (<5m waste)	0.4
Uncategorized solid waste disposal sites[5]	0.6
[1] **Anaerobic managed solid waste disposal sites.** Controlled placement of waste with one or more of the following: cover material, mechanical compacting, leveling	

[2]**Semi-anaerobic managed solid waste disposal sites.** Controlled placement of wastes with all of the following structures for introducing air into the waste layer: permeable cover material, leachate drainage system, pondage regulation, and gas ventilation.

[3]**Unmanaged solid waste disposal sites—deep and/or with a high water table.** All sites not meeting the criteria of managed sites with depths greater than 5 m and/or a high water table near ground level.

[4]**Unmanaged solid waste disposal sites.** All sites not meeting the criteria of managed sites with depths less than 5 m.

[5]**Uncategorized solid waste disposal sites.** Uncategorized solid waste disposal sites.

For disposal of agricultural commodity processing solid wastes by open burning, the IPCC default value of 6.5 kg of methane per tonne of waste should be used.

For all four disposal options, the commodity specific rate of solid waste generation must be known. In addition, information about the concentration of COD in the solid waste, on a wet weight basis, is necessary for all but the composting disposal option. However, COD concentration generally has not been used as a parameter for agricultural commodity processing solid waste characterization. The alternative is to use published values from studies of methane production potential on a volume or mass of methane produced per unit mass of wet waste, or volatile solids added basis as a first-order estimate for B_o for the waste under consideration. If the COD concentration in the solid waste is known, the methane emissions resulting from land application and landfill disposal with the appropriate MCF is calculated using Equation 2.6:

$$CH_{4\,(SW)} = TOW_{(SW)} \times B_o \times MCF_{(SW,\,D)}] \qquad (2.6)$$

where: $CH_{4(SW)}$ = annual methane emissions from agricultural commodity processing waste SW, kg CH_4 per year

$TOW_{(SW)}$ = annual mass of solid waste SW COD generated, kg per year

$MCF_{(SW,\,D)}$ = methane conversion factor for solid waste W and existing disposal practice S, decimal

2.3 DESCRIPTION OF SPECIFIC CRITERIA FOR DETERMINING POTENTIAL SECTORS

The specific criteria to determine methane emissions reduction potential and feasibility of anaerobic digestion systems are the following:

- Large sector/sub-sector: The category is one of the major livestock production or agro-industries in the country.
- High volumes of wastes going to conventional anaerobic lagoons: The livestock production or agro-industry generates high volume of wastewater.
- Wastes with high organic content: The wastewater generated has a high organic load as measured in terms of its BOD and COD.

- Geographic distribution: There is a concentration of priority sectors in specific regions of the country, making centralized or co-mingling projects potentially feasible.
- Energy intensive: There is sufficient energy consumption to absorb the generation from recovered methane.

The top industries that meet all of the above criteria are swine production, tapioca[3] processing, palm oil processing, and sugar distilleries.

2.4 AD DEVELOPMENT IN THE COUNTRY

Thailand has been promoting biogas for more than 40 years. The initial promotion was limited, however, to small swine farms and biogas for household applications. Following the enactment of the Thai Energy Conservation Promotion Act in 1992 and establishment of the Energy Conservation Fund (ENCON) in 1995, biogas utilization (or methane capture) in the livestock and agro-industry has been recognized as one of the key renewable resources for electricity generation by the Thai government, and the Energy Policy and Planning Office (EPPO), formerly known as National Energy Policy Office (NEPO), has mobilized ENCON to introduce various schemes to promote the implementation of anaerobic digestion (AD) systems, or biogas systems (as commonly called in Thailand).

2.4.1 AD Development in the Livestock Sector

Biogas production technology was first introduced to support environmental and waste management initiatives in Thailand in 1960. The initial promotion of biogas was implemented by the Department of Health (DOH) and targeted at livestock farms, mainly on swine farms, as they are one of the major pollution sources. In 1978, more than 1,500 waste stabilization ponds (WSP) were constructed, but most of them failed due to the lack of experience in proper construction and management.

Following the first oil crisis in the 1980s, the Department of Agriculture Extension (DOAE), Ministry of Agriculture and Cooperatives (MOAC), promoted biogas in swine farms and constructed more than 2,800 WSPs from 1980 to 1988; however, only 35 percent of these ponds were functional. To solve these problems, DOAE, in cooperation with Chiang Mai University (CMU) and with support from the German Technical Cooperation (GTZ), developed another phase of biogas promotion called the Thai-German Biogas Project.

After completion of the Thai-German Biogas Project in 1994, EPPO introduced biogas for power generation promotion in Livestock Farms Project, Phase I (1995–1998). This project was implemented through DOAE and CMU. The project initially focused on swine farms, by providing direct subsidies to farmers for all investment and pre-investment costs. DOAE was responsible for small livestock farms with 8, 12, 16, 30 and 50 m^3 of digester volume, while CMU was responsible for large-scale swine farms.[4] The Biogas Technology Center was also established within CMU to promote and provide technical support for these promotional programs.

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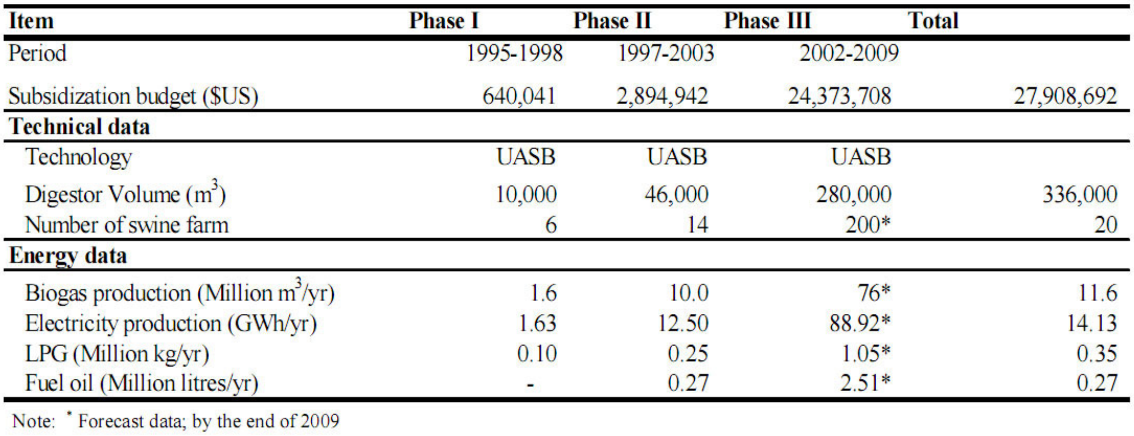
[3] Tapioca has different meanings across different continents. In this report, the term tapioca will be used to reference the starch extracted from the root of the cassava plant.

[4] Biogas Advisory Unit. www.chmai.loxinfo.co.th/~bau/thhistry.html.

Phase II of the project was then implemented from 1997 to 2003, followed by Phase III from 2002 to 2009. These biogas or methane capture projects, driven by the energy interests and environmental benefits, are just add-on products. Following EPPO's promotion and as a result of rising energy prices, most large swine farms in Thailand understand the benefits of using energy from gas production; to help encourage these farms to make the investment, EPPO offers up to a 33-percent subsidy of the total investment cost to farm owners. The total budget for all three phases is approximately US$28 million; key project data are summarized in Table 2-7.

Table 2-7: Summary of EPPO Biogas Promotions in Swine Farms in Thailand[5]



Item	Phase I	Phase II	Phase III	Total
Period	1995-1998	1997-2003	2002-2009	
Subsidization budget ($US)	640,041	2,894,942	24,373,708	27,908,692
Technical data				
Technology	UASB	UASB	UASB	
Digestor Volume (m^3)	10,000	46,000	280,000	336,000
Number of swine farm	6	14	200*	20
Energy data				
Biogas production (Million m^3/yr)	1.6	10.0	76*	11.6
Electricity production (GWh/yr)	1.63	12.50	88.92*	14.13
LPG (Million kg/yr)	0.10	0.25	1.05*	0.35
Fuel oil (Million litres/yr)	-	0.27	2.51*	0.27

Note: * Forecast data; by the end of 2009

Thailand has also been involved in the Livestock Waste Management in East Asia project, funded by GEF. This project aims to reduce the major negative environmental and health impacts of rapidly increasing concentrated livestock production. The project began in 2006 with completion expected in 2011. A key part of the project is to develop capacity and policies to deploy pollution reduction technologies appropriate for pig waste management using anaerobic digesters as the primary treatment. Several waste management demonstration projects in swine farms are under development.

2.4.2 AD Development in the Agro-Industrial Sector

Parallel with the biogas promotions in the livestock sector, EPPO has also promoted biogas projects to various agro-industries, with initial focus on the tapioca and palm oil industries. The main objective of the promotion is to generate heat and electrical energy for in-house demand. These promotions have been carried out in the same manner as in the livestock sector (i.e., providing direct subsidy to processors for the investment cost and all pre-investment cost).

The Thai government has recently strengthened promotion of biogas technology in the Thai agro-industrial sector as the Energy Conservation Promotion Fund Committee has approved strategic plans to promote biogas technology during 2008–2011 through the biogas technology promotion program. The main objective of the program is to encourage wider application of biogas technology in Thailand, which produces clean energy, results in the reduction of carbon

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[5] Wongsapai, W. (2008)

dioxide, and helps alleviate mounting environmental problems. The program focuses on five eligible agro-industrial sub-sectors:

1) Industries associated with products from flour (e.g., tapioca flour, sticky rice flour, noodle products, or other types of flour)
2) Industries that produce cooking or vegetable oil such as palm oil
3) Ethanol industries
4) Latex industries
5) Food processing industries

Through this program, ENCON will provide up to 20 percent of the funding for design and investment of biogas systems in eligible sub-sectors. A total of approximately 500 million baht (US$14 million) was allocated to this program, with different budget ceilings assigned to each sub-sector. In 2008, the program invited potential participants wishing to invest in biogas technology to submit proposals for funding, and a total of 38 biogas projects were approved for funding in the same year. Figure 2-1 and Table 2-8 summarize the status to date of this program.[6]

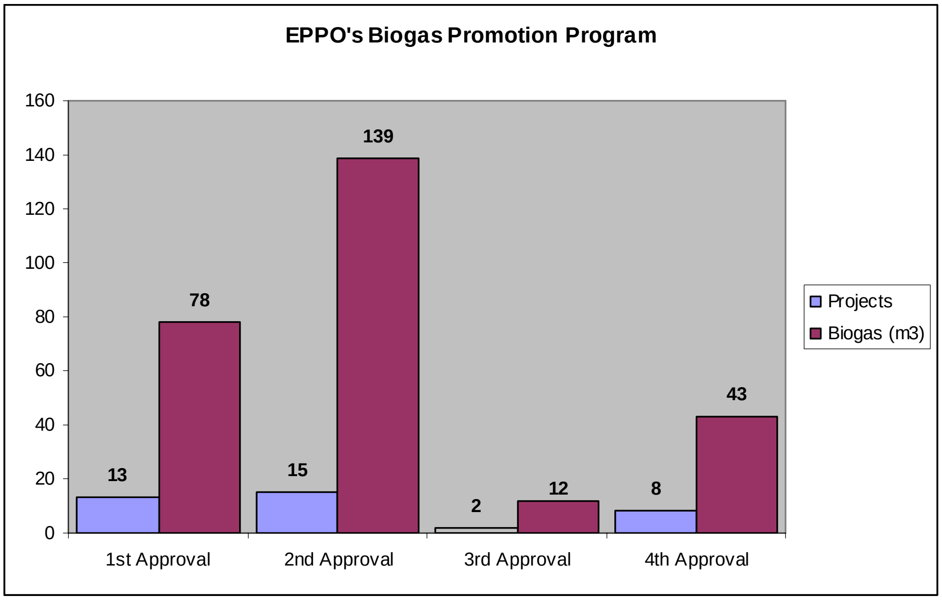

Figure 2-1: Biogas Projects Approved by the Program

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[6] Biogas Technology Promotion Programme (Thailand) 2008. www.thaibiogas.net/th/progress

Table 1-8: Approved Budget for Biogas Projects in Agro-Industrial Sector

Industry	Target		Approved			Remaining Balance (Baht)
	Factory	Million Baht	Factory	Investment Cost (Baht)	Subsidy (Baht)	
1. Tapioca	15	150	13	1,454,009,147	120,023,922	29,976,078
2. Palm Oil	11	110	13	1,019,951,496	109,038,555	961,445
3. Ethanol	5	100	8	1,697,941,222	144,804,000	-44,804,000
4. Latex	5	30	1	8,700,000	840,900	29,159,100
5. Food Processing	20	120	3	83,932,435	15,179,487	104,820,513
Total	**56**	**510**	**38**	**4,264,534,300**	**389,886,864**	**120,113,136**

2.4.3 Mechanisms Supporting AD Development in Thailand

VSPP Program

In 2002, the Roya Thai Government launched a program to promote and develop grid-connected electricity generation by renewable energy power producers that are smaller than 1 megawatt (MW), called the Very Small Power Producer (VSPP) program. The main target of the program is small biomass and biogas power producers. Other renewable technologies such as photovoltaic and wind are included in the program. The VSPP program has served as a catalyst to enhance investment in biogas or methane capture projects in both the livestock and agro-industrial sectors.

Energy Efficiency Revolving Fund

In addition to the subsidy programs administered by EPPO, Thailand has introduced Thailand's Energy Efficiency Revolving Fund, administered by the Department of Alternative Energy Development and Efficiency (DEDE) under the Thai Ministry of Energy. The fund was established to stimulate financial sector involvement in energy efficiency projects and to simplify project evaluation and financing procedures. The fund provides capital at no cost to Thai banks to fund energy efficiency projects, and the banks provide low-cost loans to project proponents, including owners, investors, and Energy Service Companies (ESCOs), with 50 million baht (US$1.25 million) maximum loan size and a fixed interest rate of no more than 4 percent per year. Government intervention in the financing process is minimized.

Although the fund has initially focused on energy efficiency projects, biogas/methane capture projects are eligible, as they provide additional energy supply and hence reduce consumption of electricity and other energy resources for heat demand. In Phase I of the fund (2003–2005), 2 billion baht (US$50 million) was allocated. An additional 2 billion baht was allocated for Phase II (2006–2007), and Phase III of the fund, announced in January 2008, has a total budget of 4 billion baht (US$100 million), of which 1 billion baht is specifically allocated for renewable energy projects, including biogas.

After five years of implementation, the fund has provided support to more than 15 biogas projects throughout the country.

CDM Mechanism

In 2007, the Royal Thai Government established a Thai Greenhouse Gas Management Organization (TGO)[7] to advise the government on matters relating to climate change and to develop national policy to mitigate GHG emissions. Following the establishment of TGO, owners of livestock and agro-industrial facilities, ESCOs, and project developers have seriously considered inclusion of Clean Development Mechamism (CDM) benefits in their investments in biogas/methane capture systems. As of 27 March 2009, 49 biogas projects were approved, and 3 biogas projects are in the pipeline for evaluation.[8]

Biogas Information Centers

Several Web-based centers providing information on biogas technologies and implementation have been established during the course of biogas promotion in Thailand. These Web-based clearinghouses (e.g. www.thaibiogas.com, www.thaibiogas.net, www.efe.or.th) offer comprehensive information on biogas technologies, supporting mechanisms, lists of technology suppliers and consultants, case studies, and more. In addition, several centers and institutes attached to universities provide support in research and development, study, demonstration, and capacity building related to waste management and utilization (e.g. the Pilot Plant Development and Training Institute (PDTI), King Mongkut's University of Technology Thonburi, and the Energy Research and Development Institute (ERDI) at Chiang Mai University).

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[7] Thailand Greenhouse Gas Management Organization. Information dated 8 July 2009.
http://www.tgo.or.th/index.php?option=com_content&task=view&id=5&Itemid=6

[8] Thailand Greenhouse Gas Management Organization. Information dated 8 July 8, 2009.
http://www.tgo.or.th/index.php?option=com_content&task=view&id=36&Itemid=40
http://www.tgo.or.th/index.php?option=com_content&task=view&id=37&Itemid=40

3.1 POTENTIALLY SIGNIFICANT LIVESTOCK AND AGRO-INDUSTRIAL SECTORS AND SUBSECTORS

Agricultural activities account for about 10 percent of Thailand's GDP (crop production: 7.5 percent; livestock production: 2.5 percent).[9] In addition to satisfying domestic demand, agricultural activities generate substantial surpluses of some commodities for export. Major crops include rice, rubber, sugar cane, cassava, fruit, cashew nuts, corn, tobacco, cotton, cocoa, peanuts, soybeans, and medicinal plants. In recent years, cultivation has been shifting towards high-value products and non-traditional crops and away from rice, cassava, and maize. Over the past three years (2006–2008), production of energy crops (i.e., cassava, sugar cane, and palm oil) has shown the highest growth rate at 17.8 percent. Annual production of key agricultural products is shown in Table 3-1. In addition, there is significant pork and poultry production.

Table 3-1: Thailand's Leading Agricultural Crops, 2006–2008 and 2009 (estimated)

Crop	Production (million tonnes)				Growth Rate (Percent) (2006 – 2008)
	2006	2007	2008	2009 (est.)	
Tapioca	22.58	26.92	25.15	29.15	5.5
Sugar Cane	50.41	67.19	76.73	72.65	23.4
Palm	6.72	6.39	8.68	9.54	13.7
Pineapple	2.71	2.18	2.28	2.56	-8.2

Source: Office of Agricultural Economics

Although a variety of agricultural commodities are processed in Thailand, the most significant commodities are: cassava, sugar cane, palm fruit, rubber, pineapple, and livestock. Cassava is processed to extract its starch (tapioca) and sugar cane to produce refined sugar with molasses as a by-product. Some of the tapioca and molasses produced then is used for ethanol production. Palm fruit is processed to extract its oil, and there is extensive canning of pineapple especially for export. In addition, there are about four million pigs and 500,000 to 600,000 head of cattle slaughtered annually to meat domestic demand and for export. Other commodities processed include fruits and vegetables and rice and other cereal grains with the manufacture of products such as such as flour, juices and other beverages, and confectioneries. Although the food processing industry is important, its contribution to the total biogas potential is less than 5 percent (see Table 3-2); therefore, it is not included in this assessment.

3.1.1 Livestock Production

Over the last 15 to 20 years, livestock farm size in Thailand has increased significantly together with improved breeds, feeding programs, housing, and farm management. Contractual

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[9] Food and Agriculture Organization. 2005. Thailand Live Stock Sector Brief, Agricultural activities account for about 10 percent of Thailand's GDP.

arrangement is a common element in domestic livestock production, particularly for poultry meat and eggs. Figure 3-1 shows livestock populations in Thailand from 1998 to 2007.[10]

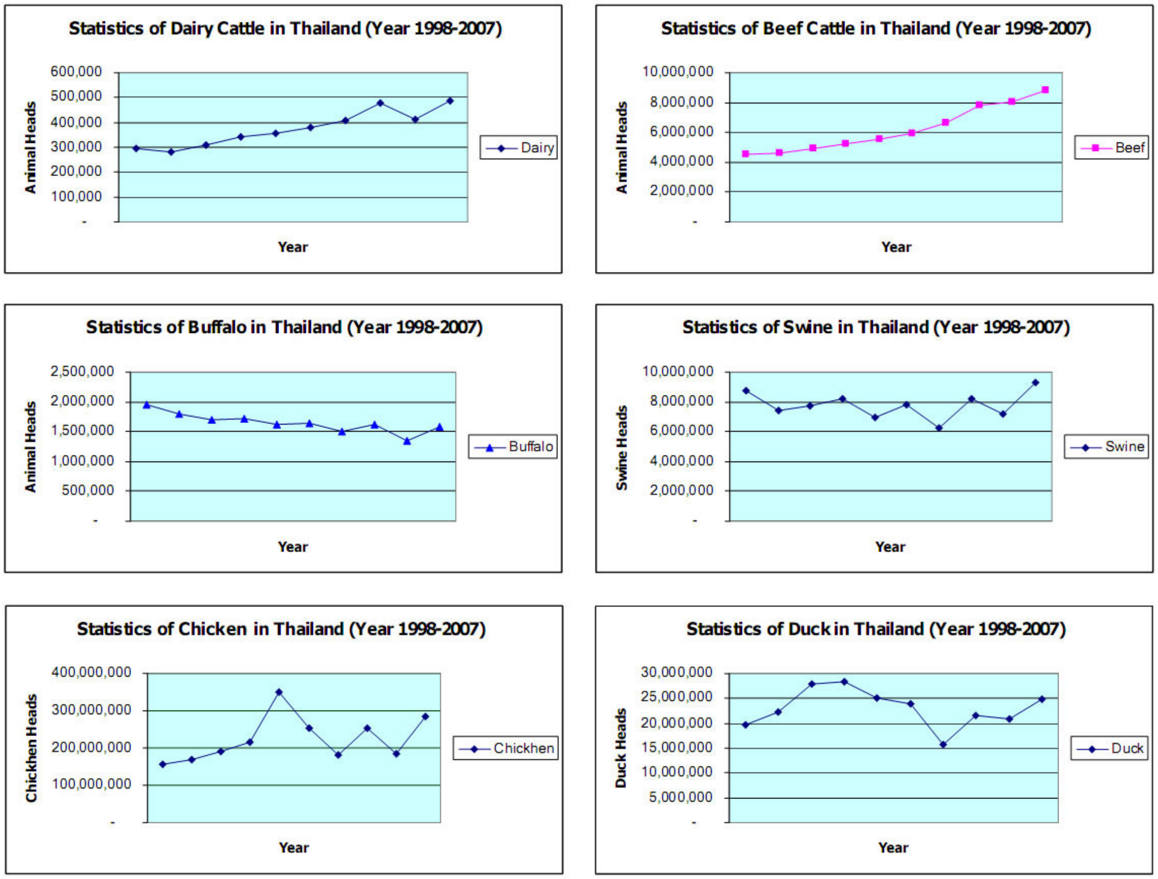

Figure 3-1: Livestock Population Statistics in Thailand (1998–2007)

Most livestock farms, except cattle farms, are highly concentrated in a few provinces in the central, eastern, and western regions around Bangkok. These provinces have all three main characteristics that make them suitable for livestock production. They are the major feed production areas and very close to Bangkok, which is the largest domestic market and main point of export for meat. The swine sub-sector in mainly serves domestic consumers. For the dairy sub-sector, industry growth has been stimulated by the government's policy to provide free milk 260 days per year for K-6 school children. Production-wise, the dairy sub-sector has been exhibiting the strongest growth out of the entire Thai livestock industry.

Before 1990, the livestock farm size in Thailand has gradually increased. The big jump in farm size—particularly in broiler, layer, and swine farms—only occurred in the 1990s after

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[10] Chaiyakul, A. Thailand Country Profile (Agriculture Segment). Department of Livestock Development, Ministry of Agriculture and Cooperatives. Thailand.

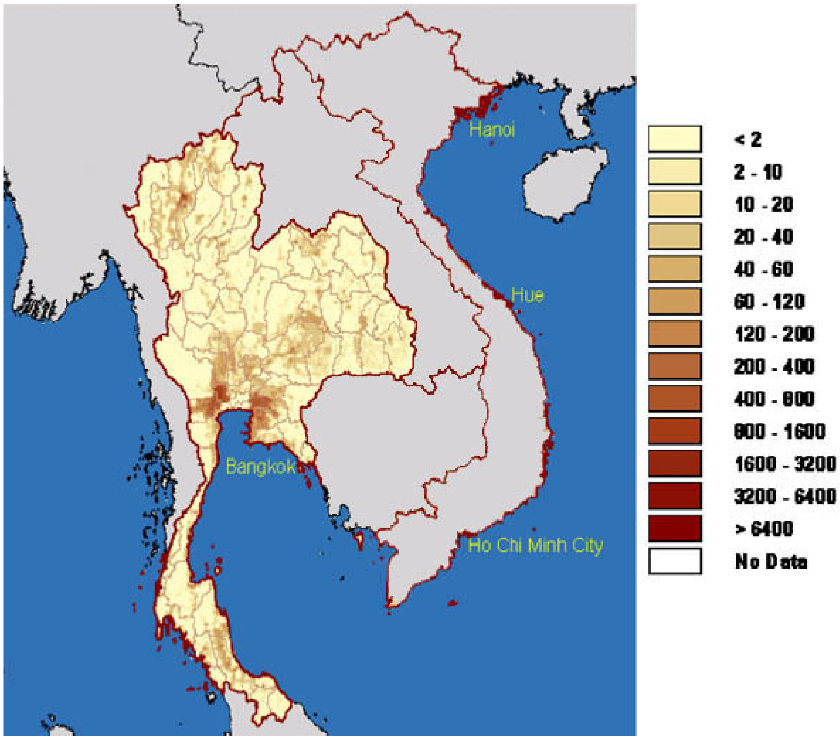
evaporative cooled housing was introduced. As the number of more efficient commercial farms increased, the backyard farms began to shrink rapidly. It is no longer efficient for the crop farmers to also raise chicken and pigs in their backyard, except in the remote rural areas. Not only was their production cost higher, but farmers also find it increasingly difficult to sell a small number of animals. Most of the middlemen prefer to do business with the commercial farms because the transaction cost per unit of animal is cheaper, as they take advantage of economies of scale.

The sharp depreciation of baht after the 1997 crisis (from 25.5 baht per U.S. dollars in 1997 to 55 baht in January 1998) boosted chicken exports for Thailand. This boost has reinforced the importance of farm sizes and economies of scale. Livestock farmers have become more specialized; however, dairy farms still remain small, despite all the government subsides and support. Contract farms have also increasingly played an important role in the livestock industry, specifically in the poultry and swine sub-sectors.

Today, all the major livestock-producing provinces are between 60 to 250 kilometers (km) from Bangkok. Initially, the major production provinces extended only as far as 150 km from Bangkok, e.g. Chacherngsao, Cholburi, and Nakorn pathom. The increased demand for livestock products, together with improvements in the road network, has resulted in the expansion of livestock farms farther away from Bangkok.

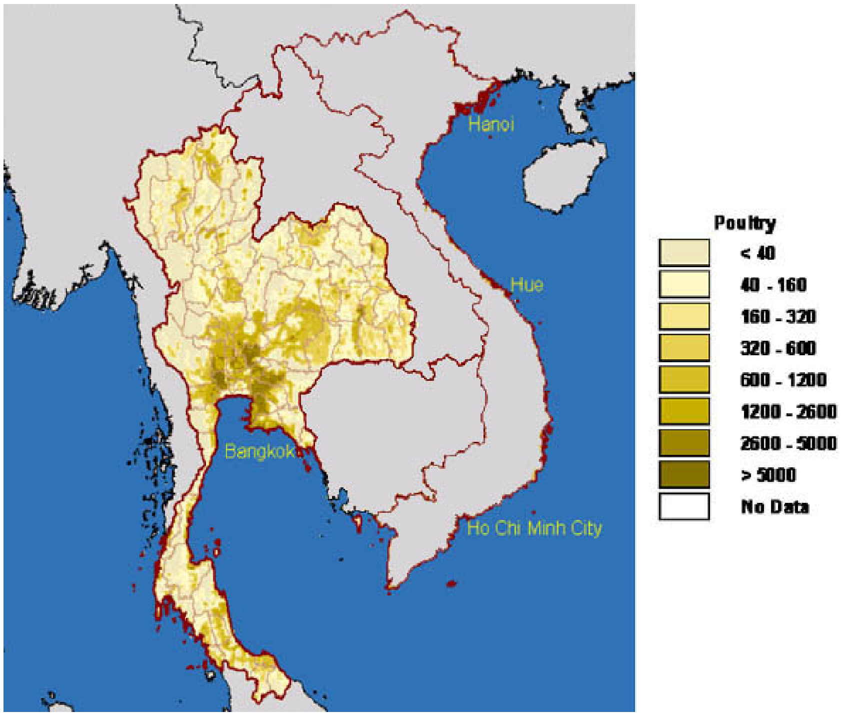
These provinces used to be or are currently major feed production areas as well. Nakorn Pathom and Chacherngsao, which used to have the largest number of pig, broiler, and layer farms, were rice-production areas and thus produced an abundant supply of rice bran and broken rice. The western province of Ratchburi is suitable for upland crops, thus providing almost a year-round supply of roughage for the dairy farms. Other eastern provinces are dominated by upland crops: cassava and sugar cane in Cholburi; cassava and corn in Prachinburi and Sakaew. Saraburi, a province in the Central Plain, is both a rice- and corn-growing area. Lopburi and the eastern district of Korat are the corn-belt areas. In all these provinces, other important crops such as rice and cassava are also frequently found. Small areas of soybean production can also be found in some of these provinces.

Considering annual production and contribution to the GDP, chicken and swine are two important sub-sectors of the Thai livestock industry. Estimated density of pig and poultry are shown in Figure 3-2 and 3-3, respectively.



Source: Food and Agriculture Organization, LEAD Livestock, Environment and Development Initiative Project[11]

Figure 3-2: Estimated Pig Density



Source: Food and Agriculture Organization, LEAD Livestock, Environment and Development Initiative Project

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[11] ftp://ftp.fao.org/docrep/fao/005/AC801e/ac801e01.pdf

Figure 3-3: Estimated Poultry Density

Livestock Waste Management

Management of livestock waste in Thailand varies depending on farm size and type of livestock. Traditional pig farms in Thailand normally manage their livestock wastes (e.g., feces and urine) by dumping them into a pond or series of ponds. Following support and promotion from the Thai Ministry of Energy (through EPPO and DEDE) and the Department of Livestock Development (DLD) under the Ministry of Agriculture and Cooperatives as well as efforts to minimize social problems due to impact of severe odor from livestock waste, better livestock waste handling and management have gradually been adopted by livestock farms in Thailand, especially medium to large farms.

AD systems are popular among swine farms due to the potential of biogas generation and financial support from the government; however, the lack of adequate waste collection in chicken and cattle farms have been a major hurdle in introducing AD systems in these sub-sectors. Typical waste managements by different livestock sub-sectors in Thailand are summarized in Table 3-2.

Table 3-2: Typical Livestock Waste Managements in Thailand

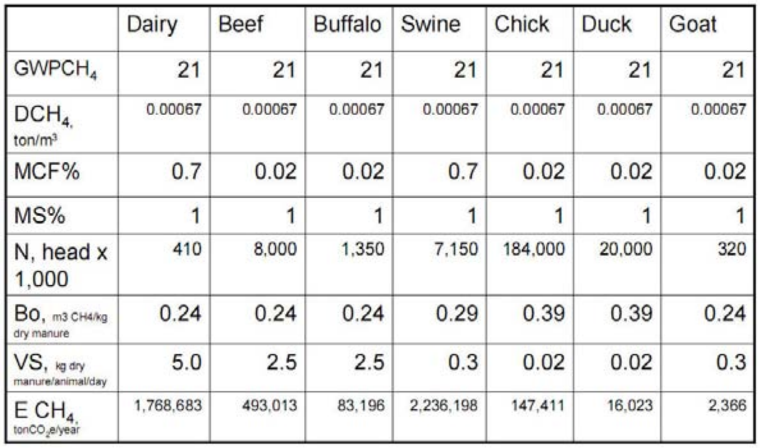
Livestock Waste	Management and Practices
Swine	• Large-scale farms - biogas system by covered anaerobic lagoon and channel digester • Medium scale farms - biogas system or open pond • Small-scale farms - fixed dome or open pond
Cattle (Diary and Beef) and Buffalo	• Grazing - no waste collection • Feeding in byre - collect and use for compost
Chicken	• Countryside farm - no waste collection • Industry farm - collect and use for fish feed and compost
Duck	• Countryside farm - no waste collection • Industry farm - collect and use for compost
Goat	• Grazing - generally no waste collection, some collection is for compost

Source: Methane to Markets Thailand Country Profile Presentation, DLD

Methane Emission Potential and Methane Captured

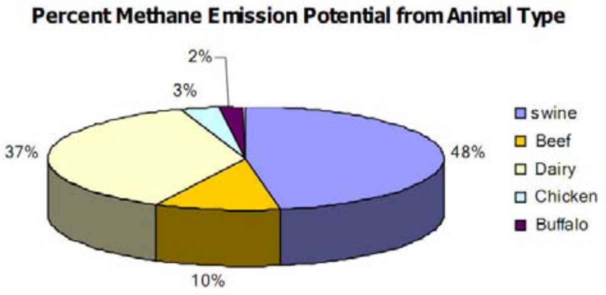
The total annual methane emission potential from livestock waste in Thailand is estimated at 4.75 million tonnes of carbon dioxide equivalent (CO_2e), as shown in Table 3-3. Emissions from the swine and dairy sub-sectors account for about 85 percent, or approximately 4 million tonnes of CO_2e (swine: 48 percent and dairy: 37 percent, see Figure 3-4).

Table 3-3: Estimated Methane Emission Potential from Livestock Waste in Thailand



	Dairy	Beef	Buffalo	Swine	Chick	Duck	Goat
$GWPCH_4$	21	21	21	21	21	21	21
$DCH_{4,}$ ton/m³	0.00067	0.00067	0.00067	0.00067	0.00067	0.00067	0.00067
MCF%	0.7	0.02	0.02	0.7	0.02	0.02	0.02
MS%	1	1	1	1	1	1	1
N, head x 1,000	410	8,000	1,350	7,150	184,000	20,000	320
Bo, m3 CH4/kg dry manure	0.24	0.24	0.24	0.29	0.39	0.39	0.24
VS, kg dry manure/animal/day	5.0	2.5	2.5	0.3	0.02	0.02	0.3
E $CH_{4,}$ tonCO$_2$e/year	1,768,683	493,013	83,196	2,236,198	147,411	16,023	2,366

Source: Methane to Markets Thailand Country Profile Presentation, DLD



Source: Methane to Markets Thailand Country Profile Presentation, DLD

Figure 3-4: Methane Emission Potential by Animal Type

Policy research on renewable energy and energy efficiency in Thailand conducted by the Thai Research Fund (TRF) in 2007 also concluded that swine and dairy sub-sector are the two key livestock sub-sectors to promote biogas for energy generation. Although the dairy sub-sector in Thailand contributes a significant portion to the total methane emissions from livestock waste, capturing those emissions is relatively difficult and expensive due to small farm size and scattered locations. The focus in this report, therefore, is on assessing methane emissions and capturing potential on the swine sub-sector only.

3.1.2 The Agro-Industrial Sector

Biogas Potential Assessment in the Agro-Industrial Sector

In 2000, DEDE conducted an assessment to identify priority agro-industry sub-sectors with significant biogas potential. The study recommended the following 10 sub-sectors: 1) tapioca production 2) sugar refining 3) palm oil extraction 4) seafood canning 5) frozen food 6) slaughterhouse operations 7) pineapple canning 8) soda 9) soft drinks and 10) brewery and distillery.

In 2007, the Thai Research Fund (TRF) conducted an assessment on biogas potential to generate heat energy and electricity from the livestock and agro-industrial sectors in Thailand. The assessment reviewed the status of biogas promotion in swine farms and other livestock sectors. Additional field surveys for the first six priority sub-sectors (i.e. tapioca production, sugar refining, palm oil extraction, tuna canning, slaughterhouse operations, and pineapple canning), as well as the ethanol sub-sector were conducted to substantiate the importance of each sub-sector in term of biogas potential as determined by DEDE. The survey found that most agro-industries in Thailand have improved their waste management practices, resulting in a lower biogas potential; for example, the sugar and tuna canning industries have separated valuable byproducts from wastes and use them for other value-added products. Better water management has also been implemented in palm oil mills and, hence, less wastewater is generated.

The priority livestock and agro-industrial sub-sectors recommended by TRF's policy research study as having significant biogas potential are shown in Table 3-4.

Table 3-4: Biogas Potential from Livestock and Agro-Industrial Wastewater in Thailand

Agro-Industry	Biogas Potential (million cubic meters / year)		
	Total Potential	Captured as of 2005	Remaining
Livestock	237	145	92
Tapioca	344	164	180
Palm Oil Extraction	84	2	82
Canned Tuna – Seafood	21	2	19
Pineapple Canning	13	2	11
Slaughterhouses	0.6	0.2	0.4
Sugar Refining	4.	-	4.
Ethanol Production	149	9	140

Source: Policy Research for Renewable Energy and Energy Efficiency in Thailand, 2007, Thai Research Foundation (TRF)

3.2 SWINE PRODUCTION

Swine farms in Thailand primarily serve demand from domestic consumers. Swine population and production statistics in Thailand from 1999 to 2006 are illustrated in Table 3-5 using official statistics from the Office of Agricultural Economics, Ministry of Agriculture and Cooperatives.

Table 3-5: Swine Population and Production in Thailand

Year	Population	Production
1999	6,369,687	9,075,303
2000	6,558,147	9,493,407
2001	6,688,904	9,716,135
2002	6,878,642	10,869,890
2003	7,064,196	11,927,563
2004	7,254,057	12,095,750
2005	7,533,690	12,257,436

2006	7,688,137	13,314,567
2007	8,381,122	13,544,699

Source: Office of Agricultural Economics (OAE), 2009.

3.2.1 Industry Structure

Swine production in Thailand occurs on a combination of “standard” commercial farms[12] registered with DLD, Ministry of Agriculture and Cooperatives (MOAC), as well as on non-registered commercial and backyard farms. Most of the latter two have less than 100 swine per farm. Based on statistical data published by DLD in 2008, there are about 3,400 standard swine farms throughout the country with sizes varying from less than 100 to more than 100,000 pigs. The swine population on standard farms accounts for about 60 percent of the total population in the country. Expert interviews and qualitative surveys conducted by the International Institute for Energy Conservation (IIEC) reveal that most small commercial farms with less than 100 swine are in general not registered with DLD, and it is estimated that the number of non-registered commercial farms is more than those registered. Given limited data available, it is relatively difficult to obtain a comprehensive view of number of total swine farms in the country; however, the Office of Agricultural Economics (OAE) has estimated that there are more than 200,000 backyard swine farms throughout the country. MONRE classifies swine farm size as shown in Table 3-6:

Table 3-6: Classification of Swine Farm by Size in Thailand

Swine Farm Size (Livestock Unit)	Swine Farm Size (Number of Swine)	Classification	No. of Standard Farms (2008)
≥6 - <60	≥50 - <500	Small Scale	2,249
≥60 - ≤600	≥500 - ≤5,000	Medium Scale	754
> 600	> 5,000	Large Scale	159

Note: 1 livestock unit of swine = 500 kg live weight

3.2.2 Geographical Location

According to OAE’s statistics, which cover both standard farms and backyard farms, the top five major swine producing provinces are Ratchaburi, Nakorn Pathom, Chacherngsao, Cholburi, and Nakorn Rachsima. Swine population density by province, and in comparison with locations of medium to large standard farms, is shown in Figure 3-5. Among 159 large-scale swine farms in Thailand, 82 are larger than 10,000 swine, and 64 of which locate in the 10 major provinces (see Figure 4-1).

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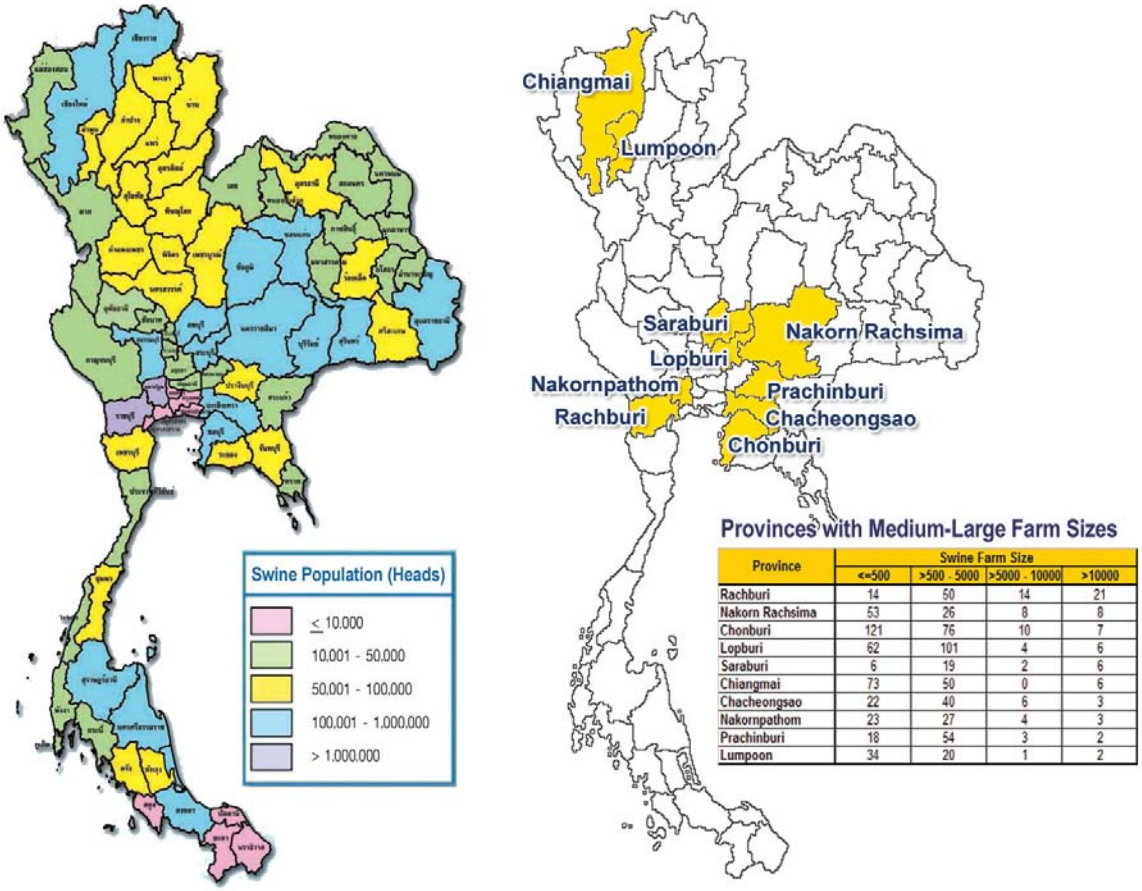
[12] Standard farm is a term used by DLD for any commercial farm registered with DLD and conform to national standards.



Provinces with Medium-Large Farm Sizes

Province	Swine Farm Size			
	<=500	>500 - 5000	>5000 - 10000	>10000
Rachburi	14	50	14	21
Nakorn Rachsima	53	26	8	8
Chonburi	121	76	10	7
Lopburi	62	101	4	6
Saraburi	6	19	2	6
Chiangmai	73	50	0	6
Chacheongsao	22	40	6	3
Nakornpathom	23	27	4	3
Prachinburi	18	54	3	2
Lumpoon	34	20	1	2

Source: OAE and DLD

Figure 3-5: Swine Population by Province, and Locations of Medium to Large Farms in Thailand

3.2.3 Waste Characteristics

Based on a review of literature, the average wastewater generated per 60-kg confined pig is about 27 liters per day with a BOD concentration of 8,000 to 10,000 mg/L. Shown in Table 3-7 is a compilation of the influent characteristics of swine farms that participated in EPPO's biogas promotion programs.

Table 3-7: Wastewater Characteristics from Thai Swine Farms

Parameter	Unit of Measure	S.P.M. Farm	Don Kaew Farm	Pak Chong Farm
Biological Oxygen Demand (BOD)	mg/liter	10,000	10,000	8,000
Chemical Oxygen Demand (COD)	mg/liter	18,000	18,000	17,000
Average Wastewater Production	m3/day	300	20	N/A
Estimated Population	individual	3,000	750	N/A

Source: www.thaibiogas.net and www.eppo.go.th

The Pollution Control Department (PCD) of the Ministry of Natural Resources and Environment (MONRE) issued a regulation in 2002 on effluent characteristics for swine farms before discharging to public water, as shown in Table 3-8.

Table 3-8: Maximum Effluent Characteristics for Swine Farm in Thailand

Parameter	Unit	> 5000 Swine	< 5000 Swine
1. pH	-	5.5 - 9	5.5 - 9
2. BOD	mg/liter	60	100
3. COD	mg/liter	300	400
4.Suspended Solids (SS)	mg/liter	150	200
5. Total Kjeldahl Nitrogen (TKN)	mg/liter	120	200

3.2.4 Waste Handling and Management Systems

Large farms in Thailand tend to have sufficient capacity to manage their waste. But large farms also sub-contract production to small farmers with little or no support for waste management. Most large and medium size farms operate closed water cycle systems, with final effluent recycling and little or no discharge to the aquatic environment; however, run-off is common during the rainy season. Manure solids often are separated and sold as organic fertilizer. The rest of the waste is channeled to a conventional anaerobic lagoon with more than a month retention time. Based on DLD information, common waste management approaches employed by swine farms in Thailand can be categorized as follows:

- Large-scale farms – covered anaerobic lagoon and/or channel digester
- Medium-scale farms – covered anaerobic lagoon and/or channel digester or open pond
- Small-scale farms - fixed dome (rigid cover) digester or open pond

Figure 3-6 and 3-7 show open ponds commonly found in typical small- to medium-scale swine farm in Thailand.

Source: Thailand’s Pilot CDM Program for Livestock Waste to Energy Presentation, Methane to Markets Partnership Expo, 2007

Figure 3-6: A Typical Medium-Size Swine Farm with Conventional Anaerobic Lagoon

Source: Biogas Prototype Presentation, Department of Alternative Energy Development and Efficiency, 2007

Figure 3-7: Open Ponds Used by Typical Small Size Swine Farms (~100 to 400 Swine)

It is estimated that there are more than 200 medium- and large-scale swine farms with biogas systems in Thailand, accounting for about half of swine population in the country. About 70 percent of those biogas systems use covered anaerobic lagoon (CAL) systems, while the remaining use a combination of channel digester (CD) and up-flow anaerobic sludge blanket (UASB) systems, and high-suspended solids–up-flow anaerobic sludge blanket (H-UASB) systems. Most CovAL systems were promoted and constructed by Charoen Pokphand Group (CP), an agricultural conglomerate in Thailand, while most of CD, UASB, and H-UASB systems were promoted and constructed under promotional schemes by EPPO. These biogas systems in medium- and large-scale swine farms in Thailand not only enjoy financial support from EPPO, but they can also use biogas to generate electricity to sell back to the grid and participate in CDM mechanism to improve the economic feasibility of their projects.

In addition to biogas promotion in medium- and large-scale swine farms, fixed dome technology was also promoted to small swine farms by the Department of Agricultural Extension from 1996 to 2004 with financial support from EPPO. A total of 1,655 fixed-dome systems (sized from 12 to 100 cubic meters for farms with 25 to 200 swine) were installed, with a 45-percent subsidy of the system cost. These fixed dome systems account for more than 200,000 pigs.

3.3 TAPIOCA

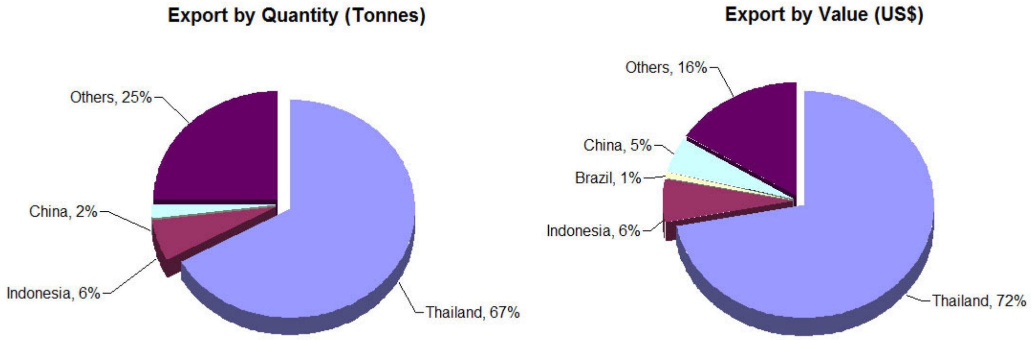
Cassava is one of the most important commercial crops in Thailand after rice and sugarcane. In 2008, Thailand's tapioca (i.e., starch extracted from the cassava root) production ranked second in the world (12 percent), after Nigeria. Thailand is also the world's largest tapioca products exporter in 2005 (72 percent market share), followed by Indonesia (6 percent) and China (2 percent), as shown in the Table 3-9 and Figure 3-8. Products derived from tapioca are exported in various forms such as fresh root, chips, pellet, meal, and sago.

Table 3-9: World Tapioca Production (thousand tonnes)

Location	2005	2006	2007	2008
World	**207,437**	**222,559**	**228,138**	**238,450**
Africa				
Nigeria	**41,565**	**45,721**	**45,750**	**49,000**
Congo, Democratic Republic of	14,974	14,989	15,000	15,300
Ghana	9,567	9,638	9,650	10,300
Angola	8,606	8,810	8,800	9,000
Mozambique	6,500	7,500	7,350	7,750
Tanzania, United Republic of	7,000	6,500	6,600	7,000
Uganda	5,576	4,926	4,456	4,000
Latin America				
Brazil	**25,872**	**26.639**	**27,313**	**26,300**
Paraguay	4,785	4,800	5,100	5,300
Colombia	2.050	2,000	2,100	2,200
Asia				
Thailand	**16,938**	**22,584**	**25,348**	**29,150**

Location	2005	2006	2007	2008
Indonesia	19,321	19,928	19,610	20,000
Vietnam	6,646	7,714	8,900	10,000
India	5,855	7,620	7,600	7,700
China, Mainland	4,000	4,300	4,350	4,500
Cambodia	536	2,182	2,000	2,100
Philippines	1,678	1,757	1,829	2,000

Source: Food and Agriculture Organization (FAO), 2008.



Export by Quantity (Tonnes)

Export by Value (US$)

Source: OAE

Figure 3-8: Share of World Trade in Tapioca Products Exports

3.3.1 Industry Structure

According to the annual planting survey, shown in Table 3-10, cassava plantations in Thailand during the 2007–2008 season (harvesting time from October to September) covered approximately 7.4 million rai, or 1.2 million hectares, of land in about 48 provinces, which produced more than 25 million tonnes of tapioca. A 15-percent increase in production is expected in the 2008–2009 season, for a record of 29.15 million tonnes.

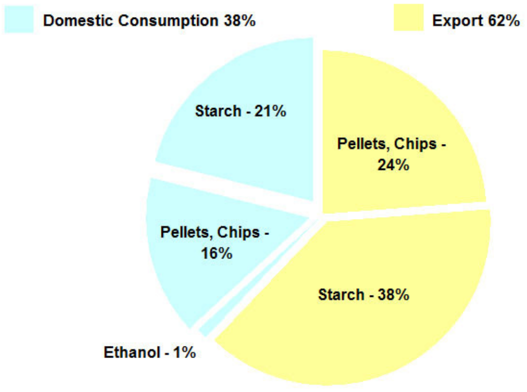
Table 3-10: Tapioca Production and Harvested Area
(Harvesting Months: October–September)

Year	Total Root Production (tonnes)	Harvesting Area rai (ha)
2008-2009	29,151,821	8,000,425 (1,281,508)
2007-2008	25,155,797	7,397,098 (1,183,536)
2006-2007	26,411,233	7,201,243 (1,152,199)
2005-2006	22,584,402	6,692,537 (1,070,806)
2004-2005	16,938,245	6,161,928 (985,908)
2003-2004	21,440,486	6,608,363 (1,057,338)
2002-2003	18,306,063	6,744,481 (1,079,117)

Year	Total Root Production (tonnes)	Harvesting Area rai (ha)
2001-2002	16,868,309	6,176,376 (988,220)
2000-2001	18,265,417	6,882,357 (1,101,177)
1999-2000	21,353,191	7,663,386 (1,226,142)
1998-1999	16,497,983	6,866,828 (1,098,692)
1997-1998	15,440,252	6,678,735 (1,068,598)

Source: TTDI (Thai Tapioca Development Institute). 2009. *Tapioca Harvested Area & Production*.

Based on the 2008 official report on the current situation of tapioca, issued by the Office of Agricultural Economics, production of native and modified tapioca constituted about 60 percent of total cassava root production, whereas chips and pellets accounted for about 40 percent (domestic, 16 percent and export, 24 percent), and ethanol production consumed only about 1 percent of total cassava root production. See Figure 3-9.



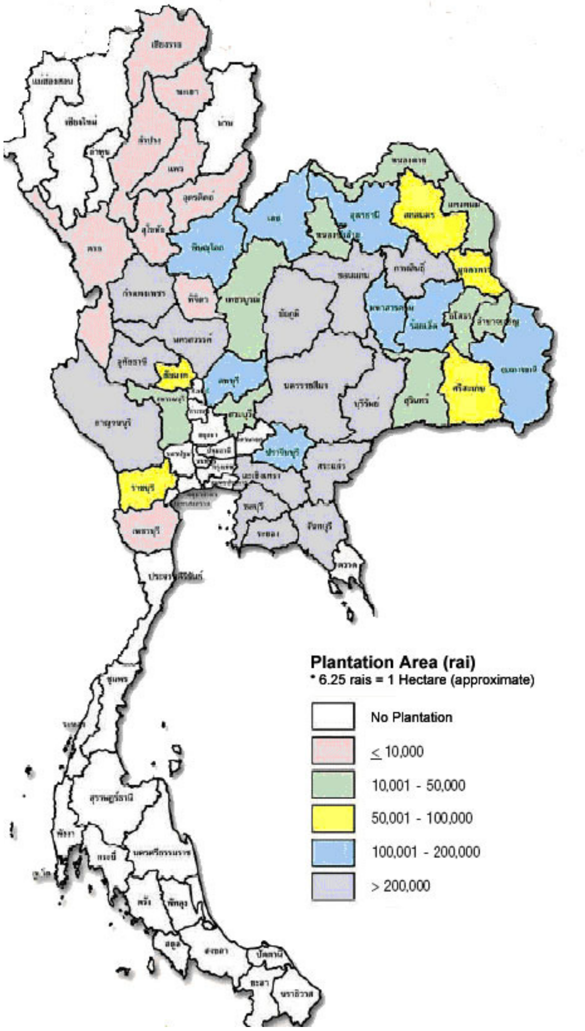
Source: Office of Agricultural Economics, 2008

Figure 3-9: Cassava Root Utilization During 2006–2008

3.3.2 Geographical Location

Cassava Plantations

The main concentration of the cassava plantations is found in the northeastern region of Thailand, followed by the north and the central (see Figure 3-10). The northeastern region accounts for almost half of the total production with around 13 million tonnes in 2008 and 15 million tonnes in 2009 (Table 3-11).



Source: Office of Agricultural Economics

Figure 3-10: Distribution of Cassava Planted Area in 2006–2007

Table 3-11 Breakdown of Production by Region in 2007–2008 and 2008–2009

Region	Planted Area (1,000 rai)		Root Production (tonne)	
	2007-2008	2008-2009	2007-2008	2008-2009
Northern	1,100,088	1,197,958	3,805,126	4,353,115
Northeast	4,043,856	4,364,605	13,448,028	15,549,505
Central	2,253,154	2,446,862	7,902,643	9,249,202
Total All Regions	**7,397,098**	**8,009,425**	**25,155,797**	**29,151,821**

Source: TTSA (Thai Tapioca Starch Association). 2009. *Quantity & Value of Export Tapioca Starch Statistics.*

Production of cassava roots in Thailand is also divided into seven zones across various provinces (see Figure 3-11 and Table 3-12).

Table 3-12: List of Provinces by Production Zone

Provinces	Region	Zone
Prachinburi, Chachoengsao, Sa Kaeo, Chanthaburi, Rayong, Chonburi, Trat (7)	East	1
Burirum, Chaiyapoom, Nakornrachasima (3)	Northeast	2
Yasothaon, Amnat Charoen, Ubon Ratchathani, Sri Sa Ket, Surin (5)	Northeast	3
Maha Sara Kham, Roi Et, Kalasin, Khon Kaen (4)	Northeast	4
Loei, Nong Bua Lamphu, Udorn Thani, Nong Khai, Sakon Nakhon, Nakhon Phanom, Mukdaharn (7)	Northeast	5
Chiang Rai, Uttaradit, Phitsanulok, Nakhorn Sawan, Uthai Thani, Kampheng Phet, Phetchabun, Tak, Sukothai, Prae, Lampang, Payao, Pijit (13)	North	6
Saraburi, Lop Buri, Chai Nat, Suphan Buri, Kanchanaburi, Ratchaburi, Phetchaburi (7)	West	7

Figure 3-11: Cassava Root Production Zone in Thailand

Based on field survey data compiled by the Thai Tapioca Development Institute, breakdowns of cassava root production by zone are shown in Table 3-13; major provinces of tapioca production are Nakhon Ratchasima (about 24 percent of the total), followed by Kampheng Phet, Sa Kaeo, Chiyabhum, and Chachoengsao, as shown in Table 3.14.

Table 3-13: Results of Survey on Tapioca Production and Trade, Crop Year 2008–2009

Zone	Harvested Area (hectares)		Production (Tonnes)		Yield per hectare (kg)	
	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009
1	258,187	275,078	5,724,006	6,598,342	22,169	23,988
2	397,378	420,396	8,274,020	9,371,728	20,819	22,294
3	47,912	57,711	1,023,123	1,330,531	21,356	23,056
4	111,300	123,068	2,308,375	2,734,193	20,738	22,217
5	90,427	97,161	1,842,512	2,113,053	20,375	21,750
6	176,014	191,673	3,805,126	4,353,114	21,619	22,713
7	102,318	116,420	2,178,636	2,650,859	21,294	22,769
Total	**1,183,536**	**1,281,508**	**25,155,798**	**29,151,820**	**21,255**	**22,748**

Source: TTDI (Thai Tapioca Development Institute). 2009. *Tapioca Harvested Area & Production*.

Table 3-14: Top Five Provinces for Tapioca Production

Province	Production (Tonnes), Crop Year 2008-2009
Nakorn Ratchasima (Zone 2)	7,075,656
Kampheng Phet (Zone 6)	1,699,752
Sa Kaeo (Zone1)	1,536,367
Chaiyapoom (Zone 2)	1,445,864
Kanchanaburi (Zone 7)	1,250,949

Starch Factories

One kilogram of tapioca at a starch content of 25 percent requires 4.4 kilograms of cassava roots. In Thailand, the large-scale processing facilities with advanced processing machines and technology have been replacing those primitive and small-scale factories. The traditional process, usually practiced in the small-scale factories, is the sedimentation process. The modern process, practiced in the large-and-medium-scale factories, generally employs a dewatering process as shown in Figure 3-12. Overall, cassava processing generates a large amount of wastewater with high organic load. For each tonne of cassava roots processed, 4-6 m^3 of wastewater are generated. Production of native starch also consumes significant amount of heat and electricity.

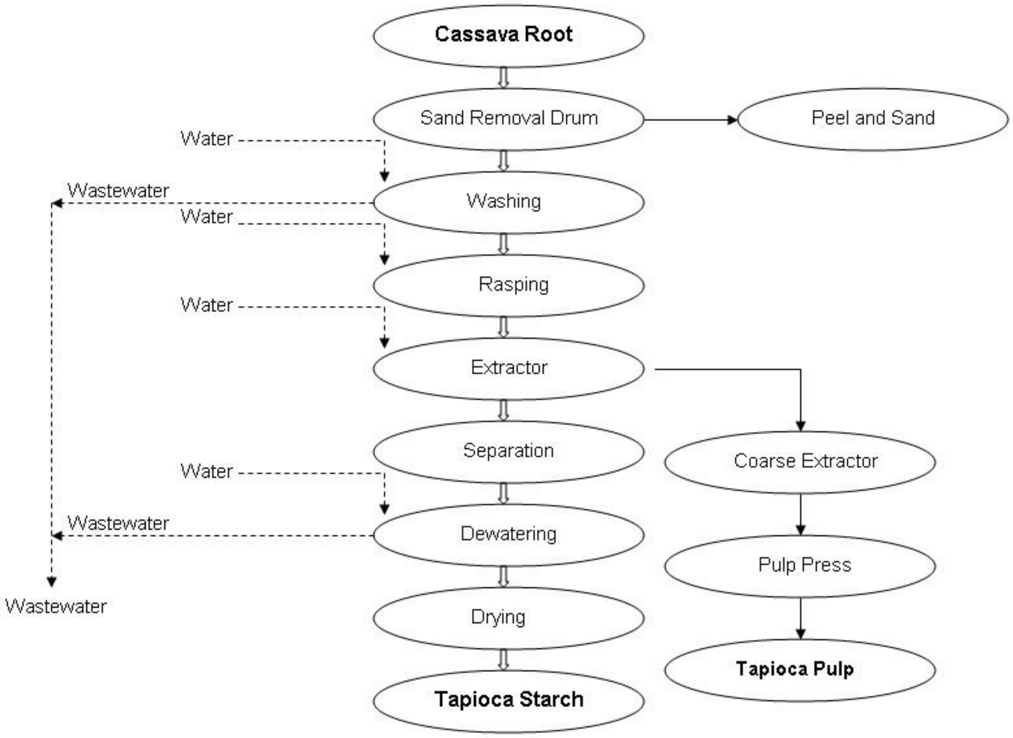


Figure 3-12: Starch Extraction Process in Thailand

Different information sources cite different number of tapioca factories in Thailand, as shown in Table 3-15. These statistics appear to be a combination of native starch and modified starch factories. We estimate that approximately 80 percent of the tapioca factories in Thailand produce native starch. About 50 factories operate year-round, while the remaining factories operate seasonally based on cassava harvesting season. These starch factories have a combined total production capacity of 3.5 million to 4 million tonnes of starch per year.

Table 3-15: Number of Tapioca Factories in Thailand

Number of Tapioca Factories	Source
85 (2005)	Information and Communication Technology Bureau, Department of Industrial Works, Ministry of Industry
69 (2006)	Biogas Potential Assessment Report (December 2006), Pilot Plant Development and Training Institute (PDTI), King Mongkut's University of Technology Thonburi (KMUTT)
77 (estimated, 2007)	Seminar on the Promotion of Production of Biogas from Wastewater as an Alternative Energy and for Environmental Improvement (August 2007), Energy Policy and Planning Office, Ministry of Energy
71	Energy for Environment Foundation (EfE), www.efe.or.th

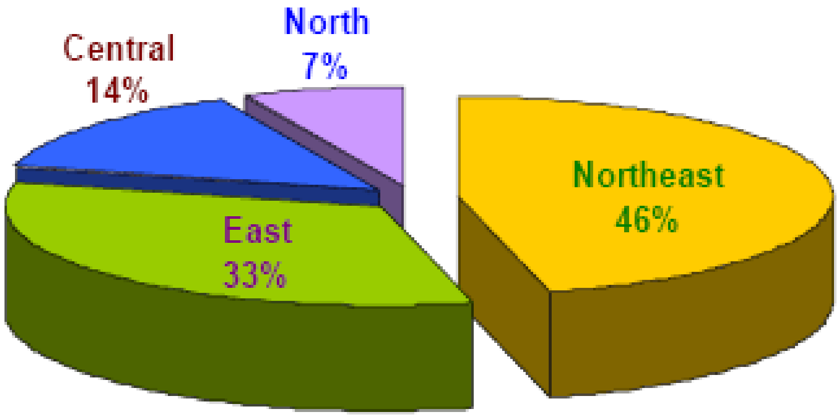
Table 3-16: Production of Tapioca in Thailand

Year	Domestic (Tonnes)	Export (Tonnes)[3]	Total Production (Tonnes)[3]
2001	907,995[1]	1,284,699	2,192,694
2002	920,734[1]	1,307,797	2,228,532
2003	1,020,236[1]	1,609,436	2,629,673
2004	1,124,018[1]	1,766,399	2,890,417
2005	1,125,919[1]	1,603,075	2,728,995
2006	1,224,732[1]	2,309,740	3,534,472
2007	1,185,053[2]	2,200,814	3,385,867
2008	1,070,022[2]	1,987,184	3,057,207

Note: 1 Calculated based on Export and Total Production Values from the Thai Tapioca Starch Association
2. Calculated based on Export value and domestic consumption and export ratio of 35%:65%
3. Source: the Thai Tapioca Starch Association, 2009.

As shown in Table 3-16, annual tapioca production figures generally correspond with root production and show an average growth of 12 percent per year during 2001–2006. About 35 to 40 percent of total tapioca production is for domestic consumption, and about 60 to 65 percent is for export. The export volume has also shown a sign of continuous growth for over the last six years.

Seventy-nine percent of tapioca factories are located in the northeastern and eastern region of Thailand (see Figure 3-13), particularly in production zone 1 and 2 where abundant cassava plantations can be found. Based on the Information and Communication Technology Bureau, Department of Industrial Works, Ministry of Industry, Nakorn Ratchasima has the highest number of tapioca factories (i.e., 20 factories), followed by Rayong (11), Chonburi (10) and Kalasin (8). All the remaining provinces have less than 5 factories in each province.



Source: Information and Communication Technology Bureau, Department of Industrial Works (2005)

Figure 3-13: Tapioca Factories Distribution

The biogas potential assessment report conducted by King Mongkut's University of Technology Thonburi (KMUTT) categorized native (Tapioca) starch factories in Thailand by production capacity (tonnes of native starch per day) into three groups (i.e. < 100, 100–400 and > 400). Based on daily production capacity data available from the Energy for Environment Foundation

(E for E) and www.thaibiogas.net, the classifications of native starch factories in Thailand, shown in Table 3-17, are referenced in this assessment report.

Table 3-17: Size of Native (Tapioca) Starch Factories in Thailand

Production Capacity (Tonnes Native Starch/day)	Number of Factories (estimated)	Percent of Total Production Capacity
< 100	22	19%
≥ 100 to <200	23	17%
≥ 200 to <400	32	48%
≥ 400	7	27%

Source: www.efe.or.th, www.thaibiogas.net

Based on Table 3-17, total production capacity of the top 39 medium- to large-scale native starch factories in Thailand (production capacity ≥ 200 tonnes of native starch per day) accounts for 75 percent the total native starch production capacity for the whole country. Most of these medium- to large-scale factories are located in 6 provinces in the northeastern and eastern region (i.e., Nakorn Ratchasima, Rayong, Sa Kaew, Chacheongsao, Chonburi and Mahasarakam), as well as 2 (Khampaengphet and Kanchanaburi) in the western region. Figure 3-14 shows the distribution of medium- to large-scale native starch factories in Thailand.

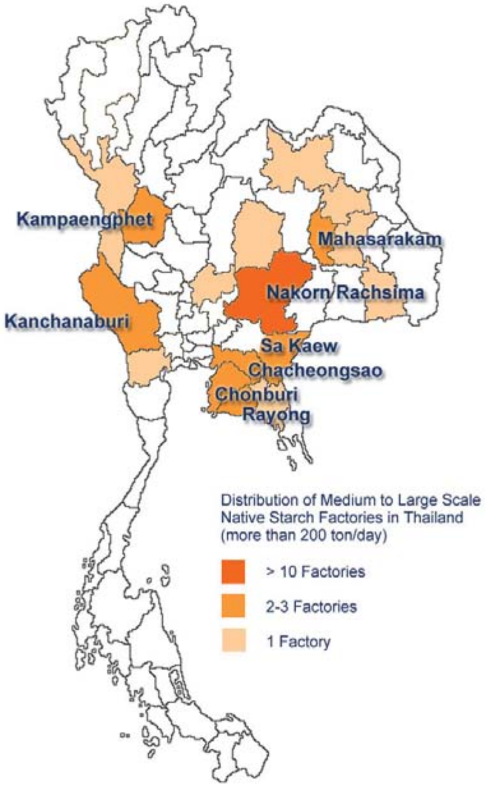


Figure 3-14: Distribution of Medium to Large Native (Tapioca) Starch Factories in Thailand

3.3.3 Waste Characteristics

One tonne of tapioca production generates approximately 11 to 33 m^3 of wastewater, with a COD concentration ranging from 13,000 to 20,000 mg/liter.[13] KMUTT's biogas potential study (2006) suggests an average 15 m^3 of wastewater is created per tonne of tapioca and summarizes characteristics of wastewater from tapioca factories in Table 3-18:

Table 3-18: Wastewater Characteristics of (Tapioca) Starch Factories in Thailand

Parameter	Value
pH	3.4 - 6.5
COD	5,000 – 37,000 mg/liter
BOD	2,500 – 16,000 mg/liter
Total solids (TS)	7,000 – 37,000 mg/liter
Suspended Solids (SS)	6,000 – 8,000 mg/liter
TKN	230 – 500 mg/liter
Total Dissolved Solids (TDS)	5,500 – 13,000 mg/liter

Large variations of the wastewater characteristics listed in Table 3-18 are due to production technologies and techniques. Shown in Table 3-19 is a compilation of wastewater characteristics from some of native starch factories that participated in EPPO's biogas promotion programs.

Table 3-19: Sample BOD and COD Values from (Tapioca) Starch Factories in Thailand

Parameter	Unit of Measure	Sengpetch Tapioca	Isan Starch	Eiamheng Tapioca Starch
BOD	mg/liter	8,220	9,000	10,250
COD	mg/liter	13,134	18,000	17,500
Average Wastewater Production	m3/day	6,000	2,500 - 3000	8,800
Starch Production Capacity	Tonnes/day	400	180 - 200	1,000

Source: www.thaibiogas.net and www.eppo.go.th

Based on various secondary sources, this report assumes an average of 15 m^3 of wastewater per tonne tapioca starch, as well as 16,000 mg/liter or 240 kg of COD per tonne of starch produced for estimating methane emissions.

3.3.4 Waste Handling and Management Systems

Most tapioca plants in Thailand retain all wastewater in open ponds within their facilities with no discharge surface water. With this practice, they are not subject to any wastewater standards currently imposed by the government (see Appendix B); however, these open ponds can cause

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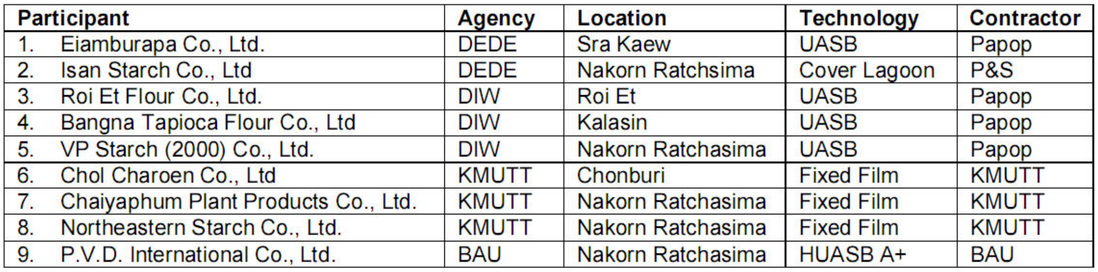
[13] EPPO (Energy Policy and Planning Office). Seminar on the Promotion of Production of Biogas from Wastewater as an Alternative Energy and for Environmental Improvement (August 2007).

odor problems and can potentially contaminate ground water and public water supply sources nearby.

Barriers initially preventing native starch factories in Thailand from investing in wastewater treatment technologies are high investment costs as well as lack of awareness and knowledge on the long-term benefits of both clean energy and a better environment. Although the open pond option requires a large area of land, most of tapioca starch factories are located in rural areas, and land prices are relatively cheap, making ponds less expensive than wastewater treatment systems.

Following the initial biogas promotion in the livestock sector, the Ministry of Energy expanded its biogas campaign into the agro-industrial sector, and focused on the tapioca starch sub-sectors. During 2003–2005, demonstrations of biogas system in the starch industry were carried out with four different technologies at nine factories. All participating factories received financial support from ENCON, through four agencies (i.e., DEDE, Department of Industrial Works [DIW], KMUTT, and the Biogas Advisory Union Foundation [BAU]). Details of the nine biogas pilot projects are shown in Table 3-20.

Table 3-20: List of Tapioca Factories Participating in EPPO's Biogas Demonstration



Participant	Agency	Location	Technology	Contractor
1. Eiamburapa Co., Ltd.	DEDE	Sra Kaew	UASB	Papop
2. Isan Starch Co., Ltd	DEDE	Nakorn Ratchsima	Cover Lagoon	P&S
3. Roi Et Flour Co., Ltd.	DIW	Roi Et	UASB	Papop
4. Bangna Tapioca Flour Co., Ltd	DIW	Kalasin	UASB	Papop
5. VP Starch (2000) Co., Ltd.	DIW	Nakorn Ratchasima	UASB	Papop
6. Chol Charoen Co., Ltd	KMUTT	Chonburi	Fixed Film	KMUTT
7. Chaiyaphum Plant Products Co., Ltd.	KMUTT	Nakorn Ratchasima	Fixed Film	KMUTT
8. Northeastern Starch Co., Ltd.	KMUTT	Nakorn Ratchasima	Fixed Film	KMUTT
9. P.V.D. International Co., Ltd.	BAU	Nakorn Ratchasima	HUASB A+	BAU

Wastewater from these nine tapioca plants is capable of producing 36.4 million m^3 of biogas per year, which can replace 21.8 million liters of fuel oil and save 174.4 million Baht.

EPPO's demonstration program has stimulated great interest from the Thai tapioca industry, and it began seeking additional financing options from government programs and private banks to support construction of biogas systems in their facilities. A number of biogas plants from starch factories in Thailand have participated in CDM. About 40 tapioca factories in Thailand are now either operating or constructing wastewater treatment systems with biogas generation, and about 60 percent of these factories are of medium or large size (≥ 200 tonnes per day). The total production capacity of these 40 plants accounts for about 60 percent of the total tapioca production capacity of Thailand. Shown in Table 3-21 are percentages of biogas implementation in each size category of native starch factories.

Table 3-21: Tapioca Wastewater to Biogas Projects in Operation or UnderConstruction in Thailand as of 2008

Production Capacity (Tonnes Native Starch per Day)	Number of Factories (estimated)	Percent of Wastewater Treatment With Biogas
< 100	22	27%
≥ 100 to <200	23	35%
≥ 200 to <400	32	53%

Production Capacity (Tonnes Native Starch per Day)	Number of Factories (estimated)	Percent of Wastewater Treatment With Biogas
≥ 400	7	100%

Source: http://www.efe.or.th, http://www.thaibiogas.net, DEDE, TGO.

3.4 PALM OIL

Thailand is the world's third largest palm oil producer, after Indonesia and Malaysia. In 2007–2008, the world production of palm oil was 41.4 million tonnes. Indonesia accounted for 44 percent of total production, closely followed by Malaysia at 43 percent, while Thailand produced only about 1 million tonnes or about 3 percent of the world's production. About 65 to 75 percent of palm oil production in Thailand is to meet the domestic demand, and the remaining is for export.

3.4.1 Industry Structure

Most of the oil palm plantation and the palm oil industry in Thailand are concentrated in the Southern part of Thailand, particularly in the provinces of Krabi, Surat Thani, Chumphon, Trang, Satun and Songkhla. The industry has become an important source of work and income to local people; however, Thailand has to further improve in palm varieties, plantation management, extraction and refinery technology and utilization, to become more competitive with its neighboring countries, namely Indonesia and Malaysia. In 2008, the harvested area for oil palm was 2.9 million rai (0.47 million hectares) and was forecasted to be 3.18 million rai (0.5 million hectares) in 2009 (see Table 3-22).

Table 3-22: Oil Palm Plantation Area and Production in Thailand

Year	Plantation Area (million rai)	Harvested Area (million rai)	Palm Fruit Production (million tonnes)	Yield (kg/rai)
2004	2.41	1.93	5.18	2,682
2005	2.75	2.03	5.00	2,469
2006	2.95	2.37	6.72	2,828
2007	3.20	2.66	6.39	2,399
2008	3.44	2.87	8.68	3,025
2009 (estimated)	**-**	**3.18**	**9.54**	**3,000**

Source: Office of Agricultural Economics (2008)

The principle of palm oil production process is to extract the oil from palm fruit using steam and pressing machine. The oil is then purified by the application of gravity inducing oil separation. A schematic flow diagram of the standard process of palm oil mills is shown in Figure 3-15.

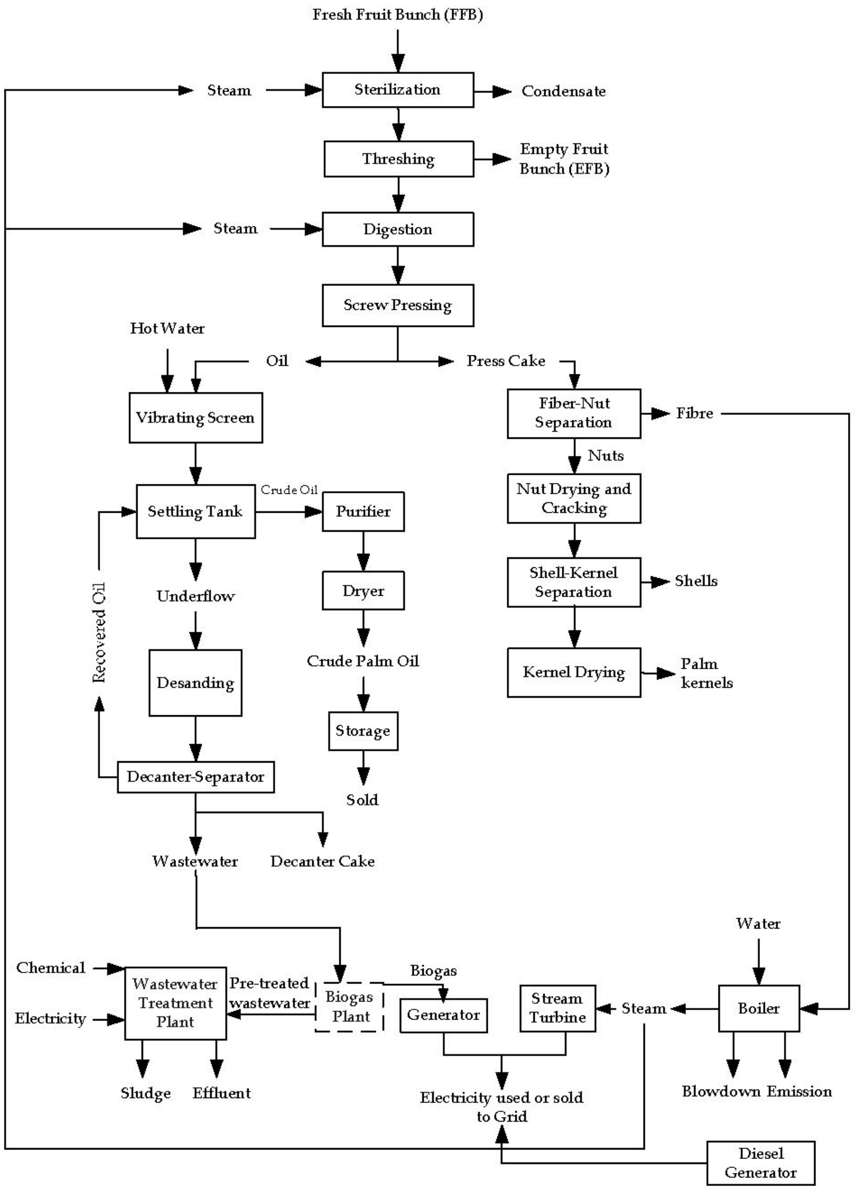


Figure 3-15: Standard Palm Oil Mill Process

The production of oil palm fruit was about 8.68 million tonnes in Thailand in 2008, leading to about 1.56 million tonnes of crude palm oil (CPO), as indicated in Table 3-23, which is a 26-percent increase from the CPO production in 2007 (1 million tonnes).

Table 3-23: Palm Fruit and Crude Palm Oil Production in Thailand

Production: million tonnes	2003	2004	2005	2006	2007	2008 (Nov 08)
Palm Fruit (Ministry of Agricultural)	4.903	5.182	5.003	6.715	6.390	**8.676**
Crude Palm Oil (Palm Oil Mills & Refineries)	0.864	0.821	0.784	1.167	1.050	**1.560**

Source: Department of Internal Trade (December 2008)

During the last five years (2004–2008), domestic demand for palm oil was growing, at up to 3 percent a year, as shown on Table 3-24. Before 2007, all domestic consumption of CPO was for direct consumption as food. As a result of the national biodiesel promotional scheme of the Thai Ministry of Energy, utilization of CPO for biodiesel production has increased its share of domestic consumption after 2007. The domestic consumption is estimated to reach 1.28 million tonnes in 2009, of which direct consumption will account for about 0.92 million tonnes and biodiesel will be about 0.36 million tonnes.

Table 3-24: Utilization of Crude Palm Oil (CPO) in Thailand During 2004–2008 (tonnes)

Year	Beginning-Year Stock (1)	Production (2)	Import (3)	Total (4)	Export (5)	Domestic Consumption (6)		Year-End Stock (7)
						Direct Consumption	Biodiesel	
2004	114,953	820,838	-	935,791	3,036	781,633	-	151,122
2005	151,122	783,953	-	935,075	-	821,406	-	113,669
2006	113,669	1,167,126	-	1,280,795	163,180	953,094	-	164,521
2007	164,521	1,115,579	-	1,280,100	219,700	909,302	62,182	88,916
2008	88,916	1,475,000	35,481	1,599,397	280,000	871,484	276,000	171,913
2009	171,913	1,536,325	-	1,708,238	150,000	920,000	360,000	278,238

Source: Office of Agricultural Economics (2008)

Notes: *1. (1), (2) & (7) are the Department of Internal Trade's figures informed by the factories*
2. (3) & (5) are only import of crude palm oil (or equivalent)
3. Year 2008 & 2009's figures are estimated numbers by the Office of Agricultural Economics
** average percentage of export during 2006-2008*

Utilization of palm oil for biodiesel production has become a topic of interest. To scale up CPO supply for biodiesel production, the Thai government has planned to convert some rubber plantations, rice farms, and new areas in Krabi, Chumphon, and Surat Thani into oil-palm plantations, with an ultimate goal of adding another 4 million rai harvested area by the end of 2012, to 2.9 million rai in 2008.[14]

Also, the government, through the Ministry of Agriculture and Cooperatives (MOAC), has provided support for the domestic palm oil industry that includes providing high-quality oil palm seedlings, technical capacity building, and enhanced access to financial support. The support is part of the Ministry's five-year palm oil strategic plan, from 2008 to 2012, to promote greater domestic consumption of the bio-energy.

3.4.2 Geographical Location

The majority (98 percent) of oil palm plantations and palm oil mills in Thailand are located in the south of the country; only two palm oil mills are located in the eastern region (i.e., in Chonburi province). The provinces with large plantation areas are Krabi (0.81 million rai), Surat Thani (0.75 million rai), and Chumporn (0.64 million rai). These three provinces account for

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[14] Bangkok Post, business section, page B4, Walalak Keeratipipatpong and Asawin Phakawan, March 2008

approximately 80 percent of the total plantation area in Thailand (see Figure 3-16). Details of oil palm plantation distribution during 2004–2008 are provided in Table 3-25.

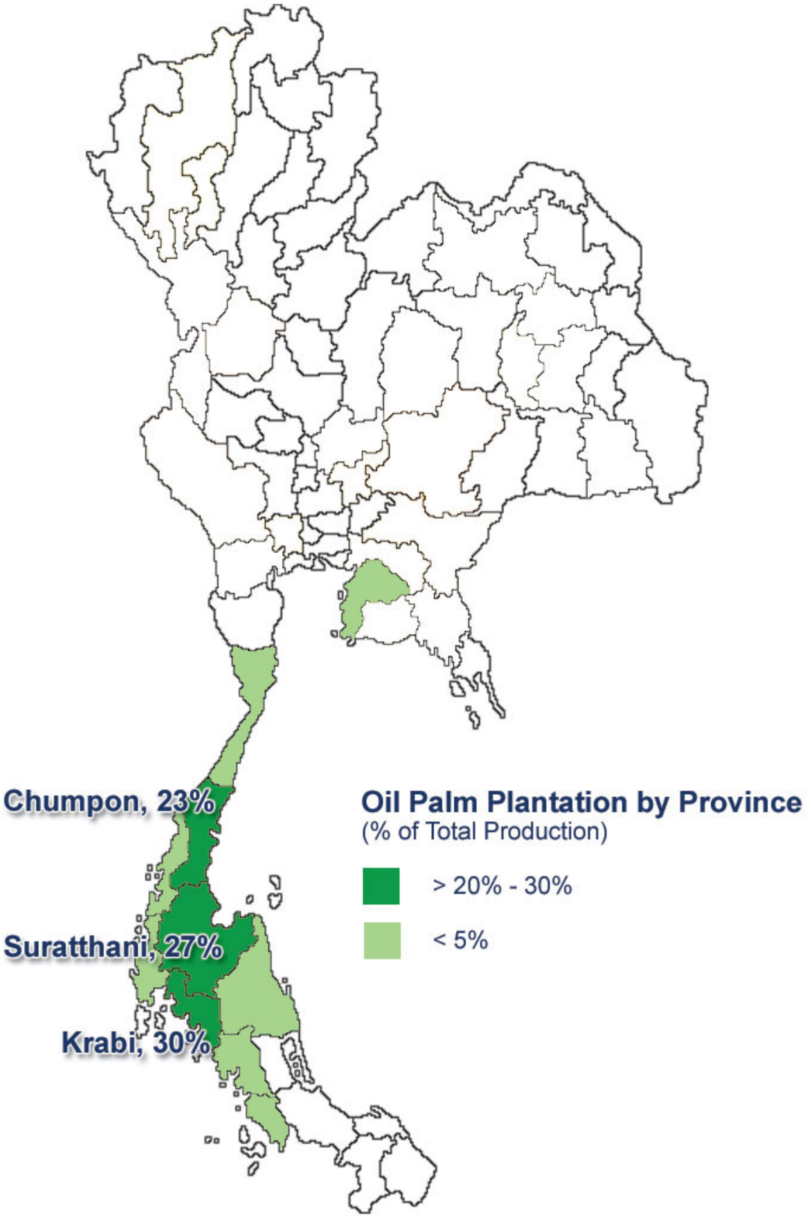

Figure 3-16: Oil Palm Plantation in Thailand in 2008

Table 3-25: Breakdown of Oil Palm Plantation by Province in 2008

Provinces	Harvested Area (rai)	Fresh Fruit Bunch (FFB) Production (million tonnes)	Yield (kg/rai)	Percent of Total Production
Krabi	806,721	2,570,473	3,186	30
Surat Thani	752,749	2,360,997	3,136	27
Chumporn	642,626	1,973,684	3,071	23
Nakorn Srithammarat	90,345	239,776	2,654	3
Satun	88,003	210,771	2,393	2
Trang	86,199	256,735	2,978	3
Prachuab Kirikhan	79,631	212,711	2,671	2
Chonburi	74,023	196,315	2,652	2
Pang Nga	81,740	223,804	2,738	3
Ranong	48,041	140,520	2,925	2
Other (13 provinces)	118,	290,684	2,094	3
Total	**2,868,463**	**8,676,470**	**3,025**	**100**

Source: Department of Internal Trade (December 2008)

In Thailand, the palm oil industry can be divided into two major segments: 1) palm oil mills; and 2) pure palm oil refineries. Similar to the Thai tapioca starch industry, different information resources cite different numbers of palm oil mills in Thailand, as shown in Table 3-26.

Table 3-26: Number of Palm Oil Mills in Thailand

Number	Source
66 (2002)	Department of Industrial Works (DIW), Ministry of Industry
38 (2006)	MIS Guideline for Eco-Efficiency Improvement in Palm Oil Industry, Department of Industrial Works (DIW), Ministry of Industry
58 (2006)	Biogas Potential Assessment Report (December 2006), Pilot Plant Development and Training Institute (PDTI), King Mongkut's University of Technology Thonburi (KMUTT)
37	Energy for Environment Foundation (EfE), http://www.efe.or.th

It should be noted that the number of palm oil mills referenced by Department of Industrial Works (DIW), Ministry of Industry and the Energy for Environment Foundation (E for E) is limited to those using the standard wet process. Recent reviews of various secondary information resources reveal that there are about 50 palm oil mills in Thailand with capacity over 5 tonnes of fresh fruit bunches (FFBs) per hour, and the total milling capacity in of these palm oil mills is about 2,000 tonnes FFBs per hour.

To avoid excessive generation of free fatty acids from enzymatic activities, which would deteriorate palm oil quality, it is necessary to process the harvested FFBs within 72 hours.[15] Considering this time constraint, the location of most palm oil mills is close to the oil palm plantation areas. Palm oil mills in three major plantation provinces (i.e., Surat Thani, Krabi, and Chumphon) account for about 78 percent of total production capacity in the country. Shown in Table 3-27 and Figure 3-17 are the number of palm oil mills and total production capacity by province.

Table 3-27: Palm Oil Mill Distribution by Province

Province	No. of Palm Oil Mills	Tonnes FFBs/hr	Percent of Overall Capacity
Surat Thani	13	755	36%
Krabi	12	530	25%
Chumphon	7	370	17%
Trang	4	130	6%
Satun	4	105	5%
Chonburi	2	70	3%
Ranong	3	45	2%
Others	>4	120	5%
Total	**~ 50**	**2,125**	**100%**

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[15] MIS Guideline for Eco-Efficiency Improvement in Palm Oil Industry (2006), Department of Industrial Works (DIW), Ministry of Industry

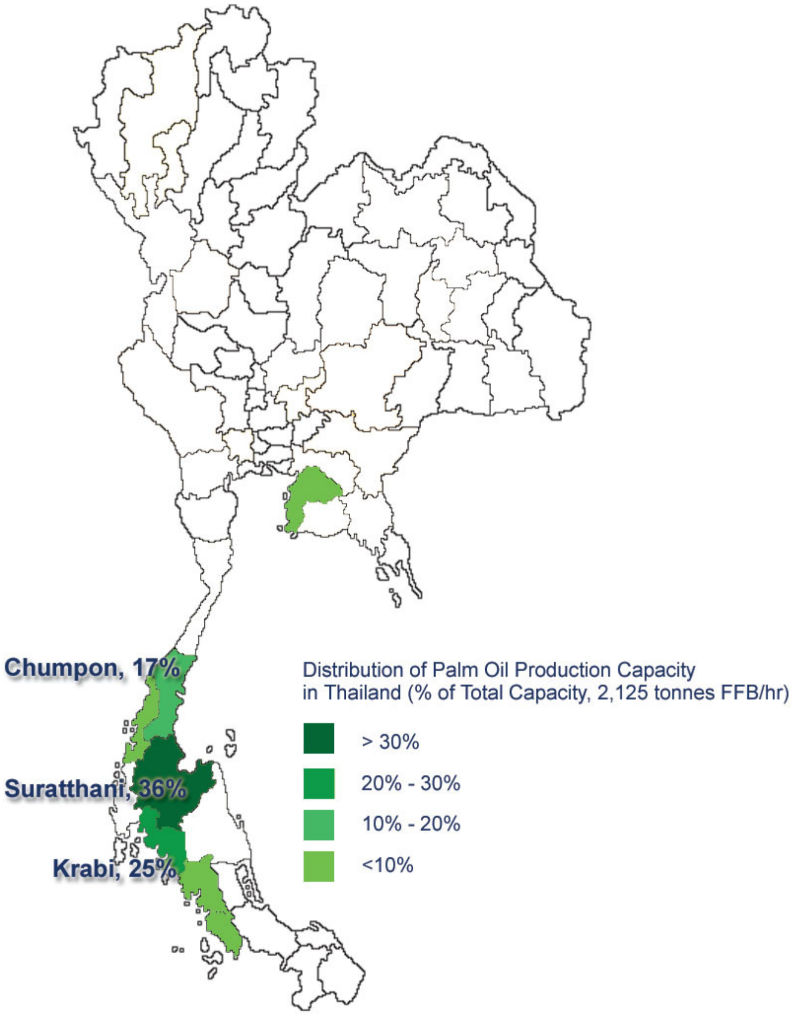

Figure 3-17: Palm Oil Mill Distribution

There is no standard classification for the size of palm oil mills in Thailand. In this assessment report, the following classifications of production capacity (tonnes FFBs per hour) are referenced: small: ≤30; medium: > 30 to < 60, and; large: ≥ 60. The number of palm oil mills and total production capacity in each category are shown in Table 3-28, and the total capacity of medium- to large-scale palm oil mills accounts for about 85 percent of the overall palm oil production capacity in Thailand.

Table 3-28: Size of Palm Oil Mills in Thailand

Production Capacity (Tonnes FFBs/Hour)	Number of Palm Oil Mills (estimated)	Percent of Total Production Capacity
≤30	>16	15%
> 30 to < 60	21	44%
≥ 60	12	41%

Source: http://www.efe.or.th, http://www.thaibiogas.net, DIW, TGO

There are about 11 palm oil refinery factories, which are mostly located in Bangkok and its suburban provinces such as Samut Prakarn and Samut Sakorn, as the important market for palm oil is in the central region.

3.4.3 Waste Characteristics

The milling process of extracting crude palm oil from FFBs requires large amounts of water. A steam boiler is used for sterilization, digestion of the fruit bunches, and the oil extraction process. The earlier study conducted by DEDE in 2000 suggests that CPO milling processes in Thailand generate approximately one m^3 of wastewater per tonne of FFB. More recent updates from EfE, KMUTT's biogas potential assessment (2006), and EPPO's biogas promotion project (2008) show that the current milling processes generates only about 0.4 to 0.5 m^3 of wastewater per tonne of FFB.

Wastewater from palm oil mills is typically a brownish, viscous, acidic, and high-oil and grease-containing slurry. The concentration of COD and BOD based on secondary data pertaining to wastewater characteristics ranges from 21,560 to 98,484 and 10,475 to 56,900 mg/liter, respectively. The other characteristics of palm oil mill effluent (POME) are shown in Table 3-29.

Table 3-29: Characteristics of Palm Oil Mill Effluent (POME)

Source		pH	Temp (˚C)	COD (mg/L)	BOD (mg/L)	TS (mg/L)	TVS (mg/L)	SS (mg/L)	Oil (mg/L)
King Mongkut's University of Technology Thonburi	**Min**	4.21	50	30,424	10,475	53,030	45,275	11,625	1,880
	Max	4.86	76	94,053	56,900	97,420	80,100	40,725	8,580
	Avg	4.64	65	62,032	29,172	65,674	56,148	23,179	5,010
Puetpaiboon U. & ChotwattanasaK. J., 2005	**Avg**	4.69 - 4.85	40-45	21,560-39,200	16,950-24,600	ND[1]	ND	ND	ND
Sommart Ichroj, 2004	**Min**	4.5	ND	58,750	17,000	ND	ND	9,233	ND
	Max	5.38		64,883	21,000			12,260	
	Avg	5.05		61,816	19,000			10,746	
Deppartment of Industrial Works, 1997	**Avg**	4-5	75-90	90,000	30,000	ND	ND	34,000	8,000
DEDE, 2000	**ND**	ND	ND	52,000	ND	ND	ND	ND	ND

Source: King Mongkut's University of Technology Thonburi (2006), ND: No Data

[1] Not determined

3.4.4 Waste Handling and Management Systems

Conventional anaerobic lagoon treatment systems have been applied mostly in palm oil mills (Figure 3-18). Biomass waste from the process is generally disposed of in pits. The sludge accumulating in the fermentation ponds is periodically removed and disposed of by land application. *Environmental Management Guideline for the Palm Oil Industry*, published by DIW and GTZ in 1997, has provided a review of suitable wastewater treatment technologies for the palm oil industry, including primary wastewater treatment, secondary wastewater treatment, and nitrogen removal. Adoption of more advanced wastewater treatment technologies in the Thai palm oil industry has only begun about 10 years ago, however, to begin to address the growing environmental concerns, especially odor problems.

Figure 3-18: Conventional Anaerobic Lagoon

Following the EPPO's biogas initiative in the agro-industrial sector in the late 1990s and the introduction of VSPP program in 2002, some palm oil mills have begun applying biogas technology for advanced wastewater management, moving away from traditional wastewater treatment in conventional anaerobic lagoons to a closed tank digester system with biogas capture and utilization. The tank-reactor technology commonly applied in industrialized countries has been adapted for Thai conditions, resulting in the use of the continually stirred tank reactor (CSTR) digester to treat liquid wastes and slurries. Shown in Figure 3-19 is one of the first few biogas systems constructed at a palm oil mill in Krabi Province in Thailand (Asian Palm Oil, Co., Ltd.).

Figure 3-19: CSTR Biogas Technology and Biogas Power Generators in Asian Palm Oil

After the successful implementation in the Asian palm oil industry and the availability of various funding mechanisms in Thailand (Energy Revolving Fund, subsidy from EPPO and CDM), more palm oil mills have seriously considered integrating biogas systems in their plants. Based on various secondary information resources, 29 palm oil mills in Thailand are either operating or constructing biogas systems, accounting for about 69 percent of total palm oil production capacity in the country (Table 3-30). Table 3-31 also shows that biogas systems are common among large-scale palm oil mills in Thailand.

Table 3-30: Implementation of Biogas System at Palm Oil Mills by Province

Province	No. of Palm Oil Mills	Tonnes FFB/hr (Overall)	No. of Biogas Systems	Tonnes FFB/hr (Biogas)	Percent of Biogas in Overall Capacity
Surat Thani	13	755	13	755	100%
Krabi	12	530	5	255	48%
Chumphon	7	370	4	250	68%
Trang	4	130	4	130	100%
Satun	4	105	1	15	14%
Chonburi	2	70	1	10	14%
Ranong	3	45	0	0	0
Others	>4	120	1	45	36%
Total	**~ 50**	**2,125**	**29**	**1,460**	**69%**

Source: http://www.efe.or.th, http://www.thaibiogas.net, DIW, TGO

Table 3-31: Implementation of Biogas System in Palm Oil Mills by Size

Production Capacity (Tonnes FFB/Hour)	Number of Palm Oil Mills (estimated)	Number of Biogas Systems	Percent of Biogas in Total Production Capacity
≤30	>16	5	22%
> 30 to < 60	21	13	62%
≥ 60	12	11	93%

Source: http://www.efe.or.th, http://www.thaibiogas.net, DIW, TGO

3.5 ETHANOL

Ethanol is one of the key biofuels in Thailand. Production of ethanol in Thailand primarily based on two major feedstocks, i.e., sugar cane molasses and tapioca. Typically, one tonne of sugarcane yields about 45 kg of molasses, out of which 10 liters of ethanol can be produced. Although this is not normally done in Thailand, the sugarcane juice can all be directly utilized in fermentation to ethanol, and one tonne of sugarcane yields 70 liters of ethanol. Another feedstock for ethanol manufacture is tapioca. Cassava roots contain 25 percent starch. Cassava roots are first hydrolyzed to sugar, and then fermented into ethanol.

The ethanol industry in Thailand is an emerging industry, developed in response to rising world crude oil prices and the national biofuel development strategy in Thailand. Ethanol is blended with gasoline (petrol), and this mixture is called gasohol. Gasohol in Thailand, containing 10 percent ethanol, is referred to as E10.

3.5.1 Industry Structure

Pornvilai International Group, the first ethanol factory in Thailand, began its operation in 2003 with a capacity of 25,000 liters per day. Currently there are 11 ethanol factories in operation, using sugar cane molasses and tapioca as feedstocks. The total output of these 11 factories is about 1.7 million liters per day. It is expected that three additional ethanol plants will be in operation by 2009, increasing total capacity to more than 2 million liters per day. Shown in Table 3-32 is a list of 17 ethanol plants, including 11 in operation, three to be in operation in 2009, and three that are under construction. Most ethanol plants in Thailand have an average production capacity of 150,000 to 200,000 liters per day.

Table 3-32: List of Ethanol Factories in Thailand

No	Company	Province	Feedstock	Capacity (liters/day)	Status
1	Thai Alcohol	Nakornpathom	Molasses	200,000	In Operation
2	Petro Green (Chaiyaphum)	Chaiyaphum	Molasses	200,000	In Operation
3	Petro Green (Kalasin)	Kalasin	Molasses	200,000	In Operation
4	Thai Sugar Ethanol	Kanchanaburi	Molasses	200,000	In Operation + Biogas System
5	Ekarat Pattana	Nakornsawan	Molasses	200,000	In Operation
6	Thai Agro Energy	Supanburi	Molasses	150,000	In Operation + Biogas System
7	Khon Khaen Alcohol	Khon Khaen	Molasses	150,000	In Operation
8	Thai Nguan Ethanol	Khon Khaen	Tapioca	130,000	In Operation + Biogas System
9	Thai Roong Ruang Energy	Saraburi	Molasses	120,000	In Operation + Biogas System
10	KI Ethanol	Nakorn Ratsima	Molasses	100,000	In Operation + Biogas System
11	Pornvilai International Group	Ayudhaya	Molasses	25,000	In Operation
12	Sapthip	Lopburi	Tapioca	200,000	To be in Operation (2009) + Biogas System
13	Ratchaburi Ethanol	Ratchaburi	Molasses	150,000	To be in Operation (2009) + Biogas System
14	ES Power	Sakaew	Molasses	150,000	To be in Operation (2009) + Biogas System
15	TPK Ethanol	Nakorn Ratsima	Tapioca	340,000	Under Construction
16	Sima Inter Product	Chacheongsao	Tapioca	150,000	Under Construction
17	PSC Starch Product	Chonburi	Tapioca	150,000	Under Construction

Source: Department of Alternative Energy Development and Efficiency, www.thaibiogas.net

The ethanol industry in Thailand has had an impressive growth over the past two years, at 42 percent in 2007 and 68 percent in 2008, due to high crude oil price and the government's subsidy program for biofuel. Overall plant utilization capacities are still relatively low, however, as shown in Table 3-33, and a surplus of approximately 1 million liters a day in capacity will be likely by the end of 2009.

Table 3-33: Total Ethanol Production Capacity and Actual Production, 2006–2009 (estimated)

Year	Total Production Capacity (million liters/day)	Average Production (million liters/day)	Percent Utilization Capacity
2006	0.855	0.37	43%
2007	1.055	0.53	50%
2008	1.725	0.88	51%
2009 (estimated)	2.175	1.36	63%

Source: Department of Alternative Energy Development and Efficiency

The government awarded 47 licenses for a total daily capacity of 10 million liters of ethanol five years ago when the country first embarked seriously on an alternative-fuel development policy. More than half of the 47 licensees for ethanol production are unlikely to get their production plans off the ground, however, in light of a steep fall in oil prices and oversupply in the market.

3.5.2 Geographical Location

As the ethanol manufacture in Thailand relies on two main feedstocks, sugar cane molasses, and tapioca, most ethanol factories are in the central and northeastern region where obtaining molasses from sugar mills is cost effective and an abundance of tapioca production can be found (see Figure 3-20).

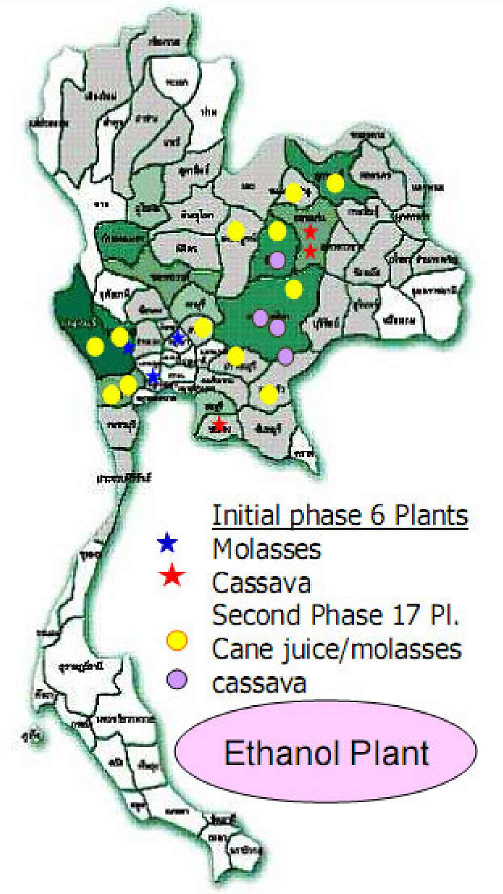

Figure 3-20: Location of Ethanol Plants in Thailand

3.5.3 Waste Characteristics

Ethanol production processes generate a high volume of wastewater with a high organic load content. Based on various secondary information resources referenced in KMUTT's biogas potential assessment (2006), production of 1 liter of ethanol generates 12 to 20 liters of wastewater with 100,000 mg/liter COD. Average wastewater characteristics are shown in Table 3-34. Data from existing ethanol production with biogas system show that 1 m^3 of wastewater generates 25 m^3 of biogas, and 1 gram of generates about 0.2 – 0.25 liters of methane.

Table 3-34: Wastewater Characteristics from Ethanol Production Process

Parameter	Unit	Average Value
1. pH	-	7.2
2. BOD	mg/liter	50,000
3. COD	mg/liter	100,000
4. TS	mg/liter	21,000 – 150,000
5. VS	mg/liter	40,000 – 110,000
6. SS	mg/liter	1,000 – 40,000
7. Total-Nitrogen	mg/liter	600 – 8,900
8. Sulfate	mg/liter	2,000 – 9,800

Source: KMUTT's Biogas Potential Assessment, 2006

3.5.4 Waste Handling and Management Systems

Most of the ethanol production plants in Thailand are less than five years old, many of which have integrated biogas/methane capture systems in the design phase. Similar to biogas implementation in other agro-industrial sectors, ethanol manufacturers have utilized various financing mechanisms available (e.g. EPPO's financial subsidy, CDM, Energy Revolving Fund, VSPP) to support integration of biogas systems into their plants. Shown in Figure 3-21is an CovAL systems under construction at Thai Roong Ruang Energy Co., Ltd. in the Saraburi province of Thailand. Conventional anaerobic lagoons are commonly applied for those plants that have not yet implemented biogas systems.

Figure 3-21: Covered Anaerobic Lagoons at Thai Roong Ruang Energy

As shown in Table 3-32, five of 11 ethanol plants in operation have implemented biogas systems capable of capturing 42 percent of total methane emissions. All three new ethanol plants to be in operation in 2009 will also have biogas systems integrated. At the end of 2009, these eight biogas systems will account for about 55 percent of total ethanol production capacity in the country.

3.6 SLAUGHTERHOUSE

3.6.1 Industry Structure

Pork is widely consumed in Thailand, and pork consumption per capita is expected to reach 15 kg per year per person by 2010–2011. About 50 percent of total pig population is slaughtered every year, or about 4 million pigs per year. In contrast, beef consumption is still relatively limited, and only about 6 to 7 percent of total cattle population, or about 400,000 to 500,000 cattle are slaughtered per year. The assessment of the slaughterhouse sector will therefore focus on pig slaughterhouses.

Although Thailand's livestock production has grown substantially throughout the last couple of years, the total pork exported is not as high a figure as forecasted because of the importation ban in some countries due to foot and mouth disease.[16] To remove this export barrier and improve the food safety and hygiene standard for domestic consumers, the government and industry organizations have started focusing on improving standards in livestock farms, slaughterhouses, and meat processing. DLD has established at least one modern slaughterhouse in each of the 76 municipalities across the country. In each province, the modern slaughterhouse is to be constructed and financed by the municipality.

A few large-scale integrated conglomerates dominate the pork industry in Thailand. These large companies distribute pork and pork products to both the domestic and export markets. The smaller farms and slaughterhouses mainly supply the local market, and distribute across the country. Based on a sector overview report on equipment and technology for pig slaughterhouses in Thailand, sizes of slaughterhouse can be commonly categorized as follows:

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[16] Royal Danish Embassy, Bangkok, 2009

- Small – 15 pigs per hour
- Medium – 100 pigs per hour
- Large – 200 pigs per hour

Typical sub-standard slaughterhouses employ manual slaughtering procedures. Although this manual activity is subject to veterinarian inspection, the hygiene is still poorer because the slaughterhouses want to keep their costs low. To improve the hygiene standard and eliminate non-registered slaughterhouses, the government has allocated funds for upgrading existing slaughterhouses and constructing new ones, including starting six to eight slaughterhouses connected to vocational schools and used for training future pig, cattle, and chicken slaughterhouse employees.

3.6.2 Waste Characteristics

Wastewater from swine slaughterhouses is produced from several processes (e.g., washing prior to slaughtering, scalding, hair removal, etc). To loosen hair, the pigs are held in water of temperature ranging from 53.3 to 62.8 degrees Celsius, measured every two to three minutes. After the hair removal and washing processes, the head, feet, and viscera, including the heart, liver, and gizzard, are removed. All of these operations generate liquid and solid wastes (e.g., manure, blood, hair, dirt, paunch manure and liquor, flesh, and grease).

Based on the KMUTT's biogas potential study (2006), the average characteristics of the effluent coming from the pig slaughterhouse are as follows:

	Parameters		**Characteristic**
1.	Wastewater Quantity	-	1.8-14 m^3/Live Weight Killed (LWK)
2.	Total Solids	-	2,650 mg/l
3.	BOD	-	717 mg/l
4.	COD	-	1,988 mg/l
5.	pH	-	7.5
6.	TKN	-	169 mg/l
7.	Total Volatile Solids (TVS)	-	1,738 mg/l
8.	SS	-	602 mg/l
9.	Oil and grease	-	466 mg/l

Notes: Pig slaughtered weight ranges from 90 to 130 kg.

1 LWK = 890.75 kg.

3.6.3 Waste Handling and Management Systems

Most slaughterhouses in Thailand either collect wastewater in open ponds or discharge to public surface water. To date, only about 10 AD systems, mostly channel digester and UASB, were constructed for slaughterhouses throughout the country. The primary function of these AD systems is treating wastewater, and biogas is just a byproduct. The main reasons for relatively smaller scale biogas implementation in the slaughterhouse sector in comparison with other agro-industrial sectors in Thailand are relatively low COD and small volume of wastewater (100 to 1,000 m^3) generated by slaughterhouses.

4. METHANE REDUCTION POTENTIAL AND TECHNOLOGY OPTIONS

This section explains the potential for reducing greenhouse gases though the use of anaerobic digesters. Anaerobic digesters reduce greenhouse gas emission reductions in two ways. First is the direct methane emission reduction from the capture and burning of biogas that otherwise would escape into the atmosphere from the waste management system. Second is the indirect reduction of CO2, methane, and nitrous oxide from the use of biogas to displace fossil fuels that would otherwise be used to provide thermal energy or electricity to the agricultural operation. Section 4.1 explains the potential methane emissions reduction from manure management systems and agricultural commodity processing waste.

The feasibility of modifying existing livestock manure and agricultural commodity processing waste management systems by incorporating anaerobic digestion will depend on the ability to invest the necessary capital and generate adequate revenue to at least offset operating and management costs as well as provide a reasonable return to the invested capital.

There are a number of options for anaerobically digesting wastes and utilizing the captured methane. For a specific enterprise, waste characteristics will determine which digestion technology options are applicable. Of the technically feasible options, the optimal approach will be determined by financial feasibility, subject to possible physical and regulatory constraints. For example, the optimal approach may not be feasible physically due to the lack of the necessary land. Section 4.2 of this chapter briefly describes the types of anaerobic digestion technology, methane utilization options, costs and benefits, and centralized projects. Appendix D provides more information regarding emissions avoided when wet wastes are sent to landfills, as well as emissions from leakages and waste transportation in co-substrate projects.

4.1 METHANE REDUCTION POTENTIAL

Based on the 2006 IPCC methodological equations outlined in Section 2.2, and data compilation and discussion in Sector 4 of this report, total methane emissions and remaining reduction potential in each priority sub-sector are estimated in Appendix C, and key findings are summarized in Table 4-1. The biogas promotional efforts led by EPPO and various financing mechanisms locally available (e.g., Energy Revolving Fund and CDM) have demonstrated their effectiveness to a certain degree, as more than half of methane emissions in the priority sub-sectors have been captured, specifically from large- and medium-scale operations. The three main sub-sectors showing high remaining methane reduction potential include ethanol, tapioca starch, and swine farm. Detailed discussions of the remaining methane reduction potential in each sub-sector are described in the following sections.

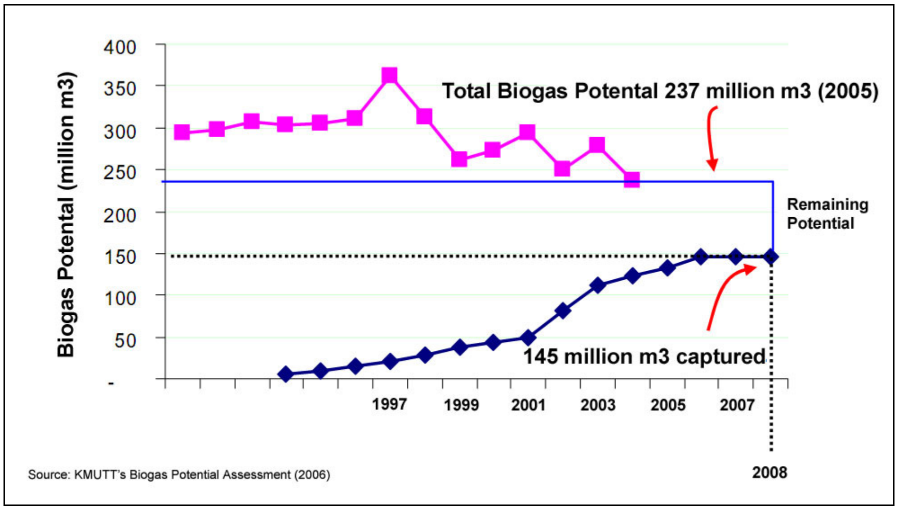
Table 4-1: Total and Remaining Methane Reduction Potential in Priority Sub-Sectors in Thailand

Priority Sub-Sector	Methane Emission Potential – 2008 (million tonnes CO_2e/ year)	Captured To Date (2008, Percent)	Remaining Reduction Potential (million tonnes CO_2e/ year)
Swine Production	2.6	50%	1.3
Tapioca Starch Production	2.8	60%	1.12
Palm Oil Extraction	1.07	69%	0.33
Ethanol Production	2.5	42%	1.45
Total	**8.97**		**4.2**

4.1.1 Swine Farms

Official statistics for biogas/methane capture implementation in the swine farm sub-sector in Thailand are not available; however, information obtained from various agencies and expert interviews[17] have revealed that most medium- and large-scale swine farms have either implemented or are building their biogas/methane capture systems. It is estimated that all biogas systems implemented in swine farms to date have covered approximately 50 percent of the total swine population in Thailand.

KMUTT's biogas potential assessment (2006) estimated biogas potential from the swine sub-sector at 237 million m^3 per year (6.29 million swine population). The assessment also conducted a biochemical methane potential (BMP) test to determine methane content in biogas produced. The test shows 54 to 64 percent methane content in biogas produced from swine waste in Thailand. This translates to 128 to 152 million m^3 of methane or 1.83 million to 2.17 million tonnes of CO_2e. The total methane emissions estimated by IPCC (Appendix C) for a 6.29-million swine population is 1.97 million tonnes of CO_2e, which is comparable to KMUTT's estimation.



Source: KMUTT's Biogas Potential Assessment (2006)

Figure 4-1: Biogas Captured and Remaining Potential from Swine Farms

KMUTT's biogas gas assessment also estimated that, in 2005, 50 percent of the biogas production potential from swine farms in Thailand has been captured. Considering additional biogas projects in the pipeline from 2005 to 2008, it is estimated that existing biogas systems can capture more than half of the methane generated by waste from the 8-million swine population in Thailand (about 2.6 million tonnes of CO_2e). The remaining methane reduction potential (as shown in Figure 4.1) is therefore about 1.3 million tonnes of CO_2e. These remaining potentials are to be accumulated from several thousand small-scale swine farms

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[17] Interview with Mr. Somchai Nitikarnchana, SPM Farm owner, January 8th, 2008

scattered throughout the country. Shown in Table 4-2 are installed capacities of biogas systems in large-, medium- and small-scale swine farms in Thailand, estimated by DLD.

Table 4-2: Estimated Installed Capacity of Biogas Systems in Total Swine Population

Swine Farm Size	Percent of Swine Population	Estimated Swine Population	Estimated Installed Capacity of Covered Anaerobic Lagoons	Estimated Installed Capacity of Channel Digesters, UASB	Estimated Installed Capacity of Fixed Dome Mixed Digesters	Percent of Installed Capacity in Total Population
Large Scale	24%	1,920,000	800,000	1,120,000	0	100%
Medium Scale	33%	2,640,000	400,000	1,550,000	0	74%
Small Scale	43%	3,440,000	400,000	0	300,000	20%
Total	**100%**	**8,000,000**	**1,600,000**	**2,670,000**	**300,000**	**57%**

Source: DLD's estimation

4.1.2 Tapioca Starch

KMUTT's biogas potential study (2006) estimated a total potential of biogas from 2,294,865 metric tonnes of starch production in 2005 at 344 million m^3, which is equivalent to 200 million m^3 of methane emissions per year, or 2.86 million tonnes of CO_2e. The estimate in Appendix C (using 2.3 million tonnes of tapioca starch production in 2005) shows 2.65 million tonnes of CO_2e, which is close to KMUTT's estimate. Based on annual tapioca root production in Table 3-10, the estimated annual methane emission potential for 2006 to 2008 are 4.1 million, 3.9 million, and 3.5 million tonnes of CO_2e, respectively.

As discussed previously, all large-scale starch factories (≥ 400 tonnes per day) and approximately half of medium-scale factories (≥200 to <400 tonnes per day) have already invested in biogas systems. It is estimated that all biogas systems implemented to date have covered approximately 60 percent of the total starch production in Thailand; however, the tapioca starch industry in Thailand still offers a great potential for methane reduction with the remaining methane reduction potential of about 1.4 million tonnes of CO_2e in 2008. This potential is to be accumulated from small- to medium-scale factories that are scattered throughout the country, but the economic viability of these new systems must be assessed prior to implementation.

4.1.3 Palm Oil

The total methane emission potential from the Thai palm oil industry in 2008 stood at 1.07 million tonnes of CO_2e, of which 69 percent has been captured through biogas systems in medium- to large-scale plants, similar to the tapioca starch sub-sector. The remaining methane reduction potential pf 0.33 million tonnes of CO_2e is to be accumulated from small- to medium-scale plants. Shown in Figure 4-2 is the remaining methane emission potential by province based on palm oil production capacity without biogas systems.

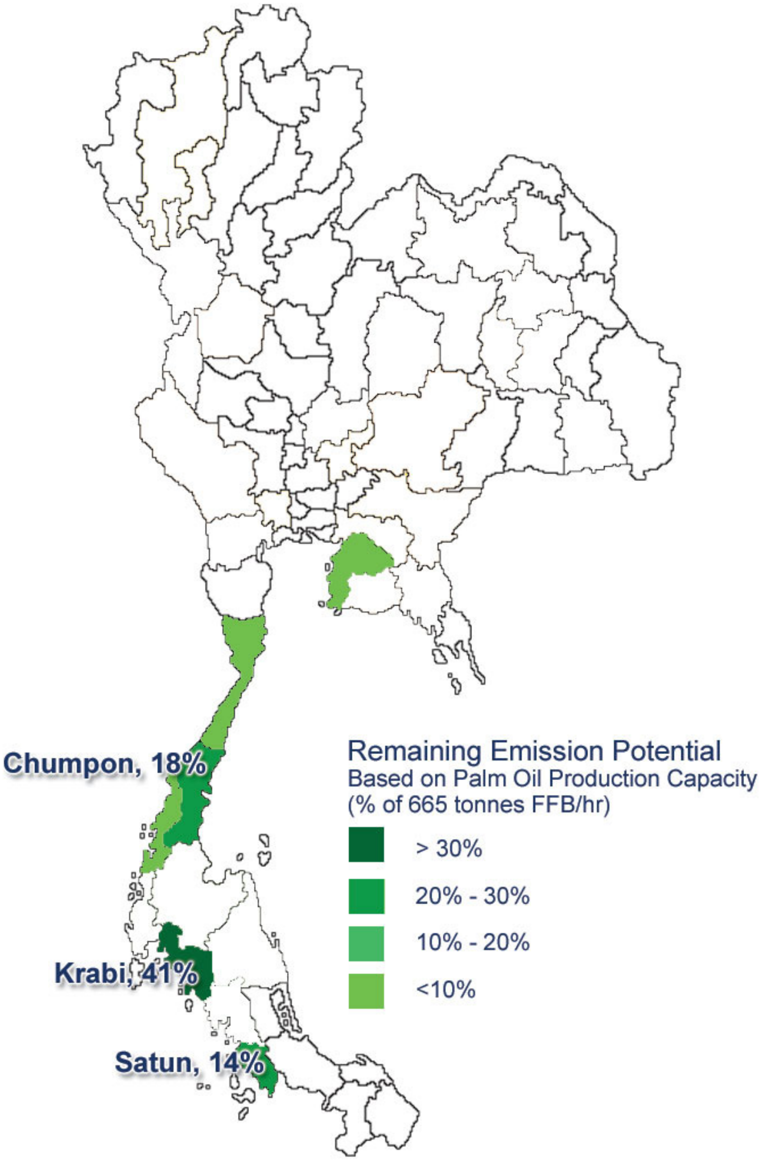


Figure 4-2: Remaining Emission Potential from the Palm Oil Industry by Province

4.1.4 Ethanol

Based on production statistic provided by DEDE, the total methane emission potential from 11 ethanol plants in Thailand in 2008 was about 2.49 million tonnes of CO_2e, of which 42 percent has been captured through five biogas systems. Ethanol production in Thailand is still expected to grow about 50 percent in 2009, compared with the 2008 production figure. Overall plant utilization in 2009 is expected to remain low, at about 60 percent, due to completion of three additional production plants in which biogas systems are integrated. The three new biogas systems increase the methane capture capacity to 55 percent of total methane generated in 2009, and the remaining methane reduction potential in 2009 is estimated at 1.7 million tonnes of CO_2e.

4.2 TECHNOLOGY OPTIONS

4.2.1 AD Technologies in Thailand

AD technologies in Thailand can be divided into two broad categories: 1) conventional; and 2) high-rate. Conventional digester systems are small wastewater treatment plants, widely promoted for use in livestock farms (e.g., swine, beef cattle, dairy cattle, broiler). The digester is designed for onsite treatment of volumes from 12 to 100 m^3, focusing on environmental concerns and applying the China-designed anaerobic fixed-dome digester. Similar systems in Thailand have been constructed with round-shaped concrete tanks buried in soil. This conventional digester design has a COD removal efficiency of 60 percent and produces a limited volume of biogas due to their small size and suitable for household applications such as cooking. The quality of treated wastewater cannot meet the wastewater effluent standards before discharging to rivers, however.

There five primary types of high-rate anaerobic digesters: 1) UASB; 2) anaerobic fixed film (AFF); 3) anaerobic baffle reactor (ABR); 4) covered anaerobic lagoons (CovAL); and 5) completely stirred tank reactor (CSTR). Each design has different pros and cons and is suitable for different applications. Combinations of different systems are mostly used in Thailand to respond to different characteristics of wastewater for anaerobic treatment. Based on a resource potential assessment conducted by KMUTT in 2006, there are approximately 300 large biogas systems in Thailand, of which CovAL systems has the largest share, at 59 percent, followed by UASB at 35 percent, AFF at 3 percent, ABR at 2 percent, and CSTR at 1 percent.

4.2.2 AD Technologies in Livestock Farms

AD technologies have been applied for wastewater treatment in livestock farms, particularly in swine farms. Thailand has a population of about 8 million swine, and these pigs are the major sources of livestock waste in Thailand. Four technologies for wastewater treatment and biogas production are commonly used among swine farms in Thailand. A summary of system characteristics is shown in Table 4-3.

Table 4-3: AD Technologies Used in Swine Farms in Thailand

Characteristics	Fixed Dome	CD and UASB	H-UASB	CovAL systems
Optimum Load Capacity	Small	Medium-Large	Medium-Large	Small-Large
Hydraulic Retention Time (HRT)	Medium	Low	Very Low	High
Organic Removal (percent)	60-80	80-90	80-90	60-80
System Stability	High	High	High	Medium
Maintenance Cost	Medium	High	High	Low
Operation Skill Requirement	Medium	High	High	Low
Environmental Impact	Medium	Low	Low	Medium
Capital Cost (US$/$m^3$)	47	132	235	Low

Source: Thailand's Pilot CDM Program for Livestock Waste to Energy Presentation, Methane to Markets Partnership Expo, 2007

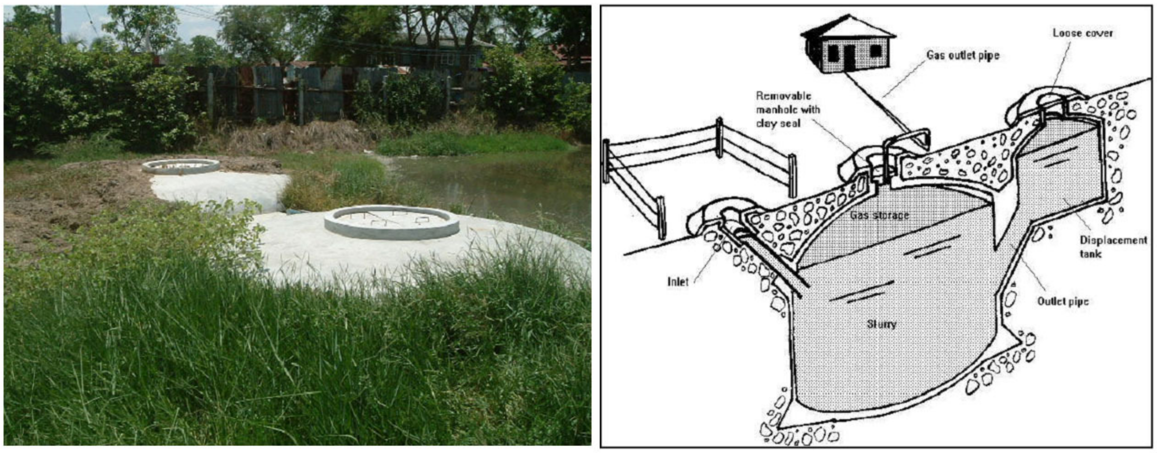


Figure 4-3: Fixed-Dome System

Fixed-dome systems, as shown in Figure 4-3, were promoted by the Department of Agriculture Extension (DOAE), Ministry of Agriculture and Cooperatives (MOAC), mostly in small swine farms. For medium and large livestock farms in Thailand, two popular biogas technologies are 1) channel digester (CDs) and up-flow anaerobic sludge blanket (UASB) reactors; and 2) ACLs.

UASB systems, promoted by CMU, are a combination of low-rate CDs with digester volumes of 300 to 1,400 m^3 and constructed concrete lined ponds, as shown in Figure 4.4. This is a two-phase anaerobic digestion process that separates acid and methane formation stages. Wastewater from CDs is then delivered to two UASB tanks, with a total digester volume of about 200 m^3 for additional treatments. Wastewater from UASB tanks is further treated with open pond and vegetated submerged bed (VSB) systems. Apart from the digestion process, the granules left from the low-rate CDs are collected from the pond and dried in a sludge-drying bed; the dried granules can be used for fertilizer production. Combination CD/UASB systems can treat about 100 to 300 m^3 per day of wastewater (depending on design), with an organic loading rate of 4 kg of total organic concentration per m^3 per day, and have a COD removal efficiency of about 70 to 80 percent. Presently, there are around 60 livestock farms that have applied CD/UASB treatment. CMU also improved its designs of H-UASB to reduce suspended solids.

Figure 4-4: CD/UASB System

CovAL systems in Thailand, as shown in Figure 4.5, have been promoted mainly by the private sector. It is estimated that there are 150 to 170 medium- to large-scale swine farms nationwide with CovAL systems. More than 85 percent of those CovAL systems are designed and constructed by a local giant agro-industry, Charoen Pokphand Foods. The remaining are designed and constructed by farm owners. Site surveys have revealed that the overall system efficiency is 60 to 70 percent; the organic loading rate us 1 to 3 kg COD/m^3 per day, and the hydraulic retention time (HRT) is more than 30 days.

Figure 4-5: Covered Anaerobic Lagoon (CovAL) System

4.2.3 AD Technologies in Agro-Industry

Industrial wastewater is one of the major causes of water pollution in Thailand. Standards and requirements regarding industrial wastewater treatment and use of the clean energy byproduct, biogas, have driven promotion and implementation of biogas systems in the agro-industry in Thailand. Main agro-industrial sub-sectors that have been utilizing biogas systems include starch, palm oil, frozen seafood, distillery, food and beverage, slaughterhouses, and paper. In addition to the agro-industry, the petrochemical industry also utilizes AD systems for wastewater treatment. AD technologies used in the agro-industry vary depending upon the characteristics of the wastewater.

Biogas systems in the starch industry: Tapioca starch production is strategically viewed as important and high value-added industry in Thailand. The average total production of tapioca starch is about 2 million to 3 million tons per year, leading to a large volume of wastewater. Although biogas systems have been imported for wastewater treatment in starch factories for more than a decade, there was no replication during the early phase, and utilization was limited to only two to three factories. In 2003, EPPO initiated a program to provide financial subsidies for biogas system construction. Following EPPO's initiatives and rising of the oil prices, biogas systems have become popular among tapioca starch factories in Thailand. It is estimated that there are more than 30 starch factories adopting biogas systems to date. UASB is the most popular technology and accounts for more than 60 percent of overall biogas systems, followed by AFF (five factories); CD/UASB (three factories); and ABR (three factories). System sizes ranges from 800 to 12,000 m^3, capable of accommodating 60 to 400 tons of daily starch production or 600 to 4,000 m^3 per day of wastewater, with 4 to 12 kg COD/m^3 per day, and 70 to 80 percent COD removal efficiency.

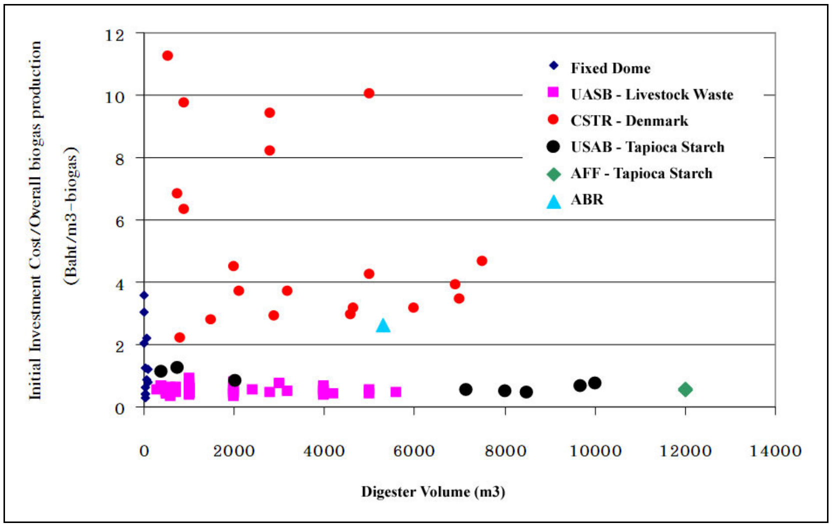
Biogas systems in slaughterhouses: Biogas systems in Thai slaughterhouses have been recently promoted by the Energy for Environment Foundation (E for E) with support from EPPO. The technology being applied is similar to the popular technology used in swine farms (i.e., CD/UASB). Wastewater treatment systems for slaughterhouses probably emphasize the environment aspect rather than the clean energy/biogas aspect, as wastewater from Thai slaughterhouses has a low organic loading rate and, hence, low volume of biogas produced. This situation has led to an unattractive return-on-investment for clean energy production.

4.3 COST AND POTENTIAL BENEFITS

The cost of AD technologies in Thailand summarized in this assessment report is based primarily on a biogas technology assessment report prepared by KMUTT in 2006 that used the following parameters and assumptions:

1. Project cost is limited to the initial investment cost of biogas system.
2. Project lifetime is 15 years.
3. Estimated rate of biogas production is assumed to be constant over the project lifetime.

A summary of the initial investment cost per m^3 of biogas generated throughout the project lifetime using different AD technology is shown in Figure 4-6.



Source: KMUTT's Biogas Technology Assessment, 2006

Figure 4-6: Initial Investment Cost per m^3 of Biogas

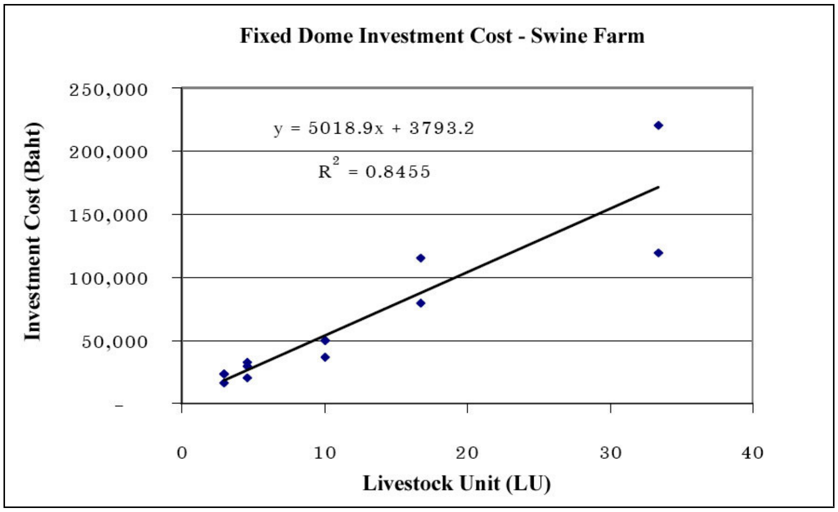
Based on Figure 4-6, the average biogas production cost throughout the project lifetime is about 1.5 baht/m^3 or 1.23 baht/kilowatt-hour for electricity generated from biogas. The initial investments for imported biogas systems are much higher compared with the systems designed and built domestically. The average fixed cost for an imported biogas system is about 60 million baht, while the local biogas systems offer much lower fixed cost at 330,000 baht for UASB and AFF; 720,000 baht for CovAL system; and 1,000 baht for fixed dome. The analysis also found that the average cost of wastewater treatment per kg of COD is about 1.29 baht.

The study also summarizes initial investment costs of different AD technologies in different livestock and agro-industrial sectors as follows:

Swine Farms

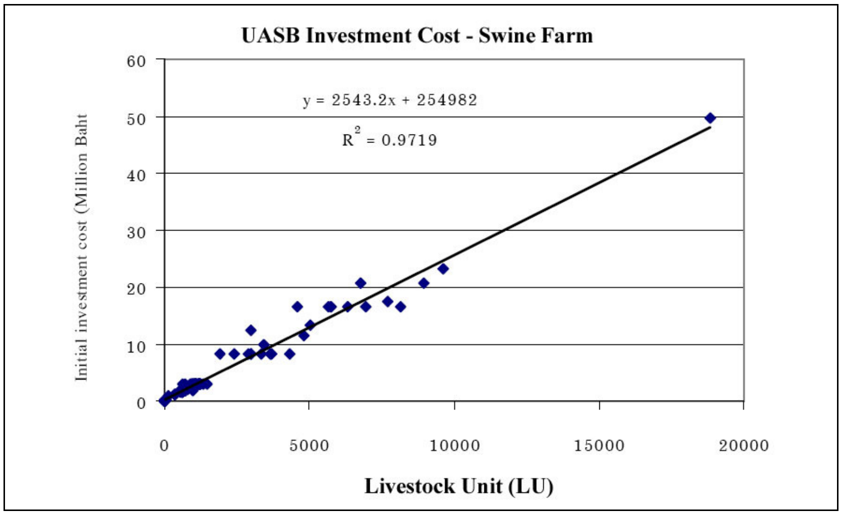
The initial investments in fixed-dome and UASB systems per livestock unit (LU) in swine farms in Thailand are shown in Figure 4-7 and 4-8. The investment cost for fixed-dome systems is about 5,000 baht/LU, and UASB systems cost about 260,000 baht/LU. The investment cost of CovAL systems is cheaper, at around 2,300 baht/LU for new covered anaerobic lagoons.

Considering the cost per m^3 of biogas generated, the average cost is about 1 to 1.4 baht/m^3. The fixed-dome systems have the highest cost, at about 1.36 baht/m^3. UASB and CovAL systems (including land cost) have similar cost at about 1 baht/m^3. As swine LU increase, the investment costs per m^3 biogas generated, as shown in Figure 4-9.



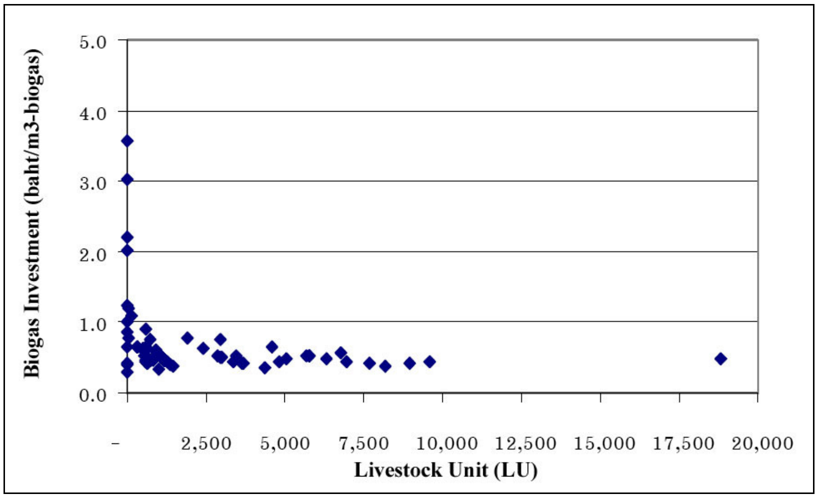
Source: KMUTT's Biogas Technology Assessment, 2006

Figure 4-7: Initial Investment of Fixed-Dome Systems in Thai Swine Farms



Source: KMUTT's Biogas Technology Assessment, 2006

Figure 4-8: Initial Investment of UASB Systems in Thai Swine Farms



Source: KMUTT's Biogas Technology Assessment, 2006

Figure 4-9: Investment Cost per m^3 of Biogas in Thai Swine Farms

Tapioca Starch

In the tapioca starch industry, the average cost per m^3 of biogas from all different AD technologies is about 0.54 baht/m^3, translating to average electricity cost at about 0.45 baht/kilowatt-hour.

Palm Oil

CSTR is the most popular AD technology implemented in the Thai palm oil industry. The average investment cost is about 20 million to 25 million baht for a 40- to 45-tonne FFB per hour plant. The average cost per m^3 biogas is about 0.84 baht.

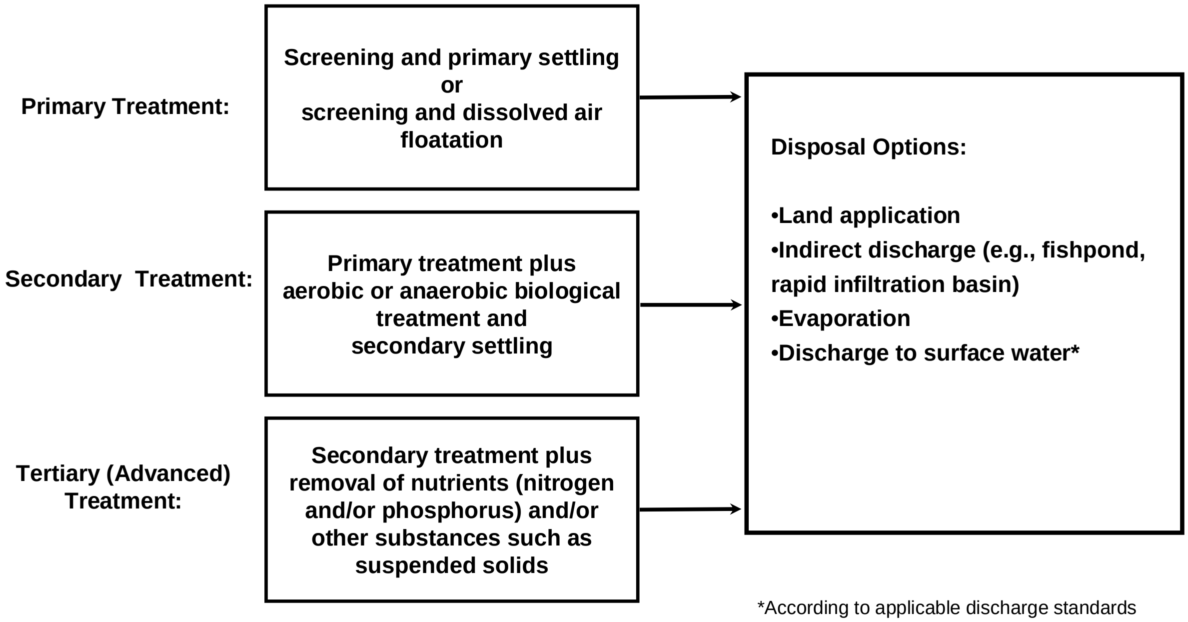
Ethanol

There is no available cost data for the ethanol industry.

Potential Benefits from VSPP

All swine farms and agro-industries with biogas systems are able to produce electricity and sell it back to the grid. Electricity tariffs vary depending on tariff schemes and also the amount of electricity purchased from the grid. Most medium to large biogas systems in Thailand with excessive biogas beyond on-site heat energy and electricity demand have participated in the Very Small Power Producer program (VSPP) to improve economic feasibility of the project.

APPENDIX A: *TYPICAL WASTEWATER TREATMENT UNIT PROCESS SEQUENCE*



*According to applicable discharge standards

APPENDIX B: *INDUSTRIAL EFFLUENT STANDARDS*

The government has enforced industrial effluent standards issued by the Pollution Control Department (PCD) in 1996. All factories, including palm oil mills, must follow these standards, such as ensuring strict levels of TDS, SS, BOD, COD, TKN, and fat, oil and grease in treated waste (not more than 3,000, 50, 20, 120, 100, 5 mg/L, respectively, including a pH value of between 5.5 and 9.0; see below Table B-1.

Table B-1: Industrial Effluent Standards in Thailand

Parameters	Standard Values
1. pH Value	5.5 - 9.0
2. Total Dissolved Solids (TDS)	Not more than 3,000 mg/l depending on receiving water or type of industry under consideration of the Pollution Control Committee (PCC) but not to exceed 5,000 mg/l
	Not more than 5,000 mg/l of existing TDS of receiving water with salinity of more than 2,000 mg/l or sea water
3. Suspended Solids (SS)	Not more than 50 mg/l depending on the receiving water or type of industry or wastewater treatment system under consideration of PCC but not to exceed 150 mg/l
4. Temperature	Not more than 40°C
5. Color and Odor	Not objectionable
6. Sulphide as Hydrogen Sulfide (H_2S)	Not more than 1.0 mg/l
7. Cyanide as Hydrogen cyanide (HCN)	Not more than 0.2 mg/l
8. Fat, Oil and Grease	Not more than 5.0 mg/l depending on the receiving water or type of industry under consideration of PCC but not to exceed 15.0 mg/l
9. Formaldehyde	Not more than 1.0 mg/l
10. Phenols	Not more than 1.0 mg/l
11. Free Chlorine	Not more than 1.0 mg/l
12. Pesticides	Not detectable
13. BOD	Not more than 20 mg/l depending on the receiving water or type of industry under consideration of PCC but not to exceed 60 mg/l
14. TKN	Not more than 100 mg/l depending on the receiving water or type of industry under consideration of PCC but not to exceed 200 mg/l
15. COD	Not more than 120 mg/l depending on the receiving water of type of industry under

Parameters	Standard Values
	consideration of PCC but not to exceed 400 mg/l
16.Heavy metals	
16.1 Zinc (Zn)	Not more than 5.0 mg/l
16.2 Chromium (Hexavalent)	Not more than 0.25 mg/l
16.3 Chromium (Trivalent)	Not more than 0.75 mg/l
16.4 Copper (Cu)	Not more than 2.0 mg/l
16.5 Cadmium (Cd)	Not more than 0.03 mg/l
16.6 Barium (Ba)	Not more than 1.0 mg/l
16.7 Lead (Pb)	Not more than 0.2 mg/l
16.8 Nickel (Ni)	Not more than 1.0 mg/l
16.9 Manganese (Mn)	Not more than 5.0 mg/l
16.10 Arsenic (As)	Not more than 0.25 mg/l
16.11 Selenium (Se)	Not more than 0.02 mg/l
16.12 Mercury (Hg)	Not more than 0.005 mg/l

Source: Notification the Ministry of Science, Technology and Environment, No. 3, B.E.2539 (1996) issued under the Enhancement and Conservation of the National Environmental Quality Act B.E.2535 (1992), published in the Royal Government Gazette, Vol. 113 Part 13 D, dated February 13, B.E.2539 (1996), (http://www.pcd.go.th/info_serv/en_reg_std_water04.html)

***Remarks**: Types of factories (category of factories issued under the Factory Act B.E.2535 (1992) that are allowed to discharge effluent having different standards from the Ministerial Notification No. 3 above as follows :*

1. *BOD up to 60 mg/l: animal furnishing factories (category 4 (1)); starch factories (category 9 (2)); food from starch factories (category 10); textile factories (category 15); tanning factories (category 22); pulp and paper factories (category 29); chemical factories (category 42) ; pharmaceutical factories(category 46) ; frozen food factories (category 92)*

2. *COD up to 400 mg/l: food furnishing factories (category 13 (2)) ; animal food factories (category 15 (1)) ; textile factories (category 22); pulp and paper factories (category 38)*

3. *TKN: 100 mg/l - effective after 1 year from the date published in the Royal Government Gazette of the Ministerial Notification No. 4; and 200 mg/l - effective after 2 year from the date published in the Royal Government Gazette of the Ministerial Notification No. 4 for food furnishing factories (category 13 (2)) and animal food factories (category 15 (1))*

APPENDIX C: *METHANE EMISSION ESTIMATION*

Swine Farm

			VS	Bo	D	MS%	MCF%	EFj		
Sector	**Year**	**Population**	**kg. dry manure/animal/day**	**m3 CH4/kg dry manure**	**Methane Density**	**% Manure Handled**	**Methane Conversion Factor**	**Emission Factor (kg CH4/kg COD)**	**CH4 emission potential (metric tonnes/year)**	**CH4 emission potential (tCO2e/year)**
Swine Farm		No. of heads*								
	2005 (KMUTT)	6,290,000	0.30	0.29	0.67	100%	70%	**14.89**	93,678	**1,967,229**
	2005	7,533,690	0.30	0.29	0.67	100%	70%	**14.89**	112,200	**2,356,199**
	2006	7,688,137	0.30	0.29	0.67	100%	70%	**14.89**	114,500	**2,404,503**
	2007	8,381,122	0.30	0.29	0.67	100%	70%	**14.89**	124,821	**2,621,238**
*source: Office of Agricultural Economics										

Agro-Industry

i		P_i	W_i			COD_i	TOWi	1 cu.m. CH4 = 0.6802 kg		MCFj	EFj	TOWi x Efi	
Industry	**Year**	**Production Unit/Year**	**Wastewater (cu.m./ production unit)**	**Amount of Wastewater/Year (cu.m.)**	**COD (mg/l)**	**COD (ton COD/cu.m.)**	**Total Organically degradable material in Wastewater (tonnes COD/yr)**	**cu.m. CH4/kg.COD**	**CH4 producing capacity (kg CH4/kg COD)**	**Methane Conversion Factor**	**Emission Factor (kg CH4/kg COD)**	**CH4 emission potential (metric tonnes/year)**	**CH4 emission potential (tCO2e/year)**
Tapioca Starch		million metric tonnes*											
	2005 (KMUTT)	2,294,865	15.0	34,422,975	20000	0.02	**688,460**	0.300	0.204	90%	**0.18**	126,438	**2,655,205**
	2006	3,534,473	15.0	53,017,092	20000	0.02	**1,060,342**	0.300	0.204	90%	**0.18**	194,736	**4,089,456**
	2007	3,385,868	15.0	50,788,018	20000	0.02	**1,015,760**	0.300	0.204	90%	**0.18**	186,548	**3,917,518**
	2008	3,057,207	15.0	45,858,108	20000	0.02	**917,162**	0.300	0.204	90%	**0.18**	168,440	**3,537,250**
*source: www.efe.or.th, www.thaibiogas.net													
Palm Oil		million metric tonnes*											
	2006	6,720,000	0.50	3,360,000	60000	0.06	**201,600**	0.319	0.217	90%	**0.20**	39,370	**826,760**
	2007	6,390,000	0.50	3,195,000	60000	0.06	**191,700**	0.319	0.217	90%	**0.20**	37,436	**786,161**
	2008	8,680,000	0.50	4,340,000	60000	0.06	**260,400**	0.319	0.217	90%	**0.20**	50,852	**1,067,899**
*source: Office of Agricultural Economics													
Ethanol		cu.m.*											
	2006	135,350	20	2,707,000	100000	0.1	**270,700**	0.300	0.204	90%	**0.18**	49,715	**1,044,018**
	2007	191,750	20	3,835,000	100000	0.1	**383,500**	0.300	0.204	90%	**0.18**	70,431	**1,479,057**
	2008	322,190	20	6,443,800	100000	0.1	**644,380**	0.300	0.204	90%	**0.18**	118,343	**2,485,202**
	2009 (est.)	495,600	20	9,912,000	100000	0.1	**991,200**	0.300	0.204	90%	**0.18**	182,038	**3,822,795**

*source: Department of Alternative Energy Development and Efficiency (DEDE)

APPENDIX D: *METHANE EMISSIONS FROM SOLID WASTES AND LEAKAGES*

Solid Wastes

Estimating the methane production potential for agricultural commodity processing wastes is confounded by the same issue regarding B_o expressed on a mass or volume of methane per unit COD basis discussed above. If the solid waste COD concentration is known, estimating methane production potential is as follows:

$$CH_{4\,(SW,\,P)} = TOW_{(SW)} \times B_o \times MCF_{(SW,\,P)}]$$

where: $CH_{4(SW,\,P)}$ = estimated methane production potential from agricultural commodity processing waste SW, kg CH_4 per year

$TOW_{(SW)}$ = annual mass of solid waste SW COD generated, kg per year

$MCF_{(AD)}$ = methane conversion factor for anaerobic digestion, decimal

Again based on limited data and best professional judgment, the MCF_{AD} values of 0.90 and 0.80 appear to be reasonable estimates respectively for heated and ambient temperature digesters for first-order estimates of methane production potential.

Leakage and Combustion Related Emissions

The reduction in methane emissions realized when anaerobic digestion is incorporated into an existing livestock manure or agricultural commodity processing waste management system will be somewhat reduced by leakage and combustion related emissions.

There is very little information regarding methane leakage from anaerobic digestion systems although some leakage probably occurs from all systems and should be incorporated into estimates net methane emissions reductions. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories provides no guidance, with an MCF default value of 0-100 percent. Thus, the use of the 2008 California Climate Action Registry (CCAR) default collection efficiency value of 85 percent in the following equation is recommended unless a higher value can be justified by supporting documentation.

$$LK_{(P)} = \left(\frac{CH_{4\,(P)}}{0.85} - CH_{4\,(P)} \right) \times 0.67\ \text{kg/m}^3$$

where: $LK_{(P)}$ = project methane leakage, kg/year

$CH_{4\,(P)}$ = estimated methane production potential from manure or agricultural commodity processing wastes or both, kg/year

0.85 = default methane capture efficiency, decimal

Because no combustion process is 100 percent efficient and all captured methane should be disposed of by combustion, combustion related methane emissions also should be accounted for in estimating a project’s net methane emission reduction. Unless higher combustion efficiency values can be justified by supporting documentation, the default values (CCAR, 2008) listed in the table below should be used.

Default Values for Methane Combustion Efficiencies, decimal

Combustion Process	Default Value
Open flare	0.96
Enclosed flare	0.995
Lean burn internal combustion engine	0.936
Rich burn internal combustion engine	0.995
Boiler	0.98

Methane emissions associated with each combustion process utilized should be based on the fraction of estimated methane production that will be captured and calculated as follows:

$$CE_{(P)} = \left[\left(CH_{4\,(P)} - LK_{(P)}\right) \times \left(1 - C_{eff}\right)\right]$$

where: $CE_{(P)}$ = Combustion related emissions, kg CH_4 per year

$CH_{4\,(P)}$ = Estimated production potential, kg CH_4 per year

C_{eff} = Combustion efficiency, decimal

Fossil Fuel Use Related Emissions

An anaerobic digestion project may result in increased fossil fuel use such as use of gasoline or diesel fuel for manure transport to a centralized anaerobic digestion facility or transport of another waste to a facility for co-digestion. The resulting increase in carbon dioxide emissions also should be accounted for using the default values for fossil fuel use related carbon dioxide emission rates, as shown in the table below.

Default Values for Carbon Dioxide Factors for Gasoline and Diesel Fuel Use for Transportation (Regional Greenhouse Gas Initiative, Inc., 2007)

Fuel	CO_2 Emission Factor, kg/L
Gasoline	2.38
Diesel	2.75

Estimate the carbon dioxide emissions resulting from increased fossil fuel use due to transportation as follows.

$$FF_{(P)} = \frac{\left(FF_{(Use)} \times C_{factor}\right)}{21}$$

where: $FF_{(P)}$ = Fossil fuel related carbon dioxide emissions on a methane equivalent basis, kg CH_4 per year

$FF_{(U)}$ = Additional fossil fuel use, L/yr

E_{factor} = Emission factor, kg CO_2/L

21 = GWP of methane as compared to carbon dioxide, kg CO_2/kg CH_4

APPENDIX E: *GLOSSARY*

Acetogenesis—The formation of acetate (CH3COOH) from carbon dioxide and hydrogen. Many methanogens grow and form methane from acetate.

Acidogenesis—The formation of primarily short-chain volatile acids such as acetic, proprionic, butyric, valeric, and caproic from simple soluble compounds produced during hydrolysis.

Activated Sludge Process—A biological wastewater treatment process in which a mixture of wastewater and activated sludge (biosolids) is agitated and aerated. The activated sludge is subsequently separated from the treated wastewater by sedimentation and wasted or returned to the process as needed.

Advanced Waste Treatment—Any physical, chemical or biological treatment process used to accomplish a degree of treatment greater than achieved by secondary treatment.

Aerated Pond or Lagoon—A wastewater treatment pond or lagoon in which mechanical or diffused aeration is used to supplement the oxygen supplied by diffusion from the atmosphere.

Aerobic—Requiring the presence of free elemental oxygen.

Aerobic Bacteria—Bacteria that require free elemental oxygen to sustain life.

Aerobic Digestion— The degradation of organic matter including manure by the action of microorganisms in the presence of free elemental oxygen.

Aerobic Waste Treatment—Waste treatment brought about through the action of microorganisms in the presence of air or elemental oxygen. The activated sludge process is an aerobic waste treatment process.

Anaerobic—Requiring the absence of air or free elemental oxygen.

Anaerobic Bacteria—Bacteria that grow only in the absence of free elemental oxygen.

Anaerobic Contact Process—Any anaerobic process in which biomass is separated from the effluent and returned to a complete mix or contact reactor so that the solids retention time (SRT) is longer than the hydraulic retention time (HRT).

Anaerobic Digester—A tank or other vessel for the decomposition of organic matter under anaerobic conditions.

Anaerobic Digestion—The degradation of organic matter including manure by the action of microorganisms in the absence of free elemental oxygen.

Anaerobic Sequencing Batch Reactor (ASBR) Process—A batch anaerobic digestion process that consists of the repetition of following four steps: 1) feed, 2) mix, 3) settle, and 4) decant/effluent withdrawal.

Anaerobic Waste Treatment—Waste stabilization brought about through the action of microorganisms in the absence of air or elemental oxygen. Usually refers to waste treatment by methane fermentation. Anaerobic digestion is an anaerobic waste treatment process.

Attached Film Digester—An anaerobic digester in which the microorganisms responsible for waste stabilization and biogas production are attached to inert media.

Bacteria—A group of universally distributed and normally unicellular microorganisms lacking chlorophyll.

Biochemical Oxygen Demand (BOD)—A measure of the quantity of oxygen utilized in the biochemical oxidation of organic matter in a specified time and at a specified temperature. It is not related to the oxygen requirements in chemical combustion, being determined entirely by the availability of the material as biological food and by the amount if oxygen utilized by the microorganisms during oxidation.

Biogas—A mixture of methane and carbon dioxide produced by the bacterial decomposition of organic wastes and used as a fuel.

Biological Treatment Processes—There are two general types of biological waste treatment processes: suspended and attached growth. Suspended growth processes generally involve mixing to enhance contact between the microbial population and the wastewater constituents. Suspended growth processes can be either aerobic or anaerobic. The activated sludge process is an example of suspended growth wastewater treatment process.

Attached growth processes are characterized by the development of a microbial population attached to a natural or artificial media when exposed to wastewater constituents. The trickling filter is an example of an attached growth wastewater treatment process. Attached growth processes also can be either aerobic or anaerobic.

Cesspool—A lined or partially lined underground pit into which wastewater is discharged and from which the liquid seeps into the surrounding soil. Sometimes called a leaching cesspool.

Chemical Oxygen Demand (COD)—A quantitative measure of the amount of oxygen required for the chemical oxidation of carbonaceous (organic) material in wastewater using inorganic dichromate or permanganate salts as oxidants in a two-hour test.

Chemical Unit Processes—Processes that remove dissolved and suspended wastewater constituents by chemically induced coagulation and precipitation or oxidation. An example is the addition of alum or lime to remove phosphorus by precipitation in tertiary treatment.

Clarifier—Any large circular or rectangular sedimentation tank used to remove settleable solids from water or wastewater. A special type of clarifiers, called upflow clarifiers, use floatation rather than sedimentation to remove solids.

Closed Water Cycle System—A system with no discharge where wastewater is reused for the hydraulic transport of wastes.

Complete Mix Digester—A controlled temperature, constant volume, mechanically or hydraulically mixed vessel operated for the stabilization of organic wastes including manures anaerobically with the capture of biogas generated as a product of waste stabilization.

Compost—The production of the microbial oxidation of organic wastes including livestock manures at an elevated temperature.

Composting—The process of stabilizing organic wastes including livestock manures by microbial oxidation with the conservation of microbial heat production to elevate process temperature.

Conventional Anaerobic Pond or Lagoon—An open treatment or stabilization structure that involves retention under anaerobic conditions.

Covered Anaerobic Lagoon—Same as covered lagoon digester.

Covered Lagoon Digester—A pond or lagoon operated for the stabilization of organic wastes including manures anaerobically and fitted with an impermeable cover to capture the biogas generated as the product of waste stabilization.

Digester—A tank or other vessel for the aerobic or anaerobic decomposition of organic matter present in biosolids or other concentrated forms of organic matter including livestock manures.

Dissolved Air Floatation (DAF)—A separation process in which air bubbles emerging from a supersaturated solution become attached to suspended solids in the liquid undergoing treatment and flat them up to the surface for removal by skimming.

Effluent—The discharge from a waste treatment or stabilization unit process.

Evaporation Pond—A pond or lagoon used for the disposal of wastewater by evaporation.

Facultative—Having the ability to live under different conditions; for example with or without free oxygen.

Facultative Bacteria—Bacteria, which can carry out metabolic activities including reproduction in the presence or absence of free elemental oxygen.

Facultative Pond or Lagoon—A natural or constructed pond or lagoon with an aerobic upper section and an anaerobic bottom section so that both aerobic and anaerobic processes occur simultaneously.

Five Day BOD—That part of oxygen demand usually associated with biochemical oxidation of carbonaceous material with in five days at 20 °C.

Fixed dome digester—A digester with a gas-collecting dome that is fixed. The digester is normally constructed using bricks and mortar and ends with a solid fixed dome.

Greenhouse Gas—A gas present in the atmosphere, which is transparent to incoming solar radiation but absorbs the infrared radiation reflected form the earth's surface. The principal greenhouse gases are carbon dioxide, methane, and CFCs.

Human Sewage (Domestic Wastewater) – Human sewage is wastewater that contains human urine and feces. It also usually contains wastewater from bathing and washing of dishes, kitchen utensils, clothing, etc. and may include food preparation wastes. It may be discharged directly, treated on-site prior to discharge, or transported by a collection system for direct discharge or treatment in a centralized wastewater treatment plant followed by discharge. Human sewage also is known as domestic wastewater.

Hydraulic Retention Time (HRT)—The volume of a reactor divided by the volumetric flow rate.

Hydrolysis—The reduction of insoluble organic and complex soluble organic compounds to simple soluble organic compounds.

Influent—Wastewater flowing into a unit waste treatment or stabilization process.

Lagoon—Any large holding or detention structure, usually with earthen dikes, used to contain wastewater while sedimentation and biological oxidation or reduction occurs.

Liquid Manure—Manure having a total solids (dry matter) content not exceeding five percent.

Manure—The mixture of the fecal and urinary excretions of livestock, which may or may not contain bedding material.

Mesophilic Digestion—Digestion by biological action at 27 C to 38 °C.

Methane—A colorless, odorless, flammable gaseous hydrocarbon that is a production of the anaerobic, microbial decomposition of organic matter.

Methanogenesis—The formation of methane from CO_2-type, methyl, and acetoclastic type substrates.

Municipal Wastewater—Wastewater treated in a municipal (publicly owned) treatment plant and can contain domestic, commercial and industrial wastewaters.

Organic Matter—Chemical substances of animal or vegetable origin, or more correctly, containing carbon and hydrogen.

Oxidation Pond—A relatively shallow body of wastewater contained in an earthen basin of controlled shape, in which biological oxidation of organic matter is effected by the natural or artificially accelerated transfer of oxygen.

Physical Unit Processes—Processes that remove particulate matter in wastewater. Screening and gravity separation to remove particulate matter are examples of physical unit processes. These processes are used for primary treatment and following secondary and tertiary treatment processes. A typical example of the use of physical unit processes in a wastewater treatment system is primary settling followed by the activated sludge treatment process, which is then followed by secondary settling before final effluent discharge.

Plug-Flow—Flow in which fluid particles are discharged from a tank or pipe in the same order in which they entered it. The particles retain their discrete identities and remain in the tank for a time equal to the theoretical retention time.

Plug-Flow Digester—A controlled temperature, constant volume, unmixed vessel operated for the stabilization of organic wastes including manures anaerobically with the capture of biogas generated as a product of waste stabilization.

Primary Treatment*—(1) The first major treatment in a wastewater treatment facility, usually sedimentation but not biological oxidation. (2) The removal of a substantial amount of suspended matter but little or no colloidal and dissolved matter. (3) Wastewater treatment processes usually consisting of clarification with or without chemical treatment to accomplish solid-liquid separation.

Psychrophilic Digestion—Digestion by biological action below 27 °C.

Raw Wastewater—Wastewater before it receives any treatment.

Secondary Treatment*—(1) Generally, a level of treatment that produces removal efficiencies for BOD and suspended solids of at least 85 percent. (2) Sometimes used interchangeably with the concept of biological wastewater treatment, particularly the activated sludge process. Commonly applied to treatment that consists chiefly of clarification followed by a biological process, with separate sludge collection and handling.

Solids Retention Time (SRT)—The average time in which solids including the population of active microbial biomass remain in a reactor.

Septic Tank—An underground vessel for treating wastewater by a combination of settling and anaerobic digestion. Effluent usually is disposed of by leaching. Settled solids are removed periodically for further treatment or disposal.

Settling Pond—An earthen basin in which wastewater containing settleable solids is retained to remove a part of suspended matter by gravity. Also called a settling or sedimentation basin and settling tanks or basins perform the same function.

Stabilization—Reduction in the concentration of putrescible material by either an aerobic or anaerobic process. Both aerobic and anaerobic digestion are examples of waste stabilization processes.

Suspended Solids—(1) Insoluble solids that either float on the surface of, are in suspension in, water, wastewater, or other liquids. (2) Solid organic or inorganic particles (colloidal, dispersed, coagulated, flocculated) physically held in suspension by agitation or flow. (3) The quantity of material removed from wastewater in a laboratory test, as prescribed in “Standard methods for the Examination of Water and Wastewater” and referred to as nonfilterable residue.

Tertiary Treatment*—The treatment of wastewater beyond the secondary or biological stage. Term normally implies the removal of nutrients, such as nitrogen and phosphorus, and a high percentage of suspended solids. Term now being replaced by preferable term, advanced waste treatment.

Thermophilic Digestion—Digestion carried on at a temperature approaching or within the thermophilic range, generally between 43 °C and 60 °C.

Total Solids—The sum of dissolved and suspended solid constituents in water or wastewater.

Treatment—The use of physical, chemical, or biological processes to remove one or more undesirable constituents from a waste.

Upflow Anaerobic Sludge Blanket (UASB) Reactor—An upflow anaerobic reactor in which influent flows upward through a blanket of flocculated sludge that has become granulated.

Volatile Solids—Materials, generally organic, which can be driven off by heating, usually to 550 °C; non-volatile inorganic solids (ash) remain.

Wastewater—The spent or used water of a community or industry, which contains dissolved and suspended matter.

Wastewater Treatment System*—A sequence of unit processes designed to produce a final effluent that satisfies standards for discharge to surface or ground waters. Typically will include the combination of a primary and secondary treatment processes.

*Appendix A illustrates the typical wastewater treatment process.

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