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# Biogas: Strengthening Green Energy Infrastructure for a More Sustainable Future

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ABSTRACT

Biogas has been available as a renewable energy source to accelerate national economic development. This research aimed to analyze the potential of renewable energy production development in Indonesia and present the application of potential waste processing into biogas. This study fills the knowledge gap through a critical review of the potential for developing renewable energy from animal waste in Indonesia, including biogas, power generation, transportation, and value-added chemicals. This study was conducted using a critical review of research articles and is supported by other related literature. The result of the study showed that Indonesia has great potential to develop biogas production due to its substrate availability, particularly from farm animal waste or other organic waste, even though its utilization has not been maximized. The data showed that primary energy consumption, especially in the industrial and transportation sectors, was dominated by fossil fuels and coal. The production of biogas technology development comprehensively included the processes and techniques of waste handling from biogas production. Most of the biogas application approaches were still in the early stage. Identifying opportunities, obstacles, policies, research, and development is still needed, particularly in this relatively new sector.

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## 1. Introduction

The availability of non-renewable energy resources is dwindling because the human population is overgrowing. That has become the leading cause of the search for current and supportable energy. According to (Hadi Mousavi-Nasab & Sotoudeh-Anvari, 2020; and Patel et al., 2020), this is the primary reason for the quest for innovative and sustainable renewable energy sources. Fossil fuel consumption is commonly viewed as the primary driver of environmental issues, including pollution and global warming (Ozturk & Dincer, 2019; Pelletier et al., 2019; Taki et al., 2018). Air pollution and global warming continue to be the most pressing issues facing the natural world today. The substantial growth in global population, as well as the significant development of greenhouse gases such as methane (CH4), carbon dioxide (CO2), and nitrogen oxides (N2O) arising from the vast burning of fossil fuels, may be ascribed to this problem (Abdeshahian et al., 2016; Bansal et al., 2013; Hosseini et al., 2013; Kapoor et al., 2020b). Greenhouse gases are recognized to play a part as determinants of CO2 and contribute the most (60%) to global warming from heat emitted from the

Earth's surface, while CH4 has a lower impact (15%) (Chowdhury et al., 2020; Hosseini & Wahid, 2014; Rahimnejad et al., 2015). Furthermore, the diminishing supply of fossil fuels due to their widespread use and the volatile price of oil crude and fossil fuel energy sources has fueled a growing trend toward the quest for renewable and cost-effective green energy alternatives (Abdeshahian et al., 2016).

The development of research on renewable alternative energy has become a trend in the 21st century to meet better energy needs. At the beginning of the 20th century, there was an explosion of rapid industrialization. No one could accurately predict the impact of greenhouse gases and global warming. However, it was not too late when scientists understood the adverse effects of greenhouse gas emissions on the environment. In recent years, there has been a rise in interest in renewable and sustainable energy research (Ahmad et al., 2019; Santos et al., 2018). According to BPS (2017) statistics report on the usage of renewable energy sources for power generation in various sectors, European countries lead the world with a 12% renewable energy share, which is higher than the worldwide average. The European Commission has passed significant measures to increase renewable energy's share in the EU's energy mix from 12% to 20% by 2020 (Lindkvist & Karlsson, 2018). Despite having suitable weather conditions for collecting various forms of clean energy such as solar, wind, and tidal, the Middle East area generates less than 1% of its electricity from renewable sources. Their lack of interest in sustainable energy is primarily due to enormous oil reserves and their status as the world's top oil exporters (Khatib, 2014). Wind, solar, and biofuel are today's most popular renewable energy sources. Bioenergy is a renewable energy source of elements produced from biological sources or biomass. Biofuels, biogas, and solid biomass are the three types of bioenergy available. Biogas produced from biomass has a production rate consistency and predictability advantage over the wind, solar, and other renewable energy sources (Agustini et al., 2018; Ahmad et al., 2019). As a result, biogas will remain a significant renewable energy source in the future (Miltner et al., 2017).

Biogas is mainly made up of methane (60%) and carbon dioxide (40%) and has been a valuable energy source for the environment (35 – 40%). Other gases included in biogas include hydrogen (H2), ammonia (NH3), hydrogen sulfide (H2S), oxygen (O2), nitrogen (N2), and carbon monoxide (CO) (Chasnyk et al., 2015; Khalil et al., 2019; Sun et al., 2015). The process of anaerobic decomposition gave rise to biogas. The reduction of organic molecules into simple chemicals by bacteria that exist as syntropic under oxygen deprivation by generating biogas is known as anaerobic decomposition (J. Li et al., 2014; Merlin Christy et al., 2014). The reduction of organic molecules into simple chemicals by bacteria that survive as syntropic under oxygen deprivation by generating biogas is referred to as anaerobic decomposition (Shen et al., 2015; Yong et al., 2015). Some advantages of anaerobic decomposition of organic waste are reducing odour release and pathogens reduction. Furthermore, the remaining organic waste that has been processed (digested) is used as fertilizer for fertile land as a substitute for mineral fertilizers and organic substrates for greenhouse cultivation (Chasnyk et al., 2015; Yong et al., 2015).

Manure waste from cattle is one of the most common organic wastes that can affect the environment if not properly managed. Animal faeces include significant levels of nitrogen (N) and phosphorus (P), causing nutritional imbalances and environmental pollution. Furthermore, cattle dung includes residues of various hazardous compounds, including growth hormones, antibiotics, and heavy metals. On the other hand, microorganisms in animal faeces can contaminate the environment, resulting in illness epidemics among people. The dumping of animal manure pollutes the environment by contaminating the air, soil, and water sources. Consequently, treating animal dung using an anaerobic decomposition process produces high-quality nutrients while minimizing smells and microbiological infections and generating renewable energy sources such as biogas (Abdeshahian et al., 2016; Ch'ng et al., 2013; Nasir et al., 2013).

Indonesia is one of the rapid population growth in Southeast Asia, so the energy needs have increased dramatically over the last two decades. On that basis, government policies strive to increase energy independence and security as a parameter of the country's progress and sovereignty. By the increasingly limited potential of fossil-based energy, particularly natural gas and oil, the main priority is the development of new renewable energy. It is because the new renewable energy in Indonesia has great potential and is relied upon for the availability of national energy in the future. Most new renewable energy sources are used for electricity, and some, such as biogas and biomass, are used for household, commercial, and industrial needs to reduce fossil energy consumption. Currently, the installation capacity of renewable energy plants in Indonesia is partly derived from hydropower, geothermal, and biomass (Energi, 2016). For energy from biogas, it has not been maximally developed, even though the potential is excellent.

Several studies on the potential of biogas production have been carried out in various countries, including Bangladesh (Chowdhury et al., 2020; Halder et al., 2016); China (Gao et al., 2019); Poland (Igliński et al., 2015); Malaysia (Abdeshahian et al., 2016); Iran (Noorollahi et al., 2015); and Indonesia (Indrawan et al., 2018; Khalil et al., 2019). However, this study reviews waste management as sustainable renewable energy, especially in Indonesia today, and the basics of optimizing biogas production. This article discusses the needs and potential of biogas production in Indonesia and the basics of overcoming biogas production waste to be more optimal. This research needs to be carried out to provide information about the potential, obstacles, opportunities, and constraints of Indonesia's biogas production and its optimization. In addition, this research can also be used as a research reference in the development of biogas production in Indonesia.

## 2. Methods

The research methodology employed in this study involves a critical analysis of the potential development of renewable energy derived from animal waste in Indonesia, encompassing biogas, power generation, transportation, and value-added chemicals. The research process commenced with systematically identifying relevant literature through comprehensive searches within scientific article databases and other pertinent information sources.

Following identifying the literature, a critical evaluation was conducted on relevant research articles about the subject matter. Previously published studies were thoroughly scrutinized to identify key findings, methodologies employed, and strengths and weaknesses inherent in each study. Moreover, this research also analyzed additional literature such as governmental reports, policy documents, and other reputable sources related to the development of renewable energy from animal waste in Indonesia. The article chosen for review in this research has been published in a reputable international journal.

Data and information obtained from the literature identification and evaluation phases were then subjected to in-depth analysis to comprehend the potential development of renewable energy from animal waste, including the challenges, opportunities, and possible solutions. This analytical approach aimed to provide a comprehensive overview of the current situation and potential development directions for the future.

Conclusions drawn from this critical analysis were subsequently integrated into the study to offer deeper insights into the potential and prospects of developing renewable energy from animal waste in Indonesia. Thus, this research methodology significantly contributes to filling the knowledge gap and expanding insights into the potential environmentally friendly energy sources for the future.

## 3. Results and Discussion

### *3.1 New Energy in Indonesia*

#### *3.1.1 Energy Consumption*

Indonesia's energy consumption is quickly rising due to economic and population expansion. According to projections, energy demand is expected to rise to 450 109 Kwh in 2026. However, non-renewable and fossil-based energy sources are employed in 80% of Indonesia's power plants, according to the International Energy Agency (IEA). According to the Ministry of Energy and Mineral Resources, oil (39%) is the primary energy source, followed by gas (31.46%) and coal (31.46%). At the same time, power plant sources, including hydropower, biofuels, and geothermal, have contributed less than 5% of overall energy production (Khalil et al., 2019).

Petroleum dominated the fossil fuel energy supply. In 2014, diesel, kerosene, gasoline, and liquefied petroleum gas were examples of these goods (LPG). Indonesia's prospective oil reserves of 7.4 billion barrels had been confirmed. Nonetheless, the supply of petroleum products has decreased, mainly owing to Indonesia's failure to produce oil and government policies that encourage local coal production and use. In 2010, oil production reduced from 517 million barrels to 288 million barrels in 2014, one of the factors was dependence on oil fields and lack of investment in finding new oil sources. As a result, petroleum products' total final energy consumption (TFEC) proportion has dropped from more than 40% to roughly 37%.

Meanwhile, there was an improvement in the share of coal from 14% to 18% (Khalil et al., 2019). The government's initiative aims to reduce dependency on petroleum-based resources while also maximizing the potential of the indigenous coal sector. In 2014, Kalimantan and South Sumatra estimated 32,270 million tons of coal for Indonesia. Most of the coal sources in Indonesia were considered suitable for power plants because most are low ash and sulfur content sub-bituminous coal. At current production rates, Indonesia's total domestic coal supply is estimated to last 272 years, making it the world's largest coal exporter, with more than 80% of coal produced being exported.

Furthermore, with a capacity of 2.8 107 KW, the country is estimated to have about 40% of the world's geothermal reserves. Plants can also be powered by hydro and biomass-based energy sources with a capacity of more than 1 108 KW. In addition, solar energy has the potential to add 1.2 109 KW of power generation capacity to Indonesia's energy supply. However, due to several technological and regulatory barriers, Indonesia currently employs just 5% of its renewable energy sources.

The majority of NRE in the energy supply is now provided by hydropower. Out of 8 106 KW of untapped hydropower sources, most of which are located on densely populated islands like Java, Sumatra, Nusa Tenggara, and Sulawesi, hydropower could only provide 5.2 106 KW of electricity in 2015. According to the government's new feed-in tariff laws, recently, there has been a surge in the construction of small-scale micro-hydropower facilities. Between 2011 and 2014, 21 new micro-hydropower plants with a total capacity of 2600 kW were erected in various locations in Indonesia, raising the total percentage of energy supply from hydropower from 14,000 KW in 2010 to 170,000 KW in 2014 (Erinofiardi et al., 2017; Khalil et al., 2019).

Geothermal energy accounts for the second highest percentage of total NRE resources in Indonesia's energy supply. Indonesia has 40 per cent of the world's total geothermal energy potential, which can be fully used (Abdeshahian et al., 2014; Khalil et al., 2019). Indonesia has at least 256 prospective regions for geothermal energy production. However, due to their closeness to the ring of fire, many active volcanoes may be found on several main islands in Indonesia. Furthermore, only roughly 4.5% of Indonesia's geothermal energy potential is now used. Additional potential NRE resources in Indonesia include biofuels and biomass solar, wind, and wave energy, which collectively provide less than 1% of the total energy supply. However, unlike hydrothermal and geothermal energy, these energy resources are still at the R&D stage or are only used in small-scale power plants.

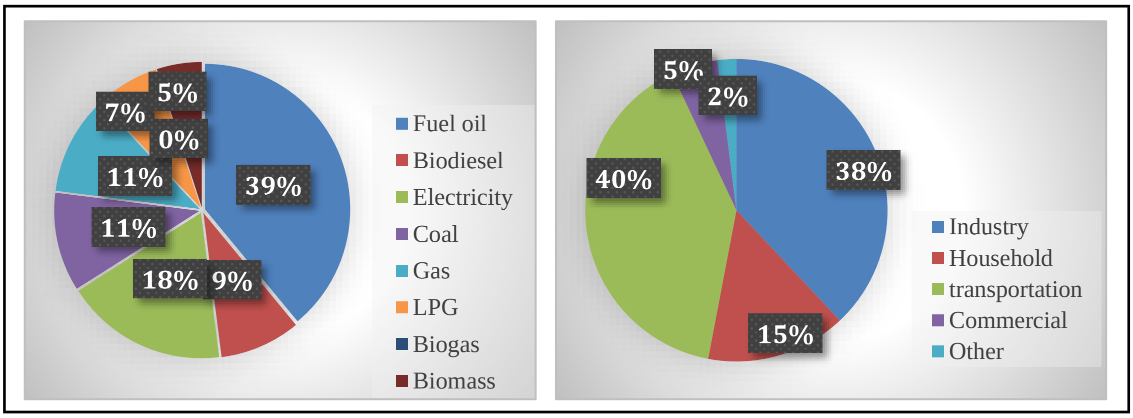
The Indonesian government strives to increase energy independence and security as a parameter of sovereign country prosperity. NRE becomes an alternative in energy supply and has priority to be developed in Indonesia when we realize that fossil energy reserves decrease as we continuously consume it. So far, most of the NRE use is for electricity, while others, such as biomass and biogas, are used for household, commercial and industrial purposes to reduce the reliance on fossil fuels. The currently installed renewable energy uses hydropower, geothermal, and biomass in the electricity sector. However, other renewable energy potentials such as solar, wind, and sea have not been fully utilized. That is triggered by the high cost of producing renewable energy plants. That makes it difficult to compete with fossil fuel energy plants, especially coal.

Another problem includes constraints on land use permits, negotiating electricity rates, the distance from the location to the center of demand, and domestic industry that is not supportive of components and renewable energy generators. The government has issued regulations to overcome these problems, including the implementation of a feed-in tariff (fit) mechanism for each type of renewable energy generator, simplifying the licensing process and implementing a one-stop integrated service system (PTSP), coordinating with the relevant ministry for land use and the permits for specific land use. Synchronization of policies related to energy use, particularly with the development plan for industrial areas, financial support continues to be carried out to encourage the development and utilization of EBT optimally. A suitable mechanism has been implemented for such a long time. However, there are many obstacles in the field, namely the unclear legal guarantees for State-Owned Enterprises (BUMN), in this case, the State Electricity Company (PLN) for above-average purchases and mechanisms related to the high cost of electricity. To overcome this, the government has formed a separate agency specifically working for purchasing renewable energy following fit. In addition, it also develops a subsidy mechanism for the price difference.

The industry has consumed the most energy in Indonesia for the past ten years. Food, chemical, mining and metal processing, wood and paper processing, and other industrial applications account for roughly 36% of overall energy consumption, according to MEMR (2016) (typically in the form of coal, natural gas, and oil). However, the transportation sector now consumes the most energy. Transportation accounted for 35.6% of Indonesia's total final energy consumption in 2015, surpassing the industrial sector's contribution of 4%. That was primarily due to an uptick in domestic motorcycle and scooter production and sales. Around 5.7 million motorcycles and scooters were manufactured in 2015, accounting for 85% of domestic sales. Finally, because 90% of transportation energy is used in the form of gasoline and diesel, the fast expanding energy consumption in the transportation sector has substantially influenced Indonesia's carbon footprint in recent years. As a result, CO2 emissions have risen unexpectedly from roughly 250 Mt in 2001 to 650 Mt in 2013, according to recent studies (Khalil et al., 2019).

Furthermore, nearly a third of Indonesia's energy is used to power buildings, such as commercial, residential, and public buildings. The bulk of home energy demands in Indonesia is met by energy for lighting, cooking, cooling, heating, and other equipment, as in most Southeast Asian nations. Commercial buildings account for just 10% of residential energy demand. According to recent studies, every year, the number of residential homes grows by 1.5%, with each residence averaging four people. Despite this, household energy consumption per home has remained stable at around 10,000 kWh per family due to the recent shift to more efficient energy sources. For example, before the government launched a large-scale conversion effort to convert kerosene into more energy-efficient sources like LPG, kerosene was Indonesia's primary cooking fuel. As a result, kerosene consumption in homes has decreased by less than 2%, while LPG consumption has increased by 13%.

Recently, Sumatra and Java are Indonesia consumes the majority of its energy. Because these islands are the country's two most inhabited places, this is the case. As a result, total energy consumption in Indonesia rose fast from 953 million BOE in 2007 to 1058 million BOE in 2016, according to a Ministry of Energy and Mineral Resources study. It has aided Indonesia's economic development and population increase; its current annual total electrical energy consumption is roughly 763 kWh per capita, or 199.30 billion kWh, making it ASEAN's top energy user (Khalil et al., 2019). According to statistics from the Ministry of Energy and Mineral Resources (2019), Indonesia consumed 875 million BOE of energy in 2018 (equivalent to barrels of oil) (Divya et al., 2015), with details as shown in Figure 1.



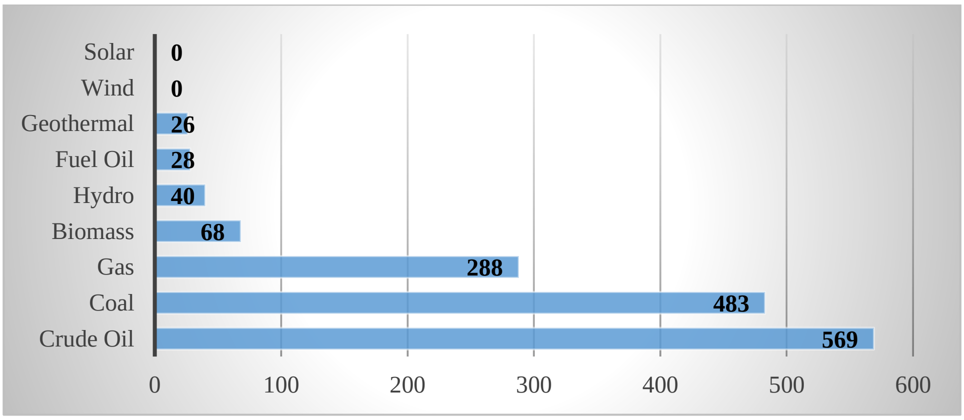
(a) (b)

*Source: Divya et al. (2015)*

**Figure 1.** Indonesian Energy Consumption in 2018: (a) by type, (b) by sector

Figure 1 shows that in 2018, the total final energy consumed per type was dominated by fuels (gasoline, diesel oil, kerosene, fuel oil, avgas, after). The use of fuel technology equipment is still considered more efficient than other equipment, especially in the transportation sector, so fuel consumption is still dominating. However, following the increasing trend of diesel oil and obligatory biodiesel by the increase in final energy consumption of fuel, biodiesel consumption has also improved. Biodiesel is used for the transportation, industrial, commercial, and power plant sectors. Meanwhile, in the data per sector, transportation is the most dominant. This sector uses almost all types of fuel, mainly gasoline.

Meanwhile, coal is used in the industrial sector. The household sector primarily uses electricity to support daily activities and LPG. The commercial sector is dominated by electrical energy, while others, such as agriculture, construction, and mining, are dominated by the use of diesel oil. Figure 1 also shows the potential for developing biogas energy sources that have not been used. That is unfortunate, considering biogas is a renewable and environmentally friendly energy source. Moreover, Indonesia has great potential to develop it. Figure 2 shows Indonesia's energy supply in 2018 with a total of 1,504 million BOE, an increase of 8.4% from the previous year.



*Source: Divya et al. (2015)*

**Figure 2.** Energy supply in Indonesia (Million BOE)

### *3.1.2 Livestock Production*

There has been an increase in Indonesia's livestock production n the last decade. Table 1 shows the number of livestock censuses in Indonesia.

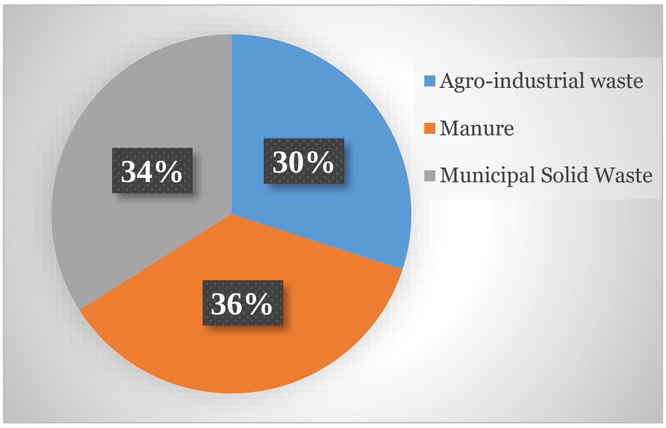
Table 1. Total livestock production in Indonesia in 2017-2019

| **Livestock** | **2017 (tail)** | **2018 (tail)** | **2019 (tail)** |
|---|---:|---:|---:|
| Beef cattle | 16. 429 .101 | 16,432,945 | 17,118,650 |
| Dairy cows | 540.441 | 581.822 | 561,061 |
| Buffalo | 1.321.904 | 894,278 | 1,141,298 |
| Horse | 409,122 | 377,929 | 393,454 |
| Goat | 18.208.017 | 18,306,476 | 18,975,955 |
| Sheep | 17,142,498 | 17,611,392 | 17,794,344 |
| Pig | 8,260,995 | 8,254.108 | 8,922,654 |
| Laying Hen | 258,843,681 | 261.932.627 | 263.918.004 |
| Broilers | 2,922,636,196 | 3137,707,479 | 3,149,382,220 |
| Free-range Chicken | 299,701,400 | 300,977,882 | 312,000,000 |
| Manila Duck | 57,557,451 | 59,551,713 | 61,221,313 |

*Source: Central Statistics Agency (BPS) Indonesia*

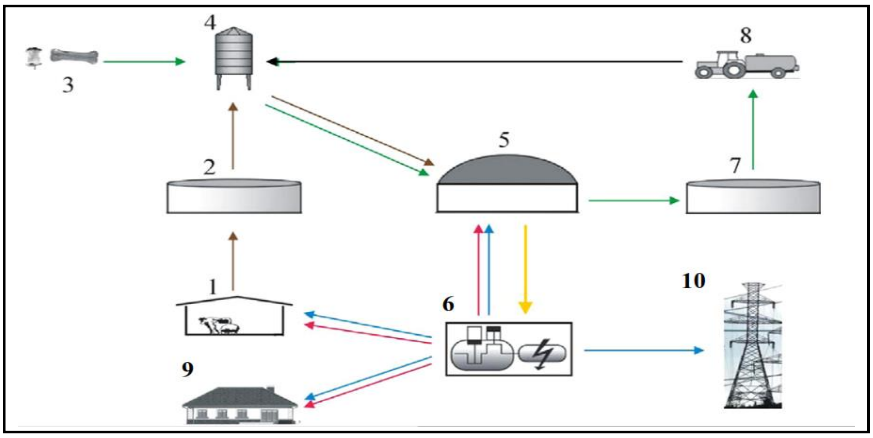
As a result that, livestock production shows from 2017 to 2019, there was an upward trend. Correspondingly, the increase in livestock population leads to an increase in the production of livestock manure which results in difficulties with the disposal of large amounts of manure. That suggests that much pollution and nutrients are released into the air (Abdeshahian et al., 2016; Nasir et al., 2013).

In anaerobic decomposition processes, for the biogas industry, dung is one of the most sustainable and cost-effective substrates (Ch’ng et al., 2014). Furthermore, treating large amounts of manure through anaerobic digestion is beneficial for appropriate manure management by reducing pollution and providing biogas as a significant energy source. In addition, converting manure to organic fertilizer aids plant development in fertile soil (Abdeshahian et al., 2016; Ounnar et al., 2012). Figure 3 shows how animal manure contributes significantly to biogas generation from the primary sources of organic waste in rural and urban regions (Abdeshahian et al., 2016; Divya et al., 2015). Figure 4 depicts a schematic representation of a biogas plant for biogas production from animal waste (Igliński et al., 2015).



*Source: Abdeshahian et al. (2016)*

**Figure 3.** The total contribution of the significant organic waste sources to biogas generation.



*Source: Igliński et al.,(2015)*

**Figure 4.** Picture of biogas installations utilizing livestock waste: (1) Livestock and poultry, (2) initial storage tanks, (3) Slaughterhouse waste, (4) Mixing tanks, (5) Digesters, (6) Power plants and cogeneration heat, (7) Post-processing tanks, (8) Fertilizer collection, (9) Office and (10) Energy distribution network (Abdeshahian et al., 2016; Igliński et al., 2015).

It has offered the effect of livestock waste as a fantastic raw material for energy producers, and early investigations to assess the biogas production capacity from animal waste have been carried out. Table 2 demonstrates the potential for biogas generation in several nations.

Table 2. The potential for biogas generation in several nations has been assessed

| | **Potential production of biogas (1000 m$^3$/ year)** | | | **Year** |
|---|---|---|---|---|
| | **Cow** | **Poultry** | **Goat and Sheep** | |
| **Turkey** | 1,477,451 | 592,099 | 108.003 | 2009 |
| **Iran** | 6,059,600 | 1,966,600 | 573,600 | 2011 |
| **Finland*)** | 197,600 - 438,000 | 6440 - 23,900 | - | 2009 |
| **Sweden*)** | 214,100 - 462,000 | 8380 - 19,700 | - | 2009 |
| **Denmark*)** | 242,200 - 509,000 | 11,300 - 41,700 | - | 2010 |

**) The potential for biogas generation in different nations has been measured (Abdeshahian et al., 2016).*

In southeastern nations, a similar study has been done, including an estimate of the energy generation potential of animal faeces, as described in Thailand. Similar studies have found that in 1997, around 3.2 million tonnes (Mt) of animal waste (in the form of dry) were generated in Thailand, with 620 million m3 of biogas plant potential and energy equivalent to 13 petajoules (PJ).

### *3.1.3 Waste in Indonesia*

Indonesia has long been known to have significant energy and waste concerns due to its fast economic expansion and urban population. In Indonesia, three types of trash are often generated: MSW, electronic and electrical waste, and industrial solid waste, every day, the country contributes around 176,000 tonnes of municipal solid trash (64 M per year). According to reports, 70% of MSW is disposed of in open dumps at over 380 landfill sites, with only a tiny portion of it able to be disposed of in a sanitary landfill or recovered and repurposed, owing to a shortage of people and disposal infrastructure. However, garbage is frequently buried, burnt, or not managed at all (Khalil et al., 2019).

Furthermore, because these landfills have reached their maximum capacity, efficient waste management must be implemented immediately. Home and market garbage, mainly organic waste, accounts for about half of the country's MSW. Furthermore, most Indonesian urban trash is not managed correctly, significantly impacting the economy, society, and environment (Kerstens et al., 2015; Khalil et al., 2019). For example, the breakdown of organic waste that is not handled correctly and controlled might have negative environmental consequences. According to a recent study by the Indonesian Ministry of Environment, organic waste accounted for up to 25% of Indonesia's greenhouse gas emissions in 2005 (excluding peat emissions and land-use change). Nonetheless, local governments are expected to give complete assistance and alternative measures by carefully considering which integrated waste management plan, based on the waste management hierarchy, will best handle Indonesia's waste problem (i.e., prevention, recycling, recovery, and disposal).

The most common strategy for dealing with waste concerns is to reduce or even limit garbage creation, followed by recycling and reusing waste. However, the most valuable strategy to handle surplus MSW production in Indonesia is to convert the garbage into electricity. Non-reusable and non-recyclable waste, such as organic materials, may be converted into sustainable energy through biofuels and biogas using waste-to-energy technology. This recovery has also been proposed as a strategy to maintain or even reduce the carbon cycle of waste. Aside from energy generators, the recovery option has other advantages, including a reduction in direct garbage volume, a reduction in negative externalities connected with waste disposal in the social and economic sectors, and a reduction in the amount of land required for landfill and disposal.

Agricultural waste, animal waste, municipal trash, and other renewable sources create bioenergy. Biomass energy is sustainable and renewable because most of it is not affect the environment. Various processes, such as anaerobic decomposition and cation gas, can be used to convert biomass into gas fuel. In addition, biomass may be converted into a kind of energy known as biofuels via different thermal and chemical techniques. Bioenergy played a significant role in worldwide primary energy consumption in 2014, accounting for 10% of total consumption. According to the Global Renewable Status Report (2015), it is expected to rise by 15 to 50% by 2050 (Energi, 2016).

That biogas is a fuel of various types with many alternatives. Biogas utilizes in the form of unprocessed (raw) or processed. Biogas is used directly from the digester at the production site for low-grade uses such as cooking and lighting. Biogas' complicated composition is the fundamental reason for its restricted applicability. CH makes biogas combustible. However, CO2, which is not generally burnt, reduces the calorific value of biogas and restricts its carrying capacity. Other biogas ingredients such as water vapour, hydrogen sulfide, and siloxane damage mechanical components, lowering their calorific value. As a result, deciding on CO2 and other corrosive ingredients to add and enhance biogas consumption is critical. Biogas' calorific value rises to 35.8 MJ/m3 once CO2 is removed (Sahota et al., 2018). As a result, as a gas combination, new and efficient biogas bidder for applications like power generation, natural gas replacement, or desirable high-value-added chemicals. Biogas may be used in a variety of ways. Raw biogas may be used for cooking and lighting right away. Physical, chemical, and biological ways of processing biogas to improve its quality or turn it into another form that may be used are examples of ancillary uses (Kapoor et al., 2019).

Traditionally, biogas's most popular and cost-effective direct application has been for burning and illumination. Direct biogas combustion is the simplest and most often utilized method. It is a tried-and-true technology that's low-cost and low-maintenance. The disposal of H2S and existing moisture is not required with this approach. Biogas is typically used straight from the digester at home, notably for cooking. The fire is bright and clear. This technology has been utilized as the most acceptable way to use biogas for the past ten years worldwide, particularly in rural regions of developing countries. It is a sensible fuel since it burns cleanly and produces fewer emissions (Kadam & Panwar, 2017). When compared to traditional fuels, cooking using biogas takes less time. Biogas has been used for cooking for many years, and biogas stoves are now commercially available. Biogas stoves may be made on-site. Traditional gas-operated equipment, such as burners and lights, may be converted to biogas by adjusting the air-fuel ratio and making minor burner nozzles to guarantee optimum combustion. Simple pipe and valve connections are required to transmit biogas from the digester to the stove. In a dual fuel burner, biogas conversion efficiency to heat is typically 80-90% (Kapoor et al., 2020a).

### *3.1.4 Biogas-Based Power Generation*

The amount of methane in biogas depends on the source and quality of the manure (Abdeshahian et al., 2016; Chowdhury et al., 2020; Mulka et al., 2016). As a result, chicken cows may produce biogas, and chicken dung contains 50-70% methane, whereas sheep manure has 40-50% (Chowdhury et al., 2020; Nasir et al., 2012; Noorollahi et al., 2015). It is known that the methane concentration of slaughterhouse waste is 60% for big ruminants, 45% for small ruminants, and 60% for poultry. The calorific value of methane generated is 36 MJ/m3. The value varies depending on the power plant, although it usually ranges from 35 to 42% for big and 25% for small turbine power plants (Benito et al., 2015). However, according to (Chowdhury et al., 2020), the value of $\eta$ is equivalent to 30%, which $E_{biogas}$ is accounted for as Equation (2). The biogas output in practice might be lower than the theoretical value of 10% of organic waste not decomposed in an anaerobic digester.

The E $Contenti_{biogas}$ stated the calorific value of biogas (Kwh/$m^3$), and biogas described the quantity of biogas produced annually ($m^3$/y). When the calorific value of biogas is 21.5 MJ/$m^3$ biogas (1 kWh = 3.6 MJ), the Energy of $Contenti_{biogas}$ is comparable to 6 kWh/m3 (Abdeshahian et al., 2016). Where Eff denotes the efficiency of the conversion device in generating electricity and the volume of methane generated in the anaerobic digestion plant, LHV denotes the lower calorific value of methane, and CF denotes the percentage of waste treated (tonnes) during the year versus the amount of waste (tonnes) that can be treated if the factory is operating at total capacity, with the capacity factor value of 85%. While the lower calorific value is 37.2 MJ/m3, the Eff is 35% (Ayodele et al., 2017; Hadidi & Omer, 2017). The installed load of the anaerobic decomposition plant while 8760 indicates the number of hours in a year the plant works.

### *3.1.5 Biogas to Standard Coal Conversion*

Changing biogas to standard coal as informed in Equation 1.

$$QC = QB * E \qquad \text{(Equation 1)}$$

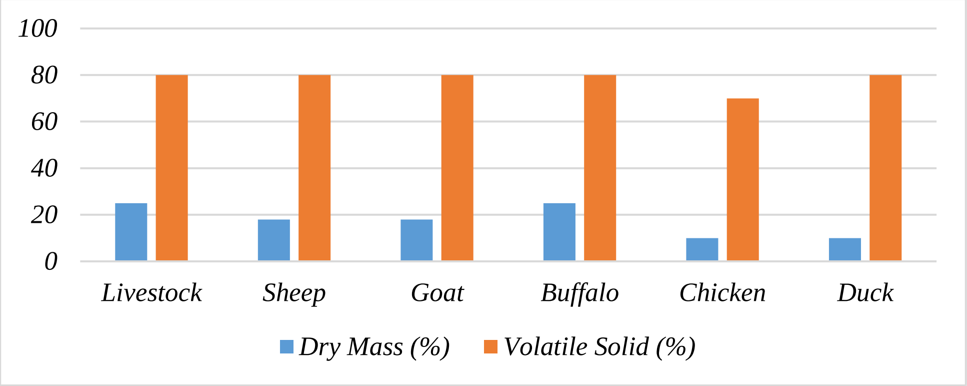
The standard quantities of coal and biogas are QC. (Kg) and QB. ($m^3$), respectively, and E is the biogas conversion coefficient for standard coal, 0.714 Kg/$m^3$.

### *3.1.6 Emissions of CO2 Which Avoided Because of Solar Movement by Methane (Biogas*)

In the electricity sector in Indonesia, the total installed power capacity reaches 31,453 MW, with approximately 77% of the total energy produced. The Indonesian power generation system occurs in Java, Madura, and Bali islands (JAMALI), the most densely populated areas. JAMALI contains 25.6%, 10.7%, and 9.5% diesel, gas, and cycle power plants, respectively (PLN, 2015). This area relies on natural gas as its primary energy source and continues to produce fossil oil to support its activities, resulting in pollutants such as CO2, CO, SO2, NOx, PM, and VOC (Indrawan et al., 2018). If biogas is utilized, emissions of CO2 can be reduced (Chowdhury et al., 2020; He et al., 2019; Indrawan et al., 2018; Yuaningsih et al., 2020).

### *3.1.7 Fertilizer Potential Expected*

Biogas and biofertilizers are two biogas-related products. Where Dry Mass denotes the fraction of solid organic waste, Volatile Solid denotes the portion of the dry mass that may be transformed into a gas. Figure 5 shows the percentages of dry mass and volatile compounds in animal faeces (Ngumah et al., 2013).



*Source: Ngumah et al. (2013)*

**Figure 5.** The presentation of Dry Mass and Volatile Solid in animal waste

### *3.1.8 Biogas Fuel Composition Characteristics and Their Benefits*

An excellent alternative gas is an option in the form of gas from biofuels. Organic resources and waste can be the primary source of biofuels. That is to reduce the volume of waste gas fuel by using anaerobic decomposition as an alternative in treating biodegradable waste, which will produce beneficial fuel. In addition, without the impact of global warming due to biogas production, waste management is not 100% free of greenhouse gases. The combustion that occurs in methane does not provide the level of carbon emissions in the atmosphere and is also cleaner in impact than burning coal. Fossil fuel combustion has a higher carbon level than biogas. Besides, carbon from biogas combustion can be well absorbed by photosynthetic plants. That will indirectly reduce the impact of carbon circulating in the atmosphere. Then it can be understood that using biomethane can eliminate pollution that impacts the environment, both air and water. As is the case with the use of fossil fuels, besides that, the production of biomethane reduces the potential risk of accidents. The use of biomethane can be an effort that can help conserve forests and biodiversity by reducing the use of fossil fuels to reduce the effects of harmful greenhouse gases. As the best option, biomethane can be used as the primary option to avoid the production of carbon that has a greenhouse effect that will be released into the atmosphere. Therefore biomethane can also easily support the ever-increasing human needs for energy fulfilment without impacting plants (Bharathiraja et al., 2018; Hung et al., 2017).

The analysis is based on biogas composition, which has several components, methane (CH4) and carbon dioxide (CO2). Besides that also a tiny amount of hydrogen (H2) and nitrogen (N2). Other constituents are supported by hydrogen sulfide (H2S), oxygen (O2), water (H2O), and saturated hydrocarbons (ethane and propane) which are included in the Biogas section. In more detail, the parts that make up biogas will be discussed in Table 3.

Table 3. Source of biogas and its composition

| Component | Landfill | Waste Digester | Organic Waste Digester |
|---|---|---|---|
| $CH_4$ (%) | 45 – 61 | 58 – 65 | 60 – 70 |
| $O_2$ (%) | 1 – 2.6 | < 1 | 1 – 5 |
| $N_2$ (%) | 1 – 17 | 1 – 8 | 1 |
| $CO_2$ (%) | 24 – 40 | 33 – 40 | 30 – 40 |
| $H_2S$ ppm | 15 – 427 | 1 – 24 | 10 – 180 |

*(Sources: Ahmad et al., 2019; Rasi et al., 2011)*

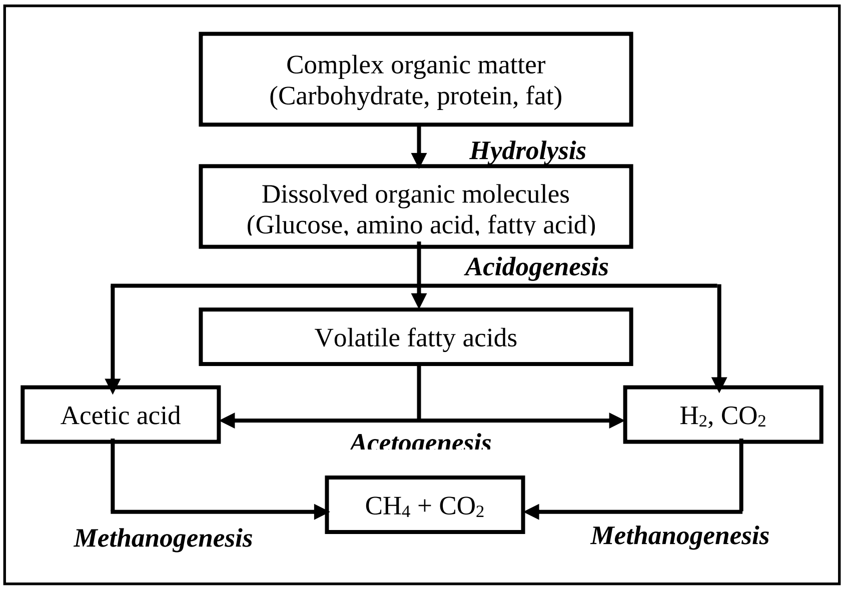
In addition, it is essential to pay attention to the importance of removing water and hydrogen toxins to avoid various impacts and side effects (Dannesboe et al., 2019; Rasi et al., 2011; Surendra et al., 2014). Therefore, in the use of biogas only as a feedstock with a single composition for ignition of sparks with due regard to its composition. In addition, the appearance of the low number of alkanes in the flue gas when the catalyst is used is low. That occurs as an obstacle that appears in emission control during biogas combustion. Finally, the last part of the combustion process is due to the presence of solid and non-polar bonds of hydrocarbons.

Methane combustion, only 1% contributes to impacted annual emissions. In addition, complete NOx emission control can be carried out if the emissions released do not include some hydrocarbons. Each gaseous fuel has a different way of handling. That is based on its impact, for example, on vehicles that use fuel. The use of fuel causes high pressure when it is stored and expands, which will cause a decrease in fuel density and changes in temperature. The same thing happens with biogas (Bharathiraja et al., 2018).

The imperfection of biogas combustion is a distinct negative characteristic due to its low energy density and slow flame rate. Despite the slow flame rate, biogas is very advantageous because it has a high level of automatic ignition resistance and requires only a tiny amount of air for the combustion process. By adding hydrogen, the combustion rate increases to increase thermal efficiency and eliminate cycle variations, realizing lighter operating conditions for improvement in power plant operation (Chuayboon et al., 2014; Crookes, 2006).

### *3.2. Principles of the Anaerobic Decomposition Process*

The decomposition process causes several stages of biodegradable organic resources to originate. These stages have differences, such as fermentation (hydrolysis) and angiogenesis, followed by the next two main stages, acetogenesis/dehydrogenation and mutagenesis (methanation). That is shown more fully in Figure 6 (Bajpai, 2017; Rajagopal et al., 2019).



*Source: Bajpai (2017) and Rajagopal et al. (2019)*

**Figure 6.** Stages of anaerobic decomposition

The process that converts organic matter into predominantly methane (CH4) carbon dioxide (CO2) under appropriate anaerobic standard conditions (ORP below 200mv) to support an anaerobic decomposition process involving several bacteria and substrates (Bharathiraja et al., 2018; Ghyoot & Verstraete, 1997). Syntrophic reciprocity with the support of different environmental conditions can be carried out in the degradation by various microorganisms. In the process, insoluble materials such as fats, carbohydrates, proteins, and nucleic acids are hydrolyzed to form compounds that mix with amino acids and fatty acids during hydrolysis. Hydrolytic bacteria degrade the hydrolyzed products in the cyclogenesis phase. In addition, these bacteria are strict anaerobes such as Clostridia and bactericides, and there are also several enzymes such as cellulases, cellobiases, xylanases, and lipases that come out of hydrolytic bacteria as well as some facultative anaerobes (e.g. Streptococci). Soluble fatty acids and alcohols are formed through most of the acidogenesis process. The processes that occur consist of fatty acids, hydrogen, and carbon dioxide as a result of the process giving rise to various variants above. If we look more closely at acidogenesis (fermenting bacteria) that gives rise to fatty acids, this is in conjunction with the presence of ammonia (NH3) and carbon dioxide (CO2), which have a direct impact. This process is followed by hydrogen (H2S) and other products (Dinopoulou et al., 1988; Qasim, 2017; Wang et al., 2014). Hydrogen and carbon dioxide in the form of acetate are derived from the acetogen process, the raw material of which is organic acid and alcohol. Moreover, some supporting bacteria, called cyanobacterium Woodii or acetogenic bacteria and Clostridium Aceticum, amplify the process. Then the existence of this biogas production process, the level of accuracy to produce suitable biogas, in the metabolic process, the increase in the amount of hydrogen is significant during the process that occurs because if there is an inaccurate amount of hydrogen present, it can inhibit acetogen.

The last stage of methanogenic activity is supported by two methanogenic bacteria, autotrophic bacteria as acetate, which will become methane and carbon dioxide. In addition, hydrogenotrophic bacteria use hydrogen as the primary consumption to produce methane, both of which function mainly as methane producers. Although many methanogenic bacteria can consume hydrogen, only a few types of bacteria can produce methane. The decomposition process requires more attention because an increase in acid with a low pH can result in incorrect reactor operation. Although the general process of the degradation rate is always the same, it is still necessary to pay attention to the level of change that exists. Carbohydrates can be degraded for several hours, while proteins, cellulose, or even fats are hydrolyzed to monomers over several days. Therefore, the complete degradation process is very concerned with accuracy in achieving success, so the nature of the substrate is very taken into account during the process that occurs (Qasim, 2017). The fuel (biomethane and fertilizer (digestate) can be produced from proper waste bioconversion management. In addition, lignocellulosic waste management consists of several main operating stages. The first process is in the pre-treatment stage, followed by anaerobic destruction. In the final stage, there is a cleaning or conditioning process that can improve the energy economy and the sustainability of sustainable race management, from anaerobic decomposition to the production of renewable fuels that are more environmentally friendly (Bharathiraja et al., 2018).

Secondly, sources of carbohydrates and free/less nitrogenous raw materials can overcome the weakness of animal waste from digestion/decomposition while continuing to significantly increase biogas production (Surendra et al., 2014). In addition, additional biomass, which consists of carbohydrates, proteins, and fats, is needed to support biogas production. In the production of biogas raw materials, cellulose and hemicellulose are needed to support the process. High gas can be produced by adding secondary substrates from organic waste from the agricultural industry and food waste. In addition, the waste collection process can also be obtained to support more of the biological waste from urban areas collected from households. Biogas yield is determined by the composition, which depends on the raw materials included during the process and the type of substrate.

Biogas and manure can be obtained by mixing cow dung with hot water in a ratio of 1:1 to be added to the final tank because cow dung is a substrate. Therefore, the manufacturing process is straightforward and does not require much special treatment, just put it in the digester. However, pre-treatment is essential to increase substrate degradation so that the results are more process efficient to avoid failures during the processing of raw materials. Although the biogas yield is not sure to be higher, the chemical, thermal and mechanical, or enzymatic processes can speed up the decomposition process.

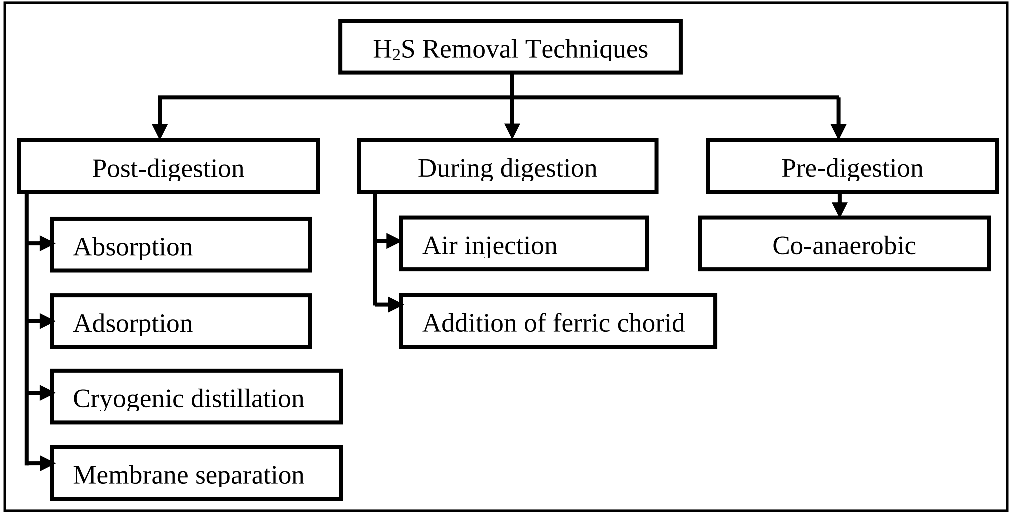
### *3.3. Hydrogen Sulfide (H2S) As Waste for Biogas Production*

H2S is the most toxic pollutant of biogas production, highly corrosive, and naturally flammable. Bacteria make hydrogen sulfide (H2S) when interacting with sulfates in organic substrates. H2S is a toxic pollutant produced by bacteria on organic substrates, so it is a highly corrosive and flammable product of biogas. H2S is a biogas production which is a very toxic pollutant. Besides its toxic nature, it is also highly corrosive and flammable (Wiheeb et al., 2013). Bacteria can produce H2S from organic substrates associated with sulfates. With the many changes and effects caused by biogas facilities, H2S is known to produce corrosion on cast iron mechanical wear and other components in steel. These are highlighted in Table 5 physical and chemical characteristics of H2S [Agency for Toxic Substances and Disease Registry (ATSDR), 2016]. Other discussions about the problems that also arise in the health and safety of workers in the workplace. In this case, H2S is a fundamental weakness in biogas production because of its destructive and toxic nature. Therefore it is essential to remove H2S so that the production of raw biogas can be improved as a significant renewable energy source (Lee et al., 2020; Marín et al., 2020). Different concentrations are in the range of 0.1% to 2.0% (v/v). In addition, H2S, with 5 ppm, can be toxic to humans for the respiratory and neurological tracts (Lewis & Copley, 2015). The smell of rotten eggs or worse is a picture of H2S diffused in the sense of smell and is more than 300 ppm. However, the content is 1000 ppm can be lethal to the human condition. Therefore it is essential for trained and professional humans with proper safety equipment to handle H2S to avoid toxins from the spread of H2S (Shah et al., 2017). Landfills have high levels of H2S production compared to biogas installations. That is due to poor control compared to biogas plants that operate on organic waste only.

Catalytic, biological, physical, and chemical techniques can all be used to remove H2S from biogas. In other words, absorption, adsorption, membrane separation, and cryogenic distillation are the four types of absorption. In addition, several ways can be optional to remove H2S from biogas content, which can be classified into 4 types. For the remover, namely absorption and adsorption, separating membranes and carrying out cryogenic distillation, there are also 4 processes, namely catalytic, biological, physical, and chemical (Shah et al., 2017).

However, there has been an increasing interest in developing low-cost reducers for biogas purification in recent decades to minimize the cost of improving biogas quality and commercialization. Using trash as a sink for H2S disposal can significantly influence waste management issues and creative H2S removal from biogas systems. In the past few decades, there have been many attempts to develop biogas purification to lower costs for improving the quality of the biogas while still utilizing waste from H2S disposal, which can significantly impact waste problems. Therefore, it is necessary to have an innovative solution to overcome H2S from biogas to remain efficient. In addition, it is necessary to maximize biogas production without causing damage to the atmosphere while continuing to eliminate H2S (Enitan et al., 2017).

The methods for removing H2S may be split into two types. First, while the process is in progress (in situ), and then after the biogas has been created. Several options are presented to remove H2S content. Here are some commonly used techniques divided into 2 main categories. Implementation throughout the first (in situ) and second (after the biogas production process) processes. Over time, the need for innovation and increased production gave rise to new methods. Controlled pre-digestive methods are therefore essential. Therefore attention is focused on increasing biogas yield by reducing the pollutants present. In the remover, the technique can be determined into three categories that can be reviewed. The first is the concept of cogeneration by reducing the concentration of H2S before digesting biogas. Second, biogas purification afterwards by minimizing biogas digestion to limit the H2S concentration in the digester. Meanwhile, the results of the biogas removal effort can be seen in Figure 7. The final concentration level can be limited to the pre-digestion and digestion stages. Although in some cases, most are still in the threshold level of concentration. Then it is still necessary to dispose of H2S after digestion must still be done.



*Source: Enitan et al. (2017).*

**Figure 7.** Pre-digestion, digestion, and post-digestion H2S removal techniques

### *3.3.1. Concentration Control H2S on Pre-digestion*

The preparation for anaerobic digestion is part of the innovation, which is a good distribution of innovation for nutrients in the digester in making biogas. To create high levels of methane, i.e. this grip includes a synchronous breakdown of two or more substrates used as rolls. Much research was carried out and continues to stay focused on increasing methane yields and collecting continuous innovations to reduce the toxins in this methane production. In biogas generation, anaerobic pre-digestion can be started from 25% to 400% higher than a single digestion (Hagos et al., 2017). Several experiments, such as those conducted by several experts (Belle et al., 2015), which combined several vegetable ingredients, namely radish with dairy cow dung, in these experiments he found a significant increase in CH4 up to a 61% increase when compared to a single-use in cow dung.

Conducted on slaughterhouse waste which is used as an ingredient with the addition of manure, as well as various plants and waste from the city (Pagés-Díaz et al., 2014). The results have increased CH4 by 31% compared to the digestion of a single individual having each substrate. The results can follow the pollutant concentration level, although this technology still requires many stages of improvement and development before commercialization efforts (Ahmad et al., 2019).

### *3.3.2 Concentration Control H2S during the Digestion*

In this section, to overcome and control, several methods can be used to better H2S during digestion. The first method, through the surface of the sludge injection, controlled air/oxygen into the digester. Then the second adds iron chloride (FeCl2). Equipment can be avoided damage if the equipment is carried out with ideal controls on oxygen injection. It is essential at this stage to save operating costs so lower. It is essential to be careful in the production process because the H2S process can be more dangerous when the H2S with an explosion limit is 6-12% by volume (Díaz et al., 2010). The reactor is a collection point for sulfur deposited which is then combined with the digested sludge. The following equation (10) tells about the reaction in the easier desulfurization method: In this section, to overcome and control, several methods can be used to better H2S during Digestion. In this section, to overcome and control, several methods can be used to better H2S during Digestion. The first method, through the surface of the sludge injection, controlled air/oxygen into the digester. Then the second is adding iron chloride (FeCl2). Equipment can be avoided from damage to equipment by ideal control of oxygen injection. It is essential at this stage to save operating costs so lower. It is essential to be careful in the production process because the H2S process can be more dangerous when the H2S with an explosion limit is 6-12% by volume. The reactor is a collection point for sulfur deposited which is then combined with the digested sludge. The following equation (2) tells about the reaction in the easier desulfurization method:

$2H2S + O2 \rightarrow 2S + 2H2O$ Equation (2)

This discussion refers to a study by (Jeníček et al., 2017) late reported the highest level of efficiency in desulfurization at 99.1%. That is according to the digester process with a capacity of 830 m$^2$/day and an air dosage of 1.20 m$^3$/hour. As a result, the H2S concentration level was reduced from 7580 mg/m$^3$ to 72 mg/m$^3$. In his discovery, the efficiency level of 99% was achieved in the research of (Díaz et al., 2010), which was measured in digester 200-I, where the level and amount of concentration changed decreased from 15,811 mg/m$^3$ to 55 mg/m$^3$. According to specific research, this can lower H2S concentrations, but the amount of H2S is still significant, and biogas cannot be used directly in the CHP machine as a replacement for the prior gas fuel. The second approach reduced the amount of H2S concentration by adding FeCl2 during disintegration, which resulted in the deposition of fees and, as a result, the concentration of H2S in biogas was reduced (Ryckebosch et al., 2011). The following is a more in-depth discussion of equations (3) and (4) in the precipitation reaction as follows:

$H2S + FeCl2 \rightarrow FeS + 2HCl$ Equation (3)

$2H2S + 2FeCl3 \rightarrow 2FeS + 6HCl$ Equation (4)

Several general processes have been used, namely salt and pumps for the biogas industry. These remove H2S with a more straightforward system (Ryckebosch et al., 2011). Micro-aeration is combined with the addition of rust remnants to the digester in this method. It was discovered that a 20 g/l dosage of iron rust increased methane output by up to 40% while lowering H2S content by more than 84 %. Another research by (Renjun et al., 2020) used iron rust residue at a dosage of 20g/I and found that methane yields might rise by up to 40% while H2S concentrations could increase by up to 84 %. Other experiments achieved different outcomes by combining iron ions with cow dung in anaerobic Digestion while keeping the iron to sulfate ratio at 7:10. The H2S level can then be decreased to zero parts per million (Hung et al., 2017). Although the removal can be effective, binding sulfide ions with iron ions to form iron sulfide fees, which are subsequently dissolved in water, has a high cost of operation. Furthermore, the ultimate objective of bio-methane synthesis is to create low and stable sulfur (Ahmad et al., 2019).

### *3.3.3. Concentration Control of H2S after Destruction*

However, to get good quality biogas, the filtration process in biogas processing is carried out repeatedly to produce biogas of good quality with a good level of control of H2S concentration. For example, in the membrane separation process, cryogenic distillation, absorption, and adsorption are carried out as processes of Post-digestion. That is a commonly used method cited in the literature for popular purification or cleaning methods.

A membrane technology that works as a gas barrier allows certain substances to flow through with force in the form of temperature, concentration, electric charge, or pressure. Membrane technology is an ecologically friendly and high-purity approach with a retentate (remaining) procedure that is more competitive in terms of purification than other methods. Some things that are included in the faeces include water, carbon dioxide, some nitrogen, H2S, and mixed hydrocarbons that are easier to filter than CH4-rich biogas (Yang et al., 2014). In the use of technology, membrane technology can remove CO2 content. Therefore handling costs increase if both are removed simultaneously (Shah et al., 2017). In handling, the concentration of CO2 is higher to make the membrane more efficient if the incoming flow is low. In addition, the high-cost level when separating other impurities with CO2 and H2S is expected to maximize the function of the stratified membrane to be better. The number of biogas plants focusing on membrane separation in Europe is increasing. Furthermore, research is still being developed on this subject (Miltner et al., 2017).

Based on the boiling point, H2S and CO2 have differences in the melting process at the temperature and pressure. In addition, at a high pressure of about 80 bar, a cryogenic distillation liquefaction process is carried out to cool the gas mixture. Therefore, each has a different boiling point, such as CO2 with -78°C, compared to CH4 -161.5°C at 1 atm, while H2S reaches -60°C. So if it is considered theoretically, it can be easily divided between CO2 and H2S from CH4 in the biogas mixture (Carranza-Abaid et al., 2021; M. U. Khan et al., 2021). However, operating costs and expensive equipment have been the main obstacles in this operation. However, for now, the method is a method that can be used to separate CO2 rather than separation in H2S.

The oldest method commonly used to purify natural gas can be done by heating the gas with water or an organic solvent carried out in gas-liquid separation. With a linear increase in pressure, the absorption rate for physisorption can increase. In chemisorption, gas solubility has a peak stoichiometric value at high pressure because it experiences low pressure in the gas, which increases sharply (Shah et al., 2017). Compared to CH4 and CO2, H2S is more soluble in H2O (Cozma et al., 2014). That is because H2S can be absorbed a lot by water which is often used traditionally from natural gas with pressures below high (10 bar). NaOH, FeCl2, and Fe(OH)3 are the three chemicals that can increase the absorption rate (Ryckebosch et al., 2011). In addition, to increase absorption, you can add nanofluids (nanoparticles in the fluid). For illustration, According to Esmaeili Faraj et al. (2014), a 0.02% by weight extension of graphene oxide has exfoliated (Self-image) into the water, extending the adsorption rate to 40%. Ordinary solvents, such as tertiary amines [methyldiethanolamine (MDEA)] and diisopropylamine (DIPA), have a specific discharge capacity for H2S rather than CO2 (Qian et al., 2010). SelexolTM, GenosorbTM, RektisolTM, and PurisolTM are commercial forms and solvents in marketing for CO2 and H2S (Miltner et al., 2017).

The investigation on this strategy is still creating vital added substances for superior fluid retaining usefulness. Membrane technology will be crucial in the future decades and signal the end of the biogas business. In any case, the financial possibility and the tall fetched of Membrane Technology will constrain this innovation's commercialization. As of now, the adsorption is being tried for biogas decontamination, and it is broadly utilized for standard gas refinement due to its straightforwardness and low investment. That adsorption is one of the most conservative H2S handles, and the evacuation of siloxanes from biogas plants is on a small scale compared to other methods due to its ease and cheap operating costs (Kuhn et al., 2017). The standard cost to evacuate H2S and siloxanes from landfill biogas facilities with a generation of 70.8 Nm$^3$/min by adsorption using a commercial permeable such as wiping press and activated carbon is nearly 0.04 USD/Nm$^3$. These values, however, are likely to vary significantly depending on the kind of biogas, the degree of pollution, and the number of cleaning units required during the process.

### *3.3.4 The Mechanism of Adsorption*

When gas molecules come into contact with solid surfaces, they strongly attract them. Science takes advantage of this natural phenomenon based on adsorption, in which the adsorbent takes up gas molecules. The porous material will be selected with care depending on its affinity for one or more molecules in the gas mixture (selective adsorption). The solid adsorbent binds to gas molecules and traps them (Ahmad et al., 2019). Adsorption purifies gas separation technique, well-established and used in various environmental sectors such as fuel biogas purification, CO2 capture, desulfurization, and H2 and CH4 purification (J. R. Li et al., 2009).

Adsorption is also known as a surface phenomenon, which an influential role in the process that is played by the surface area of the adsorbent. According to the interaction between the gas molecules and adsorbents, the adsorption can be either chemisorption or physisorption. The activation energy of a chemical reaction is known as chemisorption. The adsorbate and adsorbent are needed to create the energy of the interaction. Van der Waals forces are fundamental in physisorption, and the electronic orbital pattern remains unaffected under these conditions. (Shah et al., 2017). High temperatures or activation energy are not required for physisorption. The thermodynamic feasibility and high affinity between the adsorbate and the adsorbent will be used to choose the adsorbent for adsorption (Guru & Dash, 2014).

A suitable adsorbent should be regenerable and have appropriate adsorption kinetics. The vast surface area and high porosity are favourable for solid adsorption capability. The gas that the adsorbent captures can be found in various places. Adsorbent regeneration is used in this technique. Pressure swing adsorption (PSA) is a frequent and successful method in which pressure is used to force gas adsorption to the adsorbent based on the gas's molecular size. The adsorbent will be renewed after the adsorption by lowering the pressure. The adsorbed gas will be reclaimed from the adsorbent's tiny pores (Alonso-Vicario et al., 2010). Other approaches, such as temperature swing adsorption (TSA) and electric swing adsorption, are utilized due to the molecular nature of the dissolved gas and adsorbent (ESA) (M. D. Khan et al., 2017). The sustainability of the process is played by the regeneration of the adsorbent, which plays a crucial role. The adsorbent must be 99% renewable to minimize environmental hazards and save costs (Ngumah et al., 2013).

### *3.3.5 Common Absorbent for H2S*

Lately, there is much literature on how H2S deal with metal oxide (Ahmad et al., 2019). H2S sulfur may readily be adsorbed on the iron and hydrogen site on the adsorbent's oxygen active site in iron oxide-based adsorbents (Song et al., 2013). In a magnesium oxide (MgO)-based sorbent, H2S is split into -H and -SH species on the surface of MgO, resulting in an energy barrier of 7.77 Kcal/mol (Bagheri & Moradi, 2014). Mixed metal oxides outperformed nickel-based commercial adsorbents for H2S absorption, according to (Polychronopoulou et al., 2005). That H2S reacts faster to mixed metal oxides like copper/aluminium and copper/zinc than pure metal oxides (Rodriguez et al., 1998). Metal-organic framework (MOF) adsorbents, in addition to metal oxides and mixed metal oxide-based adsorbents, show excellent H2S removal efficiency due to their vast surface area, tailored pore structure, and varied chemical compositions (Wang et al., 2014).

Metal-based sorbents are an excellent candidate for removing H2S. However, that is also linked to the cost of the adsorbent itself and the cost of disposal. Because of that, in addition to the metal-based adsorbents, low-cost adsorbents such as zeolite and carbon-impregnated it is informed that it is also used for the H2S removal and high acid gas purification). Efficiency is validated at 97% (Ozekmekci et al., 2015; Shah et al., 2017), while activated carbon is made from carbon and impregnated. The adsorption load is validated at 150–650 mg/g (Fontseré Obis et al., 2017). This study proved that there is a propensity for cheaper selection with less use of metal to eliminate H2S (Ahmad et al., 2019).

The sulfa treat (ST) and sulfa treat select (STS) are the various commercial adsorbents for eliminating H2S. These adsorbents are formulated from mixed metal oxide and ferrous oxide. Both ST and STS can be known in many classes for different utilization. Their productivity removal is as high as 99.99% in technical data sheets (Ahmad et al., 2019). As a result, regardless of cost, mixed metal oxides are thought to have the highest chance of being used for H2S removal. Because of its enormous transformation load and potential, this is the case. There are a variety of different adsorbents available.

Furthermore, the development of low-cost adsorbents, notably waste, is rising. Therefore, the zero-waste adsorbent will have a positive economic impact on the H2S removal process. Furthermore, by lowering the concentration of H2S from a highly sour gas in the H2S removal, a low-cost adsorbent frequently obtained from waste can extend the lifetime of the commercial adsorbent.

Metal-based sorbents offer much potential for removing H2S. On the other hand, the cost of the adsorbent is typically linked to the cost of disposal. As a result, low-cost adsorbents such as zeolite and carbon-impregnated adsorbents, in addition to metal-based adsorbents, are claimed to be employed for high acid gas purification and H2S removal. Efficiency is recorded at 97% (Ozekmekci et al., 2015; Shah et al., 2017). The adsorption capacity of activated carbon formed from carbon and impregnated is measured in the range of 150–650 mg/g (Fontseré Obis et al., 2017). This study discovered that when removing H2S, there is a preference for less expensive methods that utilize less metal.

ST and STS are two types of well-known commercial adsorbents for removing H2S, in addition to the reported substance. Ferrous oxide and mixed metal oxide are used to make these adsorbents. STS and ST are available in a variety of classes for various applications. Technical data sheets claim their efficiency is as high as 99.99% (Ahmad et al., 2019). As a result, mixed metal oxides are thought to have the best possible application for H2S removal, independent of their cost. Because of its excellent regeneration load and capabilities, this is the case. There are a variety of different adsorbents available on the market.

Furthermore, there is a growing tendency toward generating low-cost adsorbents, particularly from the trash. The zero-waste adsorbent has a tremendous economic influence on the H2S removal process. Furthermore, by lowering the concentration of H2S from a sour gas in the H2S removal, a low-cost adsorbent frequently obtained from waste can extend the lifetime of the commercial adsorbent.

## 4. Conclusion

The government of Indonesia is actively pursuing energy independence by exploring various renewable energy sources, including biogas derived from livestock waste. Despite abundant potential in renewable energy, fossil fuels still dominate the energy landscape, necessitating a shift towards sustainable alternatives. Challenges such as land permits, tariff negotiations, and limited domestic industry support for renewable energy must be addressed collaboratively. Establishing dedicated institutions and fostering stakeholder cooperation are crucial steps toward realizing the full potential of biogas production from animal waste, thereby contributing to Indonesia's sustainable energy future.

Livestock waste presents a significant opportunity for biogas production in Indonesia, yet current efforts still need to be more modest and fragmented. Overcoming technical, economic, and institutional barriers is essential for scaling up biogas production and utilization, particularly in electricity generation. Enhancing the cost-effectiveness of biogas conversion to bio-methane through efficient acid gas removal methods, such as waste-derived sorbents, holds promise for improving the economics of biogas purification. Further research and development focused on utilizing biomass waste as potential adsorbents for H2S removal are necessary to advance the future economic viability of biogas purification processes.

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