

Biomethane Production as an Alternative Cooking Energy Source in Jakarta

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ABSTRACT

This study delved into the viability of biomethane as a cleaner alternative to fulfil Jakarta's substantial cooking energy needs, which is currently reliant on LPG. By harnessing waste streams from wastewater, organic waste, and crop residues in an anaerobic digester, biogas was produced and subsequently upgraded into biomethane. Sodium hydroxide (NaOH) was utilized to enhance biogas production efficiency. Biomethane production amounted to 1.58 million tons annually, covering approximately 68.74% of the cooking energy demand. Although this falls short of Jakarta's annual LPG demand of 2.88 million tons, the study proposes a distribution scheme to bridge this gap and facilitate the broader adoption of biomethane. This research underscores the potential of biomethane in reducing LPG dependency, offering promising avenues for sustainable urban energy solutions.

Keywords: Biomethane, Anaerobic Digestion, Organic Waste, Wastewater, Crop Residues.

INTRODUCTION

The Paris Agreement has catalyzed efforts worldwide towards achieving fossil-free economies and reducing greenhouse gas emissions. Many countries aim for a global net-zero carbon economy by the end of the century [1]. Despite some progress, as of 2018, most European countries (EU-27) had only reduced greenhouse gas emissions by 21% compared to 1990 [2]. Fossil-based fuels, including oil, coal, and natural gas, continued to dominate the energy mix in 2019, accounting for 84% of total energy consumption [3]. Continuous advancements and efforts in state-of-the-art renewable energy technologies are indispensable to realising the goal of fossil-free status.

As of 2018, renewable energy sources constituted approximately 13.5% of the world's total energy supply [4], indicating a significant reliance on unsustainable fossil fuels. However, achieving the objectives outlined in the Paris Agreement remains a distant reality, underscoring the urgent need for expanded renewable energy generation to drive global initiatives to reduce greenhouse gas emissions [5]. Bioenergy derived from biomass is a cornerstone of the global renewable energy portfolio. In 2018, biomass contributed approximately 67.2% to the total primary renewable energy supply worldwide, sourced mainly from food and green waste, including agricultural residues (44%) and plastic waste (12%) [6]. With an annual production of approximately 2.01 billion tons of municipal solid waste [6], the potential of biomass as a fuel source is immense. Currently, the predominant use of biomass as primary solid biofuels limits its broader application in energy production. In 2018, out of 55.6 EJ of biomass, 47.6 EJ were utilized as primary solid biofuels, with the remainder consisting of biogases and liquid biofuels. This study advocates for expanding biomass utilisation in biogas, offering versatility as a heating fuel for cooking and transportation purposes. Biogas has demonstrated significant potential as an energy carrier, with a supply of 1.36 EJ in 2018 and a growth rate of 11.5% [7].

While biogas adoption is substantial in Southeast Asia, its utilization for cooking remains largely unexplored in Jakarta, Indonesia. Despite the widespread use of biogas in the region, Jakarta relies heavily on liquefied petroleum gas (LPG) to meet around 90% of its cooking energy demand [8]. This translates to approximately 7,150 cubic meters or 7.88 kilotons per day [9], equivalent to roughly 2.30 million tons of methane annually [10]. Concurrently, significant

quantities of organic waste are generated daily in Jakarta, representing a viable alternative energy source for cooking.

In 2019, Jakarta generated approximately 6,754.7 tons of municipal waste daily [11], with organic waste comprising 65%, paper 19%, plastics 13%, and other materials 3% [12]. This study estimates that roughly 4,983 tons of organic waste are potentially available daily for conversion into energy. Furthermore, projections indicate that Jakarta is expected to produce around 3,279 cubic meters of sludge per day by 2050, with an estimated 2,923 cubic meters per day in 2020 [13]. This study explores the feasibility of utilizing crop residues (maize, cassava, sugarcane, rice, and palm oil) for biomethane production to fulfil the cooking energy demand in Jakarta. Scaling down from the Indonesian to the Jakarta population, the availability of crop residues was estimated. Despite biomass's significant contribution to global renewable energy, its broader applications remain limited. Therefore, this research aims to expand the potential of biomass in biogas for urban cooking. Jakarta, an area yet to harness its biomass potential for cooking, was selected for investigation. By enhancing the sustainability of biomass in biogas, this study endeavours to promote biomethane as a viable alternative to LPG for cooking, thus contributing to the global transition to renewable energy sources.

MATERIAL AND METHODS

Anaerobic Digestion for Food Waste

In this study, an anaerobic digester (AD) was employed to convert biomass into biogas, which primarily consists of methane (50-65%), carbon dioxide (CO₂) (24-45%), water vapour (2-4%), and trace amounts of nitrogen and oxygen (below 2%) [14]. This study focused on utilizing biogas, particularly methane, as the primary gas component.

Anaerobic digestion is a process that decomposes organic matter with the assistance of various microorganisms under oxygen-free conditions, producing biogas and organic residue [15]. AD proves highly efficient in converting agricultural wastes, food wastes, and wastewater sludge [16], as it reduces chemical oxygen demand (COD) and biological oxygen demand (BOD) from waste streams while simultaneously generating energy [15]. Figure 1 illustrates the key reactions involved in the AD process.

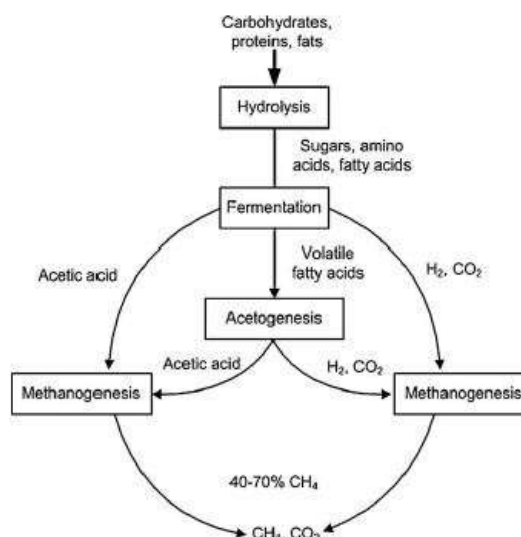


Figure 1. Anaerobic Digestion Reaction [15].

Hydrolysis, a key step in anaerobic digestion, often sets the pace for the reaction due to its relatively slow nature. Enzymes known as hydrolases or lyases, including esterase, glycosidase, and peptidase, catalyze the conversion of polymers into soluble monomers [17]. Complex organic molecules such as proteins, polysaccharides, and fats are broken down by cellulase, protease, and lipase enzymes produced by hydrolysis and fermentation bacteria [18]. The end products of

hydrolysis include soluble sugars, amino acids, glycerol, and long-chain carboxylic acids [19]. Hydrolysis is predominantly carried out by anaerobic bacteria, notably *Streptococcus* and *Enterobacterium* [20]. These bacteria play a crucial role in decomposing complex organic compounds into simpler, more readily digestible forms, facilitating subsequent stages of anaerobic digestion.

Following hydrolysis and the breakdown of complex organic compounds, the subsequent phase in anaerobic digestion is acidogenesis. Here, the products of hydrolyzed peptides, sugars, and fatty acids undergo further transformation into simpler molecules with lower molecular weights, including organic acids, alcohols, carbon dioxide, hydrogen, and ammonium. This acidification process results in a decrease in pH to approximately 4 [21].

The subsequent three steps are collectively referred to as acid fermentation. The products generated during acidogenesis are further processed by acetate bacteria, converting them into acetic acid, hydrogen, and carbon dioxide. Although no organic matter is removed during acetogenesis, it transitions from the liquid phase to the substrate phase, preparing it for subsequent methanogenesis. In the final step of anaerobic digestion, the products generated during acetogenesis undergo conversion into methane gas by two types of microorganisms known as acetoclastic and hydrogenotrophic methanogens. Acetoclastic methanogens convert acetate into carbon dioxide and methane, while hydrogenotrophic methanogens reduce hydrogen and carbon dioxide to methane. Acetoclastic methanogenesis is the dominant pathway, contributing to approximately 70% of methane production in anaerobic digestion, primarily because hydrogen availability is limited in the anaerobic environment [22]. This process is crucial in converting organic matter into methane, yielding biogas as the end product of anaerobic digestion.

Biomethane Calculation

A study reported that an AD could produce 336 Nm³ biogas/ton volatile solid (VS) of biowaste in the lab with a CH₄ content of 62% [23]. Also, 260 Nm³ biogas/ton VS of cassava [24], 327,5 Nm³ biogas/ton VS of maize [25], and 353 Nm³ biogas/ton VS of palm oil [26] can be produced from this technology. Davidsson et al. (2007) explained that feeding and residue removal were done manually once a day. The one-day-portion waste was diluted to a dry content of 5%, corresponding to an organic loading rate of roughly 2,8 kg VS/m³ day. With the value from the study by Davidsson, the daily produced biogas (V_{biogas} in Nm³) can be calculated by multiplying the daily inflow of waste streams (M in ton) and biogas conversion value of each stream as well as the percentage of VS in the waste streams.

$$V_{\text{biogas}} = M_{\text{waste}} \times \alpha \times \text{VS} \quad (1)$$

Noted that α is the Biogas conversion value. Table 1 shows the value of VS for organic waste and several crop residues used to produce biogas in this study.

Table 1. Specifications of several crop residues.

Streams	VS (%)	m ³ biogas /ton VS of stream
OW	83.30	336
Cassava	84.32	260
Maize	84.10	327,5
Palm oil (empty fruit)	90.22	353
Sugarcane bagasse	80.48	308,7
Paddy rice (husk)	77.80	700

Furthermore, for biogas production from sludge, Arthur and Brew-Hammond (2010) explained the method to produce biogas from sludge, in which the value of Total Volatile Solids (TVS) plays a significant role [27]. To calculate the biogas produced, it is necessary to consider the gas yield on the substrate. Table 2 shows the gas yield of various substrates.

Table 2. The gas yield of several substrates [28-29].

Substrate	Gas yield (L/kg TVS)
Pig manure	340-550
Vegetable residue	330-360
Sewage sludge	310-740
Cow dung	90-310

To calculate the daily TVS in sludge streams (S_{TVSD} in kg/day), it is essential to consider the TVS found in the sludge (S_{TVS} in kg/m³), 30 mg/L [30], and the daily sludge stream (S_{Flow} in m³/day). The amount of TVS present in the sludge can be determined by equation 2.

$$S_{TVSD} = S_{TVS} \times S_{Flow} \quad (2)$$

Following this, the daily biogas potential (B_{daily} in m³/day) can be derived from the daily TVS in the sludge (S_{TVSD}) and the gas yield of the sludge (B_{sludge} in L/kg).

$$B_{daily} = S_{TVSD} \times B_{sludge} \quad (3)$$

From daily biogas potential, it is known that biomethane is around 50-75% of the biogas.

$$B_{biomethane} = B_{daily} \times \% \text{Methane} \quad (4)$$

Biogas typically consists of methane at 50-65%, carbon dioxide (CO₂) at 24-45%, water vapour at 24%, and nitrogen as well as oxygen below 2% [8]. Hence, to get the amount of biomethane (Nm³) from the production, equation 5 is used in which this study considers 62% of methane consisted in the biogas produced.

$$V_{biomethane} = V_{biogas} \times \% \text{Methane} \quad (5)$$

This study uses alkali pretreatment to enhance biogas production by increasing the initial pH value of the biomass stream to pH values of 8–13 using sodium hydroxide (NaOH). Research conducted by Dasgupta et al. (2020) explained that the alkalisation experiments were done in a titrimetric fashion [31]. 5 M NaOH was added gradually to attain the desired pH while mixing was ensured by continuously stirring the stream slurry. In a further step, after reaching the desired pH, a contact period of 24 hours was aimed to ensure the hydrolysis of complex organic matter, for which the 24-hour pretreatment duration was chosen. Next, the slurry was neutralized, and pH was readjusted to 7.0±0.2 by concentrated 37% hydrochloric acid (HCl).

Neutralization is crucial after alkali pretreatment to warrant an optimal pH suitable for microbial growth and activity during anaerobic digestion, prevent reactor corrosion due to excessive alkali, and nullify degradation inhibitors during pretreatment. To minimize the impact on the total solids (TS) concentration of waste stream slurry, a concentrated solution of alkali and acid was used in the pretreatment process. Dasgupta's study also described that the precise pH value cannot be achieved due to the pretreatment with a concentrated solution of alkali and acid.

RESULTS AND DISCUSSIONS

Biomethane Production in Jakarta

The need for LPG as Jakarta's primary fuel for cooking is enormous, whilst the daily biomass stream is massive to be converted into biomethane. However, LPG and biomethane are different fuels and should be converted first. This study makes a conversion to make an equal amount, as seen in Table 3.

Table 3. Biomethane demand in Jakarta.

	Million tons/year	LPG to energy*	Energy to methane**
LPG Demand	2.88	14.1 TJ	2.30 Mt/year

*1 kg LPG = 49 MJ

**1kg CH₄= 61,3 MJ

The demand for biomethane for cooking activities in Jakarta is estimated to be around 2.30 million tons per year, as indicated in Table 3. Meeting this demand requires substantial biomethane production. This research leverages the daily organic waste (OW), various crop residues, and wastewater generated by citizens. Figures 2 and 3 illustrate the production and coverage of the produced biomethane relative to the energy demand for cooking, respectively. These figures provide insights into the scale of biomethane production required to fulfil Jakarta's cooking energy needs and the extent to which this production can meet the demand.

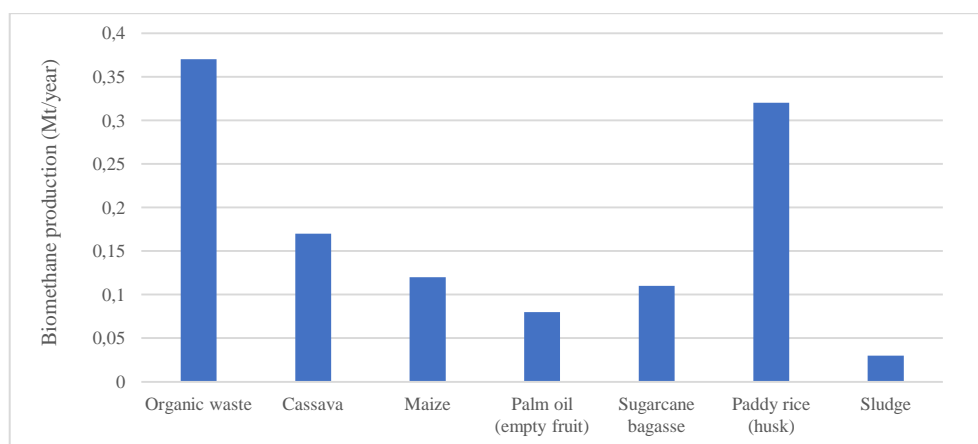


Figure 2. Biomethane production in Jakarta.

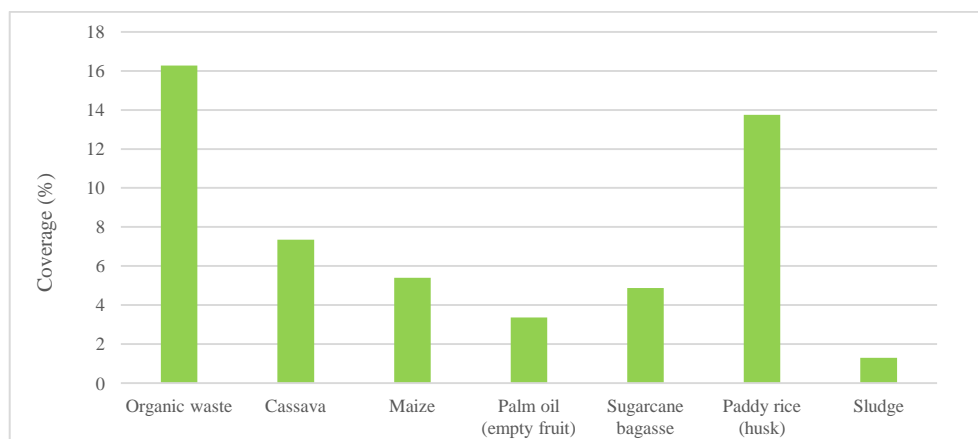


Figure 3. Biomethane coverage in Jakarta.

From Figure 2, organic waste contributes the most biomethane to production, while palm oil is the least among other solid wastes. Next, sludge in Jakarta has an insignificant percentage, with only 1.30% of all the demand. This study enhanced the production of biomethane by increasing the initial pH value of the biomass stream to pH values of 8–13 using sodium hydroxide (NaOH). After that, the slurry was neutralized, and pH was readjusted to 7.0 ± 0.2 by concentrated 37% hydrochloric acid (HCl). Figure 4 shows the comparison of conditions between pre- and post-NaOH treatment.

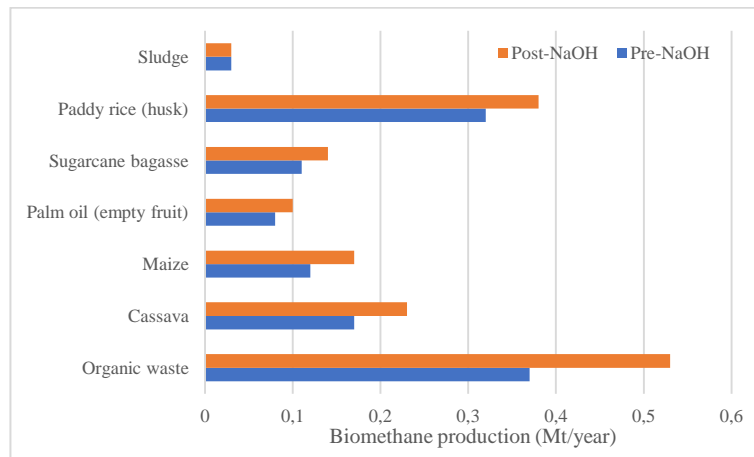


Figure 4. Pre and post-NaOH treatment production of biomethane.

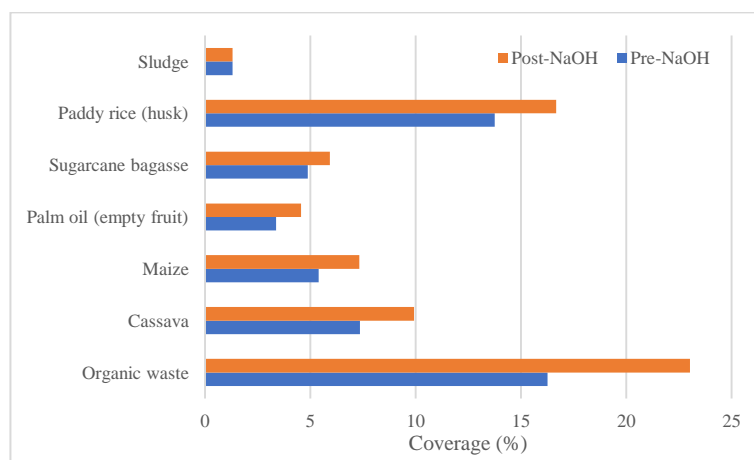


Figure 5. The Coverage of biomethane in pre- and post-NaOH treatment.

From Figure 4, the biomethane production can be elevated using NaOH pretreatment. This method can add up to 27.2% to the methane yield, with 68.9% methane content in the biogas. In the end, more than 15% of extra production can be achieved by this method, yet the coverage towards the demand is only less than 70%. This is due to the great demand for energy for cooking in Jakarta. With approximately 10.56 million inhabitants living in Jakarta and stating this area as the fifth most populated province in Indonesia [9], Jakarta consumes a considerable amount of energy for cooking. In addition, people in that area used to cook intensively to cook their food daily regardless of the seasons. Also, a lack of data, such as for several crop residues, can hinder the more outstanding production of biogas. Apart from the possible difficulties, there is a need for specific scenarios for implementing and distributing the biomethane to the customers.

The Scenario of Using Biomethane in Jakarta

Jakarta is a province with six cities with different population densities. Not all areas have decent facilities to use methane to fire up their burner [29]. Some areas are full of monumental buildings and apartments, while others are residential areas with detached houses. The current condition shows that the citizens who live in detached homes use LPG in 3 kg up to 12 kg tubes, whereas packing biomethane in tubes is not as easy as doing that for LPG. A feasible scheme is needed to distribute biomethane production, which is less than the demand. Methane is a gas that cannot quickly transform into a liquid phase and is very sensitive to high pressure [32]. Owing to this, this study offered a particular scenario to replace LPG demand for cooking in Jakarta. First of all, Jakarta is a province with six districts with different population densities living in each district and different conditions of buildings and facilities. The total biomethane production, which was 1.58 mt/year for Jakarta, can meet the supply needed (1.25 mt/year) for Jakarta through the

scheme offered in this study (see Table 4). Seribu Island (Thousand Islands) is a district with eleven small islands in which houses there are still traditional. The people there still use wood and kerosene, and some use LPG. No facility can distribute the biomethane there, and transmission for each island is costly. Hence, the supply for that district is zero.

Table 4. Population and biomethane supply in each district in Jakarta.

Cities	Population	Percentage to the whole population	Biomethane demand (million tons/year)	Biomethane supply (%)	Biomethane supply (million tons /year)
DKI Jakarta	10,557,810	100	2.30	68.74	1.58
Seribu Island	24,295	0.23	0	0	0
South Jakarta	2,264,699	21.45	0.49	50	0.25
North Jakarta	2,937,859	27.83	0.64	50	0.32
Central Jakarta	928,109	8.79	0.20	100	0.20
West Jakarta	2,589,933	24.53	0.56	50	0.28
East Jakarta	1,812,915	17.17	0.39	50	0.20
<i>Total</i>					1.25

In contrast, central Jakarta is full of huge buildings and apartments, giving this area a 100% supply. For the rest of the areas, this study assumes that huge buildings and apartments that can be supplied by biomethane are 50%. North Jakarta is the area with the highest supply because this city has the most population among five other districts.

The following scheme proposed by this study uses electricity for cooking. Like other megapolitan cities, Jakarta needs to consider using electricity for cooking. Jakarta can generate electricity from an offshore installation in Jakarta Bay, either from solar panels or wind turbines. Without any agricultural area, Jakarta has a sea, as indicated in Figure 6, which can be used for an offshore installation of solar panels or wind turbines.



Figure 6. Map of Jakarta [32].

With the biomethane produced in this study, the demand will remain at 0.72 mt biomethane/year, which equals 12.28 GW/year. To meet that amount, offshore solar panels with 2.8 MW capacity (around 7,007 panels with 400 watts of each panel) or 5.6 MW capacity of an offshore turbine (only one turbine with 8 MW of turbine) can harvest the energy for that purpose. Even though it looks feasible, electrification cannot be done directly in the area. This study also

assumed that the electrification could first approach the area that does not receive the biomethane supply.

Comparison among LPG, Natural Gas and Electricity for Cooking

Cooking with different fuels may result in different conditions, such as energy consumption and appliances. Cooking with natural gas (methane) is typically cheaper, less harsh on the environment (less carbon dioxide emitted) and more constant flow of supply directly to known. However, LPG is better in portability, has higher heat due to higher energy content, and fits the area with no natural gas pipeline [34]. Therefore, the pluses and minuses of these two different fuels should be considered before deciding what source will be used. LPG suits specific areas like the Seribu islands mentioned in this study. Furthermore, using electricity for cooking seems feasible for specific areas in Jakarta, such as areas with decent electrification, though it differs from using natural gas. Cooking with electricity works well at low temperatures and efficiently controls the heat, while using natural gas is harder to control at low heat. In addition, there is a risk of a gas leak and explosion and more expensive installation for cooking with natural gas, whereas using an electric stove needs less installation cost, less risk of a gas leak but can transfer 90% of its heat, higher than natural gas stove can do [35]. Another plus of using natural gas is that it may still work during a power outage, making people living on islands feel better using natural gas.

CONCLUSION

In Jakarta, converting nearly 1.82 million tons of organic waste, 2.68 million tons per year of crop residues, and 1.1 million tons of sludge into biomethane could surpass the annual demand for 2.88 million tons of LPG. The produced biogas is upgraded to biomethane, serving as an alternative to LPG for cooking needs in Jakarta. Initially, biomethane production could cover 52.34% of the cooking demand, increasing to 68.74% with sodium hydroxide treatment, yet falling short of total demand. While biomethane production can meet some demand with suitable receiving facilities, addressing the remaining demand requires strategic distribution. This study proposes a scenario where biomethane distribution is tailored to each district's conditions and advocates for using electricity for cooking where feasible. Additionally, authorities could embark on development initiatives to equip specific areas with facilities compatible with electric cooking. Future research could explore the development of anaerobic digestion technologies or alternative methods for converting biomass into biogas. Furthermore, comprehensive data on various agricultural residues is crucial. Lastly, the design of distribution infrastructure for biomethane requires attention, considering its distinct characteristics compared to LPG.

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