Department of Biosystems and Agricultural Engineering
MICHIGAN STATE UNIVERSITY

BE 487 - Spring 2022
Biosystems Design Projects

BE 487 – Microscale Biogas Plant Design

Trenten Beemer, Zach Buhro, Kaitlin McHenry, & Jordan Neal
Client: Goloka Eco Model Faculty Advisor: Dr. Dana Kirk

Background

The Goloka Design Team was tasked with turning 3 cu. ft per day of plant biomass from two onsite greenhouses and manure from seven cows into a renewable energy source from the Goloka Eco Model farm in Maybee, MI. The team collected samples from the farm site to analyze the feedstock types. The feedstock characteristics were used to select a design type and predict the feedstock energy potentials. Due to the high solids content of the feedstocks, ranging from 29.1 – 43.3% total solids, it was determined a high solids digester would be the appropriate design. The low-tech design utilizes 55-gallon drums and a heating chamber to perform the mesophilic digestion process. The digester will produce nearly 16,793 cu. ft of biogas per year which contains a maximum of 51% methane. The biogas will be burned in a furnace to provide heat to the digester and greenhouses. The digestate will be used as an organic fertilizer.

Problem Statement

Design an anerobic digester capable of converting both cow and plant biomass into a sustainable energy source for a small-scale farm.

Design Alternatives

The team compiled a selection of digestors best suited to achieve the design objectives. The system will be heated and able to handle the loading rate and set retention time of the feedstocks. The system will be fitted to generate heat using a biogas compatible furnace.

Four anaerobic digestor designs were evaluated for this project:

- Plug Flow
- CSTR
- Screw-Type
- High Solids

Each design was evaluated on the following criteria:

- Cost
- Maintenance
- Compatibility
- Energy Consumption
- Constructability
- Life Expectancy

The high solids design was the best choice for the project due to its high scores in each criteria and its ability to best handle the most important feedstock characteristic; total solids (TS) of 43.3% for manure and 29.1% for plant biomass. This follows the U.S. EPA digester code 366 which states that any feedstocks with a TS higher than 23% should use a high solids digester[3].

Selected Design

The high solids design will keep the digestion process airtight by storing the feedstock in 55-gallon plastic drums. The drums will also space the loading and emptying labor in a way that is compatible with the farm which collects cow manure and plant biomass daily. Fifteen drums were chosen to meet the volumetric loading rate and limit the decay of the feedstocks. The drums will be stored in a well-insulated structure that consists of five compartments. Each will hold three drums with lines for gas that split connecting to each drum individually and heated using forced air convection. Gas lines will converge to a biogas bag to allow for pressure to build up before being directed to the biogas furnace. Figure 1 shows the front, back, and side while Figure 2 shows the cross-section views.

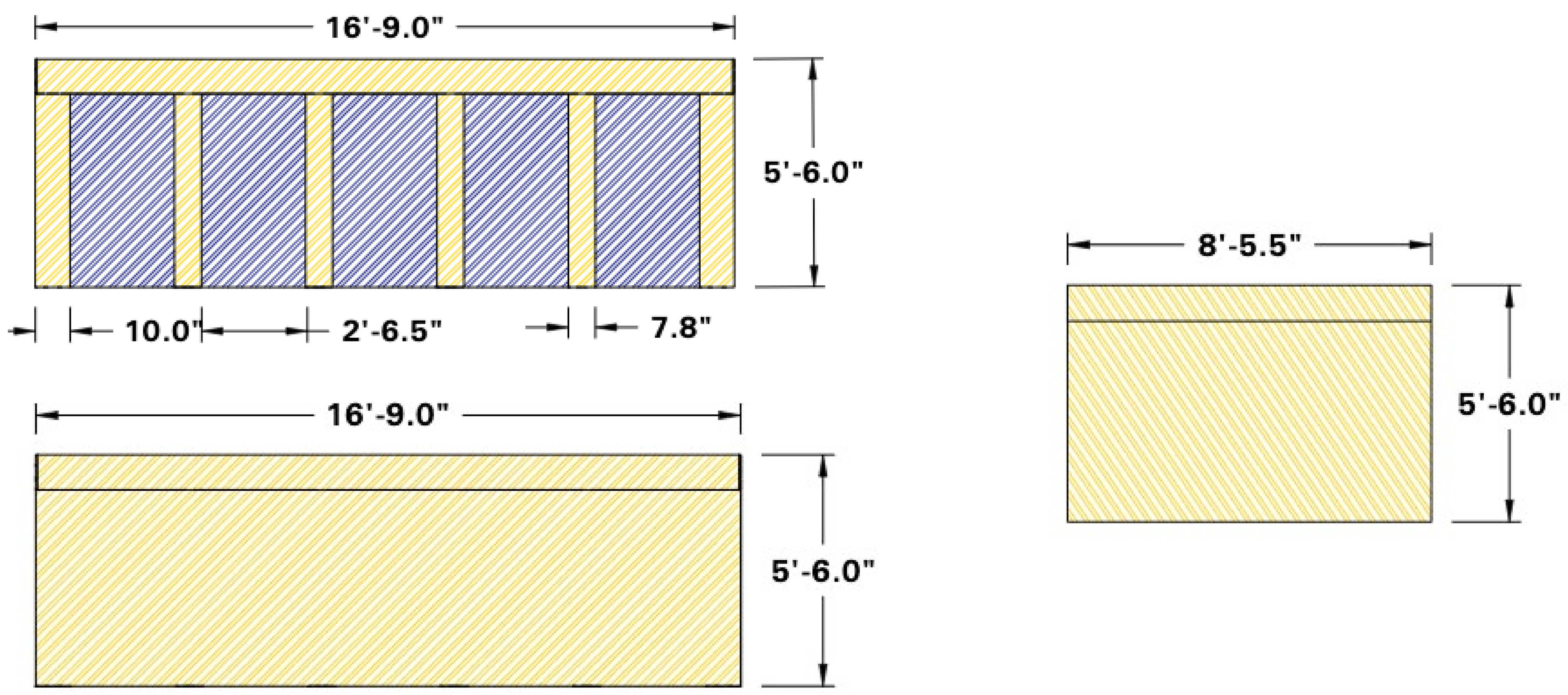

Figure 1: Goloka biogas plant front, back and side views.

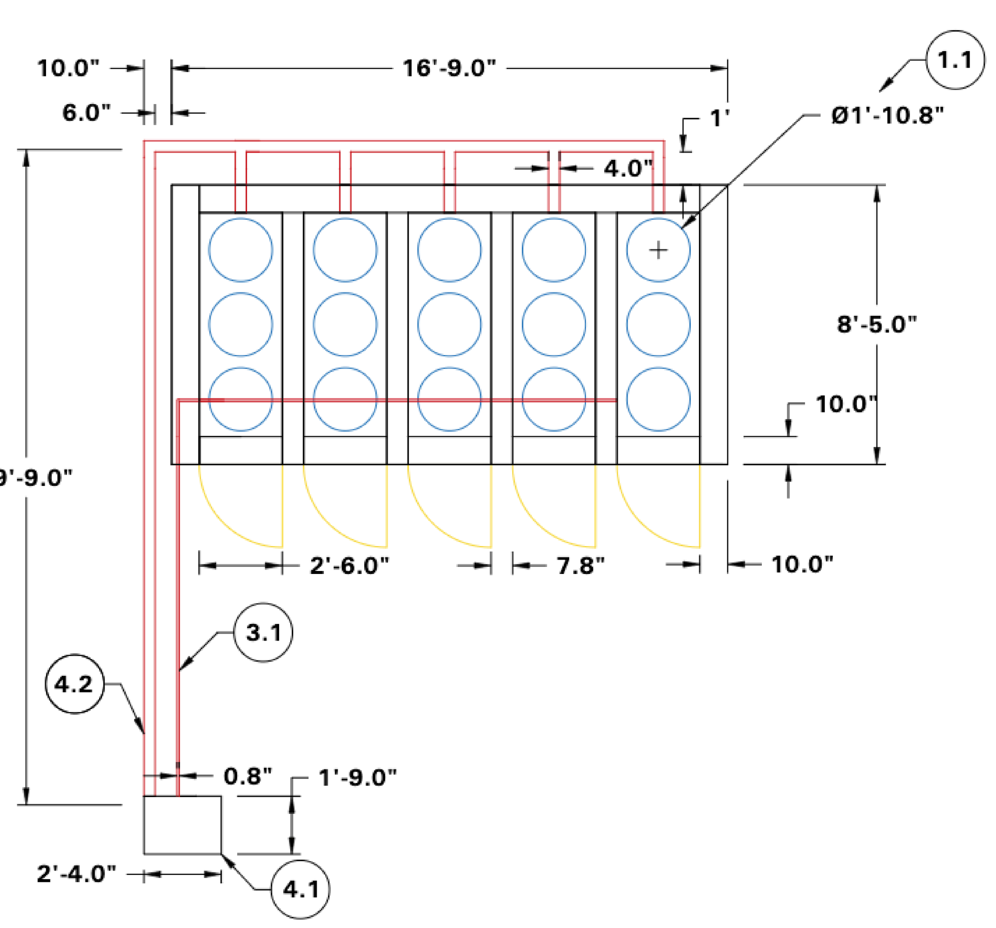

Figure 2a: Goloka biogas plant footprint where 1.1 is 55-gallon drums, 3.1 is 0.75" natural gas piping, 4.1 is a biogas furnace, and 4.2 is 4.0" ductwork.

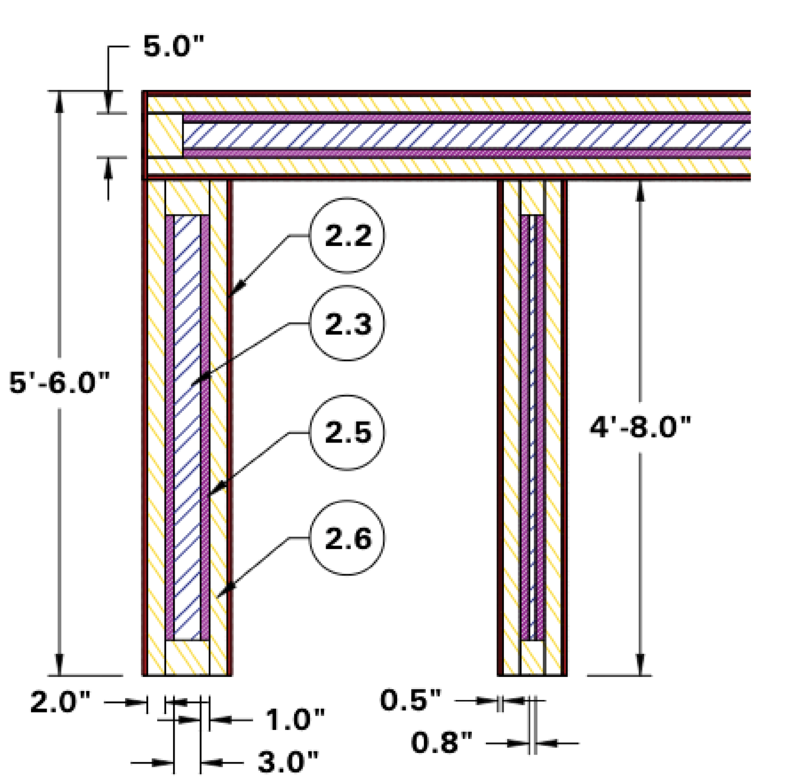

Figure 2b: Cabinet cutaway where 2.2 is 0.5" plywood, 2.3 is 3.0" and 0.75" straw, 2.5 is 1.0" foam sheathing, and 2.6 is 2" by 4" lumber.

Objectives

The design will be low-tech, simple to use, and require little maintenance for an increased lifespan. These objectives can be summarized as followed:

- Quantify onsite feedstock availability and energy potentials
- Model the theoretical energy output of the digester from feedstock data
- Design a low-tech high solids digester
- Validate manufacturability and applicability to global small-scale farms
- Mitigate rural greenhouse gas emissions

Constraints

Constraints for this project include the size, location, and land characteristics of the farm site as well as the standards set by the United States Department of Agriculture (USDA). These constraints can be summarized as followed:

- Optimal internal temperature of 95°F[1]
- Varied feedstock < 5,278 lb/yr
- Airtight digestive chamber
- Gas tight system
- $25,000 budget for implementation

Design Parameters

The design team visited the Goloka Eco Model farm on November 4th, 2021, to collect feedstock samples of cow manure and plant waste. These samples were taken to Michigan State University's ADREC lab where serum bottle batch assays were conducted to determine the biogas potential of the feedstocks. A summary of the report can be seen in Table 1.

Table 1: Summary of BMP results.

Feedstock	TS (%)	VS (%)	TS:VS (%)	Biogas / Raw VS (ft^3/lb)	Max. Methane (%)
Wheel Barrel	43.3	32.2	74	4.7	48
Plant Waste	29.1	24.3	84	7.4	51

The calculation of biogas yield based on Table 1 feedstock characteristics is 46.01 ft^3-biogas/d. The design assumes the maximum amount of biogas production to ensure proper sizing of gas storage. The calculation of methane yield based on biogas production is 20.16 ft^3-methane/d. The design assumes the maximum amount of methane will be produced. These values are summarized in Table 2.

Table 2: Biogas calculations using BMP values.

Feedstock	Loading rate (lb/d)	Biogas yield per day (ft^3/d)	Methane yield per day (ft^3/d)
Manure	14	43.15	18.82
Plant Waste	0.46	2.86	1.34

To determine how many 55-gallon drums would be needed the total feedstock volume which includes manure and plant biomass, as well as the retention time was used. These design assumptions can be summarized as followed:

- Loading rate: 3 ft^3/d
- Drum volume[2]: 7.35 ft^3
- Retention time: 35 d
- Days to fill one drum: 2.3 d
- Number of drums needed: 15 drums

After calculating the heat generated, lost, and required for each uninsulated drum the total energy required for the system was determined to be 49,455 BTU/hr. This value, as well as a sizing factor, was used to determine the minimum biogas compatible furnace size needed of 74,182 BTU/hr. These design inputs and assumptions can be summarized as followed:

- Heat generated: 775 BTU/hr
- Heat lost: 4,026 BTU/hr
- Heat required: 46 BTU/hr
- Furnace sizing factor: 50 %

Economics

The cost of materials for the biogas plant was determined to be $15,285. The cost of labor to build the proposed biogas plant was calculated to be $1,868. A total capital cost of $17,153 is proposed for the final design implementation. The total cost brings the project $7,847 under the project budget of $25,000. Table 3 summarizes these values.

Table 3: Economic analysis of biogas plant.

	Items	Cost/Benefit
Capital Costs	Materials	$ 15,285
	Labor	$ 1,868
	Subtotal	**$ 17,153**
Annual operating costs	Labor	$ 5,545
	Energy input	$2,219
	Maintenance	$ 891
	Subtotal	**$ 8,655**
Annual value	Energy offset	$ 2,219
	Digestate	$ 778
	Subtotal	**$ 2,997**

Conclusion

The following are actual characteristics of the Goloka Farm:

- Client has secured external funding to cover all capital costs
- Farm has live-on ranch hands to reduce annual labor costs
- Energy offset by the digester will replace the annual energy input cost
- Digestate will be used onsite as fertilizer year-round

The payback period was not calculated as it would not have been feasible due to annual costs outweighing the value. This is one reason why small scale-digesters are not as common as large industrial sized ones.

Select References

1. Eze, J., Ofoefule, A., Onwuka, N., & Uzodinma, E. (2007). Optimum mesophilic temperature of biogas production from blends of agro-based wastes. *Trends in Applied Sciences Research, 2, 39-44.* 10.3923/tasr.2007.39.44
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3. USDA. (2017). *Conservation Practice Standard Anaerobic Digester Code 366.* https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcseprd1335265&ext=pdf