# Master’s Thesis Engineering Technology

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# Design and implementation of a sustainable solution for upgrading and distributing biogas in rural Tanzania

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## SITUATION

Across rural Africa, charcoal and firewood still dominate household energy, driving deforestation and indoor air pollution. Through anaerobic digestion, kitchen waste and agricultural waste can be transformed into renewable biogas, a sustainable fuel for cooking and heating. To explore this potential, Ardhi university deployed a test setup in Kimbiji, a rural ward in Tanzania. Figure 1 illustrates this test site. Figure 2 shows the digester at this test site.

*Figure 1: The Kimbiji test site*

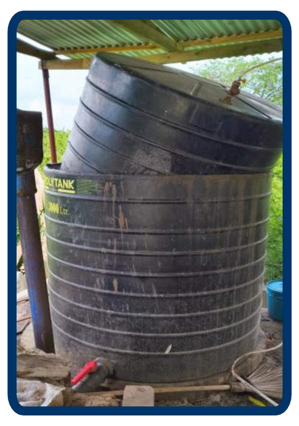

*Figure 2: Digester*

## PROBLEM DEFENITION

The current setup produces a low-pressure, unpurified biogas stream. Due to the low methane concentration and the presence of impurities (Table 1), combustion is inefficient, making it difficult to generate enough heat for cooking. Additionally, the low pressure complicates storage and transport, limiting the practical usability of the gas.

*Table 1: Typical biogas composition [1]*

| Component | Symbol | Concentration (Vol-%) |
|---|---|---|
| Methane | $CH_4$ | 55-65 |
| Carbon Dioxide | $CO_2$ | 35-45 |
| Water | $H_2O$ | 2-7 |
| Hydrogen sulphide | $H_2S$ | 20-20000ppm (2%) |

## OBJECTIVES

The aim of this master’s thesis is twofold: designing and implement an installation that purifies and compresses the biogas. The final product should reach at least 75% methane to ensure efficient combustion and reduce $H_2S$ levels to below 5 ppm to ensure safety. The biogas should be pressurized to 8 bar to facilitate transportation.

## METHOD

To design this biogas purification and compression system, several steps were taken:

1. **Literature review**
   Identified the most promising $CO_2$ removal and $H_2S$-scrubbing techniques under local conditions.
2. **Small-scale testing at Ardhi University**
   Tested and compared two $CO_2$ removal processes and four $H_2S$ absorbents.
3. **Large-scale setup & validation in Kimbiji**
   Implemented the most suitable $CO_2$ removal process and $H_2S$ absorbent at the Kimbiji test site, and supplied a sustainable, independent power supply.
4. **Techno-economical analysis**
   Evaluated the technical viability of the setup and compared it with a larger scale implementation and the other traditional fuel sources.
5. **Conclusion & recommendations**

## UNIVERSITY SETUP

A test setup was constructed at Ardhi University (Figure 4) to evaluate suitable purification methods under local conditions. Firstly, two $CO_2$ removal techniques were compared:

1. absorption using calcium hydroxide ($Ca(OH)_2$),
2. water scrubbing.

Secondly, for $H_2S$ removal, four locally available adsorbents were tested:

1. iron wool,
2. rusted iron wool,
3. granulated $Fe_2O_3$,
4. activated carbon.

*Figure 3: QR code*

Finally, to ensure longevity of the project, manuals and guide videos were made, accessible though the QR code (Figure 3).

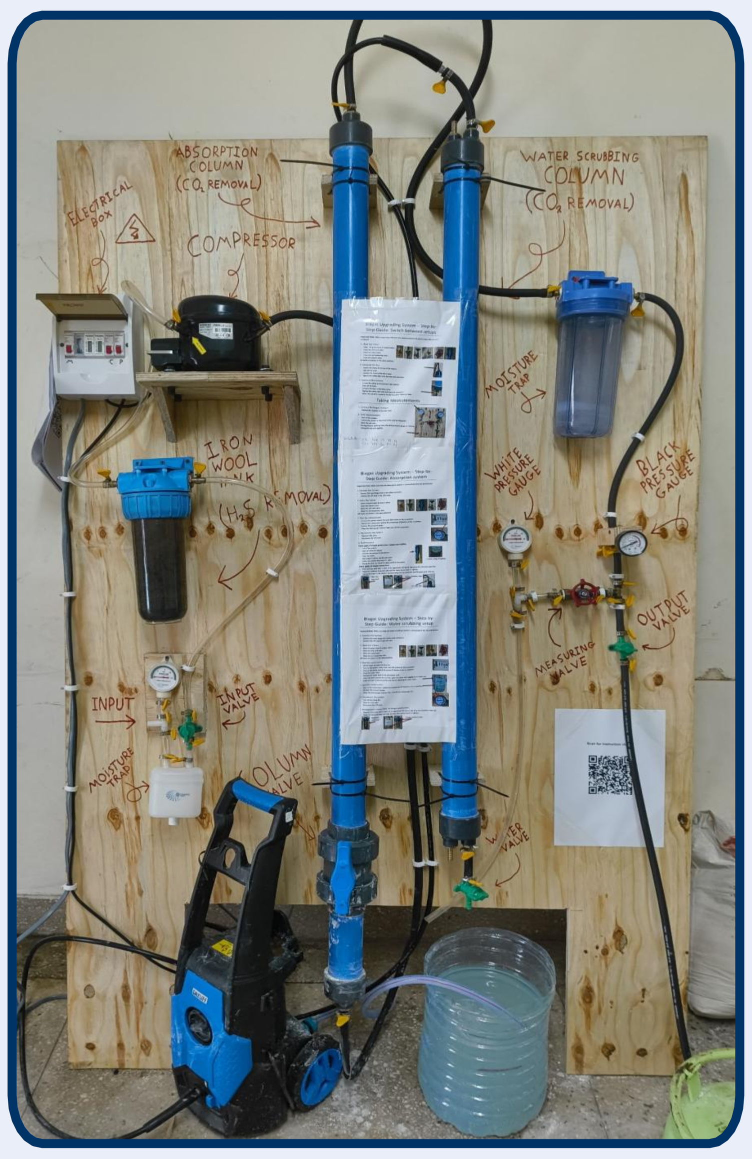

*Figure 4: The university setup*

## PURIFICATION

Firstly, the $H_2S$ removal techniques were tested. $H_2S$ removal is important to improve safety and prevent corrosion of the downstream components. The tested absorbents react with the $H_2S$, removing it from the biogas.

Table 2 illustrates the results from the $H_2S$ removal test. The untreated biogas had 795 ppm $H_2S$. The granular $Fe_2O_3$ reached the highest removal, achieving 3 ppm. The more cost-effective rusted steel wool also performed well, reducing the $H_2S$ concentration to 7 ppm.

Secondly, the $CO_2$ removal techniques were evaluated. In the water scrubbing process, water flows countercurrent to biogas, allowing $CO_2$ to dissolve into the liquid phase. The removal efficiency proved pressure dependent, negligible in the beginning and rising as the pressure rises. However, the systems water pump failed at 5 bar, unable to achieve the 8 bar. The results are illustrated in Figure 4.

The absorption setup, where $Ca(OH)_2$ reacts with the $CO_2$ to form $CaCO_3$, showed more stable results. It reached 8 bar while maintaining consistent removal efficiency.

*Table 2: $H_2S$ removal using different absorbents*

| | $H_2S$ concentration [ppm] |
|---|---|
| Before removal | 795 |
| Granulated $Fe_2O_3$ | 3 |
| Steel wool | 279 |
| Activated carbon | 7 |
| Rusted steel wool | 11 |

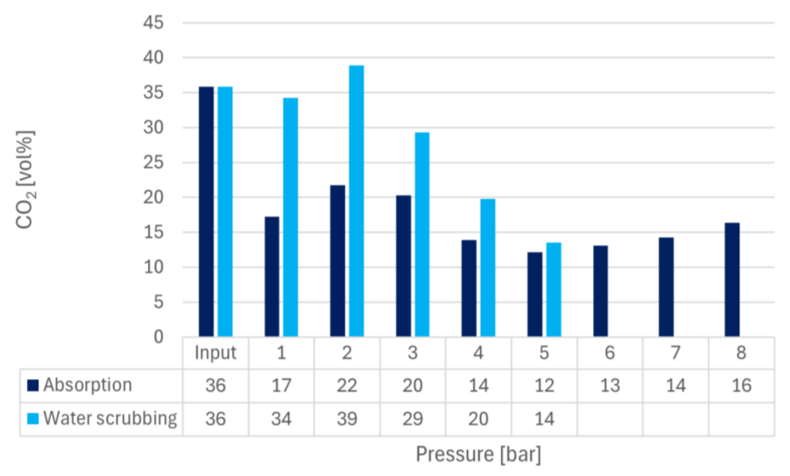


*Figure 5: $CO_2$ concentration during the purification process*

## KIMBIJI SETUP

For the Kimbiji setup (Figure 6), capable of producing 100 L of biogas daily, $Ca(OH)_2$ absorption is selected for $CO_2$ removal and rusted iron wool is used for $H_2S$ removal.

The results for this setup show $CO_2$ reduction to 16% and $H_2S$ reduction to 2 ppm. To enable distribution, the gas is pressurized to 8 bar and stored in LPG cylinders.

To power the system, a solar energy supply is used as there is no electricity available at the site. Additional electrical capacity is foreseen to power lighting on the site.

The key energy supply components are:

1. 2 x 200 Wp 12 V solar panels,
2. 50 Ah 12V battery,
3. A PWM controller of 60A 12V,
4. A 600 W Inverter.

*Figure 6: The Kimbiji setup*

## ECONOMICAL ANALYSIS

In addition to the small-scale system, a large-scale biogas setup was also evaluated. An economic analysis was done on both setups, determine the selling price if no profit would be made. These prices were compared to the levelized cost of energy (LCOE) of other traditional fuels in Figure 5.

Small-scale biogas purification results in a high LCOE of 1,572 TZS/kWh, making it economically unfeasible in comparison to other fuels. It would have a total discounted cost of ownership of TZS 2,823,433, with a capital cost of TZS 2,144,500 and an annual TZS 82,526 maintenance cost. In contrast, the large-scale setup, capable of processing 6,500 L of unpurified biogas per day, achieves a much lower LCOE of 241 TZS/kWh. This cost is lower than the cost of LPG at 270 TZS/kWh, underscoring the critical impact of scale on cost efficiency.

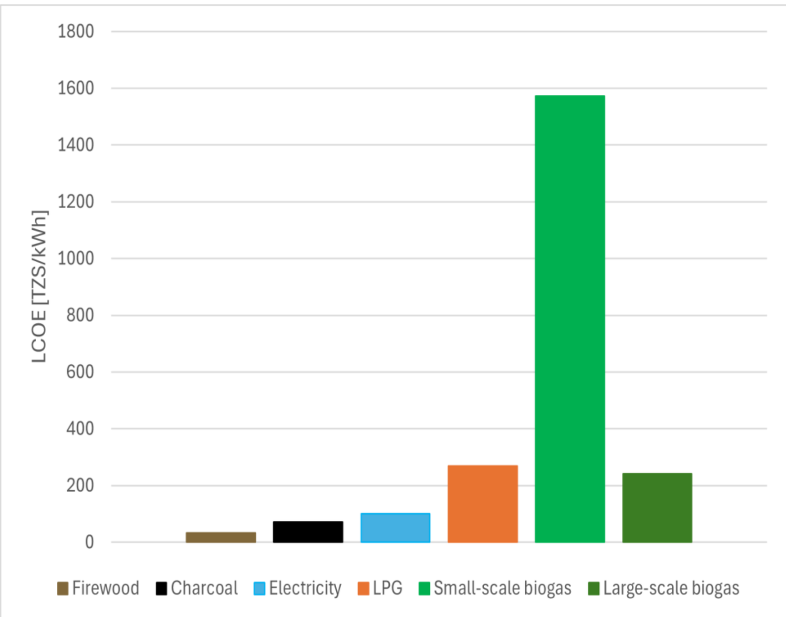


*Figure 7: LCOE comparison of different energy sources*

## CONCLUSION

$Ca(OH)_2$ absorption and rusted steel wool scrubbing were found most optimal for the local Kimbiji situation, reducing **$H_2S$ from 277 ppm to 2 ppm**, and **boosting methane purity to 85%**. Distribution is achieved by a compressor effectively compressing the biogas to **8 bar**.

Considering economic viability, the small-scale system has **an LCOE of 1,572 TZS/kWh**. Scaling to 6,500 L/day lowers **LCOE to 241 TZS/kWh**. This signifies the importance of scale and community cooperation.

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[1] C. Vögeli, R. R. Lohri, S. Gallardo, S. Diener, and C. Zurbrügg, Anaerobic Digestionof Biowaste in Developing Countries. Dübendorf, Switzerland: Eawag, 2014.