Energy Plant Plantation and Technic for Biogas Production and Utilization: Comparison of Experiences in Thailand and Germany

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ABSTRACT

The current, at the status of June 2013, Alternative Energy Development Plan (AEDP) of Thailand has the goal of an installed biogas electricity capacity of 3,600 MW by 2021. This goal can only be achieved by the usage of the energy plants as a substrate for the biogas production. Napier grass (Pennisetum purpureum) is currently the most important energy plant in Thailand. However, according to the author knowledge, at the status of May 2014, Thailand has few experiences both on the plantation and on the biogas production process from this grass.

On the other hand, energy plants have been commonly used for some decades in Europe for the Biogas production. Large scaled farming for the plantation of these plants is a usual practice by the European agricultural sector. The proper biogas production and utilization technic which are implemented in Europe result in a reliable commercial-scaled level biogas production for the heat and electric generation.

In this article, the broad overview on experiences in biogas production from energy crops in Thailand and Europe will be given. However this article will only focus on the experiences in Germany. The information in this article is based on literatures and on the public information available in the field of biogas production from energy crops. The article will focus on two major aspects. The first aspect is the experience in the plantation of the energy crops in both countries. The second aspect is the technic for biogas production and utilization.

The key differences between both countries will finally be discussed and summarized. The information from this article shall be served as the basis data for future research works on the application of energy crops for biogas production in Thailand and South East Asia region.

Keywords: Energy Plants, Biogas Production, Biogas Utilization, Anaerobic Digestion

INTRODUCTION

Biogas is a flammable gas comprised of difference gases. It is produced by an anaerobic digestion process of the organic matter such as manure, municipal waste, green waste, energy plants and crops. The Biogas can be used as a fuel gas of the gas engine for the electricity and heat generation. Biogas plays an important role in the effort against the climate change as an alternative fuel to the fossil fuel and natural gas. It can be considered as a CO₂-neutral source of energy due to the fact that the CO₂ that is released when the biogas is burned is original came from the CO₂ in the atmosphere which has been withdrawn by the biomass during the photovoltaic process.

Thailand has experienced with the biogas production and utilization since the 1960’s. It began with the biogas production from waste water from agricultural industry and pig farms. The generated biogas is used mostly for the electric generation. The Thai government has subsidized the generated electricity from biogas since the 1990’s. Due to the continuous support policy of the Thai’s authority, at current almost all medium-sized and large manioc or palm oil mills possess their own biogas facilities, which either reduce their own energy consumption or feed power into the grid. The total capacity of 240 MW of electricity from biogas was registered in September 2013 and more
than 500 pig farms produce biogas from pig manure (Holzhausen et al. 2014). Table 1 shows the current overview of installed facilities in Thailand (Holzhausen et al. 2014).

The new challenges aroused in June 2013 after the Thai National Energy Policy Council has raised the extension objective for biogas electricity contained in the Alternative Energy Development Plan (AEDP) - from an installed capacity of 600 MW to 3,600 MW by 2021. These goals can only be achieved by the usage of the energy plants as a substrate in addition to the current substrate of manure and agriculture waste. The major reason of this necessity is the possible gas yield of the substrate. The manure has a possible yield rate between 40 to 60 cubic meters of biogas per ton of fresh mass. In the case of energy plants such as maize a yield rate of approximately 160 cubic meters of biogas per ton of fresh mass can be expected, One Stop Service 1, DEDE 2013. This yield rate differences leads to an avoidable alternative to implement energy plants as the substrate in order to guarantee the economic success of the biogas power plant project which will finally leads to the achievement of the AEDP plan.

Napier grass (Pennisetum purpureum) is currently the most important energy plant in Thailand. Although, according to the author knowledge, at the status of May 2014, Thailand has few experiences on the ‘Industry Level’ plantation of this grass. Additionally, there are yet few experiences with the biogas production and utilization from this grass in commercial biogas facilities within Thailand, with the exception of smaller experiments at universities. Current fermentation systems in Thailand are not suitable for the use with the energy plants substrate which has a high solid content. Most of the agriculture industries and farms with biogas facility implement a modified diesel engine for the electric generation for their internal electric usage.

In Europe, however, energy crops have been used as a biogas power plant substrate for some decades. Germany is one of the nations which have the longest experience in this field. In Germany, Maize, Whole-Crop Cereal and Grass are major substrates in biogas power plants. Large scaled farming with the usage of heavy agriculture machine for the plantation of these plants is a usual practice in Germany. The fermentation process which is specially designed for the implementation with high solid contented substrate is commonly used in Germany. A gas engine specifically designed to use biogas as fuel is commonly used for heat and electric generation.

In this article, the broad overview on experiences in biogas production from energy crops in Thailand and Germany will be given. The information in this article is based on literatures and on the available public information. The article begins with the overview in formation on the biogas production and its utilization process. It is then followed by the information on the substrates and energy plants plantation experiences in both countries. The biogas production process which is implemented in both countries will then be discussed. How the generated biogas is utilized will then be addressed. Finally the key differences between both countries will be summarized.

### BIOGAS

#### What is Biogas?

Biogas, which is a mixture of different gases, is created from a decomposition process of organic substance under an anaerobic environment. This biological process can also be found in nature such as the process taking place in the rumen of ruminants.

There are four major steps in the anaerobic digestion process to produce biogas. These four steps are: hydrolysis stage, acidification stage, acetic acid formation stage, and methane formation stage. Each of these steps involves different groups of microorganism. Figure 1 shows the simplified schematic diagram of this process. It is not the intention of this article to give the full detail on this aerobic digestion process. The reader can find this information, as for example, from Eder et al. 2012.

The biogas comprised of three major gases: methane (CH₄, 50-75% Vol.) carbon dioxide (CO₂, 25-50 vol. %) and water vapour (H₂O, 2-7% Vol.). Biogas also consists, in small quantities, of hydrogen (H), hydrogen sulphide (H₂S), ammonia (O₃) and other trace gases. Methane is the most important gas of the biogas. The higher the content of methane, the greater is the energy content of biogas. The ratio for the composition of the gases in the biogas depends essentially on the implemented substrates. As a result, a correct selection, plantation, formulation and preparation of energy plants are a key to a high biogas (methane) yield.

As mentioned above, the anaerobic process involves various works of microorganisms. These works require an optimum environmental condition and parameter such as an optimum pH value and an optimum supply of nutrients. The anaerobic process is also sensible to disturbance both from operational process and from alien inhibitors. This can have a great adversely impact on the anaerobic process and finally on the biogas yield. Thus a proper selection, operation and control of the fermentation technic play a very important role in the optimum biogas
Following sections will give the information on the experiences in Germany and Thailand on these two major aspects of energy plants plantation and fermentation technics. However the next section will give first the overview on biogas production and utilization process.

**BIOGAS PRODUCTION and UTILIZATION PROCESS OVERVIEW**

Figure 2 shows a simplified scheme of biogas production and utilization process of an agricultural based biogas plant. Figure 3 shows an agricultural based biogas plant in the town of Jühnde, Germany (Ruppert et al. 2010). The process begins with the plantation and harvest of the energy crops. Energy crops together with liquid manure from animal farms will then be delivered to the receiving area of the biogas plant where the delivered mass is measured and the initial quality control is performed. The liquid manure will then be stored in the storage tank. Energy crops and other co-substrates will then be stored in a separate area. Figure 4 shows the example of this storage area. The removal of contraries and the disintegration of the energy crops happen during this storage period. These two processes are important in the accelerating of the decomposition rate by the microorganisms during the fermentation phase. In the case of substrates that may have a potential health risk such as organic waste or food waste, they must be treated with a pasteurization system before the fermentation process. After the pretreatment process, the substrates will be fed to the digester. The solid substrates such as energy crops will be fed to the digester via the feed-in machine unit. The liquid substrates such as the liquid manure will be pumped from the manure storage tank into the digestion system.

There are different types of digestion system. There are two major types of digestion system according to the type of the substrates flows into the digester. These two types are: the continuous system and the discontinuous system. The generated biogas will be stored in the gasholder. One of the most common types of the gas holder is the integrated storage roof on the fermenter as shown in Figure 5. The biogas from the gas holder will then fed to the gas purification unit. This unit removes particles, condensate and hydrogen sulphide (H2S) from the biogas before the feeding into the electric generator engine. This is done to protect the gas engine from corrosion.

The purified biogas will then be used as a fuel gas by the combustion engine to produce heat and electricity. The plant that can produce both heat and electricity is called a Combined Heat and Power Plant, CHP. The produced heat and electricity can be used within the farm or it can be fed into the heat and electrical grid. In addition to heat and electricity generation the purified biogas (50-55% methane content) can also be upgraded to biomethane (methane content over 87%). Biomethane can be used as a fuel in the transportation sector.

Concerning the digestate which is the residue left after anaerobic digestion, it can be used as an organic fertilizer back into the plantation farm of energy crops.

**ENERGY PLANTS PLANTATION and BIOGAS SUBSTRATES**

**Germany**

Biogas can be produced from different organic substrates. In the case of Germany, most of the biogas plants are farm-based. The most important two substrates are animal excrement (e.g. cattle and pig liquid manure) and energy crops. Table 2 shows the overview of biogas yields of various substrates (One Stop Service 1 DEDE 2013). Energy crops are used due to its high biogas yield and its availability (with plantation and storage management) for the whole year long. Common energy crops in Germany are: maize, grain, grasses and sugar beet. At current, maize shares the greatest part of bioenergy crops in Germany.

Maize is commonly used because its high dry matter yields and energy yields per hectare. Maize is also one the crops that require less fertilizer and plant protection product than, for example, grain crops. In addition, maize is the crop that is easy to handle during the plantation and harvest. The cost and the technological effort during the storage and fermentation of maize are also economically acceptable. In most cases, the maize is growth during the summer time of June until October. The harvest is in general happened in October.

The entire maize is commonly chopped during the harvest and then stored in the silos or at the storage area. Figure 6 shows an example of the harvest of maize with a heavy machine (One Stop Service 2 DEDE 2013). Figure 7 shows an example of the chopped entire maize storage area at one of the biogas power plant in Germany. During the
storage period certain water content will be lost. However the humidity of the stored maize must be optimum. If the dry matter is too low, it can lead to a considerable escape of seepage water, associated with significant energy losses during the fermentation process. On the other hand if the dry matter is too high the silage will has a high lignin content and is thus harder to be digested. After an optimum humidity and storage time have reached, the maize will be fed into the fermenter.

Although maize has various advantages to be used as biogas plant substrates, the rapid-growing cultivation of maize in Germany is currently being criticized. Monoculture of maize is a major concern at current in Germany. Research efforts are now focused on cultivation alternatives. The goal is to find cultivation method of energy crops that guarantee the sustainability of environmental resources. Other energy crops such as sugar beets can also deliver the same gas yield performance as maize. Number of research projects, on the application of sugar beets as biogas plant substrates are currently in progress.

In addition, certain research works are currently focus on the cultivation of mixed crops, wild flower and other new energy crops such as sorghum. Figure 8 (Eder et al. 2012) shows an example of the mixed cultivation of maize and sunflower and of maize and sorghum. The profit of the mixed cultivation is e.g. a better utilization of the nutrients, a stable production yield and a reduction of the monoculture problem of the spreading of pest and diseases. Despite these advantages, there are still few experiences in the mixed cultivation. The fully understanding of the technic for the gas production and utilization from mixed crops are also still limited.

Thailand
As mentioned above, Thailand began the utilization of biogas with the use of agriculture waste and farm manure. Today these two substrates are still the most common substrates in Thai biogas power plant. However with the new biogas electricity target in the revised AEDP plan, energy crops are now the new focus of the Thai biogas community. As the result, this section will only concentrate on the overview information of the energy crops in Thailand and not on the agriculture waste and farm manure. It will also focus only on the Napier Grass which is currently the most important energy crop in Thailand.

Napier Grass (Pennisetum purpureum) or Elephant Grass is a species of perennial tropical grass native to the tropical grasslands of Africa. It is now in the focus of Thai biogas community due to its various advantages such as a high content of carbon, a high ratio between carbon and nitrogen, a high yield of dry mass, it can be cultivated and harvested multiple times per year, and it has low water and nutrient requirements.

According to the Department of Alternative Energy Development and Efficiency, DEDE 2014, although napier grass may be a rather new energy crop, it is no stranger to Thai farmers as it has been planted locally for over 30 years, with over 130 species. However, only three species have been popular among local farmers comprising Napier Grass, King Grass, and Mott Dwarf Elephant Grass.

It is also stated in DEDE 2014 that the napier grass specie that suits best as energy crop is Pakchong 1. It can be harvested 5-6 times a year and yield as much as approximately 400 tons fresh mass/year/hectare. Its nutrition structure fits for microbe to grow and generate methane gas. Pakchong 1 can approximately generate biogas at 42,000-48,000 m³/hectare/year.

However based on the author’s survey, there are still various researches going on in Thailand on other napier grass species and on other aspects of napier grass plantation. In Vinijchevit et al. 2014, the biogas yield of three different napier grass species of Pakchong 1, Bana, and Mott are investigated. The result has shown that other napier grass species are also having a high yield of biogas. In Pongtip et al. 2014, the effect of the water management on the productivity yield is investigated. In Kulasuwan et. al. 2014 the effect of the seasonal and cutting interval of napier Pakchong 1 on biogas yield is investigated.

It should also be noted that the current information concerning napier grass in Thailand is based on, according to author’s knowledge, an experimental result from a very well controlled research plantation field. Figure 9 shows the example of this research field at one of the Kasetsart University napier grass research fields. The author is not able to find the information available for the public on the real world experience of an industry scaled plantation of napier grass in Thailand. Finally, the author is also not able to find the information available for the public on the industry leveled experience in Thailand on the harvest, the post-harvest treatment and storage method of napier grass.
BIOGAS PRODUCTION

Germany
As stated previously, the current most common substrates in Germany are maize and animal excrement. The following paragraph will give an overview on the biogas production (fermentation) process that is used in Germany with these two substrates.

There are two types of digestion systems commonly used in Germany: the continuous and discontinuous system. The following paragraphs are taken from the Department of Public Relations, FNR 2009 for the explanation of these two systems.

In the discontinuous biogas process, also known as batch process, the fermenter is completely filled with fresh substrate and hermetically closed. The substrate remains in the container until the end of the selected retention time without substrate added or removed. The fermenter is then emptied and filled with new substrate. Gas production begins slowly after filling and subsides again after the maximum value has been reached. Discontinuous feeding is the process most widely used for dry fermentation.

Continuous processes are characterized by regular feeding of the digester. The digester also acts as a digestate storage tank in which the substrate is kept until it is spread. The disadvantage is the high energy consumption necessary to heat the large reactor room; the advantages are the low investment cost and the use of biogas from secondary fermentation.

Semi-continuous fermentation is the most widely used process in Germany. This system is suitable for the wet anaerobic digestion of the mixed substrate of slurry and solid biomass (energy crops). The substrate is pumped into the digester several times daily from the holding tank/liquid manure store. A quantity of fresh substrate equivalent to that added to the fermenter is expelled or removed into a downstream fermenter. This results in fairly regular gas and therefore electricity production. When the retention time has elapsed, the fermentation substrate is introduced into the covered digestate storage tank.

The common fermenter type used in the semi-continuous digester is the “Continuous Stirred-Tank Reactor, CSTR”. An agitator (a stirring device) in the fermenter ensures that the substrate is equally distributed throughout the reactor and that the gas that forms can escape from the substrate. Figure 10 shows a schematic diagram and an example picture of the ‘flat rounded’ CSTR fermenter with the past (second) digester and gas storage in the Semi-continuous fermentation process (Kayser et al. 2012). The system shown in Figure 10 is the most used system in Germany.

The produced gas will then be stored in a gas holder. In Germany, the integrated inflated roof over the fermenter is the most founded gas holder system. Figure 10 also shows this type of gas holder over the rounded fermenter. The gas from the gas holder is then flows to the gas utilization unit.

Thailand
The most common substrates in Thailand at current, as stated above, are farm manure and agricultural industry waste. The fermentation system that is implemented in Thailand thus is the system that is suitable for the use with this substrate.

There are two common types of fermenter that are currently used in Thailand. The first type is the anaerobic cover lagoon fermenter. The anaerobic cover lagoon fermenter is a deep earthen basin with the impermeable cover mostly of High Density Polyethylene, HDPE or PVC. The cover traps gas produced during the digestion of the manure. The cover lagoon is easy to construct because it does not require additional air from outside, heat, or mixing unit. However it requires certain time for the digestion of the substrate. The substrate that is suitable for the cover lagoon is the liquid substrate such as pig farm slurry. This fermenter is not suitable for the substrate with high solid content as for example the energy crops due to the absence of the mixing unit in the fermenter. Figure 11 shows an example of this fermenter in a pig farm in Thailand, DEDE 2008.

The second common type of fermenter in Thailand is the anaerobic plug flow digester. In the case of the plug flow digester, there is a ‘flow’ of the substrate during the fermentation process. The substrate enters the plug-flow digester and decomposes during its travel through the digester. New substrate added to the digester tank pushes older substrate through the digester to the discharge end. An impermeable cover from HDPE or PVC over the digester collects the produced biogas. The advantage of the plug flow system is that it can handle higher amount of substrates. Figure 12 shows an example of this fermenter in a pig farm in Thailand, DEDE 2008.

Concerning the fermentation system for energy crops, the author is not able to find concrete information on the commercial level experience of this system in Thailand. The information on the biogas yield from the napier grasses mentioned in the literatures above is based on the experiment performed in the university leveled laboratory.
At the status of September 2014, few companies have constructed and start operating the napier grass based biogas plants. However the detail information on the fermentation system of these plants is not available for public. Some proposals on the fermentation system for napier grass are given in One Stop Service DEDE 2013. Although this guideline does not give a clear recommendation on which fermentation system shall be used with napier grass.

**BIOGAS UTILIZATION**

**Germany**

As mentioned above, the biogas is also comprised of water, H$_2$S and CO$_2$. These must be removed before entering the gas engine to prevent the engine from corrosion. There are several methods for the desulphurization and cleaning of Biogas. Figure 13 shows an example of the pressurized water scrubbing unit for the removal of the CO$_2$ from the biogas (Eder et al. 2012). The cleaned gas can then be used in different ways. In Germany, biogas is mostly used to produce electricity and heat in a Combined Heat and Power Plant, CHP.

CHP is a unit with an internal combustion engine using biogas as a fuel. The mechanical output of the engine is used to drive the electric generator for electricity production. The heat generated by the cooling and exhaust system of the combustion engine is utilized by the heat consumer such as residential houses or industry factories nearby the biogas plant. There are two major types of combustion engine that are commonly used in the CHP unit in Germany. The first type is the gas-otto engine. It is the Otto (Gasoline)-principle engine which has been specially designed to use biogas as a fuel. The second type is the pilot ignition engine which is a diesel-principle engine that has been specially developed to use biogas instead of the diesel.

The gas-otto engine is able to operate with the biogas that has the methane content of only 45%. The pilot ignition engine, on the other hand, requires the mixture of ignition oil (diesel) of approximately not more than 10% volume with biogas to ignite the combustion process.

The gas-otto engine has the advantages of as for example: a specially designed to run on gas, a low maintenance engine and an overall efficiency higher than the pilot ignition engine. The disadvantages of the gas-otto engine are for example: a higher investment cost than the pilot ignition engine and a lower electrical efficiency than pilot ignition gas engines in the lower power output range. The pilot ignition has the advantages of as for example: a lower investment cost and a higher electrical efficiency in the lower power output range. The major disadvantages are for example: a short service life, a possible coking of injection nozzles which results in a possible more maintenance services and an overall lower efficiency lower than the gas-otto engines. Figure 14 shows an example of both engine types in the CHP plant in Germany (Eder et al. 2012).

Biogas can also be used as a substitute fuel of the natural gas. However it requires an upgrading unit or plant to raise the methane content of biogas from 50-50% to approximately above 87% which is the methane content level of the natural gas. The upgraded biogas is called ‘biomethane’. It can be used as fuel for vehicles or it can be used as a fuel for the conventional natural gas electricity power plant. In Germany the biomethane is mostly used as a substitute of the natural gas in a conventional heat and electricity power plant. It is mostly fed into the existing natural gas grid infrastructure in Germany.

Figure 15 shows a schematic diagram of the biogas upgrading process (Department of Public Relations, FNR 2009). There are several technologies that are used for the upgrading of biogas e.g. pressurized water scrubbing, pressure swing absorption and physical and chemical absorption process. The purified biomethane is then fed into the natural gas grid via a feed-in station. Figure 16 shows an example of this station. The reader can found more detail on biogas upgrading to biomethane in different literatures such as Eder et al. 2012.

**Thailand**

In Thailand the biogas produced from manure substrate is also purified before entering the gas engine. Figure 17 shows an example of the desulphurization unit used in Thailand, DEDE 2010. At current the produced biogas are commonly used in two ways. The first usage is the direct burning of the gas to generate heat. The generated heat is used in a normal household or in an industry. Figure 18 shows an example of the usage of the heat generated from the direct burning of the biogas in Thailand, DEDE 2008. The second usage is the electric generation. According to DEDE 2008, there are two common types of combustion engine that are used in a small and medium farm and agricultural enterprise in Thailand. The first engine type is the modified benzin engine. The second type is the modified diesel engine. Both types of the engine are standard diesel or benzin engines that are locally modified in Thailand to be able to use the biogas as a fuel. Figure 19 shows an example of these two engine types. In the case of
large scaled farm or enterprise, with the electricity capacity of more than 200 KWs, the imported engine that is specifically design to use biogas fuel, as shown in Figure 14, is commonly used, DEDE 2008. One important remark is that, unlike the usage of the engine heat by the CHP unit in Germany, the author is not able to find the same kind of experience in Thailand.

Upgrading biogas to biomethane in Thailand is new. Few companies have constructed and start operating the napier grass based biogas plants for biomethane production. However the author is not able to find a concrete reference on the experience of these biogas plants.

One of the alternative utilization of biogas in Thailand is the replacement of Liquified Petroleum Gas, LPG with biogas in the Thai household. Most of the Thai household in Thailand use LPG gas for their daily cooking. However during the last years the price of the LPG, which is mostly imported, is increasing in the same way as the fossil fuel. In 2012, the DEDE of Thailand has launched a pilot program to replace the LPG with the biogas in the Thai community, DEDE 2012. However there is still no detail information on the construction, operation and the result of this project.

CONCLUSION

This article provides the overview on the experience in Thailand and Germany in the field of energy plants plantation. The overview on the technic experience in both countries for the biogas production from energy crops and its utilization has also been given.

Energy crops plantation for the use as biogas substrate is a new field in Thailand. Napier grass is currently the most important energy crop in Thailand. As because it is the new field, Thai biogas community still lacks in experience concerning the industry scaled plantation and harvest method of this grass. This aspect can be learned from the German experience with the industry scaled maize plantation. Thailand can also gain knowledge from the German experience in the storage and pre-process of energy crops. However, the technic that is used in Germany may not be able to be used directly in Thailand due to the different environment and different energy plants property. Further development of the suitable technic for Thailand is mandatory.

The current problem of maize monoculture in Germany is a very important aspect that the Thai biogas community must also concern. The Thai biogas community must pay attention to the biodiversity aspect when it begins the large scale plantation of energy crops. This is very important in order to guarantee the long term environment sustainability of the biogas production from energy plants.

Concerning the biogas production technic, Thailand has few experiences with the fermentation of biogas crops. The semi-continuous fermentation process with the CSTR fermenter generally used in Germany is a good alternative for the implementation in Thailand. However, as same as in the case the napier grass plantation, further modification of this technic to suit Thai environment and Thai napier grass property is required.

Thailand has long experiences in using biogas for electric generation. However the heat from the engine cooling and exhaust system is not commonly utilized. The utilization of this heat, in the same way as the CHP plant in Germany, shall be considered in the future in order to increase the overall efficiency of the biogas plant. The reliability of the gas engine shall also gain more priority in order to guarantee the overall reliability of the future Thai commercial leveled biogas power plant.

The upgrading of biogas to biomethane for the transport sector to reduce the fossil fuel usage is a very interesting alternative for Thailand. In addition the replacement of the LPG with the upgraded biogas in the Thai household will have a direct positive impact to the Thai people. Further researches and studies shall be performed on these two aspecrs in the future.

Finally, the cooperation between the Thai and German biogas community (research institutions, enterprises, and government organizations) to investigate the open issues mentioned above will be beneficial. Both communities will be benefited from the knowledge exchange and also from the economical perspective. This cooperation shall be considered in the future.
REFERENCES


### Table 1. Overview of installed biogas facilities in Thailand (Holzhausen et al. 2014)

<table>
<thead>
<tr>
<th>Industry</th>
<th>Installed facilities</th>
<th>Biogas Production in m.m³/yaear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pig farms (Subsidy phase I-III, 1995-2010)</td>
<td>271</td>
<td>88.60</td>
</tr>
<tr>
<td>Pig farms (2008-2012)</td>
<td>263</td>
<td>74.81</td>
</tr>
<tr>
<td>Small agriculture operations</td>
<td>575</td>
<td>9.51</td>
</tr>
<tr>
<td>Slaughterhouses (pigs)</td>
<td>12</td>
<td>0.74</td>
</tr>
<tr>
<td>Slaughterhouses (poultry)</td>
<td>5</td>
<td>6.02</td>
</tr>
<tr>
<td>Cassava starch</td>
<td>59</td>
<td>385.82</td>
</tr>
<tr>
<td>Palm Oil</td>
<td>88</td>
<td>211.00</td>
</tr>
<tr>
<td>Ethanol</td>
<td>21</td>
<td>263.05</td>
</tr>
<tr>
<td>Caoutchouc</td>
<td>7</td>
<td>2.08</td>
</tr>
<tr>
<td>Foodstuff residues</td>
<td>47</td>
<td>51.27</td>
</tr>
<tr>
<td>Catering waste from hotels etc.</td>
<td>80</td>
<td>2.28</td>
</tr>
<tr>
<td>Others</td>
<td>140</td>
<td>427.37</td>
</tr>
<tr>
<td>Total</td>
<td>1,568</td>
<td>1,522.55</td>
</tr>
</tbody>
</table>

### Table 2. Overview of biogas yield of different substrates (One Stop Service¹, DEDE 2013)

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Biogas Yield (m³/ton-Fresh Mass added)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicken Manure</td>
<td>58.90</td>
</tr>
<tr>
<td>Duck Manure</td>
<td>58.98</td>
</tr>
<tr>
<td>Elephant Manure</td>
<td>56.97</td>
</tr>
<tr>
<td>Rice Straw</td>
<td>199.73</td>
</tr>
<tr>
<td>Empty Bunch</td>
<td>213.46</td>
</tr>
<tr>
<td>Pineapple Peel</td>
<td>61.24</td>
</tr>
<tr>
<td>Cassava</td>
<td>121.36</td>
</tr>
<tr>
<td>Hyacinth</td>
<td>46.84</td>
</tr>
<tr>
<td>Cattail</td>
<td>77.64</td>
</tr>
<tr>
<td>Maize</td>
<td>167.4</td>
</tr>
<tr>
<td>Napier Grass</td>
<td>116.4</td>
</tr>
</tbody>
</table>
Substrates: Fats, proteins, carbohydrates (long-chain polymers)

Hydrolysis

Fatty acids, amino acids, sugar (short-chain polymers and dimers)

Acidification

Short-chain organic acids (e.g. propionic acid), alcohols

Acetic acid formation

Acetic acid (CH₃COOH), carbon dioxide (CO₂), hydrogen (H₂)

Methane formation

Biogas: Methane (CH₄), carbon dioxide (CO₂), hydrogen sulfide (H₂S), Water etc.

Fig. 1. A simplified diagram of a decomposition process of organic substrates to produce biogas

Fig. 2. A simplified scheme of a biogas production and utilization process of an agricultural based biogas plant
Fig. 3. An agricultural based biogas plant in the town of Jühnde, Germany (Ruppert et al. 2010)

Fig. 4. An example of the biogas substrates receiving and storage area (Photo: S. Cumnuantip)

Fig. 5. An example of an integrated biogas holder roof on the fermenter (Photo: S. Cumnuantip)
Fig. 6. An example of the maize harvest with heavy machine (One Stop Service*, DEDE 2013)

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Fig. 8. a) An example of the mixed cultivation of maize and sunflower b) An example of the mixed cultivation of maize and sorghum (Eder et al. 2012)
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