Feasibility Study of an On-Campus Anaerobic Digester

Duke UNIVERSITY | BASS CONNECTIONS

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Bass Connections in Energy & Environment

Background & Objectives

- New waste management methods are needed for Duke University to achieve the objectives set forth in the Duke Climate Commitment.
- Duke's 2024 Carbon Neutrality goal currently relies on carbon offsets to mitigate 25% of its emissions from the 2007 baseline[1].
- Anaerobic digestion (AD) takes advantage of bacteria to transform food waste into energy.
- AD has three main benefits:

Waste Management

GHG Emissions

Natural Gas Offsets

- Build two iterative low-budget prototype anaerobic digesters to generate methane from Duke's food waste.
- Compare relative methane production rates over time with different feedstocks.
- Examine benefits of using generated methane to offset natural gas usage for building heating via two separate scenarios.

Methods

Biogas Analysis

- Three separate samples (Marketplace food waste, food waste + cow manure, and food waste + Duke Campus Farm compost) were digested in a prototype AD (shown in Figure 1).
- Biogas volumes and samples were collected during a period of three weeks. PPM values of methane and carbon dioxide in the biogas were determined using Gas Chromatography.

Energy and Economic Analysis

- *Bottom-up analysis*: We calculated the energy content in one pound of steam used to heat buildings on campus, accounting for boiler efficiency. Then, we calculated the equivalent volume of methane from an AD required to meet the steam demand of any given building on campus.

$$\text{Food Waste Needed (Tons)} = \frac{\text{Methane Used By Boiler}}{\text{Methane Per Ton of Food Waste}} = \frac{\text{Natural Gas Used x Natural Gas Percent Methane}}{\text{Biogas Produced Per Ton Food Waste x Biogas Percent Methane}}$$

Equation 1: Conversion from food waste weights to volumes of natural gas

- *Top-down analysis*: We calculated the amount of food waste that would be required to run a boiler in the West Campus Steam Plant (WCSP).

$$\frac{Ft^3\text{ Methane}}{Ft^3\text{ Biogas}} \cdot \frac{Ft^3\text{ Biogas}}{\text{Ton of Food Waste}} = \frac{Ft^3\text{ Methane}}{\text{Ton of Food Waste}}$$

$$Ft^3\text{ Methane needed to run WCSP for a month} \cdot \frac{\text{Ton of Food Waste}}{Ft^3\text{ Methane}} = \text{Tons food waste needed to run WCSP for month}$$

Equation 2: Conversion from food waste weights to volumes of natural gas

Prototypes and Results

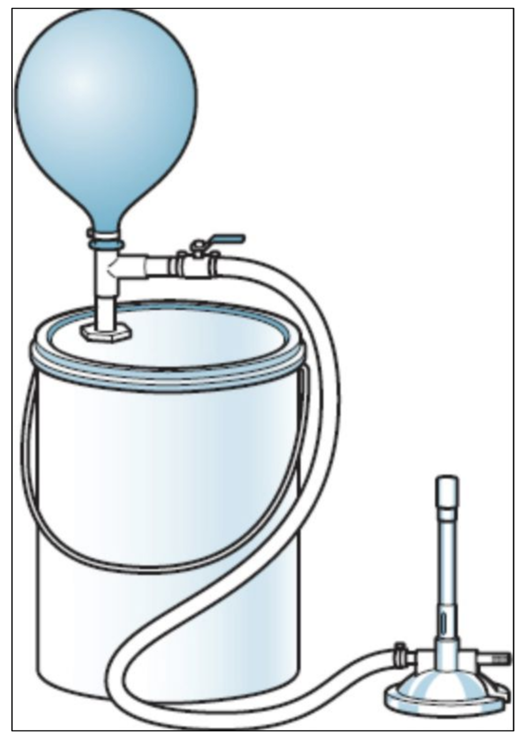


Figure 1: First prototype[2]

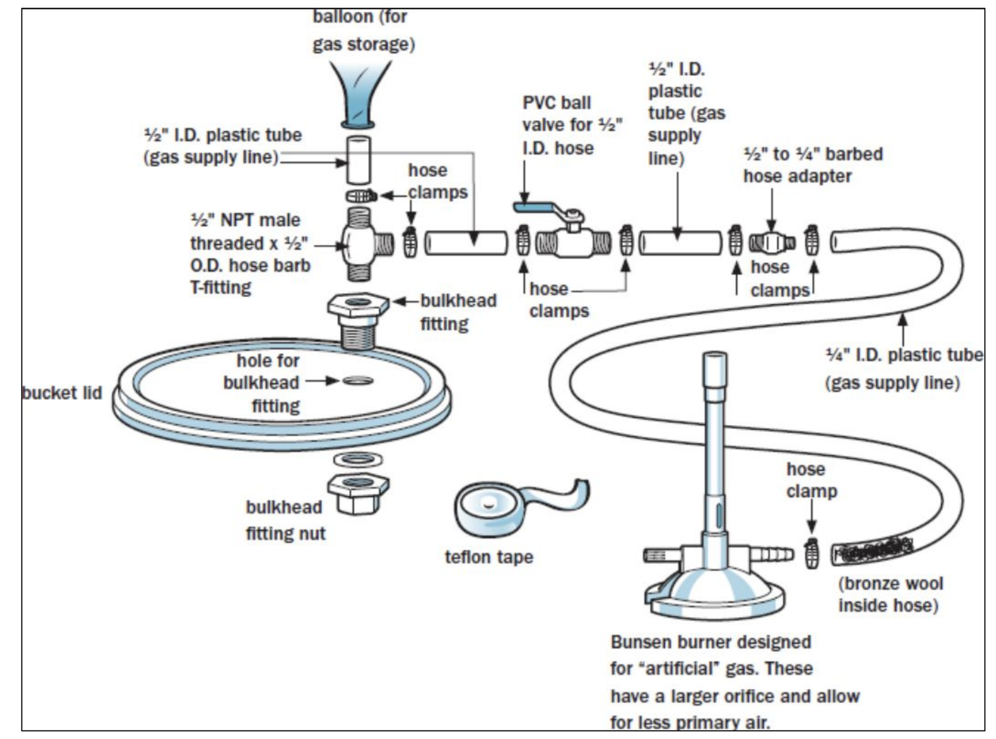


Figure 2: Hose fittings[2]

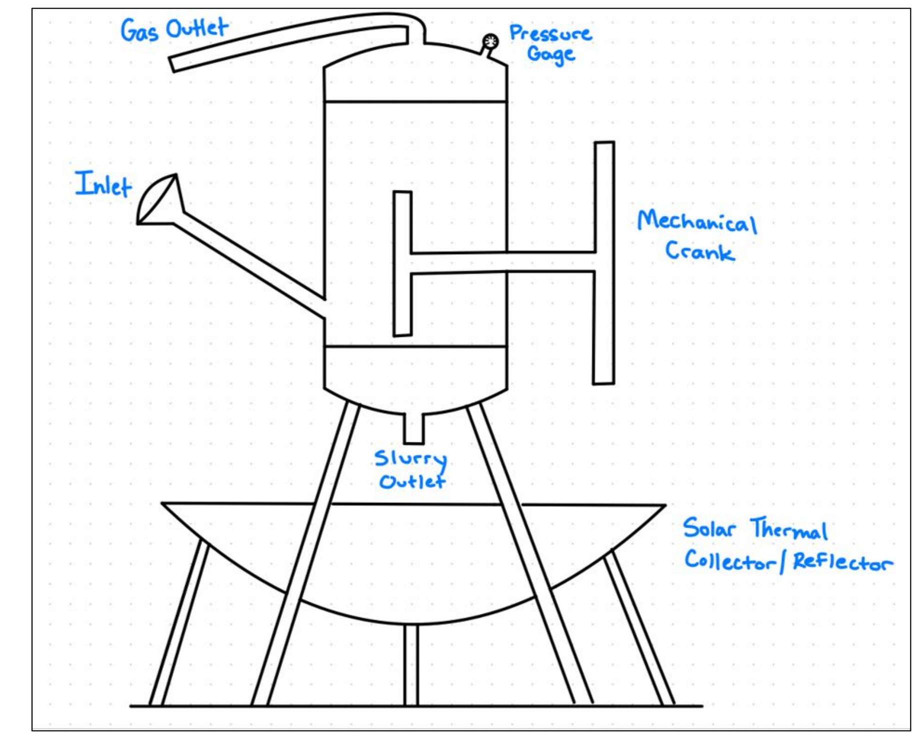
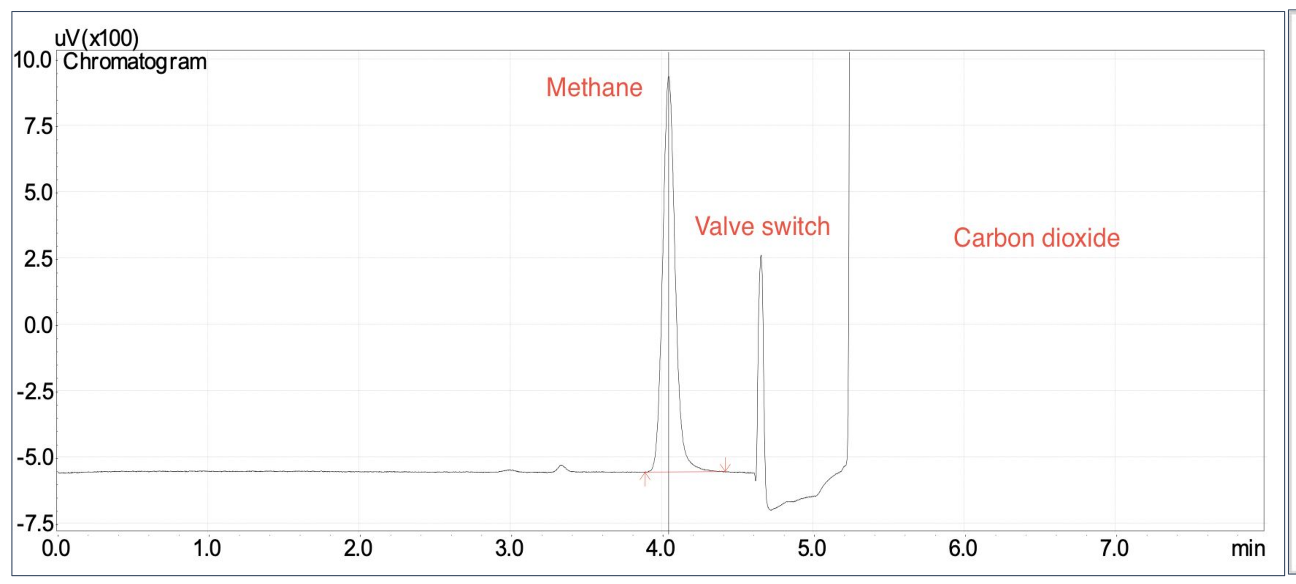
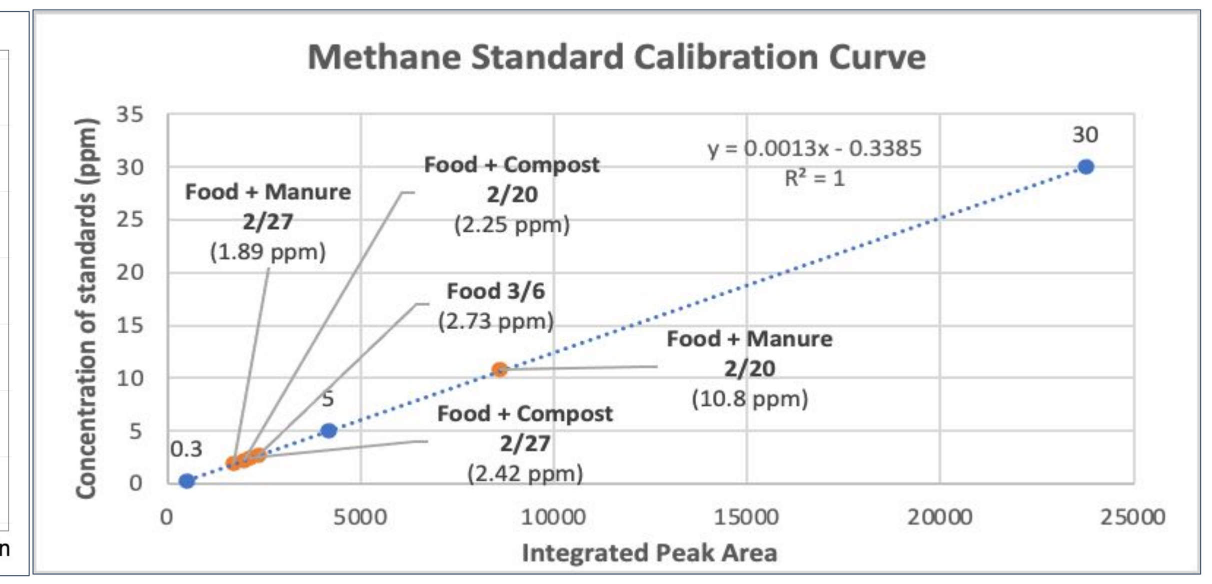


Figure 3: Final prototype design



Graph 1: Biogas analysis results



Graph 2: Methane standard calibration curve with 3 standards (blue) and samples (orange)

Scenarios

Scenario One: Bottom-Up Analysis

Use Estimates of Duke's Food Waste to Size an Anaerobic Digester to Meet the Steam Demand of Specific Buildings on Campus

Three different waste amounts:

1) CompostNow: **288 tons per year**
2) Duke Office of Sustainability: **659 tons per year**
3) The arithmetic average: **474 tons per year**

Steam Production from Proposed AD		Methane composition of biogas		
		50%	65%	75%
Biogas evolved/ton of food waste (CCF)	70.6	**1.15**	1.49	1.72
	123.6	2.01	**2.61**	3.01
	159	2.58	3.35	**3.87**

Table 1: Sensitivity of steam production (in million pounds) for medium-waste scenario (474 tons)

Steam-equivalent weights produced by methane allows for comparison of buildings whose annual heating requirements can be met with the digester biogas production:

- Nasher Museum: 2.51 million lbs of steam
- Jordan Building (Duke Police Dept): 60,600 lbs of steam

Project NPV (Bottom-up)		CAPEX Scenarios		
		Low	Medium	High
Gas Production Scenarios	Low	$40,773	-$114,355	-$269,575
	Medium	$57,496	-$86,857	-$231,339
	High	$74,219	-$59,359	-$193,102

Table 3: Net present value of anaerobic digester based on bottom-up assumptions

Scenario Two: Top-Down Analysis

Use Amount of Energy Required for a Steam Boiler in WCSP to Estimate Digester Size & Food Waste Requirements

The average West Campus Steam Plant natural gas powered boiler has an annual consumption of **315,000 CCF Natural Gas**, which is **302,400 CCF** of methane.

Food Waste Needed to Run One WCSP Boiler		Methane composition of biogas		
		50%	62.5%	75%
Biogas evolved/ton of food waste (CCF)	70.6	**108**	87	72
	123.6	66	**53**	44
	159	48	38	**31**

Table 2: Food waste needed to produce the natural gas equivalent used by one WCSP boiler annually (thousand tons)

- Top-down CAPEX was calculated based on the size of the AD needed to process the necessary amount of food waste.
- Generated biogas can be cofired with natural gas to improve reliability.

Project NPV (Top-down)	CAPEX Scenarios		
	Low	Medium	High
Baseline (378MN ft^3/yr)	$17.72M	-$3.74M	-$13.31M

Table 4: Net present value of anaerobic digester based on top-down assumptions

Economic, Environmental, and Location Analyses

Economic Analysis:

- A positive NPV is possible for both bottom-up and top-down scenarios, but only for a small CAPEX.
- Grants and tax credits can be leveraged to reduce capital costs.
- The analysis did not account for intangible benefits of an AD.

Environmental Analysis:

- Using the EPA Waste Reduction Model, from the bottom-up scenario with 474 tons of food waste, Duke's net CO_2 emissions decrease by 165 $MTCO_2$.
- From the top-down scenario, Duke's net CO_2 emissions decrease by 23,056 $MTCO_2$.

Location Analysis:

- The optimal location for an AD is central campus
- Central campus has undeveloped open space and is close to the identified loads of the Nasher Museum and the Jordan Building (Duke Police Station).

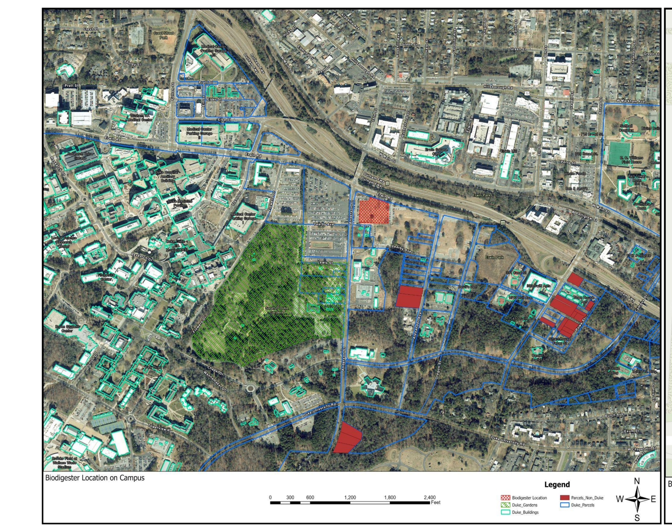


Figure 4: AD Location on Campus

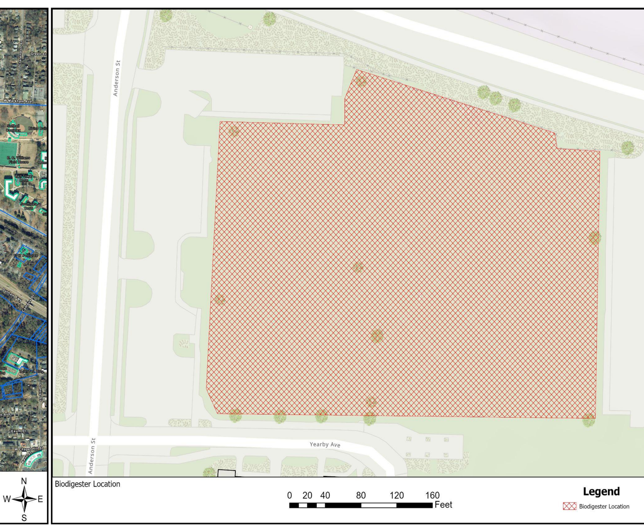


Figure 5: AD Location (Close Up)

Conclusion

- Duke can feasibly implement an anaerobic digester on central campus to heat the Nasher Museum and the Jordan Building from Duke's food waste.
- Duke could avoid annual emissions of 165 tons of CO_2 equivalent by sending all food waste generated on campus into an anaerobic digester.
- An AD feedstock of food waste + manure yielded 4x as much methane compared to only food waste, but methane production decreased rapidly because prototype 1 lacked mixing, heating, and feedstock replenishment capabilities.
- While expensive, an AD can provide intangible benefits, such as class learning module integration, research opportunities, the Campus-as-Lab initiative, and jobs for Durham residents.
- An AD on Duke's campus can serve as a model for projects around the country and drive change for more sustainable use of organic waste.

References

1. Emissions and offsets. Sustainability. (n.d.). Retrieved March 27, 2023, from https://sustainability.duke.edu/about/ssp2021/emissions-and-offsets
2. Scheckel, P. (2013). *The homeowner's energy handbook: Your guide to getting off the grid*. Storey Publishing.