

## Development of Biogas Technology for KHDTK Wanagama I Communities

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### ABSTRACT

**Background:** KHDTK Wanagama I have strong interactions with surrounding communities, many of whom rely on cattle farming. However, many farmers have not adequately considered the environmental pollution impacts associated with cattle farming activities. Therefore, an alternative utilization of organic waste in the form of cow manure was implemented through biogas production, which can be used as a household-scale fuel.

**Contribution:** This study contributes by integrating technical redesign of small-scale biogas system with a participatory community-based approach, supported by measurable performance indicators. This study evaluates system performance, durability improvement, and practical usability, providing a replicate model for sustainable rural biogas implementation.

**Method:** A participatory action research approach was applied through baseline surveys, stakeholder coordination, biogas system redesign, technical implementation, and performance evaluation using technical and social indicators.

**Results:** The system produced approximately 0.20 m<sup>3</sup>/day of biogas from one cow, with a digester capacity of 2.01 m<sup>3</sup> and a loading period of about 10 days. This output enables 45-50 minutes of daily cooking, indicating that the system technically feasible for basic household energy needs in small scale rural settings.

**Conclusion:** Through this community service activity, it is expected that a fostered village and biogas demonstration site utilizing cow manure can be established and utilized by the community for household or group needs, as well as serve as an environmental education site for learning about environmentally friendly alternative energy.

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## **1. Introduction**

Environmental sustainability through the management of natural resources using environmentally friendly technologies has been regarded as a primary approach in addressing climate change issues [1]. One applicable strategy is the enhancement of community capacity in managing existing resource potential based on sustainability concepts [2]. In addition, community-based approaches may be implemented through the utilization of waste into environmentally friendly products [3]. Agricultural waste utilization may include biogas production from livestock manure [4], compost production from food waste [5], biochar production from agriculture residues [6], charcoal briquette production from wood waste [7], and mushroom production from corn cobs waste [8], and others. Despite these community-based approaches, the implementation faces practical challenges such as the local communities in KHDTK Wanagama I.

KHDTK Wanagama I (Wanagama Forest) is a green area that possesses significant potential for communities residing in the surrounding forest area [9]. Currently, the local community in Wanagama Forest depend on timber resources and livestock, particularly cattle for their livelihoods. Farmer groups that depend on cattle have adopted a stall-feeding system, in which cattle are confined and not released into the forest to forage independently. However, the environmental pollution impacts arising from cattle farming activities have not yet been adequately addressed, including waste disposal onto soil and surface water, as well as emissions released into the atmosphere [10]. Runoff water during rainfall originating from cattle sheds or cleaning activities inundates surrounding land and causes water body pollution. Livestock manure that merely piled without proper management, producing foul-smelling and harmful gases. In addition, livestock manure generates gaseous emissions (NH<sub>3</sub>, N<sub>2</sub>O, and CH<sub>4</sub>) that result in combined impacts on air quality and climate [11]. These gases are harmful to livestock health and productivity [12]. Environmental pollution from livestock activities can manifest as soil, water, and air pollution, posing risks to both animal and human health. Similarly, many agricultural wastes remain underutilized.

One alternative utilization of organic waste from cow manure is biogas production. Biogas is a flammable gas generated through the fermentation of organic materials by anaerobic bacteria [13]. Biogas training activities for communities surrounding Wanagama Forest were previously conducted by Biomaterials Chemical Conversion Laboratory, Faculty of Forestry UGM. In 2019, training and construction of a biogas facility as a demonstration unit were implemented at a resident's house in Banaran 2 Village. However, the current condition of the demonstration unit is no longer feasible, and renewal of installations and appropriate technology improvements are required to restore its function as a demonstration and educational media. The implementation of biogas demonstration has provided benefits to the community, not only for household energy needs but also as an environmental education to raise the rural community's awareness of renewable energy program [14]. However, education, socialization, and biogas installations remain limited and need further enhancement.

Based on the above, community service activities were conducted by Biomaterials Chemical Conversion Laboratory to improve community skill capacity surrounding Wanagama Forest and to update previously taught biogas skills. Appropriate technology in biogas installations was designed using more durable materials to function as a better learning medium. These community service activities are planned to continue over the next three years in collaboration with Wanagama Forest.

## **2. Method**

This study applied a participatory action research (PAR) approach within a community-based development framework to ensure active community involvement and sustainable program implementation [15]. The activities were conducted by involving village communities surrounding Wanagama Forest, particularly Wanagama partners in Banaran 2 Village along with village official and Wanagama Forest managers.

The research was carried out through several structured stages. The first stage was a baseline assessment using field survey and observations to identify the technical condition of existing biogas installations as well as social and practical constraints faced by the community. The second stage involved participatory coordination with stakeholders to align perceptions, define roles and formulate intervention strategies. The third stage consisted of technical implementation through the renewal and redesign of biogas installation to improve system durability and performance. This was followed by assistance and demonstration of household scale biogas system as a practical learning medium for the community.

Biogas capacity calculations and performance testing were conducted based on standard assumptions of biogas yield from cow manure (m<sup>3</sup>/kg), referring to previous studies [4]. Education and socialization activities were also carried out to enhance community knowledge regarding operation, maintenance, dan benefit of biogas systems. Data were collected using filed observations, semi structure interviews, and technical measurements of system performance. The main variables measured included biogas production (m<sup>3</sup>/day), digester capacity (m<sup>3</sup>), cooking duration (minutes/day), and system functionality.

Program evaluated was conducted using predefined indicators, including technical performance (system functionality gas production), utilization level (daily use for cooking), and community participation. Data analysis was performed using descriptive quantitative methods for technical data and qualitative analysis to assess community engagement and program and program impact. This methodological framework ensure that the program is implemented and evaluated in systematic and replicable manner.

## **3. Results and Discussion**

### **3.1. Field Survey and Observation Activities**

The implementation of the community service activities related to the utilization of cattle manure waste as a biogas feedstock in the area surrounding Wanagama Forest was initiated with a preliminary stage consisting of field surveys and observations. The purpose of this

survey was to obtain baseline data on the existing condition of previously constructed biogas installations, as well as to identify technical and non-technical problems that constrained their utilization.

Based on the field observations in [Figure 1](#), it was found that most of the drum digesters buried underground had suffered severe physical deterioration. The drum surfaces exhibited heavy corrosion, with several units perforated and leaking, thereby preventing the maintenance of the closed system required for anaerobic fermentation. This condition resulted in suboptimal methane gas production, and in some locations, gas formation did not occur at all. In addition, the connecting pipeline system and gas channels were found to experience leakage and blockage due to prolonged service life and a lack of routine maintenance.

Based on these findings, recommendations for improvement and refinement of the biogas installation design were provided by the community service team. The development of designs and modifications of biogas installations can improve the operational performance and adaptive capacity of the biogas system [16], [17]. One of the main improvements involved replacing the old metal drum digesters with new digesters made of concrete rings, which are more resistant to corrosion and have a longer service life. The digester design was also modified from a horizontal to a vertical configuration to facilitate the removal of residual sludge and to maintain the efficiency of the gas formation process. The inner surface of the digester was recommended to be coated with a special adhesive or plastered to prevent leakage and to enhance airtightness.

Furthermore, the survey results indicated the need to improve the material input and output systems to ensure smoother organic material flow and to prevent blockages. The importance of technical training and socialization for the community was also emphasized, particularly with regard to routine maintenance and early detection of gas leakage, in order to ensure that the improved biogas system could be utilized sustainably [18], [19].

The observed deterioration of the previous digester indicates that material selection plays a critical role in the sustainability of small-scale biogas system. The use of metal drum digesters is highly susceptible to corrosion due to prolonged exposure to moisture, organic acids, and anerobic microbial activity. This condition leads to gas leakage and system failure. Previous studies have also highlighted that inappropriate material selection is one of the main causes of inefficiency and failure in household scale digesters [16]. Therefore, the replacement with concrete based digesters is expected to significantly improve system durability and operational stability.

This survey activity served as the basis for planning the subsequent stages, namely the improvement of the biogas installation and assistance in developing household scale biogas demonstration units. The field findings were also used to develop technical guidelines for installation improvement and as educational materials for the community in subsequent socialization programs.



**Figure 1.** Condition of the rusty and damaged biogas digester

### 3.2. Coordination with Stakeholders

Coordination was carried out by the community service team from Biomaterials Chemical Conversion Laboratory in collaboration with the target community who owned the biogas installation sites, namely residents who possess cattle sheds and cattle in Banaran 2 Village. Cow manure from these livestock served as the primary raw material for biogas production; therefore, the active involvement of livestock owners was considered a key factor in the success of the program. Field coordination activities were conducted directly by involving landowners and several local residents who participated in the renovation and reconstruction of the digester installation. Coordination activities have been recognized a crucial role in building synergy with project partners [20].

During these activities as seen in [Figure 2](#), explanations were provided by the community service team regarding the improvement plan, technical specifications of the materials to be used, and a more efficient and sustainable layout of the installation. Through on-site discussions, community members were able to convey their input, needs, and constraints encountered during the utilization of the previous biogas installation. This participatory approach encouraged a sense of ownership toward the program and increased community motivation to maintain and utilize the biogas facilities in a sustainable manner.

In addition to direct field coordination, communication was also conducted through online media, namely the WhatsApp application, which facilitated rapid information exchange and decision-making. Through this platform, the community service team was able to monitor field preparation progress, material requirements, and work schedules without the need to be continuously present at the site. This online coordination proved effective in maintaining communication continuity, particularly when team members or partners were unable to meet in person.

The coordination activities resulted in several important agreements, including the selection of the digester renovation site, the distribution of tasks between the community service team and the community, and the scheduling of the biogas installation renovation. Furthermore, the community expressed a commitment to actively participate in the construction process and in the maintenance of the installation after the completion of the activity. Thus, the coordination stage functioned not only as an administrative process but also

as a means of community empowerment and strengthening collaboration among academics, village authorities, and local communities in supporting the implementation of biogas technology around Wanagama Forest.



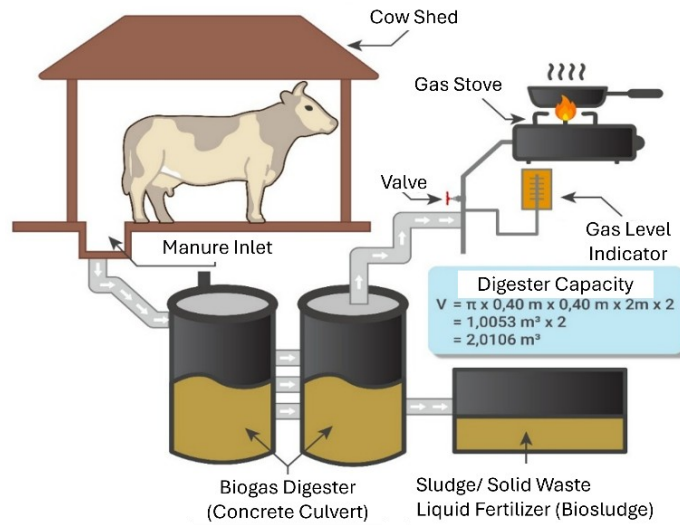
**Figure 2.** Coordination with land owners

### **3.3. Design Development and Construction of Household Scale Biogas System**

The stage of biogas installation improvement constituted the core activity of this community service program and was carried out as a follow-up to the results of the survey and coordination with the community and relevant stakeholders. Based on previous observations, the old biogas installation had experienced significant damage due to corrosion of the digester tank made from metal drums and leakage in the piping system. These conditions caused methane leakage within the biogas system and make the system to no longer function optimally [21]–[23]. Therefore, a redesign and reconstruction of the biogas installation were conducted to develop a more durable system that was suitable for local environmental conditions.

The improvement activities included the procurement of equipment and main materials, such as concrete rings for digester construction, PVC pipes for input and output channels, airtight adhesive, and other supporting materials. In addition, repair and reinstallation were carried out for all components of the biogas system, including the construction of a new digester tank, assembly of the inlet and outlet channels, and the gas discharge system leading to the main storage unit. The construction process was carried out over a two-month period and involved the community service team, community members, and digester owners as the direct users of the system.

The new biogas design as seen in [Figure 3](#) was configured with a vertical orientation [24] to improve efficiency in accommodating organic materials, to enhance the circulation of fermentation slurry, and to facilitate the removal of residual sludge. The digester was constructed using concrete rings coated with a special adhesive and finely plastered on the inner surface to increase airtightness and resistance to soil moisture. In addition, the positions of the inlet and outlet were adjusted to facilitate the loading of raw materials in the form of cow manure and the discharge of liquid effluent from the fermentation process.



**Figure 3.** Design of biogas digester

During the construction process, community members were actively involved in both physical activities and technical discussions, which enabled them to become not only beneficiaries but also to gain an understanding of the operational principles of the installation. On-site assistance was provided by the community service team to ensure that each stage of the construction process was carried out in accordance with the planned specifications and technical standards. The final outcome of this activity was the completion of a biogas installation that was fully constructed and ready for use. With the completion of this improvement process, the new biogas installation is expected to operate more optimally and to have greater durability compared to the previous system.



**Figure 4.** Construction of biogas installation

### 3.4. Biogas Capacity, Production, and Performance Testing

The following section presents a technical discussion of the digester capacity and gas production testing practices for the installation shown in Figure 4. Table 1 summarizes the daily biogas observations for a single cow, based on conventional calculations assuming a gas production rate of 0.02 m<sup>3</sup> per kilogram of manure.

The calculation of biogas production in this study was on standard assumptions of biogas yield from cow manure. Previous study has reported that the biogas production potential ranges from 0.018-0.024 m<sup>3</sup>/kg of fresh manure under typical household scale conditions [4]. In this study, a conservative value of 0.02 m<sup>3</sup>/kg was used to reflect realistic field conditions.

**Table 1.** Calculating daily observations of biogas digester trials for ownership with 1 cow

Parameter	Value	Description
Number of cows	1 cow	1 adult female cow
Cow dung production	10 kg/day	daily average
Biogas potential	0.02 m <sup>3</sup> /kg	conventional score (average standard)
Biogas production per day	0.20 m <sup>3</sup> /day	10 kg × 0.02 m <sup>3</sup> /kg
Digester capacity	2.01 m <sup>3</sup>	design result
Stove consumption rate	0.25 m <sup>3</sup> /hour	household biogas stove
Supported cooking times	0.8 hour (48 minutes)	0.20 m <sup>3</sup> ÷ 0.25 m <sup>3</sup> /hour
Digester full filling time	approximately 10 days	2.01 ÷ 0.20

The results of the performance testing of the biogas installation as seen in Figure 5 developed through the community service activity indicated that one cow producing approximately 10 kg of manure per day was able to generate approximately 0.20 m<sup>3</sup> of biomethane per day. This volume was obtained based on conventional calculations assuming that each kilogram of fresh cow manure has the potential to produce 0.02 m<sup>3</sup> of biogas. The digester capacity of approximately 2.01 m<sup>3</sup> indicated a storage capability of about 10 days of operation without excessive pressure buildup. Initial testing demonstrated that the produced gas was able to fuel a household biogas stove for approximately ± 45–50 minutes per day. This value is considered realistic for household-scale applications with a limited number of livestock [25].

The estimated biogas production of 0.20 m<sup>3</sup>/day in this study is influenced by several key operational parameters inherent to anaerobic digestion processes. Factors such as temperature, pH, carbon to nitrogen (C/N) ratio, and feedstock characteristics play a significant role in determining biogas yield. Under optimal mesophilic conditions (approximately 30-30 °C), biogas production is generally higher and more stable. However, in field-based applications such as this study, temperature fluctuations are not strictly controlled, which may limit microbial activity and reduce gas production efficiency.

In addition, the use of single feedstock (cow manure) without co-digestion may result in sub optimal C/N ratios, which can affect the metabolic activity of anaerobic microorganisms. Previous study has reported that balance C/N ratios (typically between 20-30) and stable pH conditions (around 6.8-7.5) are critical for maximizing methane production [4]. The absence of

controlled monitoring of these parameters in this study suggests that the obtained biogas yield reflects practical field conditions rather than optimizing system performance. When compared with results from previous studies, the biogas production value obtained in this activity remained within a conservative range. The previous study [26] reported that under optimal mesophilic anaerobic conditions, a mixture of cow manure and grass was able to produce biogas up to 0.192 m<sup>3</sup> per kilogram of volatile solids, or approximately 0.03–0.05 m<sup>3</sup> per kilogram of fresh material. This indicates that under more stable operating conditions and an optimal C/N ratio, the biogas production potential from one cow could increase up to twofold compared to the results of this community service activity.

Furthermore, a study [27] on household-scale digesters reported biogas production in the range of 0.018–0.024 m<sup>3</sup> per kilogram of fresh cow manure, which is highly comparable to the results obtained in this activity. These findings reinforce that the value of 0.02 m<sup>3</sup>/kg used in this community service program is consistent with the average empirical results observed in field applications. These findings highlight that improving process control and feedstock management is essential to enhance biogas productivity in community-based systems.



**Figure 5.** Biogas trial for cooking with a gas stove

### **3.5. Socialization and Utilization of Biogas as an Educational Media**

The utilization of the biogas installation in Figure 6, resulting from the community service activity was not only intended as a means of converting livestock waste into alternative energy, but also as an educational medium for the community and participants in academic activities. The constructed biogas installation was capable of accommodating cow manure from partner cattle sheds and producing methane gas, which was distributed through pipelines to a household biogas stove. The generated gas was proven to be usable as an energy source for simple cooking activities [28].

In addition, the installation of biogas is associated with social impacts not only for the local community but also for students [29]. The installation can be utilized as a learning facility in educational activities such as the Forestry Summer Course 2025 organized by the Faculty of Forestry, Universitas Gadjah Mada. Through this activity, students from various countries obtained hands-on experience with the waste-to-energy concept and the application of

appropriate technology in the fields of forestry and environmental management. These educational activities encouraged participants to understand the linkages among livestock waste management, forest conservation, and climate change mitigation through the use of clean energy. From these activities and other educational visits, the community members who owned the biogas installations also gained economic benefits through visits and training programs (educational packages) conducted in collaboration with Wanagama.



**Figure 6.** Education about green energy from biogas

The utilization of biogas as an educational medium is consistent with the findings that reported [30], which stated that the potential of biogas as a renewable energy source in community training activities was able to enhance public knowledge regarding biogas and waste management. In addition, the previous study [31] also reported that the implementation of community-based biogas installations can be implemented as a waste management solution to support the application of circular economy principles at the household level. Therefore, this activity not only contributed to improving community capacity in utilizing alternative energy sources, but also strengthened the function of the Wanagama area as a learning center for land rehabilitation and renewable energy innovation [32].

The social impact of the program was evaluated using several indicators, including community participation during implementations, utilization of the biogas system for daily activities, and the role of the installation as an educational medium. Active involvement of community members in the constructions and operations stage indicates a high-level engagement and ownership of the technology. Furthermore, observational findings showed that community members were able to operate and utilize the biogas system for cooking activities, demonstrating practical adoption of technology. The use of the biogas installation as a learning site in educational activities also indicates its function as an effective medium for knowledge transfer related to renewable energy and waste management.

These findings suggest that the integration of technical implementation and community involvement contributes to increased awareness and acceptance of renewable energy at the household level. The direct use of biogas for daily needs reflects a positive shift in community

behavior toward more sustainable practices. These findings suggest that the integration of technical implementation and community involvement contributes to increased awareness and acceptance of renewable energy at the household level. The direct use of biogas for daily needs reflects a positive shift in community behavior toward more sustainable practices.

### **3.6. Activity Evaluation**

The evaluation of the activities was conducted to assess the extent to which the objectives of the community service program had been achieved, both in terms of outputs (direct results of the activities) and outcomes (impacts perceived by the community). The evaluation was carried out based on predetermined performance indicators, namely the improvement of the biogas installation, the development of household-scale biogas demonstration units, and the successful utilization of biogas products as alternative energy sources.

Evaluation instruments were developed to ensure that the achievement of activity outcomes could be measured objectively. Details of the indicators and their corresponding measurement methods are presented in [Table 2](#).

**Table 2.** Achievement Indicator of Community Service Activities

<b>Indicator</b>	<b>Method</b>	<b>Achievement</b>
Improvement of biogas installation	Equipment installed according to design (vertical concrete digester, pipes, valves, and gas outlet)	100% installed and ready to use
Biogas pilot unit	Biogas pilot unit installed at partner site	One household biogas is actively used
Biogas product	The biogas stove installed and ready to use	The stove functions normally for cooking $\pm$ 45–50 minutes per day
Socialization/Educational activities	Has been used as an educational media	Used as an environmentally friendly energy education in the 2025 Forestry Summer Course activities

Based on [Table 2](#), all performance indicators of the activity were successfully achieved. The biogas installation was successfully improved with a more durable design, the household-scale biogas demonstration system was constructed and operated, and the produced biogas was proven to be usable for cooking purposes. These results indicate that the community service activity optimally achieved its targeted technical and functional outputs. Overall, this community service program fulfilled all predetermined indicators, both in technical and social aspects. The biogas installation functioned in accordance with its design, the biogas product was practically utilized, and the community demonstrated increased knowledge and motivation in the management of environmentally friendly energy while also obtaining practical benefits.

#### 4. Conclusion

This study highlights that integrated technical improvement with community participation is essential for the successful implementation of household scale biogas systems. The redesigned digester improved system functionality while supporting its role as an educational medium for renewable energy adoption. However, the study is limited by the absence of structured quantitative evaluation of social impacts and lack of controlled monitoring of key operation parameters. Future studies should incorporate more rigorous evaluation methods and optimize system performance. The developed model also has strong potential for replication in other areas with similar characteristics.

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