BIOGAS ENERGY POTENTIAL IN RIAU INDONESIA

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Abstract: The increasing of crude oil prices recently in the world, the need for an alternative source of fuel in the Indonesia is urgently required. In addition, growing concern about climate change is driving the need for “low-carbon” fuels. One highly potential form of renewable and low-carbon fuel is biogas from anaerobic digestion of organic wastes. Anaerobic digestion is a naturally occurring process of decomposition of organic matter by microbes in an oxygen-free environment. Anaerobic digestion has been used throughout the globe for many years, especially in areas outside of the Indonesia. However, it has not been applied widely for production of biogas as a power generator fuel. Millions of tons of wastes are generated each year from agricultural, municipal, and industrial sources. Agricultural wastes such as palm oil mill effluent (POME) and Sago mill effluent can be used as the feedstock to produce biogas. The waste can be converted into usable biogas through anaerobic digestion. This can reduce the adverse impact on the environment and can be used on the farm to take care of a part, if not all, of its energy needs. In addition, biogas can be cleaned and upgraded to biomethane, a gas indistinguishable from conventional natural gas that can be used as a fuel. The purpose of this paper is to introduce a potential biogas production from agricultural wastes and conversion to a fuel. In order to understand the potential of biogas production, we provide a brief overview of the two main stages such as production of biogas via anaerobic digester and the uses of biogas as fuel for power generator.

Keywords: *biogas, digester, anaerobic, methane, energy,*

I. INTRODUCTION

Total area for Indonesia palm oil in 2006 was estimated at 6.07 million hectares and Riau region was estimated around 1.4 million hectares according to information from the Indonesia Palm Oil Board (IPOB) [1]. Indonesia is forecast to produce 18.3 million metric tons of palm oil in 2007/08. It is estimated that about 28 m^3 of biogas is generated for every m^3 of palm oil waste in the waste treatment plant of palm oil mills. In the palm oil mills, solid wastes are burned directly in the boilers to generate steam. 1 m^3 of biogas is equivalent to 20 MJ. When used as fuel for co-generator, 1 m^3 of biogas can produce 1.7 kWh of electricity and 7.7 MJ of heat [2]. These solid wastes include the fiber, shell and empty fruit bunch (EFB). However, there are large quantities of water based wastes that are not able to burn by themselves. These wastes have to be processed or digested in the waste treatment plant in order to comply with the Department of Environment regulation before they can be allowed to be discharged into the water course. During the fermentation process, biogas is the unavoidable but valuable gaseous product of such a process.

Riau has a significant number of large agricultural operations. These agricultural operations produce a considerable amount of organic waste in the form of palm oil mill effluent (POME). Handling such large amounts of organic waste, especially POME, in an environmentally friendly manner is a highly challenging. Producers, scientists and other stakeholders are exploring various options to tackle this issue, and using anaerobic digesters is a promising one among them. Anaerobic digesters are specially designed tanks used to facilitate the anaerobic digestion process under a controlled atmosphere. Anaerobic digestion is a natural process that occurs in the absence of air. During this process, microorganisms stabilize the waste organic matter and release biogas as a byproduct. Biogas consists mainly of methane and carbon dioxide gases. Burning biogas can produce energy like natural gas. The energy produced using biogas is renewable, unlike natural gas. Some scientists and academics anticipate that renewable energy sources will be preferred over the natural fossil fuel energy sources in the near future to slow the global warming effect. Stabilized organic wastes from a digester, known as digestate, contain less odor than the unstable waste or no odor at all, yet retain almost all the nutrients from the feed material. Applying the digestate to cropland may replace commercial fertilizers, so anaerobic digesters can bring several benefits.

II PRODUCTION OF BIOGAS

Several bacteria are present in agricultural waste, compost and other feedstock each serving a specific function. The facultative bacteria in a digester break down complex feedstock molecules using oxygen in the feedstock and water through a process known as hydrolysis [3]. These bacteria function both in presence and absence of oxygen and require temperatures of about 37°C. This is followed by the formation of volatile fatty acids, carbon dioxide and hydrogen by the acidogenic bacteria in a process referred to as acidogenesis. These bacteria function only in the absence of oxygen. If there is any air/oxygen present during this process, the digestion of the feedstock stops and the digester gives off a distinctive smell of the acids present. Finally the methanogenic bacteria break down the fatty acids in the feedstock into simpler molecules namely: carbon dioxide, water and methane in a process referred to as the methanogenesis. These bacteria also function only in absence of oxygen. The composition of biogas depends heavily on the feedstock but mainly consists of 50-70% methane, 30-40% carbon dioxide, 5-10% Hydrogen, 1-2% Nitrogen, 0.3% water vapor and trace amounts hydrogen sulfide [4]. Figure 1 below shows the stages in biogas production, as discussed above.

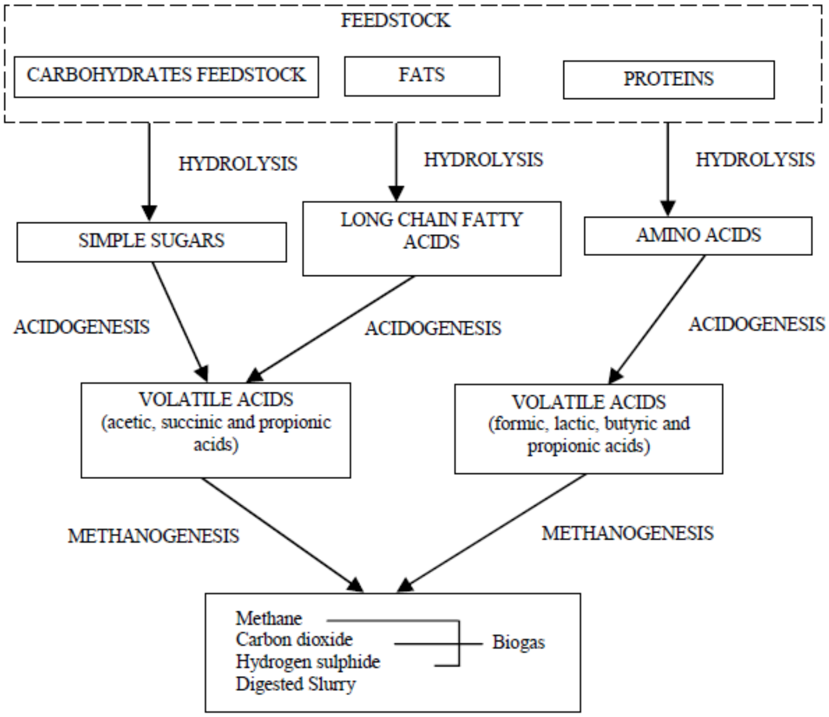

Figure 1: Stages in the production of biogas [5]

The main controlling factors in the production of biogas are the loading rate, retention time and temperature of the biogas digester. The loading rate will vary with digester feedstock and types of digesters but is normally given in terms of the weight of the total volatile solids (TVS) per day per unit volume of the digester or the weight of TVS added per day per weight of TVS already in the digester. Volatile solids define the amount of organic matter in a material or the organic component that is burnt off when a material is heated to 538°C. [4]. The higher volatile solid content in a substrate, the higher the amount of biogas produced. Over-loading leads to increased acidity of the digester and the attendant reduction in the production of methane, while under-loading gives rise to low gas production. The retention time is a measure of the amount of time a substrate remains in the digester before being discharged and is normally equal to the volume of the digester divided by the daily inputs of substrate. It is important to optimize the retention time in order to ensure, proper digestion of the slurry and extraction of as much biogas as possible before discharge of the slurry. The cellulose, hemicellulose and lignin components in fibre are difficult to biodegrade, which contributes to a reduction in the production and content of methane in biogas from the high fibre content POME substrate. It is necessary therefore to introduce phase separation processes that separate the fibre from the rest of the substrate so that the fibre may be digested for longer periods apart from the rest of the substrate. The efficiency of phase separation processes however are dependent on a number of factors including, the type of substrate, organic loading rate (OLR), hydraulic retention time (HRT) and the configuration of digester reactors used [6]. Biogas is mainly produced through the anaerobic digestion of animal and plant organic waste, primarily in simple and low technology systems. Biodigestion is not solely attractive for the methane gas produced but also as it provides a means of converting organic waste that would otherwise be an environmental hazard into readily usable compost, reduction of pathogens in the organic waste, odor control, mineralization of organic nitrogen and weed seed destruction [8]. The main by-products of bio-methane production, carbon dioxide and hydrogen sulfide, increase the storage and handling requirements of biogas, reduce the gas value of the biogas produced, in addition to which hydrogen sulfide is pungent. It is therefore advisable to remove these gases from the biogas before storage or use [9]. Efficient storage of methane, like natural gas, requires that it be compressed into an easily stored and transporter liquid. Methane unlike butane however, is not easily liquefied by pressure at normal temperatures and is only easily amendable to pressure-liquefaction at cryogenic temperatures.

III FACTORS AFFECTING THE PRODUCTION OF BIOGAS AND ITS QUALITY

Biogas production and its quality are dependent on maintaining a delicate balance between the acid forming and methanogenic bacteria in a digester, which is done through control of several factors including, the type of substrate, the C/N ratio of the substrate, temperature, pH, organic loading rate and the concentration of solids in digester charge [7].

A. Effects of pH

The pH is the negative logarithm to base 10 of the concentration of hydrogen ions. The pH in a working biogas plant normally lies between 7 and 8 and the optimum biogas production is achieved for digester inputs with a pH lying between 6 and 7. The solids content in biogas digesters should lie between 2 – 12% by weight, the rest being water. Solids content lower than 2% gives rise to reduced production of biogas per unit solids due to a decrease in the active bacteria population in the digester, while solids content higher than 6% may lead to a drop in the quality of biogas produced as a result of increased acidity [7].

Production of biogas in a well designed and properly seeded semi-continuous batch loaded feed unit should start within 24 hours, while a typical batch digester starts producing gas after 2 – 4 weeks and continues producing for between 3 – 4 months [4]. A maximum production rate after only two days of production from start up and a production of more than 90% of the total biogas-yield from a grass substrate have been reported after 9 to 11 days of operation of a batch type digester. A continuous feed digester takes between 2 – 3 weeks to start producing biogas when started from scratch. Continuous feed digesters may also be started and operated as batch systems till the production of biogas stabilizes in about a week’s time [7]. Once production of biogas commences, 1/3 of the total biogas is produced in the first one week, another 1/4 in the second week and the rest in another 6 weeks [12]. Seeding a newly started batch type digester with active sewage waste whose volume is 15% of that of the digester, reduces the stabilization period of methanogenic bacteria to a point where optimum gas production is achieved, from between 2 – 3 months to 4 weeks. In a balanced digester, the action of methanogenic bacteria that feed on acids formed by acetogenic bacteria, helps maintain a neutral pH of slurry to 8 [7]. Digestion of nitrogen by the methanogens produces ammonia, NH_4, which increases the pH of slurry. A pH value that is higher than 8.5 is toxic to the methanogenic bacteria. In a newly started digester however, the acid forming bacteria become active before the methanogens. This coupled with the fact that the reaction rate involving acid forming bacteria is faster than the one involving methanogens, normally leads to an initial reduction of the slurry pH to below 7 [4]. Moreover, methanogic bacteria take time to multiply to the numbers required to maintain a stable production of methane. It is necessary therefore to buffer a newly started digester using baking soda (sodium bicarbonate - $NaHCO_3$), lime (calcium oxide – CaO), or ammonium hydroxide (NH_4OH) in order maintain the pH within a range that is conducive for methanogenic bacteria to operate [10]. The activity of methanogenic bacteria begins to become inhibited at a pH of 6.6 [7] and pH values below 6 are clear indication that too much acid is being formed as a result of too few methanogenic bacteria. pH values above 5 though low can be corrected by the addition of lime or dilution of the digester feed. pH values below 5 on the other hand, will almost certainly lead to a stoppage of digesters, which then requires a complete replacement of the slurry and a fresh restart [10].

B. Effects of Temperature

Bacteria may be classified by their preferred operating temperatures: i) Cryophilic (Psychrophilic) bacteria work best at temperatures between 10°C and 20°C ii) Mesophilic bacteria work best at temperatures between 20°C and 40°C iii) Thermophilic bacteria work best at temperatures between 40°C and 60°C.

While anaerobic digestion is very efficient in Thermophilic regions, digesters in the tropics may operate adequately in the mesophilic region. Gas production efficiency, which is the gas produced per unit kilogram of feedstock, generally increases with temperature, roughly doubling for every 10°C rise between 15°C and 35°C. The quantity of ammonia, in a digester increases with increasing temperature, which because of its inhibitory effect on methanogenic bacteria as a result of increasing pH activity, leads to a decrease in the production of biogas [11]. High digester operating temperatures in digesters are therefore preferable, for so long as the production of ammonia is limited. Methanogenic bacteria are also known to be very sensitive to temperature changes, the degree of sensitivity being dependent on the range of temperature change.

C. Carbon and Nitrogen (C/N) Ratio

C/N ratio is an important parameter in biogas production since anaerobic bacteria need nitrogen for growth, however, if not properly controlled, it can inhibit methanogenic activity. The optimum C/N ratio for a digester lies in the range 20-30: 1. C/N ratios that are too high inhibit the production of biogas as the nitrogen levels are too low for the production of new cell structures by the methanogenic bacterial required to replicate themselves. Low C/N ratios on the other hand inhibit methanogenic acitivity due to the production of excess amounts of ammonium that may lead to an increase in the alkalinity of a digester beyond the tolerable pH level of 8.5 [4]. Where sewage slurry is used, this ratio is maintained naturally due to the composition of the feedstock. In case the ratio falls, it can be raised by adding components with a high C/N ratio such as saw dust into the digester slurry.

IV. ANAEROBIC DIGESTION AND TYPES OF DIGESTERS

Anaerobic digestion is a biochemical process whereby organic biomass sources are broken down by a diverse population of microorganisms in a low-oxygen environment, thus producing biogas as a natural byproduct. Since the microorganisms are already present in all organic material the process is triggered once the biomass is placed in a low-oxygen environment, such as underwater in a lagoon. Anaerobic digestion occurs in a digester that can be of various configurations. The following is a brief description of the major types of anaerobic digesters currently used listed from simple to more complicated configurations:

- *Covered Lagoon* – This is the simplest and least expensive type of anaerobic digester. It is intended to be used on large volume, liquid manure lagoons, typically on a dairy or swine farm. It is intended for use on farms where plug flow and complete mix digesters may not be suitable for use due to the high water content. The design consists of a non-porous, plastic cover over a manure lagoon with a built-in biogas collection system. The cover traps gas produced during the decomposition of the manure.
- *Complete Mix* – This type of anaerobic digester is more expensive than a covered lagoon. It consists of either above- or below-ground tanks with a built-in mixing and biogas collection system. The mixing system, either mechanical or gas-based, helps to speed up the digestion process and increase the overall efficiency.
- *Plug-Flow* –The design is similar to the complete mix digester but without the mixing system. Plug-flow digesters are cheaper to construct and operate than complete mix digesters but are also less efficient. The design of a plug flow digester is a long trench that is built either above or below ground sealed with an airtight cover on top. The substrate is fed through one end of the digester over a specific period of time. As new substrate is added, the old slurry is pushed across the trench, where it is continuously being decomposed, producing biogas underneath the airtight cover.
- *Multiple-Tank (2-Stage)* – This type of anaerobic digester is similar to the complete mix digester design except that digestion occurs sequentially in two phases. The first phase is a higher temperature phase at 55ºC followed by a second, lower temperature phase at 35ºC. While laboratory tests of this design show promise for increased digester efficiency, there is very little data on field-scale systems yet.

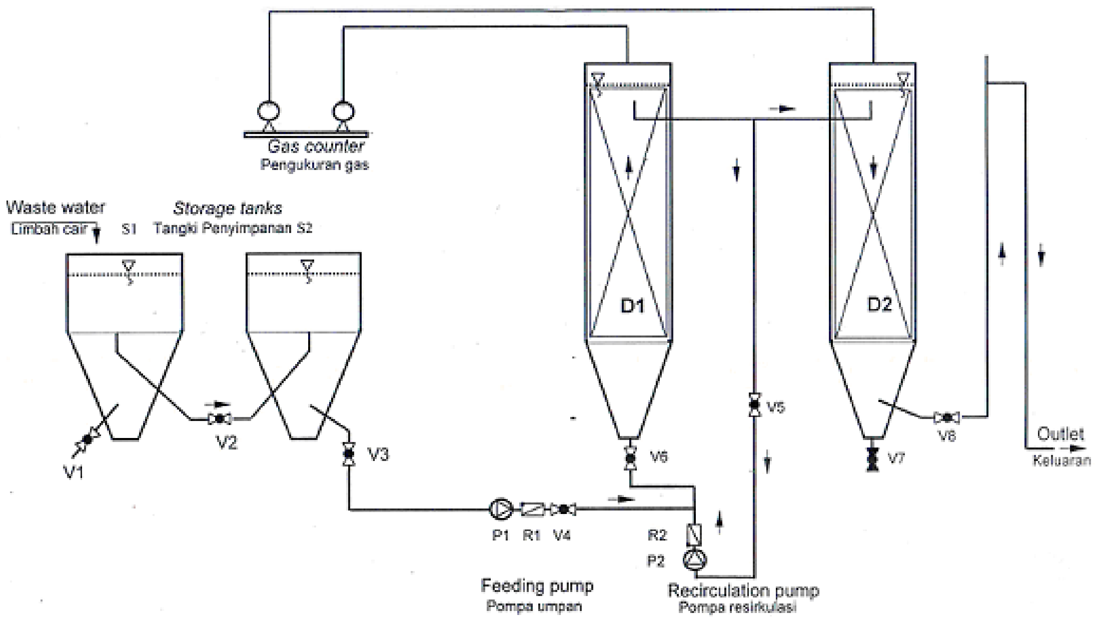

Figure 2: Proposed Digester System [12]

V. BIOGAS CLEAN-UP

Once the biogas is picked-up or produced, the best way to use it is enhancing its value. Several ways are possible: producing heat, electricity, cogeneration, vehicle fuel or injection in the natural gas grid. The heat and electricity productions are now well known techniques whereas the two other ways are still on their development phase. The choice between those solutions depends on numerous technical and economical criteria into which the nature and the localization of the production site are the main factors. Actually, the site may need intern energy (heat for the digester and premises, electricity in order to feed the machinery). It may happen that potential users of this energy are situated around the site. But the site is very often isolated (this is a common case for the dumps), and in this case the only possible upgrading is the production and sale of electricity.

Biomethane production involves upgrading, or "cleaning-up", raw biogas to a higher quality gas. This involves primarily removal of carbon dioxide, hydrogen sulfide, water vapor, as well as trace gases. The resulting biomethane will have a higher content of methane and a higher energy content making it essentially identical to conventional natural gas [2].

The primary steps in the biogas upgrading process are:

- Removal of Carbon dioxide (CO_2)
- Removal of Hydrogen sulfide (H_2S)
- Water (H_2O) removal and
- Removal of other contaminants

Depending on the technology used, some of the biogas upgrading steps may be performed simultaneously or as separate steps in the process. In addition, there may be further processing required depending on the composition of the raw biogas, the final form of the biomethane (e.g. low pressure gas, compressed, liquefied) and its intended usage.

A. Removal of carbon dioxide (CO_2)

Reducing the relative amount of carbon dioxide (CO_2) in the biogas is the main task of the biogas upgrading process. Raw biogas contains typically 60–70% methane and 30–40% carbon dioxide and biomethane contains 97–99% methane and 1–3% carbon dioxide. Note that typical natural gas pipeline specifications require a CO_2 content of less than 3% whereas vehicle fuel specifications require a combined $CO_2 + N_2$ content of 1.5 – 4.5%). Since the methane content of the gas is directly proportional to its energy content, increasing the relative methane content by removing CO_2 results in gas with a higher heating (calorific) value.

The following are the most common methods used to decrease the CO_2 content and increase the methane content of biogas:

- Membrane separation
- Pressure Swing Adsorption (PSA)
- Water scrubbing (with and without regeneration)

B. Removal of hydrogen sulfide (H_2S)

Hydrogen sulfide is a contaminant present in biogas produced during the digestion process. Depending on the biomass feedstock and biogas production process, the H_2S content of the raw biogas may vary from 50 to 3000 ppm (parts per million) or higher. H_2S should be removed from the gas stream early in the treatment process because of its corrosive nature. In addition, the release of the compound into the atmosphere is carefully regulated as it is extremely toxic and it contributes to air pollution. Pipeline gas and vehicle fuel standards require an H_2S content of less than 16 ppm. Some of the technologies used to reduce the H_2S content to acceptable levels are:

- In-situ reduction of H2S within the digester vessel by adding metal ions
- Removal of H_2S with metal oxides
- Oxidation with air
- Adsorption of H_2S on activated carbon
- Biological H_2S removal

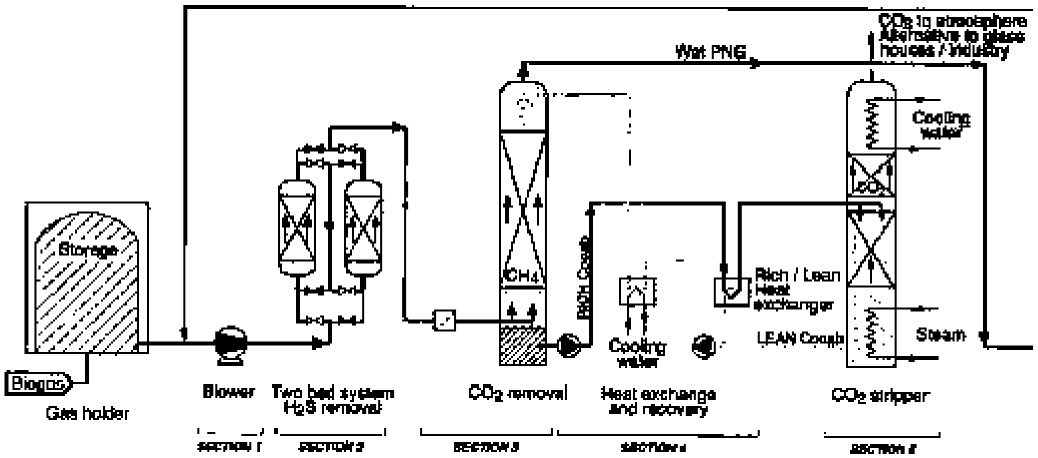

Figure 3 Biogas upgrading process [2]

C. Water Removal

Raw biogas is saturated with water vapor. Depending on the biogas upgrading technology used, later stages in the biogas upgrading process may also be fully or partially saturated with water. Since water is potentially damaging to natural gas pipeline equipment and engines, pipeline and vehicle fuel requirements regarding water content and dew point are very strict.

The removal of water can be performed via a number of different methods at varying points in the biogas upgrading process. The following are some of the most common methods used for removing water from biogas (sometimes referred to as drying the biogas):

- Refrigeration
- Adsorption
- Absorption

D. Removal of Other Contaminants

In addition to H_2S, H_2O and CO_2, there may be other trace contaminants present in the biogas which are potentially harmful to equipment and/or people and must therefore be removed or reduced to acceptable levels. These additional contaminants include particles, halogenated hydrocarbons, ammonia, nitrogen, oxygen and organic silicon compounds (e.g. siloxanes). A number of effective, commercially available technologies exist to reduce or eliminate these contaminants including filters, membranes, activated carbon and other absorption media.

E. Odorization

Odorization is normally accomplished by introducing sulfur containing compounds such as tetrahydrotiophen or mercaptans into the gas via a controlled dosing process. Concentrations are typically in the range of 5 to 30 mg/m^3 and their presence in the gas helps identify leaks. This is required if the biomethane will be injected into a dedicated pipeline, a natural gas pipeline network, or used as a vehicle fuel for CNG vehicles.

VI. COST ANALYSIS OF BIOGAS PRODUCTION

The capital, operating and maintenance costs of biogas production and upgrading systems vary significantly due to the different types of technologies currently available as well as the scale of production. Currently, upgrading biogas to biomethane for transportation use is only possible for large biogas producers due to the high initial capital and operating and maintenance costs. The initial capital costs take into account the startup costs, planning necessary, as well as the cost of the equipment and its installation. Operations and maintenance costs take into account what it costs to run the equipment on a daily basis, including its energy costs, small and large repairs, and various other aspects necessary for the successful performance of the systems. While, this information is still very sparse due to its relatively new adoption in this study, meaningful data will be collected from various sources including reports from palm oil industry, government sponsored research projects, and data from the literature. As the data is readily available, we will perform an extensive review to obtain costs per cubic meter of biogas produced.

VII. SUMMARY

Biogas renewable energy will be useful in reducing the global warming effect while paving the way for better POME management and odor control. Even though capital investment is high, biogas energy production can result in an additional revenue stream for producers while increasing rural employment opportunities. Biogas is a naturally occurring byproduct of the breakdown of organic material, and is actively produced from a variety of sources, including agricultural wastes using a process called anaerobic digestion. The main constituent of biogas is methane. When further cleaned and upgraded, biogas can be turned into biomethane, a high-quality methane fuel that is indistinguishable from conventional natural gas. Biomethane can be used as a blend with or replacement for natural gas, and can be used as a renewable fuel.

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