ExploRE
Strategic Exploration of Economic Mitigation Potentials through Renewables

Desktop Study Report

Biomethane Utilization from Palm Oil Mill Effluent

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“Biogas Plant in Palm Oil Mill Terantam, PTPN V”, photo by GIZ

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1. Introduction

1.1. Background

The Government of the Republic of Indonesia is carrying out a national energy mix target commitment of 23% is come from renewable energy by 2025. To achieve these targets, the National Energy General Plan (RUEN) stipulated through Presidential Regulation (Perpres) Number 22 Year 2017, serves as a reference for development planning in energy sector for central and regional Governments. In the regulation, the target is separated into electricity and non- electricity. Most of the time, Government is focus on electricity target which is still struggling to compete with fossil fuel-based electricity. For non-electricity, the main attention is going to biodiesel that being pushed by the government via B-30 program. In the other side, biogas not yet get the same attention from the government despite of its big potential.

Based on the regulation, the utilization target for biogas for non-electricity application is 489,8 million m^3. Most of this application come from communal biogas program that convert manure into biogas that used for cooking gas, while there is huge potential of biogas that not yet utilized from palm oil mill effluent (POME). With the current technology, biogas can be upgraded into biomethane and can be used for various application. Biogas upgrading application already widely utilized in Europe and USA as environmentally friendly vehicle fuel. But in Asia and especially Southeast Asia, biogas upgrading application is still limited and mostly is funded partially by government and not commercially feasible yet. In Indonesia, only one project of biogas upgrading into biomethane plant currently in construction and others is still wait and see the development of the projects.

1.2. Objective

This study aims to give an overview of the utilization, technology, financial and market potential of biomethane from palm oil mill effluent (POME) in Indonesia.

1.3. Methodology

This study will collect reference from literature review and project data from local and international that already build biogas upgrading plant. Local data will be limited because currently only one biogas upgrading project in Indonesia that still in construction. For the technology and financial part, the data will be collected from scientific journal and directly from the vendor that provide the technology. For the market study, the data will be collected from Central Statistics Agency (BPS), GIZ internal data and DG-NREEC data.

"Palm Oil Mill Terantam, PTPN V", photo by GIZ

2. Biomethane from POME

2.1. Biogas Development in Indonesia

In 1970s, biogas technology was introduced in Indonesia as a waste management program that focus on rural areas. In 1981, Food and Agriculture Organization (FAO) United Nation funds the Biogas Development Project to develop biogas installation in Indonesia, 7 biogas installations being built in several provinces as example model. Begin in 2000s, low price small-scale biogas reactors (household) have been developed with simple construction made of plastic in a ready-to-install manner.

According to research done by Faculty of Animal Science, Gadjah Mada University, biogas can meet up to 13.3 percent of cooking fuel and electricity needs in Indonesia. Energy decentralization strategy through biogas will supports regional energy independence and security as well as promoting low carbon development, helps achieve national electrification targets, and develops village economy and energy up to Rp 64.3 trillion per year. The potency of generating biogas from organic waste is high as the number of organic wastes is reaching 39 million tons per day. However, the use and distribution of biogas currently is still very low at 1.24 percent. In fact, optimizing the use of biogas is important to help local energy transitions as well as reducing LPG imports. Meanwhile, government subsidies for LPG continue to increase each year, reaching 6.6 billion metric tons in 2018.

The development of industrial scale biogas is started in 2006 by the initiation of Clean Development (CDM) program. CDM is one of the Flexible Mechanisms defined in the Kyoto Protocol, it provides emissions reduction projects which generate Certified Emission Reduction units (CERs) which may be traded in emissions trading schemes. Currently, there are 80 industrial scale biogas plant in operation in Indonesia with various feedstock, with majority come from palm oil mill effluent (POME). Most plant generate electricity only for captive power usage and less than 50% that selling electricity to the grid. Not attractive tariff, uncertainty of regulation, difficult procedure, and obligation to transfer (BOOT) the plant to the utility when the contract ends becomes huge challenges to sell electricity to the grid. These are the main reason explain the small number of biogas plant in Indonesia despite of huge potential of agricultural waste and animal manure. However, by the introduction of biogas upgrading technology which offer alternative utilization of biogas other than electricity, it is expected that it will help the biogas industry to develop.

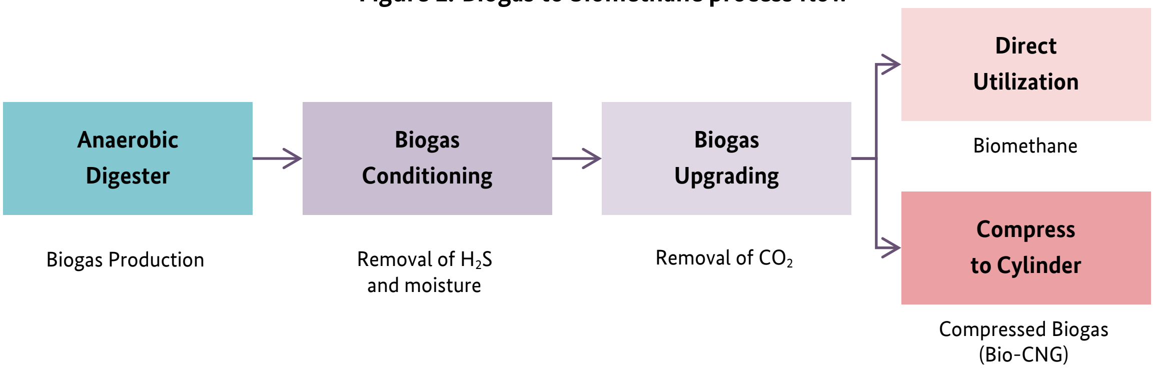
2.2. Biogas Upgrading to Biomethane

Biogas is a mixture of gases, produced by the breakdown of organic matter in anaerobic condition. Biogas consists mainly of methane (CH_4) and carbon dioxide (CO_2) and it can be utilized as a substitute for natural gas, as a vehicle fuel, or as a renewable energy source. Different biogas treatment steps are necessary, depending on the end use. Some application which requires high energy content in the gas such as using biogas as vehicle fuel or for grid injection, the gas should be upgraded. The energy content of biogas is directly proportional to methane concentration. Therefore, removing carbon dioxide in the upgrading process, makes the energy content in the gas increase.

Biogas that has been upgraded to a similar quality to natural gas and having a methane concentration of 90% or greater is called biomethane. It is also called renewable natural gas because it came from renewable source and can replace natural gas. Biomethane that being compressed and bottled into cylinders is called compressed biogas or bio-compressed natural gas (Bio-CNG).

Main impurities in biogas that produced from anaerobic digester are hydrogen sulfide (H_2S) and water (see Figure 1). Those impurities might cause corrosion and mechanical wear of the upgrading equipment, compressor, and other mechanical material from carbon steel. Therefore, biogas conditioning process is very important to remove the impurities. In order to avoid corrosion in plant components and to ensure the quality requirements for vehicle fuel or grid injection, the value of H_2S in biogas need to be reduced until below 10 ppm. Common method to reduce H_2S is biological scrubber due to their low operating costs that uses special sulfur-oxidizing bacteria to convert H_2S to SO_4. Other method is chemical scrubber and water scrubber. Chemical scrubber uses a chemical such as NaOH to convert H_2S to SO_4. Water scrubbers, working based on the physical absorption of dissolved gases in liquid, use high-pressure water.

Figure 1. Biogas to biomethane process flow



Common method to remove the water from biogas is by using chiller to cool the biogas until it reaches it dew points and then separated the water from the gas. This helps optimize the combustion process in the engine, prevent condensation, and protect the engine from acid formation. The water removal process is being done after the H_2S scrubber because scrubbing process will increase the water content of the biogas.

Conditioned biogas then enters the biogas upgrading system to remove the CO_2. Removing the CO_2 will increase the methane concentration, meaning that biogas is converted into biomethane. This will result in an increased energy density since the concentration of methane is increased as well. Several technologies for biogas upgrading are commercially available and others are at the pilot or demonstration plant level. This study will focus on the most common and proven method to upgrade the biogas, which are membrane separation, water scrubbing and pressure swing adsorption. Biomethane produced can be directly utilized and injected to the gas grid or compressed into cylinder for various utilization.

2.3. Biomethane Characteristic

Biomethane has similar characteristic with natural gas as both have the same main component which is methane. The major difference is that natural gas come from fossil source that is non- renewable but considered as the cleanest fuel compare with another fossil fuels. On the contrary, biomethane is come from renewable source as it can be produced from almost any biological raw materials. Biomethane component can be varies depend on the upgrading technology and its utilization. The component comparison between biogas, biomethane, and natural gas are show on Table 1. It shows that biomethane and natural gas are mainly consisting of methane.

Table 1. Properties of natural gas, raw biogas and biomethane (Mel, Ahmad, & Sinaga, 2018)

Gas Composition	Biogas	Biomethane	Natural Gas
Methane (CH4)	50-75%	94-99.9%	93-98%
Carbon Dioxide (CO2)	25-45%	0.1-4%	1%
Nitrogen (N)	<2%	<3%	1%

Gas Composition	Biogas	Biomethane	Natural Gas
Oxygen (O2)	<2%	<1%	-
Hydrogen (H2)	<1%	Traces	-
Hydrogen Sulfide (H2S)	20-20,000 ppm	<10 ppm	-
Ammonia	Traces	Traces	-
Ethane	-	-	<3%
Propane	-	-	<2%
Siloxane	Traces	-	-
Water	2-7%	-	-

As shown in Table 2, biomethane has the same calorific value with natural gas, although in the actual condition it will be slightly difference depend on the methane percentage of the biomethane. Biomethane also has higher calorific value per kilogram if compared with LPG and diesel fuel.

Table 2. Fuels Calorific Value Comparison (M. S. Shah, 2017)

Gas Composition	Calorific value (MJ/kg)
Natural Gas	52,0
Biomethane (97% methane)	52,0
LPG	46,0
Diesel	44,8

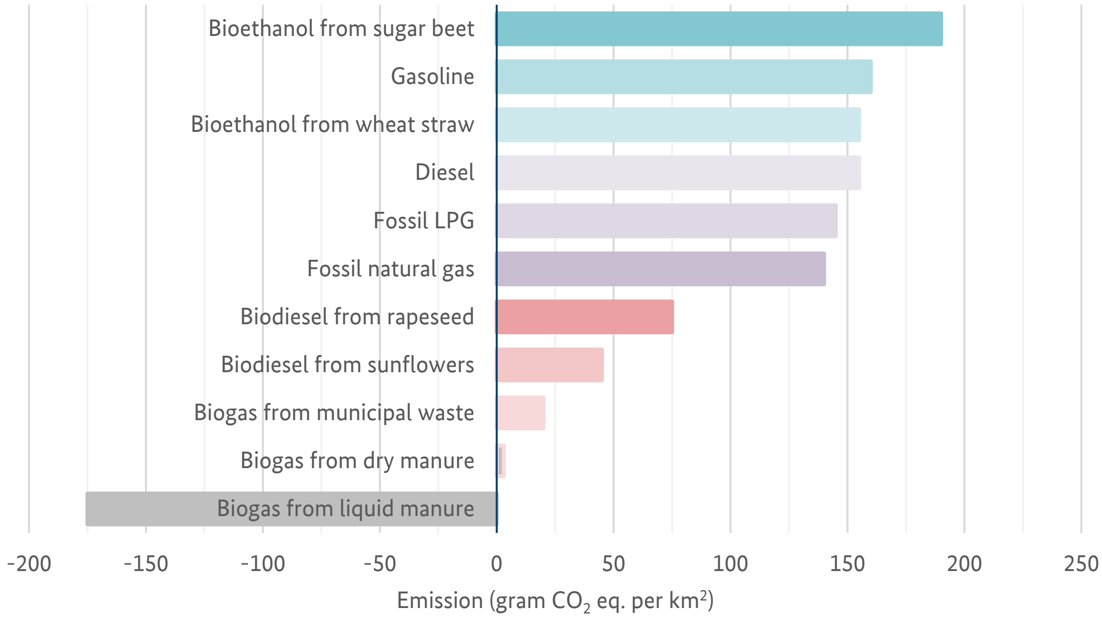
Different country has its own standard for upgraded biogas that have slightly different characteristic. Indonesia already has national standard for high pressure biogas based on SNI 8019:2014 as shown in Table 3 below. The methane percentage in the standard is only 80% that quite low compared to other reference.

Table 3. SNI 8019:2014 for high pressure biogas quality standards

No	Parameter	Unit	Values	Analysis Method
1	Dew point on 20000 kPa (200 Bar)	^{O}C, max	5	ASTM D1142
2	Wobbe Index	MJ/Nm^3	34 - 41	ASTM D3588/ISO 6976/GPA 2172
3	Methane Number		80 - 118	ISO/TR 22302
4	Methane	&vol., min	80	ISO 6974-5/ASTM D1945/GPA 2261
5	Hydrogen Sulphide	Mg/Nm^3, max	23	ASTM D4084/ISO 11119739
6	Hydrogen	%vol., max	0,1	ISO 6974-5/ASTM D1945/GPA 2261
7	Carbon Dioxide	%vol., max	18	ISO 6974-5/ASTM D1945/GPA 2261
8	Oxygen	%vol., max	1	ISO 6974-5/ASTM D1945/GPA 2261
9	Total sulphur	Mg/Nm^3, max	50	ASTM D4468/ASTM D 6667
10	Relative Density		0,55 – 0,75	ISO 6976/ GPA 2172/ASTM D3588

Even though biomethane has the similar characteristic with natural gas, biomethane emit much less carbon emission because of its renewable sources. Biogas from liquid manure is not only carbon neutral but also carbon negative that reduce carbon footprint in the atmosphere (see Figure 2)

Figure 2. Comparison of Biofuel Emissions (Robert, Jean-Francois, & Jean-Christophe, 2011)



2.4. Biomethane from POME Potential

Palm oil mill effluent is the biggest and most viable source for biogas generation in Indonesia compared to other source such as starch waste, municipal waste and manure. Currently there are more than 800 palm oil mills in Indonesia, and only 10% that already build biogas plant. From that number, only 2% biogas plant is selling electricity as IPP (Independent Power Producer), 43% is selling electricity as excess power and 55% is using the electricity for captive power or flaring only. So, only very small percentage of biogas that already utilized and less than half is being used to produce electricity and sell it to the grid. Captive power usage usually only very small amount because palm oil mill is already self-sufficient from its biomass power plant. Therefore, still a lot of biogas potential that still can be utilized as biomethane.

Table 4. Fuel subsidy quota 2015 – 2019 1

Year	Diesel (Billion liter)	Kerosene (Million liter)	LPG (Billion kg)
2015	14,1	738	5,6
2016	13,7	536	6
2017	14,5	527	6,3
2018	14	610	6,5
2019	14,5	610	6,9

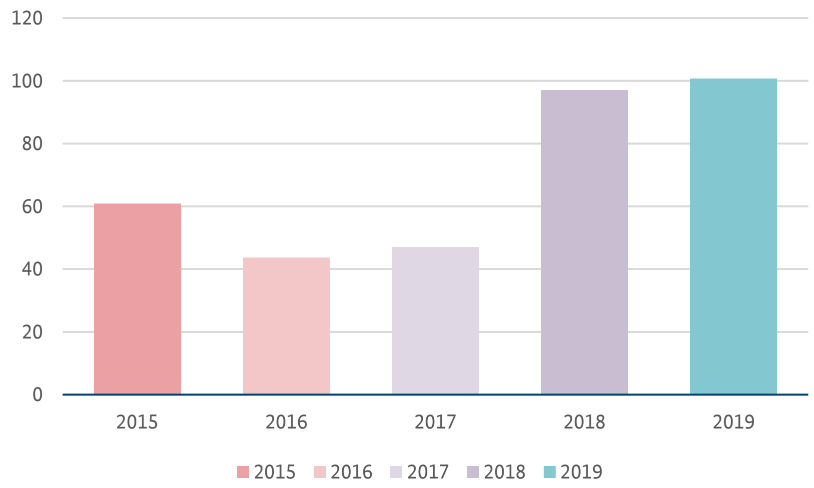
Indonesia government is giving a lot of subsidies for energy, including diesel and LPG. Based on data in Table 4, fuel subsidy volume is increasing from 2015 for diesel and LPG. In term of money, the subsidy reaches 100,68 trillion rupiah in 2019 (see Figure 3) and will not go down if government still depend on

[1] https://www.cnnindonesia.com/ekonomi/20180823121910-85-324305/dilema-subsidi-energi-di-tahun-politik

imported fuel. Biomethane have potential to reduce this fossil fuel subsidy and the advantage is the source is available locally.

Based on GIZ calculation, biogas from POME can generate 1290 MW of electricity that equivalent with 4,5 million m^3 of biogas or 2,7 billion m^3 of biomethane annually. This number is equivalent with 2,4 billion liters of diesel and 1,8 billion kg of LPG. If biomethane can replace that amount of diesel or LPG, government can save around 5,6 trillion rupiah.

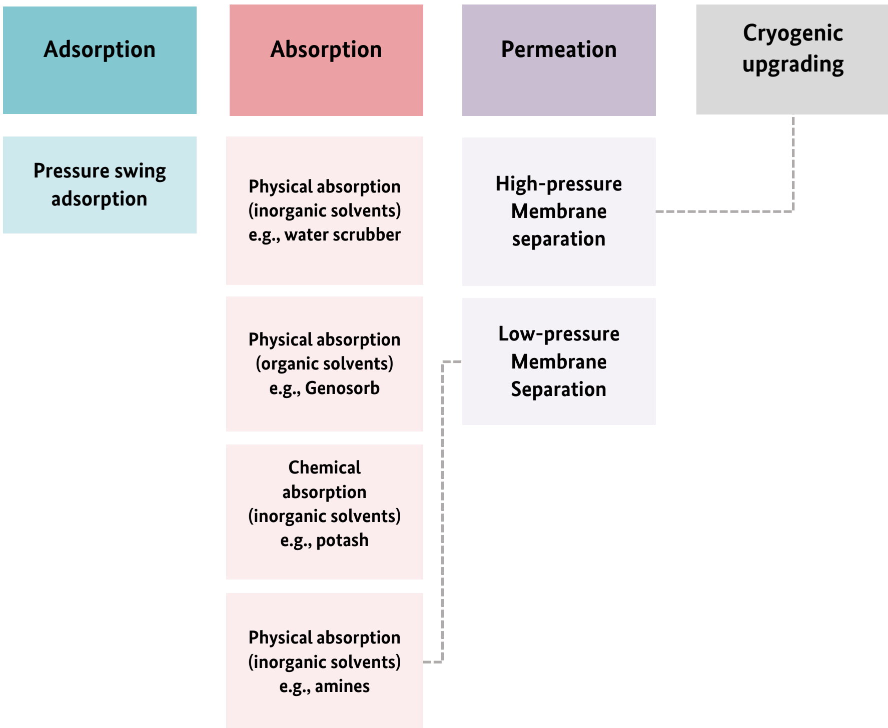
Figure 3. Government fuel subsidy over the years (in IDR Trillion)



3. Biogas Upgrading Technology

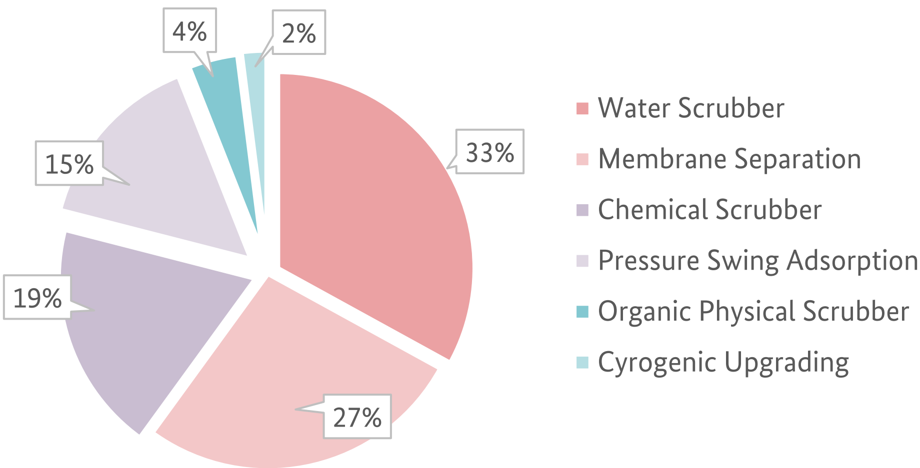
In upgrading biogas to biomethane, the main process involved is separating CH_4 and CO_2 in order to achieve high methane purity and methane losses with low energy consumption. There are several upgrading technologies available on the market that have been used for many years. These technologies can be divided into four categories namely, adsorption, absorption, permeation, and cryogenic upgrading. More detail for each technology category can be seen in Figure 4 below.

Figure 4. Overview of biogas upgrading technologies (Wellinger, Murphy, & Baxter, 2013)



Based on the chart in Figure 5, the majority of biogas upgrading technology used worldwide respectively are water scrubber, membrane separation, chemical scrubber, and pressure swing adsorption. This desktop study will only be discussed about water scrubber, membrane separation and pressure swing adsorption that considered mostly used in Southeast Asia region.

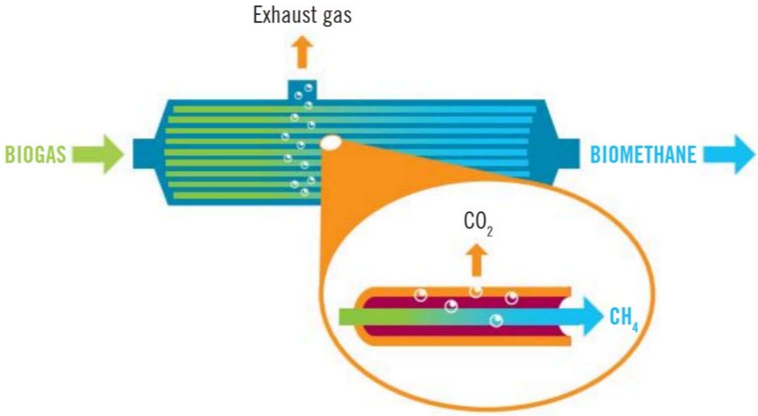
Figure 5. Distribution of Biogas Upgrading Technologies (Upgrading Plant List, 2017)



3.1. Membrane Separation

The principle of membrane separation method is based on the diffusion of gases through membranes at different speeds. Material that might be used as a membrane is polymer. The properties of good membrane are having high permeability to smaller molecules such as CO_2 but impermeable to larger molecules such as CH_4. The aim of using membrane separation technology is to achieve the highest possible permeability with high selectivity. For membranes that typically used, the permeability of CO_2 is about twenty times higher than CH_4.

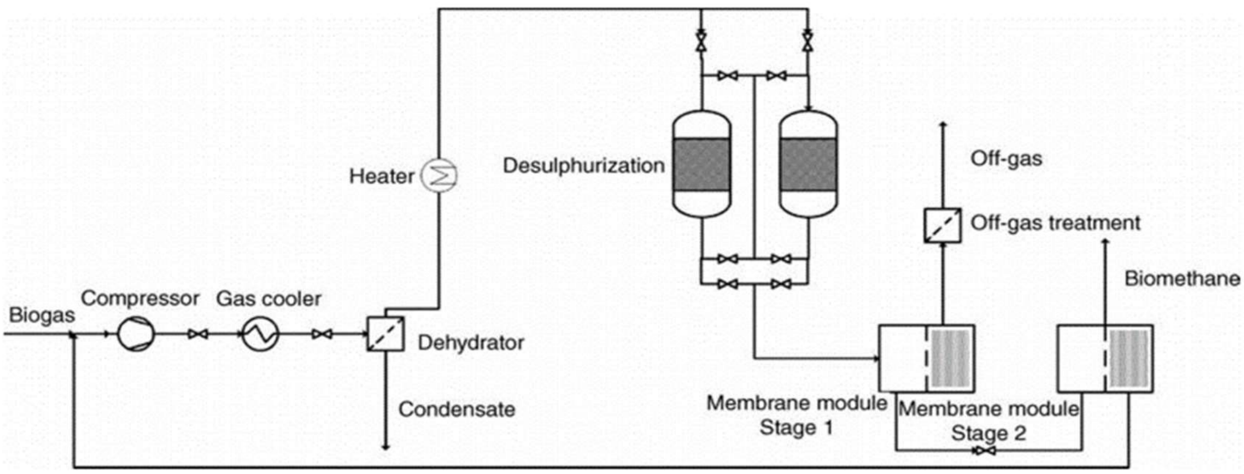
Figure 6. Physical and technical principle of membrane separation (Wilken, 2017)



As shown in Figure 6, membranes are usually in the form of hollow-fiber polymers, which are combined in a tube bundle to provide maximum surface area. Gas components such as CO_2, O_2, H_2O and H_2S coming from blown biogas (biogas), diffuse well through the fiber wall then discharge outside the hollow fiber while CH_4 and N_2 remain inside. The size of membrane is very thin (about 0.1–0.2 micrometers) and are thus unstable. Due to unstable membrane the tube shell functioned to protects the membranes, prevents bending, and thus provides the optimum shape. Biogas that enters the membrane separation need to be cleaned to reduce the moisture and H_2S until below 10 ppm to avoid damage in the membrane system.

Membrane separation methods are available in different designs. The tube bundles are often connected in two-stage or three-stage cascades, to achieve high methane purities. A two- stage cascade means that the biogas is separated in an initial column where the exhaust gas is blown off. Then, the methane-rich product gas that still contain CO_2 is passed into a second column in which CO_2 is further diffused. The diffused CO_2 results in higher CH_4 concentration of the gas product. Some CH_4 also diffuses through the membrane, causing methane losses into the exhaust gas which should be converted to CO_2. Typical operating pressures in membrane separation methods are 7 to 15 bar. See Figure 7 for the process flow diagram of a two-stage membrane separation system.

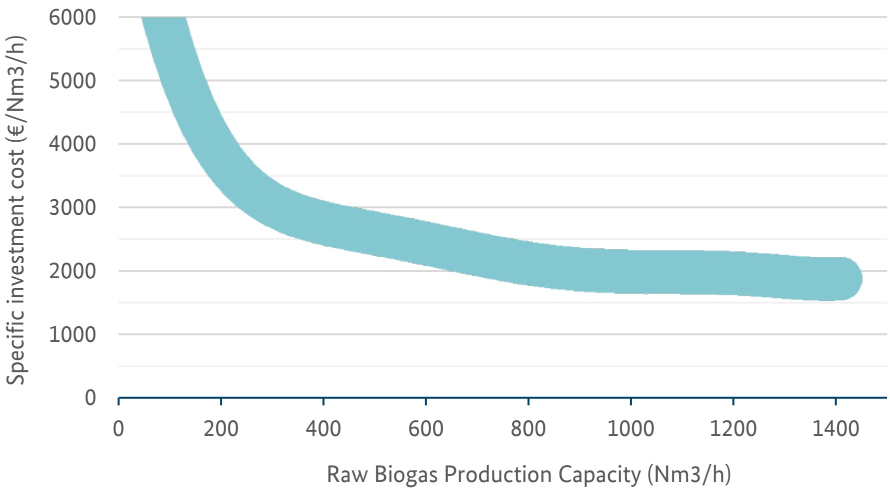
Figure 7. Two stage membrane separation system process flow (Wellinger, Murphy, & Baxter, 2013)



Over decades, the membrane separation process has been substantially improved. Problems such as high methane loss, limited membrane service life, high-pressure loss with an excessive power requirement, have largely been resolved.

The approximate range of the investment costs for biogas upgrading units can be seen in Figure 8. The capacity of the plant is highly contributed to high investment cost. The values in the figure are referring to plants designed for a specific capacity that are not prepared for future expansion or redundancy on key components. Neither gas cleaning nor off-gas treatment is included in the price.

Figure 8. Investment cost for membrane-based biogas upgrading plant

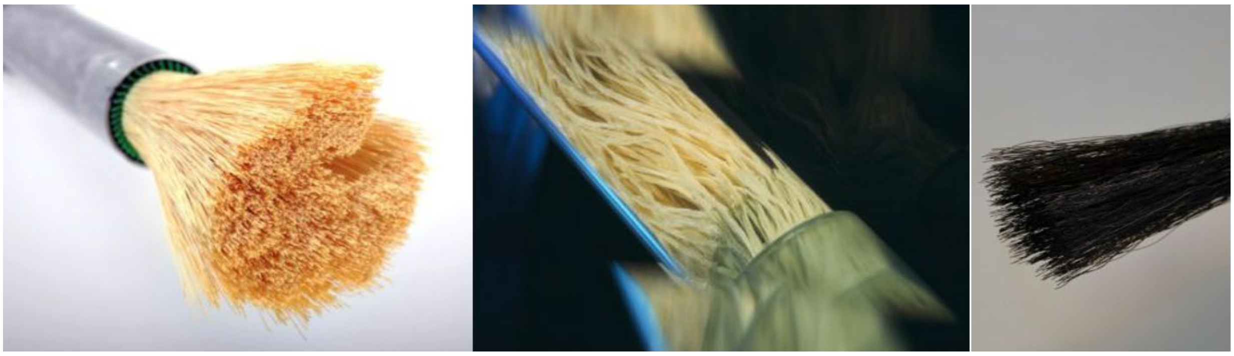


Service contracts which also includes membrane replacement are offered by most manufacturers for an additional cost of 3-4% of the investment cost. Few consumables are used in a membrane upgrading unit. Commonly, oil for the compressor and activated carbon for the removal of hydrogen sulfide is needed. Another thing such as additional maintenance costs for other pretreatment steps could also be of importance.

The lifetime for the membranes is estimated around 5-10 years. The membrane separation upgrading plant energy consumption is mainly determined by the energy needs of compressor. The energy consumption of a compressor depends very little on the methane concentration in the raw biogas. Therefore, the energy consumption will be independent of raw gas composition but the volume.

On the market, membranes produced by several manufacturers for biogas upgrading e.g., two types of polymeric hollow fiber membranes produced by Air Liquide and Evonik and one carbon membrane manufactured by MemfoACT AS (see Figure 9). In order to get higher selectivity, higher permeability and cheaper manufacturing cost, the membranes manufacturers are continuously improved its product features.

Figure 9. Membrane from Evonik (left), Air Liquide (middle) and Memfo (right)



Advantages of membrane separation:

- Modular design so can be adjusted depend on the required size and methane content.
- Can be used for small biomethane capacity until 100 m^3/h.
- Almost no maintenance for the membrane module, mainly only for compression blower.
- Already used in several biomethane project in Southeast Asia.

Disadvantages of membrane separation:

- Still have methane loss between 0.5 and 2 %.
- Power requirement between 0.18 and 0.33 kWh per m^3 of biogas.
- A lean gas burner is advisable and, in some countries, required.

3.2. Water Scrubbing

Scrubbing, also referred to as absorption, is based on the effect whereby gas components are soluble in different fluids to varying degrees. For example, CO_2 dissolves much better in water than CH_4. The most important influential variables in scrubbing processes result from the properties of the solvents used and the solubility of the gas components. In general, the solubility of the gas improves with increasing pressure or decreasing temperature.

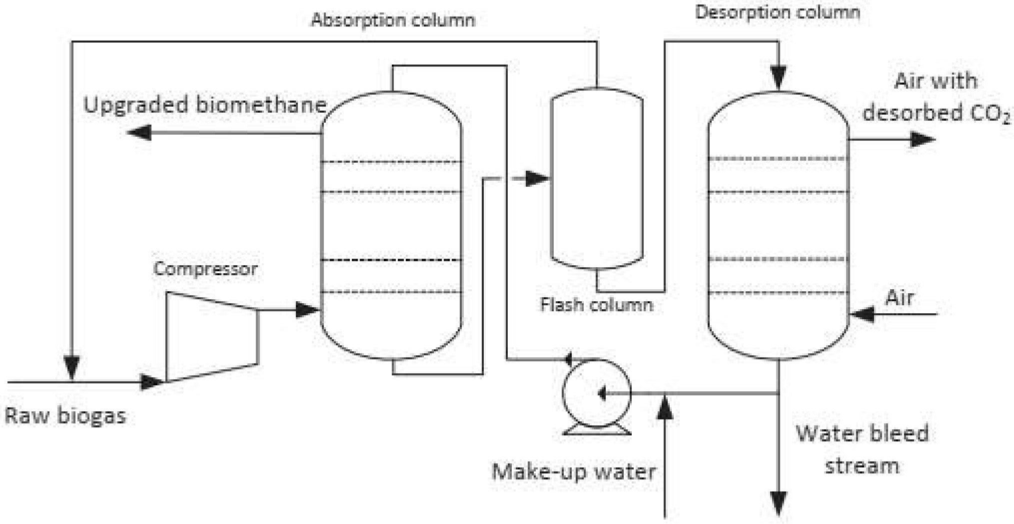
The pressurized water scrubbing method use water as a solvent. Water scrubbing is usually taking place at 4 to 10 bar pressures, this is due to the CO_2 solubility in water is higher when the system is pressurized. A tall scrubbing column is used, in which water is sprayed from above, similar to a shower. Biogas is directed upwards from the bottom of scrubbing column. As the biogas rises, it contacts to the falling water from above. In order to ensure a greater transitional surface area, filling bodies are added to the columns, in which the water runs down. In addition, multiple intermediate floors are installed, in which the water is collected and sprayed again into the lower gas space below. The purified biomethane, with small constituents of O_2 and N_2, is suctioned off at the top of the scrubbing column. Depending on the design of the column, the methane content might reach 90 to 99 vol%.

The water is collected at the bottom of the column, along with CO_2 and small amounts of other gas components (e.g., H_2S or NH_3). In order to regenerate the water, the liquid is first pumped into a vessel referred to as a flash column, where the pressure is partially released. This process will cause some dissolved gas components released. Since some CH_4 is discharged along with CO_2 in this column, the flash gas is fed back to the beginning of the process, in order to decreases methane losses. Subsequently, the pressure in the stripping column is released to ambient pressure and air is blown in. The principal removal of the carbon dioxide takes place at this point CO_2 is usually blown off into the environment as exhaust gas. The regenerated water is now pumped back to the first process inside the scrubber.

During compression process, the biogas temperature is increase. According to thermodynamic principle, less gas is dissolved in liquid if the system is at higher temperature. Therefore, the compressed biogas is cooled down. The temperature inside the scrubber is about 15–20°C. This cooling makes it possible to recover surplus heat from the scrubbing process, which can then the heat is available for external use such as digester heating.

However, a proportion of less soluble gas components (e.g., CH_4) will always dissolve in the washing liquid, just as some of the easily soluble gas components will not dissolve. The liquid gas separation can never be absolute. Biomethane plants based on simple technology may have methane losses reaching several percent. Therefore, all pressurized water scrubbers must be equipped for post-combustion of the exhaust gas to prevent the CH_4 release to environment.

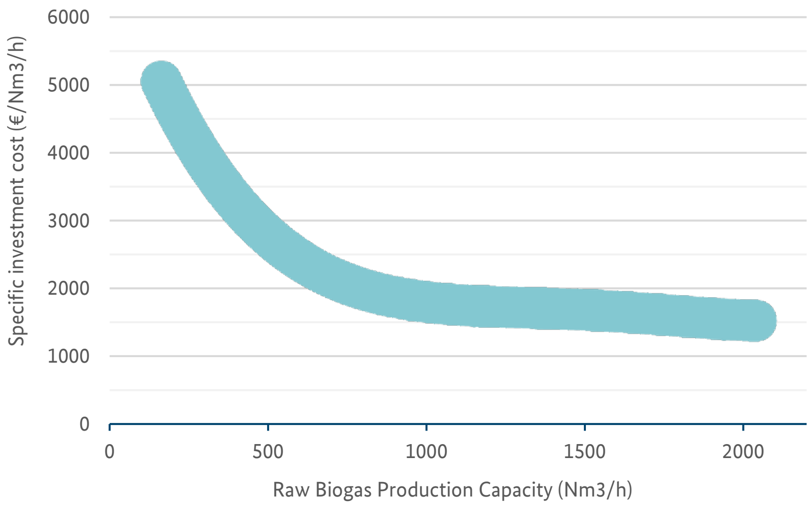
Figure 10. Water scrubber process diagram (Bauer, Hulteberg, Persson, & Tamm, 2012)



Water scrubbing treatment might also function as a desulphurization technique because H_2S also dissolves very well in water, which simplifies the pre-treatment of the Sulphur. In practice, however, an additional fine desulphurization process is generally used for biogas pre-treatment. One reason is that the H_2S remains in the exhaust gas stream and the amount of emissions should or must be reduced.

Figure 11 shows the approximate range of the investment costs for water scrubbers. The values in the figure are referring to plants designed for a specific capacity and not prepared for future expansion or redundancy on key components.

Figure 11. Investment cost for water scrubbing plant



The availability of a plant is commonly guaranteed to be 95-96%. However, if additional investment costs are added, higher availabilities are possible to achieve by getting redundancy of key components such as compressors and water pump. Very low amounts of consumables are used in a water scrubber. The most important is water that needs to be replaced to prevent accumulation of undesired substances from the raw biogas and also to avoid decreased pH originating from oxidized H_2S, if this is not solved using other methods. Common water consumption is around 0.5-5 m^3/day. However, the volume of water needed varies between different plants and sizes and their operating conditions. Except for water, also oil for the compressors is depends on compressor type, another thing is small amount of antifoaming agent also could be required. The maintenance cost for a water scrubber is annually around 2-3% of the investment cost and service contracts can be signed with some of the manufacturers.

There are three main sources that consume significant amount of energy in upgrading biogas with a water scrubber, namely the compressor, the water pump and the cooling machine all have significant energy demands. The amount of energy that is consumed by these units depends on the design of the water scrubber, the properties of the raw biogas, and the surrounding climate. All energy consumptions that are discussed in this study are referred to Nm^3 of raw biogas entering the unit. The energy needed for compression is usually quite constant around 0.10-0.15 kWh/Nm^3 in modern applications operating at pressures around 6-8 bar.

On the market, one of water scrubbing vendor is Greenlane. Greenlane's systems produce biomethane from organic waste sources including landfills, wastewater treatment plants, dairy farms, and food waste, suitable for either injection into the natural gas grid or for direct use as vehicle fuel. Greenlane has supplied over 100 biogas upgrading units in 18 countries worldwide, including the world's first and second largest biogas upgrading facilities.

Advantages of pressurized water scrubbing method:

- Proven technology and many project references in Europe.
- Technically it is a relatively simple method.
- Water is a harmless, low-cost solvent that is easy to handle.
- An external heat source is not needed, and surplus heat can be used.

Disadvantages of pressurized water scrubbing method:

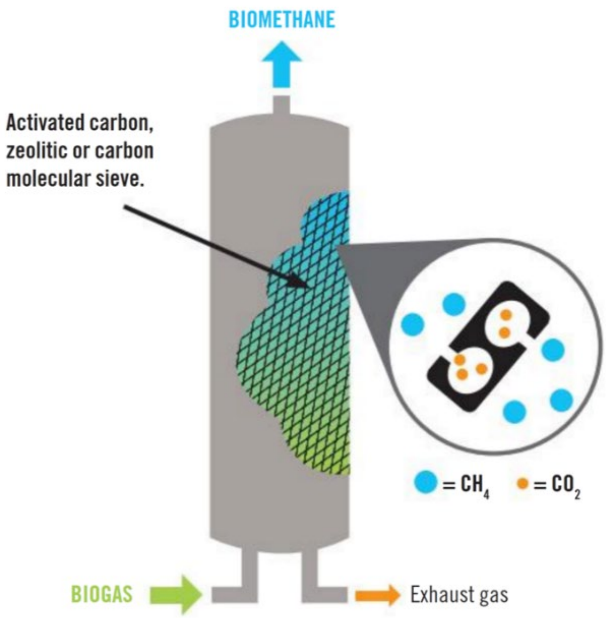
- Power requirement between 0.2 and 0.3 kW per m^3 of biogas.
- Methane loss between 0.5 and 2 vol%.
- Water is less selective than other solvents and not suitable for dry area.
- No project reference in Southeast Asia region.

Water Scrubber in Sweden
(Bauer, Hulteberg, Persson, & Tamm, 2012)

3.3. Pressure swing adsorption (PSA)

Pressure swing adsorption is a proven method of separation and has been used for decades. Previously, this method is used in the gas industry and has been adapted to meet the requirements of biogas processing. Pressure swing adsorption works based on adsorptive principle which is different gas components are attracted differently to specific surfaces (adsorbed) or penetrate to varying degrees into the pores of the material. In principle, adsorption is higher at higher pressures and lower temperatures. Adsorptive biogas upgrading processes mainly use pressure differences to carry out the separation. The essential component for separating the gases is a column filled with activated carbon, zeolitic molecular sieves or carbon molecular sieves (see Figure 12). These substances stand out for offering a large surface area and a certain pore size.

Figure 12. Physical and technical principle of pressure swing adsorption (PSA) (Wilken, 2017)



The gas separation is carried out in the following steps.

(1) First, the biogas is compressed to 2–7 bar in compressor that also increases the temperature of the gas.

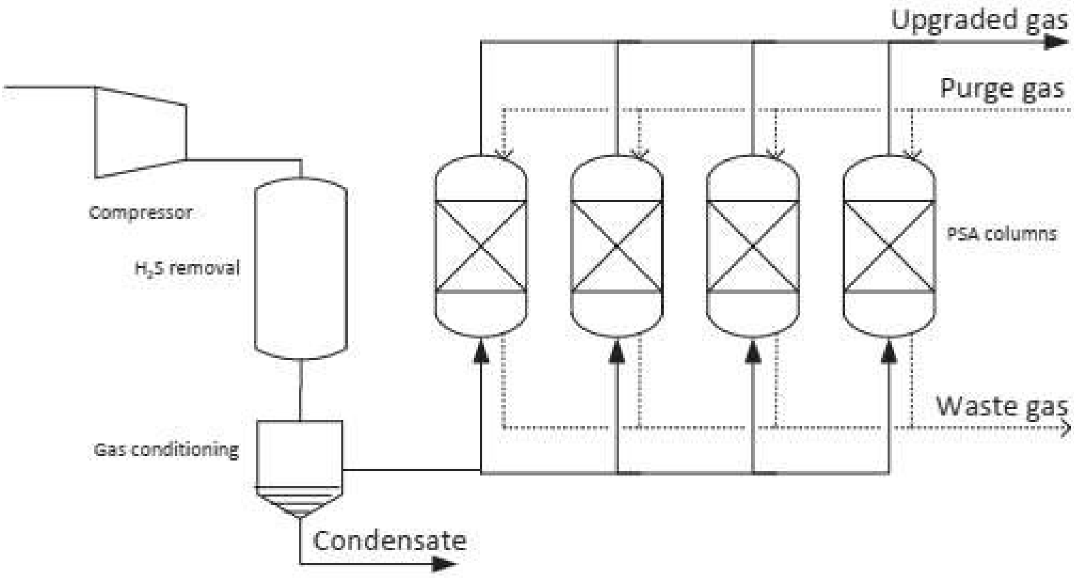
(2) Then, the gas is cooled down to about 70°C and channeled into the adsorption column to improve the adsorption. CO_2 molecules, which are smaller than methane molecules, accumulate to a much greater degree on the surfaces or in the pores than CH_4.

(3) A valve at the column head is opened, and the biomethane flow from the column.

(4) After closing the valve, the pressure inside the column is released. The CO_2 then dissolves from the surfaces, returns into the gas phase and can be blown off resulting CO_2-rich exhaust gas.

(5) The column can be filled with biogas again. Since the pressure swing adsorption is a batch process, several columns, typically 4 to 8, are operated and work in a slightly time-delayed manner to equalize the gas production.

Figure 13. PSA process diagram (Bauer, Hulteberg, Persson, & Tamm, 2012)



In order to prevent corrosion inside the column, fine cleaning must be carried out to remove H_2S before the biogas is pumped into the adsorption column (see Figure 13). The methane losses are heavily dependent on the design of the system.

PSA technology provider that already well known is Xebec and Quadrogen, both from Canada. Xebec designs, develops, builds, sells, and services a range of pressure swing adsorption and membrane gas purification systems for biogas purification (BGX Solutions™). Quadrogen is a privately held clean-tech company based in Vancouver, Canada, that produces customizable biogas clean-up and processing solutions that allow wastewater treatment plants, landfills, and agricultural digesters to convert waste biogas into sources of clean, renewable heat and power.

Advantages of pressure swing adsorption:

- Many reference plants and many years of operating experience.
- No solvents are used.
- Heat is not required for the regeneration.

Disadvantages of pressure swing adsorption:

- Power requirement between 0.15 and 0.35 kWh per m^3 of biogas.
- Methane loss between 1.5 and 2.5 vol%.
- The high-speed loading, pressure retention and release of the column require a very finely tuned valve clearance.
- Mechanical stress to the equipment is therefore relatively high.

3.4. Technology Comparison

It is not easy to compare the difference between several biogas upgrading technologies, because several important parameters are strongly dependent on local conditions and requirements. The development of most biogas upgrading technologies is presently enough to satisfy any potential plant operation. The relevant measure of comparison between biogas upgrading technologies is their ability to remove CO_2 from the inlet biogas (assuming a typical composition of biogas is 60% CH_4 and 40% CO_2). The PSA is capable of removing 98-99% of the inlet CO_2. Most membrane manufacturers can guarantee a 98% CH_4 purity, which is also possible for the physical scrubbers in most applications.

Table 5. Parameter comparison between upgrading technology (Vienna University of Technology, 2012)

Parameter	Unit	Water scrubbing	PSA	Membrane
Typical methane content in biomethane	%	95.9-99.0	95.9-99.0	95.9-99.0
Methane recovery	%	98,0	98,0	80-99.5
Methane slip	%	2,0	2,0	20-0.5
Typical delivery pressure	bar	4-10	4-7	7-15
Electrical energy demand	kWh_{el}/m^3 biomethane	0,46	0,46	0.25-0.43
Desulphurization requirements		process dependent	yes	yes
Consumable demand		antifouling agent, drying agent	activated carbon	
Typical investment cost				
100 m^3/h biomethane	USD/(m^3/h) biomethane	11.110	11.440	8.030
250 m^3/h biomethane	USD/(m^3/h) biomethane	6.050	5.940	5.170
500 m^3/h biomethane	USD/(m^3/h) biomethane	3.850	4.070	3.850
Typical operational cost				
100 m^3/h biomethane	cent/m^3 biomethane	15,4	14,08	11,88
250 m^3/h biomethane	cent/m^3 biomethane	11,33	11,11	8,47
500 m^3/h biomethane	cent/m^3 biomethane	10,01	10,12	7,15

In Table 5, it shows that membrane technology presents several advantages. For example, it has the possibility to adjust the plant layout to local particularities such as area which has low demand of electric energy, low investment, and operating costs. The problem about lower methane recovery which is 80% also could be improved to 99.5% using multiple membrane steps and multiple compressors or efficient membrane configurations. Membrane also don't need consumables for the operation compared to other technology. It is also clear that both investment and operational costs are lower for membrane separation processes. However, this comparison is only valid for low-capacity equipment below 1000 m^3/h. Membrane technology also already being used in biomethane plant from POME in Malaysia, Thailand and one project under construction in Indonesia. Therefore, for the economic calculation in the next chapter will be used membrane technology.

4. Biomethane Economic Aspect

This chapter will explain about biomethane economic aspect including investment and production cost for biomethane that produced from 60 ton/hour palm oil mill. This capacity is selected as the most common size of palm oil mills in Indonesia. The scope of discussion is including the design and construction of biogas installations, biogas upgrading to biomethane facility and compression to bio-CNG, not include the distribution or any conversion work. The biogas upgrading technology used for the calculation is membrane separation.

4.1. Investment Cost

The biogas will be produced from 60 ton/hour palm oil mill effluent that estimated will generate 1000 Nm³/hour biogas (see Table 6). From this number, 250 Nm³/hour will be used for biogas and biomethane plant parasitic load, and the balance of 750 Nm³/hour will be upgraded and compressed. With assumption 60% CH_4 content and 90% methane yield from the upgrading phase, the estimated biomethane produced will be 405 Nm³/hour or 2.430.000 Nm³/year.

Table 6. Biomethane production calculation

Parameter	Value	Unit
Palm Oil Mill Capacity	60	ton/hour
Raw Biogas Flow	1.000	Nm³/hour
Biogas for Parasitic Load	250	Nm³/hour
Biogas for Upgrading	750	Nm³/hour
CH4-content	60	%
Methane yield	90	%
Operation Time	20	hour/day
	300	day/year
	6.000	hour/year
Biomethane Production	405	m3/hour
	8.100	m3/day
	2.430.000	m3/year

The biogas plant system is using covered lagoon technology including bio scrubber and 1-unit x 600 kW of gas engine to supply electricity for parasitic load (estimated 500 kW). One set of centrifugal type blower (1 operational and 1 standby) coupled with variable speed drive (VFD) are to be installed after the dehumidifier to draw the biogas from under the cover of digester. The biogas will pass through bio-scrubber to reduce H_2S to under 200 ppm and dehumidifier under vacuum state before gas blower. The pressure at the discharge of gas blower is approximate 200 mbar in order to cater for pressure loss in the delivery gas pipe from blower to gas engine. The biogas and upgrading plant as well as compression and filling station are powered by the biogas engine. When the biogas engine is under maintenance or not running, the power will be supplied from a 250 KVA standby diesel genset.

The biogas produced from the digester with 60% methane content and 200ppm H_2S will then feed into the biogas upgrading system that using membrane technology. The biogas will be further cleaned and upgraded to produce biomethane through different processes as follows:

- H_2S reduction to a target less than 10 ppm through activated carbons system in order to achieve non-hazardous concentration in the final output biomethane.
- Pre-compression and further elimination of residual humidity
- CO_2 separation through 2 phase membranes system

Further cleaning through several filters and demisters installed in different points of the process to guarantee a clean gas in- and/or output at each point of the process, where required, in order to ensure a trouble-free and long-life operation of each equipment. The biomethane produced then compressed to its final pressure at 250 bar to feed the CBG storage to be used further depend on the utilization. This system includes a high-pressure compressor, similar as used in conventional CNG Stations with additional features dedicated for its integration to the biogas upgrading system. This station includes a flow control system to follow possible fluctuations during the production of the biomethane that could be reconducted to several factors at the biogas inlet point. The investment cost breakdown of the plant can be seen in Table 7.

Table 7. Investment cost of biomethane plant for 1000m3/h raw biogas [2]

No	Item	Cost (IDR)	Cost (USD) 1 USD = IDR 14.000
1	Biogas Plant System		
	- Biogas facility	25.200.000.000	1.800.000
	- Gas Engine 600 kW for parasitic Load	6.300.000.000	450.000
2	Biogas Upgrading and Compression System		
	- Upgrading facility inc. compression	23.800.000.000	1.700.000
	- Storage Buffer & Mechanical Piping Work	2.800.000.000	200.000
3	Logistic, Engineering, Project Management	2.100.000.000	150.000
Total Cost		**60.200.000.000**	**4.300.000**

4.2. Production Cost

For the production cost calculation, biomethane plant divided into biogas plant and biogas upgrading and compression system as mentioned in Table 8.

Table 8. Biomethane plant production cost breakdown

No	Item	Labor Cost	Maintenance Cost	Overhead Cost
1	Biogas Plant	1. Plant Head Supervisor Maintenance & Electrical Staff Plant Operators Laboratory and Administrator Staff Security Housekeeping	1. Maintenance for Biogas engine 2. Maintenance for other equipment (pump, blower, chiller, scrubber, etc)	1. Insurance Coverage (Public Liability & Fire Protection) 2. General Upkeep (Office, utilities,

[2] Investment cost for biogas plant with covered lagoon and biogas upgrading with Evonik membrane system

No	Item	Labor Cost	Maintenance Cost	Overhead Cost
2	Biogas Upgrading	Operator	Maintenance for upgrading system (compressor, activated carbon, membrane)	housekeeping, etc) 3. Vehicle (Amortization, diesel & upkeep) 4. General Administration
3	Compression	Operator	Maintenance for compression system (compressor, dispenser, storage)	

In general, each of the main component have production cost breakdown into labor cost, maintenance cost and overhead cost (see Table 9). For biogas plant, the biggest cost is the labor cost because it has the most labor compared to other system. The second is the maintenance cost that mainly for the biogas engine maintenance. For biogas upgrading part, maintenance cost and labor cost is almost the same. Maintenance cost for upgrading system mostly is for the low-pressure compressor, activated carbon and the membrane module. For compression system, the biggest cost is to maintain the high-pressure compressor to compress the biomethane for storage or to the filling station.

Table 9. Biomethane plant production cost

No	Item	Labor Cost (USD)	Maintenance Cost (USD)	Overhead Cost (USD)	Total Cost (USD)
1	Biogas Plant	82.583	85.304	14.324	182.210
2	Biogas Upgrading	33.248	32.283	14.324	79.854
3	Compression	46.118	26.586	14.324	87.027
Total Operational Cost		**161.948**	**144.173**	**42.971**	**349.092**

“Maintenance Activity in Biogas Plant PTPN “V”, photo by GIZ

Table 10. Biomethane and Bio CNG selling price

Parameter	Biomethane		Compressed Biomethane (Bio CNG)	
	IDR/m3	USD/MMBTU	IDR/m3	USD/MMBTU3 [3]
Operation Cost	1.510	3,52	2.011	4,69
Profit Margin	2.167	5,05	2.389	5,57
Selling Price	3.676	8,57	4.400	10,27

Based on the calculation in Table 10, the operational cost to upgrade and compress the biogas is IDR 2.011/m^3 or USD 4,69/MMBTU. To determine the selling price, need to determine how much the appropriate profit margin. The minimum profit margin is calculated from the minimum profit needed to pay back the loan. From the project investment cost, it is assumed that 70% is come from loan with WACC (Weighted average cost of capital) of 11%. Based on the assumption, the minimum profit margin needed to pay back the loan is Rp 2.389/m^3 and the selling price for compressed biomethane (Bio CNG) is Rp 4.400/m^3 or USD 10,27/MMBTU (see Table 10). Meanwhile, the other reference from Bio CNG plant in Sungai Tengi, Malaysia, the production cost is MYR 25.5/MMBtu or USD 6,38/MMBtu and the selling price is MYR 40-46/MMBtu or USD 10,0 – 11,5/MMBtu (see Table 11).

Table 11. Economic analysis of the 400 m3/hour Bio CNG plant in Sungai Tengi, Malaysia (MPOB, 2017)

Description	Value	
	Bio-CNG plant only	with Biogas Plant
Investment cost, in million MYR	7,00	12,00
Annual production, in million m3 @7200 hour/year Assumption: Bio-CNG selling price @ 40 – 60 MYR/MMBtu Operational expenditure @ 25.50 MYR/MMBtu	2,46 (~80.000 MMBtu)	
Net Present Value (NPV) 10%, in million MYR	1,82	0,17
Internal rate of return (IRR), in%	14,36	10,25
Payback period, in year	6,03	7,50

[3] 1 m^3 of biomethane (90% methane) = 0,0306 MMBTU (Noyola, 2006)

5. Biogas Upgrading Distribution and Utilization

Biomethane has similar chemical properties to natural gas, and it is possible to fed directly into the natural gas grid, where it is stored and distributed. It can then be converted into electricity or heat or employed directly for heating or cooking to replace LPG. In addition, natural gas-powered vehicles can be refueled using biomethane since the relevant fuel pumps are supplied via the natural gas grid at petrol stations. Alternatively, designated service stations may be supplied directly from the biomethane plant in order to fuel vehicle fleets. In addition, biomethane can be filled into high-pressure cylinders for transport and storage purposes as Bio CNG.

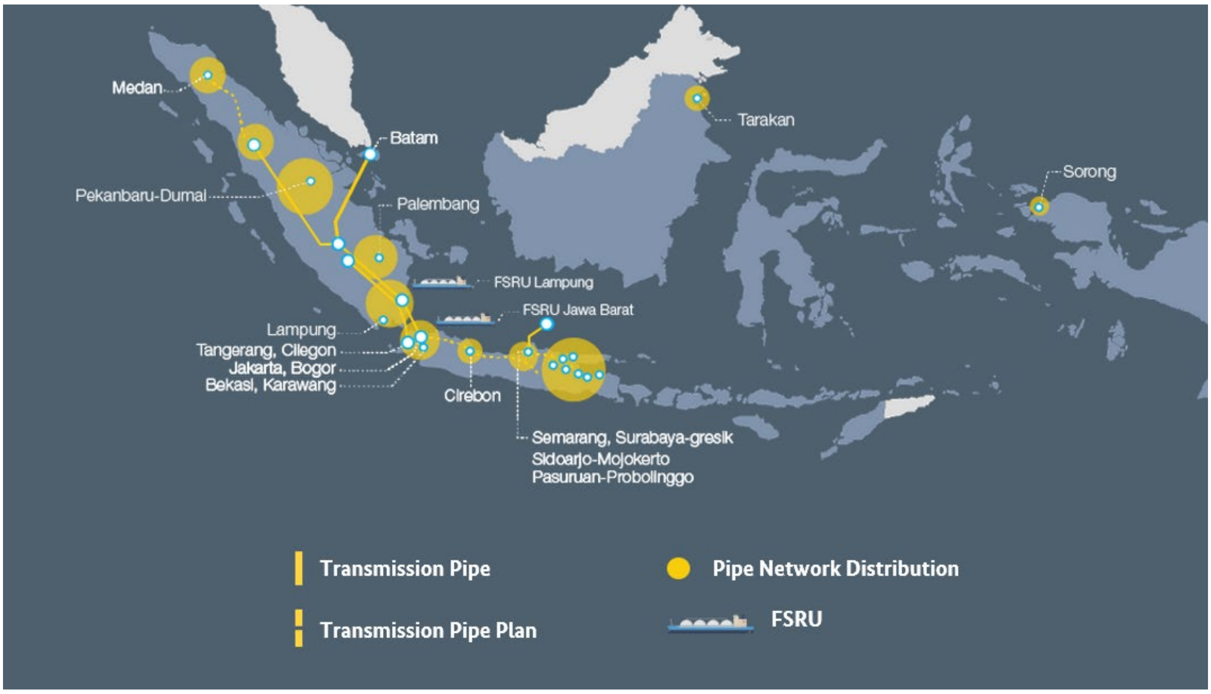
5.1. Distribution Method

5.1.1. Direct Injection to Gas Grid

Indonesia has the longest gas pipe network in Southeast Asia that managed by PT PGN (National Gas Company). At present, PT PGN has more than 9,900 km of gas pipe in Java, Sumatra, Kalimantan, and Papua that can be seen in Figure 14. This gas pipe network is divided into transmission pipe and distribution pipe. Transmission pipe is to transport gas in long distance from the production site to the local distribution area that will distribute the gas directly to the consumer via gas distribution pipe.

Natural gas resources in Indonesia mostly concentrated in Sumatra, that located in Aceh, Natuna, Jambi and South Sumatra with gas pipe network to distribute the gas from the north to south, until West Java. Other than that, natural gas also produced from LNG (Liquified Natural Gas) plant in Bontang (East Kalimantan), Tangguh (West Papua) and Donggi Senoro (Central Sulawesi). Gas pipe network is constructed to distribute the natural gas from the source to location that have demand for gas, such as industries or a city. However, the natural gas source is limited, and some locations have decrease in production like in Arun.

Figure 14. PT PGN Natural gas pipe network (PT. Perusahaan Gas Negara, 2018)



Biomethane has potential to be directly injected to the existing gas grid as an alternative source of gas. Therefore, the biomethane plant location ideally must be in proximity of the gas grid. Biomethane produced also need to follow the technical requirement of the gas grid, for example in Germany in Table 12. In Indonesia, there are no such requirement for gas injection in transmission pipe, except that need to follow the pressure around 40 bar.

Table 12. Requirements for gas grid injection in Germany according to DVGW G 260 (Wilken, 2017)

Characteristics	Unit	Gas Value
Wobbe index	kWh/m^3	13,6 – 15,7
Calorific value	kWh/m^3	8,4 – 13,1
Relative density	-	0,55 – 0,75
Total sulphur content	mg/m^3	< 8 (short-term up to <30)
Total hydrogen sulphide content	mg/m^3	< 5
Water content	mg/m^3	< 50 in grids > 10 bar < 200 in grids ≤ 10 bar
Hydrogen	vol%.	< 2 in exceptional case up to < 10
Carbon dioxide content	vol%.	In L-gas grids < 10 In H-gas grids < 5
Oxygen content	vol%.	< 3 at injection in dry grids < 0,5 at injection in wet grids

The main benefit to inject biomethane directly to the gas grid is to utilize existing gas grid (transmission/distribution) so no need additional investment to build the gas network. The gas grid usually is big enough to accommodate the volume of the biomethane injection. This also open access for biomethane producer to the larger market of potential buyers than if the biomethane were to be sold and used locally.

The other benefit is no need to invest in high pressure compressor to compress the biomethane and store it to cylinder. This also depend on where the biomethane is injected to the gas grid. If biomethane is injected to the transmission pipe, it needs to be compressed to approximately 40 bars and for distribution pipe between 1- 5 bars [4].

The challenge for biomethane injection is the gas pipe network only limited in the certain area that have the natural gas source and the location of the gas pipe is usually far from the palm oil mill where the biogas plant is build. Technically it can enter the transmission / distribution pipeline but there are regulatory constraints (min volume), and economically less because of the small volume. To build the gas pipe also need high investment cost, around 1,2 million USD/kilometer [5]. This mean that the investment only feasible if there are big enough volume of gas that will be transported through the pipe. For comparison, the current gas grid is built with flow capacity ranged from 22 to 268 MMCFD [6] and typical biogas plant from POME can produce 10,000 Nm^3/day of biomethane or only 0,35 MMCFD, far below the natural gas pipe capacity.

To be able to inject in the gas grid, biomethane also to compete with the current natural gas price, that is currently on average between 5-7 USD/MMBTU in the gas well head source depends on the location. The price to the end user through pipeline distribution can vary between 7-10 USD/MMBTU depending on how

[4] Data from Indonesia CNG Company Association (APCNGI)

[5] https://www.cnnindonesia.com/ekonomi/20180212200558-85-275709/bangun-pipa-gas-pemerintah-perlu-us-2055-miliar

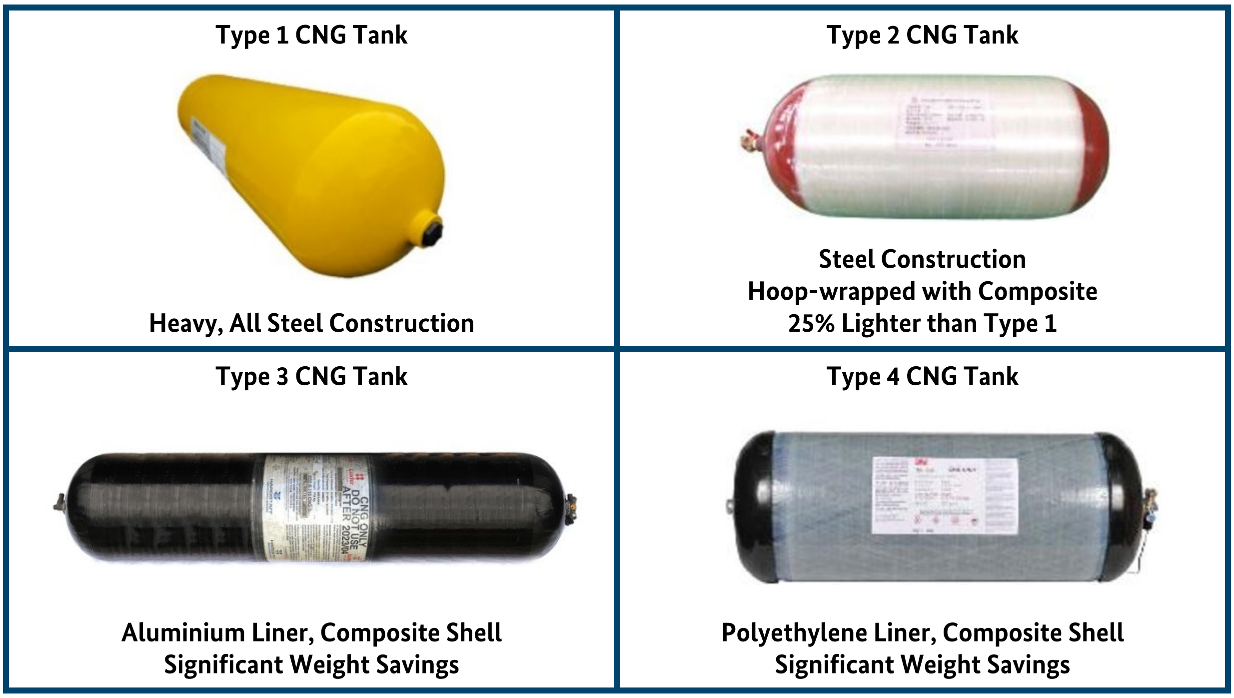
[6] https://industri.kontan.co.id/news/pipa-transmisi-pertagas-duri-dumai-tahap-ii-resmi-beroperasi

far the location from the gas source. Furthermore, need to calculate in more detail for the distribution cost / toll fee and service cost through the gas pipe. Currently, gas toll fee is proposed by the gas pipe operator, mostly owned by PGN, and the Government under the BPH MIGAS will then approve on the set toll fee. Biomethane that injected to the gas grid can be utilized for industry and city gas network that will be discussed in more detail in the next chapter.

5.1.2. Compressed Biogas (Bio CNG)

Compressed Natural Gas (CNG) is basically natural gas that are being stored in highly pressurized cylinder tanks. As the natural gas are being stored, it can then be transported to supply certain area that not yet reached by the gas pipe network. Like natural gas, biomethane, which even can have a better-quality composition than natural gas, also can be compressed and stored in the gas cylinder. Compressed biomethane gas, or bio CNG, is compressed to 200-250 bar to get maximum energy storage density. Compression to lower pressure is possible but will reduce the energy stored. The gas can be stored in various cylinder size depend on the requirement that make it flexible for different application and easy to transport. The cylinder material also varied from steel to lighter composite material as shown in Figure 15. The lighter the cylinder then the price tends to more expensive. Whatever type or size of the CNG Cylinders available in the market, it must be manufactured and follow the ISO Standard applicable for the purpose, pressure, material being used, and other consideration for example ISO 11439, ISO 9890, ISO 11120, and ECE R110.

Figure 15. Different type of CNG cylinder [7]



The advantage of bio CNG compared to the grid injection is it does not depend on the gas grid availability in the area, and the investment cost for the relatively small capacity gas volume and long distance tends to be much lower than to invest for gas grid injection. This distribution method is more feasible to implement because it is suitable with the typical size of biogas plants in Indonesia. Investment cost of bio CNG will depend on the utilization and size of the cylinder storage that will be covered in more detail in the next chapter. The flexibility of bio CNG make it can be utilized into various application such as vehicle fuel, power generation, industry boiler or for cooking gas.

On the other side, bio CNG also have safety concern for its high-pressure cylinder, although the cylinder specification is already designed and manufactured to hold the pressure. The gas form of bio CNG also make

[7] Τσώνος, Ά., & Tsonos, A. (2017). Structural design of CNG storing composite pressure vessels for marine applications.

its energy that can be stored is much lower compared to other liquid fuel in the same size of storage. There is various size for the gas transport module that include the vehicle, cylinder/skid that can be used for transporting the bio CNG (see Figure 16). The technical specification for the gas transport module required is dependent on:

(1) Purpose of gas usage by the end user. Bio CNG can be utilized to various end user such as genset, commercial, industry etc. that have different parameter of operating hour.

(2) Inlet pressure and volume of the gas required per hour by the end user. This will determine the Pressure Reducing System specification to reduce the gas pressure from 200 bar to the inlet pressure required.

(3) Road condition and distance from the bio CNG plant to the end user. This will determine the size, type, and volume of the CNG skids module used. The road condition and size will determine the vehicle and container size used to transport the gas, such as 10 ft, 20 ft or 40 ft.

Figure 16. Different type of CNG skids and volume [8]

5.2. Utilization

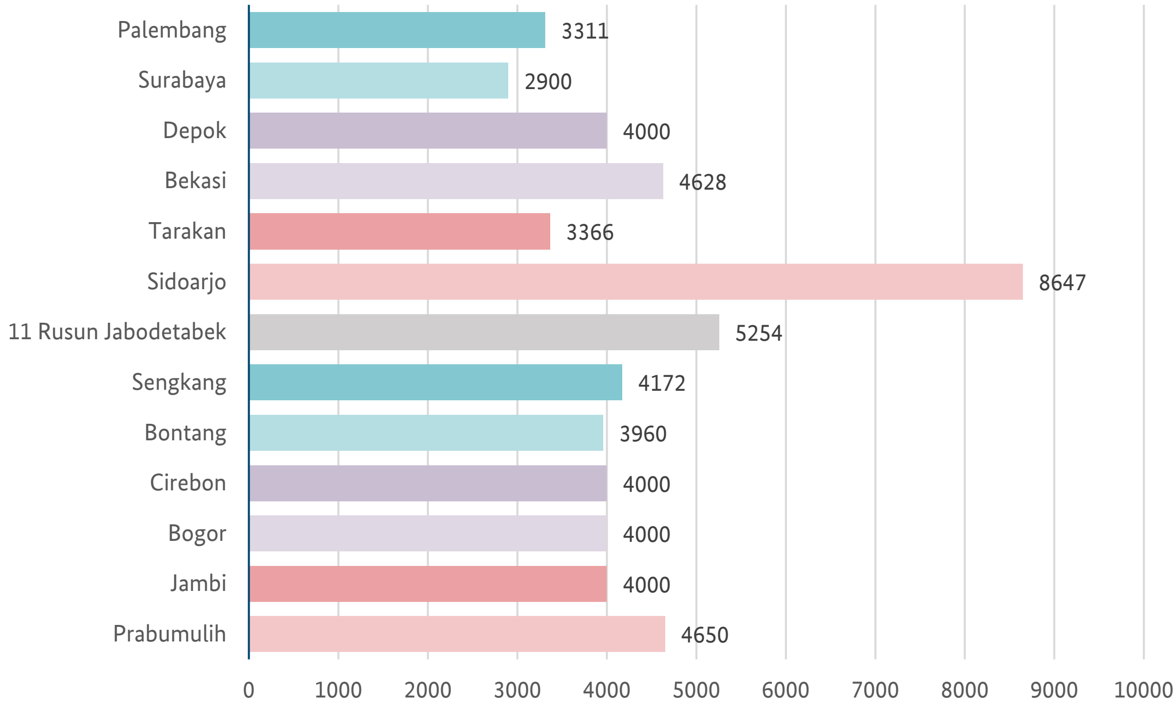
5.2.1. City Gas Network

The development of a gas distribution network for households or city gas network is one of the national priority programs aimed at diversifying energy, reducing subsidies, and providing clean and cheap energy to the public. The city gas network development program for households is built in cities or areas close to natural gas sources and has a natural gas transmission network. The weakness of the city gas network is on

[8] Photo courtesy from RRS Group

the side of the cost of developing the distribution network which is very expensive. This is due to the volume of natural gas fuel consumption the average household per day in a year is very small. For those who are profit oriented, this is not interesting because the payback period will be very long. This is what prevents or reduces investor interest, both local and international, to invest. That is why most of the city gas network is built by government (see Figure 17 for the distribution of city with gas network installed). By 2020, government plan to build 293,533 house connections in 54 districts / cities for city gas network with funds of Rp 3.2 trillion [9].

Figure 17. Number of houses with gas city network installed [10]



There's reference for gas specification that being distributed by Pertamina to city gas network in Depok as shown in Table 13. It shown the methane content of natural gas is only 80,93 % that can be easily achieved by biomethane with > 90% of methane content.

Table 13. Gas Composition for Depok City Gas (Directorate General of Oil and Gas, 2013)

No	Component	Unit	Value
1	N_2	%	6,21
2	CO_2	%	7,98
3	CH_4	%	80,93
4	C_2H_6	%	2,32
5	C_3H_8	%	1,39
6	Gross Heating Value	Btu/ft³	940,9756

[9] https://migas.esdm.go.id/post/read/pemerintah-bangun-jargas-293-533-sr-tahun-2020-pemda-diminta-berikan- dukungan
[10] Directorate General of Oil and Gas, Ministry of Energy and Mineral Resources, 2013

Biomethane from POME have potential to be utilized and injected into the natural gas pipe to supply the gas network for the city that near with the palm oil mill, for example Jambi and Tarakan. The challenge to inject biomethane to the gas network already explained in Chapter 5.1.1. For city gas, the gas price is varied depend on the user as below:

Table 14. City Gas Price [11]

Customer Type	Gas Price IDR/m³	Remarks
RT-1	4250	Flats, Simple Houses, Very Simple Houses, and the like
RT-2	6000	Middle and upper houses, luxury homes, apartments, and the like
PK-1	4250	Government Hospital, Health Center, Orphanage, Places of Worship, Government Educational Institutions, Institutions, Religion, Government Offices, Social Institutions and the like
PK-2	6000	Hotels, Restaurants / Restaurants, Hospitals, Private Offices, Private Offices, Private Educational Institutions, Shops / Shops / Offices / Markets / Malls / Supermarkets, and similar commercial activities

If compared to biomethane selling price calculation of Rp 3.676/m³ in Table 10, biomethane price is still below the city gas network price but need to remember that this selling price is not included the distribution cost from the biomethane source to the end user. The distribution cost is depending on the type and size of the gas transport module used and the distance. For the financial calculation, it is assumed the investment and operation cost of the biomethane distribution is USD 1/MMBtu [12].

Table 15. Financial calculation for city gas utilization

Parameter	Value		Unit
Investment costs			
Upgrading & Compression	4.300.000		USD
Distribution	74.426		USD
Total investment	4.374.426		USD
Operation Cost			
Upgrading & Compression	349.092		USD/year
Distribution	74.426		USD/year
Total operation cost	423.518		USD/year
City Gas Category	R1/PK1	R2/PK2	
Gas Price	0,304	0,429	USD/m3
Revenue	737.678,571	1.041.428,571	USD/year
Profit	314.160,924	617.910,924	USD/year
Payback period	13,9	7,1	year

Based on the calculation in Table 15, it is shown that to use biomethane for city gas utilization is not too attractive because the payback period is 7 – 13 years.

[11] BPH Migas data in 2019

[12] Data from National Gas Company (PGN)

5.2.2. Vehicle Fuel

Most internal combustion engines be such as small cars, heavy-duty trucks or heavy equipment can be made to run on methane gas. Most Natural Gas Vehicle (NGVs) in the world is converted from gasoline petrol into bi-fuel, so the vehicle can run on both CNG and petrol, independently. However, dedicated (methane only) vehicles also are being used, mostly in heavy-duty vehicles to take advantage of methane's clean burning characteristics. The main utilizations for CNG in Indonesia are for vehicle fuel especially for public transport, but the development is still slow. Until 2017, there are 17,832 unit of natural gas vehicle (NGV) in Jakarta and 103 natural gas filling station all over Indonesia (see Table 16). The program to promote gas as vehicle fuel already start from 1997. The standard for CNG as fuel for transportation already established in 2011 as shown in Table 17.

Table 16. Natural gas vehicle data in Jakarta [13]

No	NGVs Type	Quantity
1	Transjakarta Fleet	
	- Articulated Bus	199
	- Single Bus	254
2	Taxi	2.500
3	Small Public Transport	600
4	Local Government Car	64
5	Bajaj	14.000
6	Personal Vehicle	200
7	Truck	15
Total		17.832

Even though the Indonesia government, through the Ministry Energy and Mineral Resources, had distributed free converter kits in 2016 and 2017 to encourage public to convert their car fuel into gas, as well as setting the CNG price at the gas station at IDR 3100/LSP (Petrol Liter Equivalent) for area in Jakarta and IDR 4.500/LSP for outside Jakarta, still the growth of number NGV vehicles have stagnant. One of the problems lies in the low number of gas station infrastructure that makes people difficult to find the station also longer time needed to fill the gas storage in the car compared to petrol.

Table 17. Standard for CNG as fuel for transportation [14]

Parameter		Unit	Limit		Test Method
			Min	Max	
1	Component				
	C_1	%vol.	77,0		GPA 2261/ISO 6974
	C_2	%vol.		8,0	GPA 2261/ISO 6974
	C_3	%vol.		4,0	GPA 2261/ISO 6974
	C_4	%vol.		1,0	GPA 2261/ISO 6974
	C_5	%vol.		1,0	GPA 2261/ISO 6974
	C_6	%vol.		0,5	GPA 2261/ISO 6974

[13] Data from Indonesian CNG Company Association (APCNGI) in 2017
[14] Director General of Oil and Gas Decree No 247 Year 2011

Parameter		Unit	Limit		Test Method
			Min	Max	
	N_2	%vol.		3,0	GPA 2261/ISO 6974
	H_2S	ppm vol		10	ASTM 2385/UCP 212
	Hg	µg/m³		100	ISO 6978
	O_2	%vol.		0,1	GPA 2261/ISO 6974
	H_2O	lb./MMSCF		3,0	ASTMO 1142/ISO 10101
	CO_2	%vol.		5,0	GPA 2261/ISO 6974
2	Particulate size > 10µm	-	FREE		EPA M-05
3	Relative density*	-	0,560	0,850	GPA 2172/ISO 6976
4	Calorific value*	Btu/ft³	960	1175	GPA 2172/ISO 6976
5	Wobbe index*	Btu/ft³	1050	1313	GPA 2172/ISO 6976
6	Odor	CNG must have an odor, the lowest odor content is in a concentration of 20% of the lower limit of flammability			ISO 13734/ASTM D6228

Note
*) At a temperature of 15°C 1 atm pressure used the ISO 6976 method At 60°F pressure of 1 atm is used GPA 2172 method

There are basically 3 (three) types of conversion from petrol/diesel fueled engine system to CNG:

Mono or Dedicated Conversion System (Mono)

An engine being converted to a mono or dedicated system is when the engine after being converted can only runs on methane gas, or in other words the substitution value to methane gas from petrol fuel is 100%. A dedicated conversion is commonly done for a diesel type engine, whereby it can be either done by replacing the entire engine block with a natural gas engine, which is known as repowering, or the original engine itself have gone through a limited modification towards its engine piston cylinders. In other words, when an engine is converted to Mono Gas fuel from diesel, basically the engine characteristic becomes as similar as a gasoline engine. This system is the most profitable because can get 100% fuel savings from the difference of diesel and CNG price. In the other hand, the vehicle owner will be depending on CNG and can't switch to other fuel if the gas is not available.

Dual Fuel System (DDF)

This system is also mostly used only for diesel engine conversion. Through this conversion the diesel engine is modified to be able to use methane gas together with the diesel fuel. The engine is basically unchanged and continues to use compression ignition of diesel for ignition of the methane gas fuel. Unlike the dedicated system, whereby the engine now can only burn methane gas fuel, the dual fuel system the engine will burn methane gas and diesel fuel simultaneously. For a typical DDF conversion for a High-Speed Genset, the fuel ratio is generally around 60% or more (less than 80%) gas fuel, and remaining diesel fuel. This ratio may varies considering the variation of the gas composition and condition of the engine itself. DDF when used on trucks, however, the ratio may not be as stable when being used in Genset where the RPM is mostly stable. The average is 50% ratio with normal road condition and speed 40km/hour, while trucks will depend on the variation of torque and RPM during the truck's operation. At lower RPM and idle speed, the truck using a DDF system tends to use more diesel than gas, and vice versa when the truck is running at high RPM and stable speed. The benefit of DDF, although the savings is less than dedicated system, it is safer for operation because not depending of one type of fuel.

Bi-Fuel System (Switch)

This system is also called “switchable” systems and used only for gasoline type engine. Through this conversion system the engine operator/driver can freely switch the engine to run on gasoline or methane gas fuel. No modification is done toward the engine. With the Bi-Fuel system, the methane gas is injected into the engine intake air the same way gasoline fuel is injected into the gasoline type engine. Thus, the engine will function the same way as a gasoline engine where the fuel-air mixture is compressed during the piston upstroke cycle and ignited by a spark plug where the expanding gases produce mechanical energy in the form of rotational forces that propel the vehicle. Bi-fuel system have the same advantage as dual fuel system for diesel, that do not depend on one type of fuel. Table 18 below shows the conversion cost estimation from gasoline/diesel vehicle to enable it to use gas as fuel (see Figure 18 for the illustration).

Table 18. Conversion Cost Estimation [15]

No	Conversion Kit Type	Type of Vehicle	Type of Engine	Gas Fuel Efficiency	Volume Tank of CNG	Total Conversion Packaging Price
1	Bi Fuel	Car	Gasoline	Depend	15 m^3	USD 1.500 ++
2	Bi Fuel	Pick-up Car	Gasoline	Depend	30 m^3	USD 3.000 ++
3	Dual Fuel	Pick-up Car	Diesel	50%	30 m^3	USD 3.500 ++
4	Dual Fuel	Small Truck	Diesel	50%	60 m^3	USD 9.000 ++
5	Dual Fuel	Large Truck	Diesel	50%	150 m^3	USD 11.000 ++
6	Dedicated Fuel	Small Truck	Diesel	100%	60 m^3	USD 11.000 ++
7	Dedicated Fuel	Large Truck	Diesel	100%	150 m^3	USD 18.000 ++

Figure 18. Dual-fuel or dedicated system for diesel trucks

[15] Data from Indonesian CNG Company Association (APCNGI)

Because of its similar characteristic with natural gas, bio CNG can be used in natural gas vehicles (NGVs) or converted from petrol or diesel vehicles. The advantage of using bio CNG to replace regular CNG is its low emission compared to its fossil equivalents. Figure 19 shows that biomethane have 60-80% less CO_2 emission per km compared to gasoline/petrol and 50-70% less compared to natural gas.

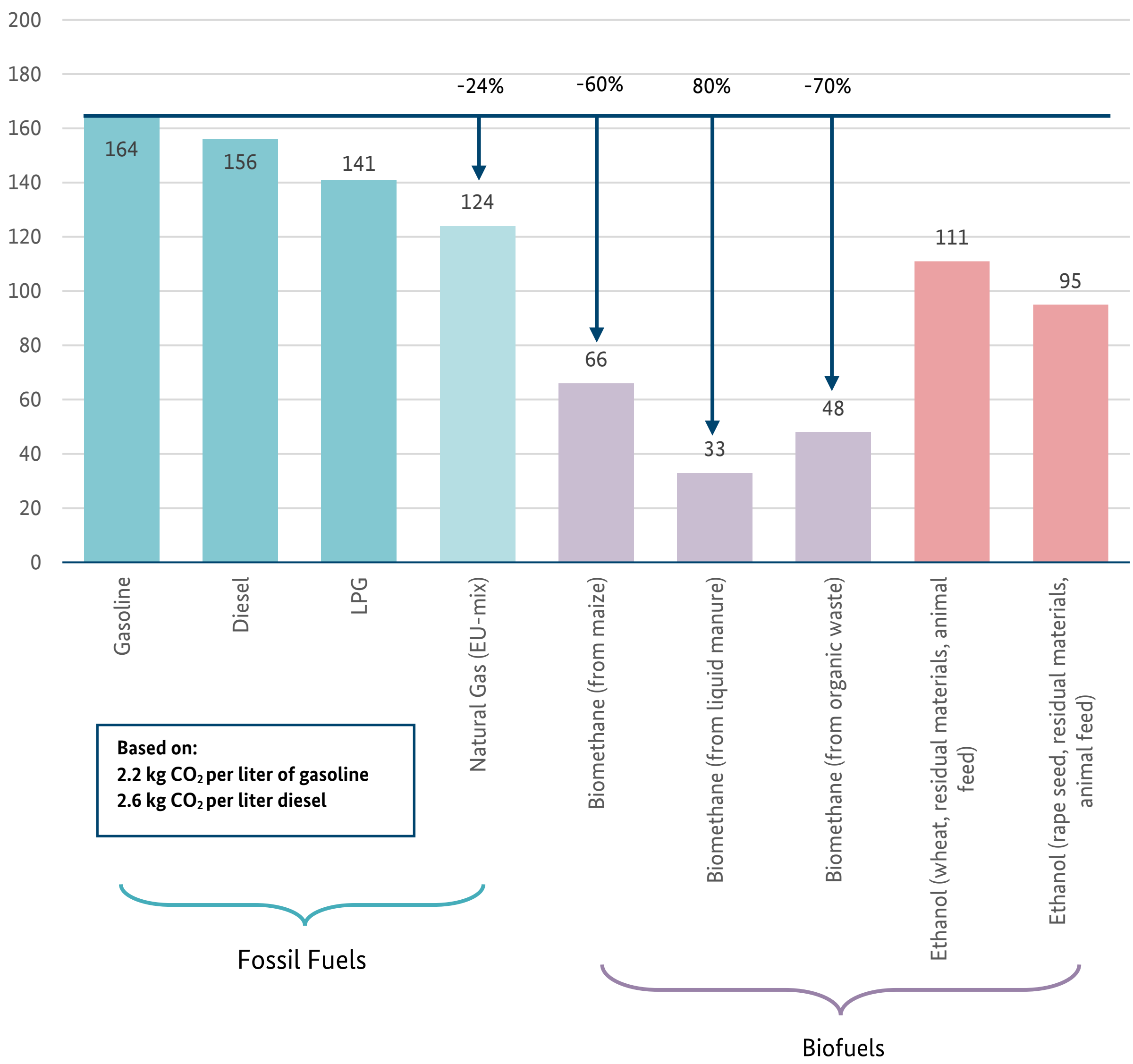


Figure 19. GHG emissions from different fuels comparison (IRENA, 2018)

The challenge for NGVs if compared to petrol vehicles that there will be increase in load and reduction in space due to the addition of the gas tubes in the vehicle. The capacity of the fuel storage is also smaller than petrol fuel, so the mileage is limited and need to refuel more often [16]. Lack of gas fuel station build also make the NGVs owner difficult to find location to refuel. For Bio CNG from POME, the biggest challenge to sell it in the gas station is to meet the price of natural gas RP 3100/LSP, which is subsidized by the government for the transportation sector. So, the best option is to use bio CNG to fuel vehicle for the internal need of the plantation such as truck for delivering FFB and heavy equipment, which are prohibited to use subsidize fuel. In this case, bio CNG will be replaced diesel with price varied between Rp 9,000 – 11,000 in the plantation area. This will provide palm oil mill with cost saving for the fuel depend on the conversion system used that explained previously.

[16] 1 liter of fuel water capacity = 0.252 m3 of gas at a pressure of 200 bar

Financial calculation in Table 19 shows that replacing diesel fuel with bio CNG for truck in the palm oil mill plantation can give payback period from 4-5 year. This calculation using assumption that all of the biomethane produced is utilized. The number of trucks needed to consume all the biomethane is shown in table 5-6, that also depends on the how far the truck is travelling each day and the road condition of the road that can affect fuel efficiency of the vehicle. Should be noted also that the truck owned by the plantation company usually not sufficient to consume all the bio CNG produced so need to also add trucks from outside the plantation to utilize all the gas. The ideal scenario is if the palm oil company have several mills and plantation in the same area so can have a lot of vehicle/truck that can be converted.

Table 19. Financial calculation for biomethane to replace diesel fuel in the palm oil mill plantation

Parameter	Vehicle Conversion Type		Unit
	DDF (50%)	Dedicated	
Biomethane production	2.430.000		m^3/year
	2.505.232		liter/year
Diesel price	0,71		USD/liter
Fuel consumption	160,00		liter/day/truck
No Truck	89	45	Units
Investment costs			
Upgrading & Compression	4.300.000		USD
Conversion	11.000	18.000	USD/unit
	984.198	805.253	USD
Total investment	5.284.198	5.105.253	USD
Operation Cost			
Upgrading & Compression	349.092		USD/year
Conversion	447.363	223.681	USD/year
Total operation cost	796.455	572.773	USD/year
	0,318	0,229	USD/liter
Fuel Savings	0,396	0,486	USD/liter
	992.997	1.216.678	USD/m^3
Payback period	5,3	4,2	year

5.2.3. Diesel Genset

Basically, conversion from diesel genset to be feed by biomethane is the same as in vehicle. The difference is, with dual fuel genset, the gas ratio can be as high as 60-70% compared to dual fuel vehicle that is 60% or less because it depends on the engine rotation per minute (RPM). Furthermore, there are 2 processes of converting diesel engines to 100% dedicated gas. First is repowering where diesel engines are converted to CNG by replacing the entire engine block.

The second is the retrofit process where the original diesel engine is modified into a 100% CNG engine. The cost of diesel genset conversion for various size is shown at Table 20.

Table 20. Diesel genset conversion cost and diesel consumption [17]

Diesel Genset Size	Retrofit/Repowering (USD)	DDF (USD)	Diesel Consumption (Liter/hour)
500 KVA / 400 KW	132.143	42.143	107,0
350 KVA / 280 KW	92.857	38.571	75,0
200 KVA / 160 KW	48.214	35.000	42,8
100 KVA - 80 KW	40.000	12.500	21,4
50 KVA / 36 KW	16.429	8.929	10,7
30 KVA / 24 KW	12.500	6.429	6,4

In palm oil industry, most of the mills and estate still using diesel genset because of its remote location. Palm oil mills that not connected to PLN grid need to use diesel genset for start up the boiler and to supply electricity to the mill office and housing when the mills is not in operation. Typical size of diesel genset used in the mills is from 250 to 500 kVa. Palm oil estate use smaller genset from 10-100 kVa to supply electricity to the estate office and housing. Biomethane produced need to be compressed into 200 bar cylinder/gas transport module (GTM) and transported to the genset location then a Pressure Reduction System (PRS) shall be required in order to have the pressurized gas from 200 bar can flow at a stable and constant rate to the dual fuel engine, which generally required 0,5 bar.

Figure 20. Dual fuel or dedicated system for generator

This Foto picture is the property of PSI & RGS

[17] Data from Raja Rafa Samudra

Table 21 below shows the calculation of bio CNG utilization for 400 kW diesel genset fuel with dual fuel (60% and 70% bio CNG mix) or dedicated (100% bio CNG). There are 2 scenarios, first is genset used for palm oil mill start up that in average only running 5 hour/day and the second is genset for power plant that operate 20 hour/day for comparison. This calculation assumed to use existing genset that converted into dual fuel or dedicated gas engine so no new investment for new genset. The result is clear that the more the genset operated, the faster the payback period. Dedicated conversion also gives faster payback than dual fuel, but the risk is high when the availability of the bio CNG can't be maintained.

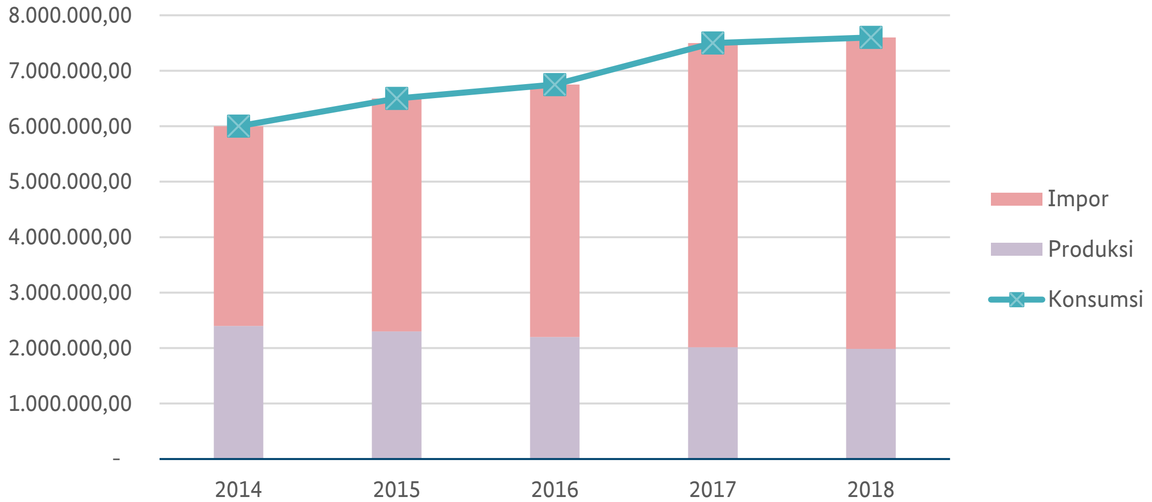
Table 21. Financial calculation for biomethane for diesel genset fuel

Parameter	Vehicle Conversion Type				Unit
	DDF (60%)	Dedicated	DDF (70%)	Dedicated	
Biomethane production	2.430.000				m3/year
	2.505.232				liter/year
Diesel price	0,71				USD/liter
Genset operation hour	5,00		20,00		hour/day
Fuel consumption	535		2.140		liter/day/genset
No Genset	22	13	6	3	unit
Investment costs					
Upgrading & Compression	4.300.000		4.300.000		USD
Conversion	42.143	132.143	42.143	132.143	USD/unit
	927.143	1.717.857	252.857	396.429	USD
Distribution	74.426	74.426	74.426	74.426	USD
Total investment	5.301.569	6.092.283	4.627.283	4.770.855	USD
Operation Cost					
Upgrading & Compression	349.092		349.092		USD/year
Genset	220.000	130.000	60.000	30.000	USD/year
Distribution	74.426	74.426	74.426	74.426	USD/year
Total operation cost	643.518	553.518	483.518	453.518	USD/year
	0,257	0,221	0,193	0,181	USD/liter
Fuel Savings	0,457	0,493	0,521	0,533	USD/liter
	1.145.934	1.235.934	1.305.934	1.335.934	USD/year
Payback period	4,6	4,9	3,5	3,6	year

5.2.4. LPG Replacement

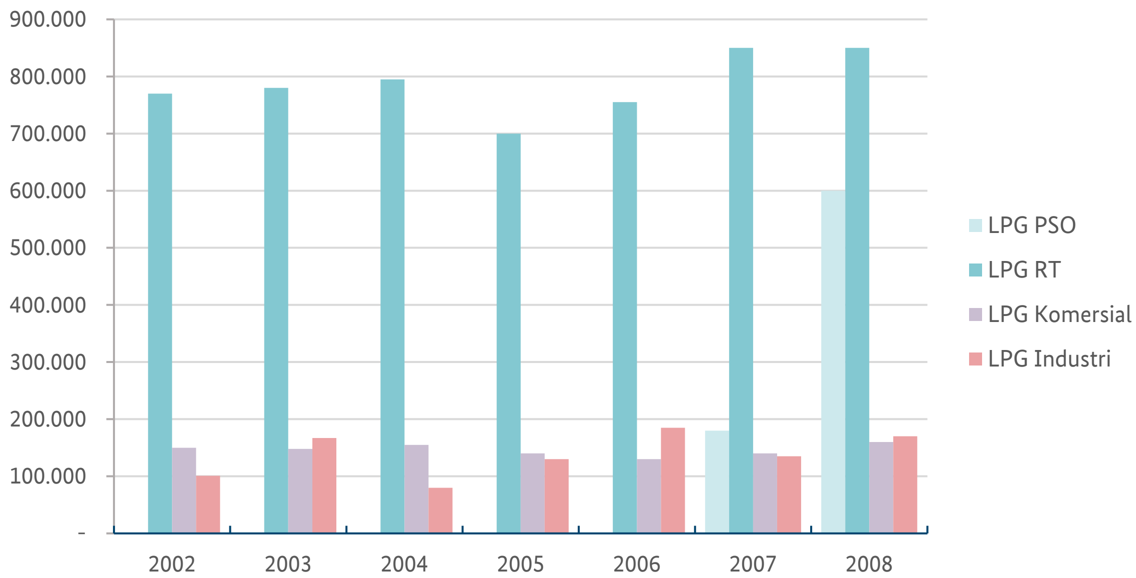
LPG or Liquefied Petroleum Gas is one of the most widely used fuel by the public in Indonesia. Since 2007 the Government has been implementing a kerosene to LPG conversion program that successfully increased LPG consumption significantly. LPG production in the last five years is decreasing while the amount of LPG consumption continues to increase, until more than 7 million ton/year. This resulted in a deficit that caused LPG need to be imported from abroad to meet domestic LPG needs. In 2018, more than 74% of LPG is needed from imports to meet domestic LPG needs (see Figure 21), while the rest comes from domestic LPG refineries.

Figure 21. Supply-demand for LPG (Directorate General of Oil and Gas, Ministry of Energy and Mineral Resources, 2018)



Although LPG was originally produced to meet the needs of household gas fuels, but later it also developed to meet other needs such as industrial and transportation needs. Broadly speaking, the use of LPG as an energy source is used to meet the needs of heat, lighting, and power sources. Heat utilization for of LPG is driven by household needs such as cooking, heating, water heating and so on. These needs then dominate Indonesia's LPG consumption patterns.

Figure 22. LPG consumption based on user groups [18]



[18] Data from Pertamina 2008

Based on Figure 22, the group that dominates the use of LPG is the household group. Meanwhile, the use of LPG for households also continued to increase especially in 2007, because in that year the subsidized kerosene supply had been reduced by carrying out a kerosene to LPG conversion program. This conversion was demonstrated by the emergence of LPG PSO (Public Service Obligation) consumption in 2007. Even though household is the biggest user for LPG, bio CNG have better potential to replace LPG for industrial and commercial (B to B) use. The consideration is the gas requirement of industrial and commercial will be more suitable for bio CNG from POME that can produce 0,2 – 0,5 MMSCFD of bio CNG.

LPG have high an average calorific value of 11058 kcal/kg because of its liquid form and usually stored in the cylinder with 8 bar pressures. Compared to LPG, bio CNG have lower calorific value of 7,715 kcal/m^3 and need much higher pressure to store (200-250 bar) because of its low energy density. This higher Bio CNG storage pressure requires a heavier, more space and more expensive cylinder for storage. This will be the main challenge to replace LPG with bio CNG that with proper design and calculation, can be offset by the economic benefit. Another challenge for bio CNG is to find commercial or industry that located in the range of 200 km from the palm oil mill because of its location mostly in remote area.

The advantage of bio CNG compared to LPG lies in its availability that have plenty of resources and can be found locally. POME is the largest source for producing bio CNG that available on hundreds of palm oil mill spread mainly in Sumatra, Kalimantan and Sulawesi. In the other hand, LPG source is limited because it is attached to the oil refinery that only operated in few locations in Indonesia.

LPG and bio CNG appliances are not interchangeable and need to be converted. As with the regulators, the gas appliances operate at different pressures. LPG also requires an air (oxygen) to gas ratio of approximately 25:1 whilst bio CNG is 10:1, for proper combustion. To achieve this difference, LPG is typically provided in a smaller quantity but at a higher pressure, drawing more oxygen with it into the burner. For industry application, the conversion from LPG to Bio CNG does not need many changes, just in the settings for the boiler because of the difference in calories. For bio CNG, it also needs PRS to decrease the pressure down to 5 bar then there is a regulator to further decrease down to 2-5 bar for the boiler. The user may have bigger safety concern because bio CNG pressure is much higher than LPG. In reality, Bio-CNG is safer because if it leaks it disperse directly into the air, whereas LPG will go down if it leaks because it is heavier than air and will have higher risk for fire. Table 22 shows further comparison between bio-CNG and LPG.

Table 22. Bio-CNG and LPG Comparison [19]

Parameter	Bio-CNG	LPG
Constituents	Methane	Propane and Butane
Source	Obtained from purified biogas from organic material through anaerobic digestion	Automatically generated from gas fields when natural gas is extracted from the reservoir. By- product of cracking process during crude-oil refining.
Uses	Substitute for gasoline in automobiles.	Heating and cooking in homes, refrigeration, industrial, agricultural, catering and automobile fuel.
Environmental effects	Carbon neutral because come from renewable energy source	Releases CO_2 which is a greenhouse gas but is cleaner when compared to gasoline.

[19] https://www.pluginindia.com/blogs/biogas-never-ending-source-of-fuel-electricity-fertilizer

Parameter	Bio-CNG	LPG
Properties	Gas form, lighter than air and hence disperses quickly in the event of spillage.	Liquid form and highly inflammable. It is heavier than air and on leakage will settle to ground and accumulate in low lying areas.
Safety	Easily disperses, hence risk of ignition is minimized.	Since it is difficult to disperse risk of fire is more.
Price & availability	Cheaper and easy to produce locally	More expensive and depend on import, so if the stock decrease can increase the selling price, especially in the region

The biggest advantage of replacing LPG with bio CNG come from its relatively low cost compared to LPG. The government by PT Pertamina already set the official LPG price Rp 593,000 for 50kg or Rp 11,860/kg. Size of 50 kg cylinder is the size that mostly used by commercial and industrial. Table 23 provide financial calculation if LPG is replaced by bio CNG for commercial or industrial consumption. It shows that by replacing LPG with bio CNG, there can be cost saving around 1,1 million USD per year with payback period 3,7 year.

Table 23. Financial calculation for LPG replacement with Bio CNG

Variable	Value	Unit
Biomethane production	2.430.000	m^3/year
Investment Costs		
Upgrading & Compression	4.300.000	USD
Distribution	74.426	USD
PRS (Pressure Reduction System)	37.213	USD
Total investment	4.411.639	USD
Operation Cost		
Upgrading & Compression	349.092	USD/year
Distribution	66.633	USD/year
Total operation cost	415.725	USD/year
	0,171	USD/liter
Economic Benefit		
LPG Price	0,660	USD/m^3
Cost savings	0,489	USD/m^3
	1.188.440	USD/year
Payback period	3,71	year

6. Biogas Upgrading Projects

6.1. Sachsendorf Plant, Germany

Biogas upgrading plant in Sachsendorf, Germany is owned by Envitec Biogas and already operated since 2013 and using maize and chicken dung for the feedstock. This plant is the first biogas upgrading plant from EnviTec Biogas AG to use highly selective membranes to refine the generated biogas to a biogas purity level of over 97% CH_4 in a three-stage process by using membrane modules developed by Evonik Industries. The biogas upgrading plant have capacity of 350 standard cubic metres (Nm^3/h) is maintained by a total of four employees, has been feeding biomethane into the 1-bar line of the gas grid since its commissioning. The customer, EnviTec Energy, uses the produced biomethane in decentralized co-generation plants (CHP) for generating power and heat.

Figure 23. Sachsendorf biogas upgrading plant using membrane system

6.2. Sungai Tengi Plant, Malaysia

For South East Asia, the first commercial biogas upgrading plant from palm oil mill effluent was built in Felda Palm Oil Mill Sg. Tengi, Malaysia on 2015. The plant with investment of MYR 7 million processes 600 m^3/hour of raw biogas, sourced from a covered lagoon, to produce 400 m^3/hour of biomethane. The POME raw biogas is upgraded from composition of 60% CH_4, 35% CO_2 and 3000 ppm H_2S to biomethane of > 94% CH_4 content. The biomethane produced is compressed into 250 bar Bio CNG and dispensed into CNG trailers to be sent to factories. The first factory to receive this Bio CNG is OMI Alloy (M) Sdn Bhd, located about 45 km away from the Plant. The factory is replacing their LPG fuel with Bio CNG, thus enjoying fuel cost savings and reducing carbon footprint of the factory.

This plant is a result of strategic venture between the Malaysian Palm Oil Board (MPOB), Felda Industries Sdn Bhd (a subsidiary of Felda Global Venture, FGV), and Sime Darby Offshore Engineering Sdn Bhd (SDOE). SDOE is the engineering, procurement, construction and commissioning partner in this venture. SDOE and Gas Malaysia Berhad (GMB), the local natural gas distribution company in Malaysia, had also entered into a joint venture to off-take the BioCNG produced from this plant and transporting it by CNG trailers to customers. SDOE sourced the biogas upgrading and CNG compression equipment from SAFE Spa, Italy that use membrane module from Evonik.

Figure 24. Bio-CNG plant at Sg Tengi Palm Oil Mill in Malaysia

Figure 25. Main operation unit of Sg Tengi Bio CNG plant

6.3. Khon Kaen Plant, Thailand

In Thailand, according to the Department of Alternative Energy Development and Efficiency (DEDE), the Ministry of Energy has defined the Alternative Energy Development Plan (AEDP) with a target to produce about 1,200 t/d of CBG by 2021. Biogas upgrading plant start to be developed in Thailand since 2011 for pilot project and the first commercial project is built in 2014 in Khon Kaen using feedstock from chicken manure with using membrane separation technology. The pig farm at the Faculty of Agricultural, Khon Kaen University (KKU) produce pig manure and hen manure of more than 15 m^3/day and used as feedstock for biogas production by anaerobic co- digestor in channel digester. The biogas production goes through biogas upgrading process for removal gas such as H_2S, CO_2, NH_3 and H_2O. After the upgrading process, obtained biomethane has more than 83% CH_4. It is then, compressed at high pressure (200 barg) to obtained compressed biomethane gas (Bio CNG). Bio CNG production from this process is used as a fuel for the shuttle bus in Khon Kaen University (KKU).

Figure 26. Bio-CNG plant in Khon Kaen University, Thailand

7. Conclusion and Recommendation

7.1. Conclusion

- Indonesia has high potential to utilize biomethane to reduce imported fuel such as diesel and LPG that imported and need to be subsidized heavily by the government
- Only around 10% of biogas utilized from POME and only one converted into biomethane in Indonesia
- Membrane separation is the most widely used biogas upgrading technology in Southeast Asia, including in Thailand and the first biomethane plant in Malaysia. It has advantage of modular system; low electricity usage and less maintenance compared to other technology.
- Biomethane can be directly injected to the grid or compressed and stored in the cylinder depend on the utilization.
- Biomethane can be utilized into various method with the most common utilization as below:

Utilization	Advantage	Challenge	Economic Return
City gas	○ can utilize existing gas network ○ high demand for gas and include in the government planning ○ no high-pressure compression needed	○ small profit margin because need to follow city gas price ○ procedure to tap into existing gas network is unclear ○ limited location in proximity of gas network	Low
Vehicle Fuel	○ most truck in the plantation area using diesel that can be converted into bio CNG ○ diesel vehicle conversion to natural gas vehicle already common implemented for NGV	○ low gas fuel price for NGV set by government ○ high investment cost to convert diesel fuel vehicle ○ engine efficiency for dual fuel depends on the road condition that affect engine RPM	Medium
Diesel Genset	○ plantation still using diesel genset for the mill and housing ○ - more efficient for dual fuel application because more consistent load	○ additional investment for gas distribution and PRS ○ economic feasibility strictly depend on engine running hour	Medium - High
LPG Replacement	○ high consumption for LPG for commercial and industry ○ high price for LPG compared to biomethane ○ locally available and not depend on import	○ need technical modification to accommodate bio CNG ○ additional investment for gas distribution and PRS ○ industry availability near the biomethane plant that mostly in remote area	High

7.2. Recommendation

- The calculation in this report is based on ideal condition with assumption all the biomethane produced is utilized with consistent volume that might be different in the real condition. Need to conduct more detailed study based on real case study with actual data to get more accurate financial calculation.
- There is no regulation specifically set for biomethane in term of commercial and technical safety so need to refer to oil and gas regulation temporarily and adapt it along the way if the market already formed.
- Biomethane utilization for palm oil mill plantation captive energy such as fuel for trucks or diesel genset have more potential for implementation and offer interesting financial return because replacing costly diesel fuel. Can start with mills that already have biogas plant but not yet fully utilized.
- Need to promote the biomethane utilization potential to more stakeholder such as government, private sector and public to support the biomethane development in Indonesia.


"Palm Oil Mill Terantam, PTPN V",
photo by GIZ

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