Department of Biosystems and Agricultural Engineering
MICHIGAN STATE UNIVERSITY

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Biosystems Design Projects

Evaluating the Feasibility of Corn Stover-Manure Anaerobic Digestion (Under NDA)

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Background

Anaerobic Digestion (AD)

- Microbes decompose waste in a tank without oxygen
- Produces renewable natural gas, composed of CH_4, CO_2, and H_2S

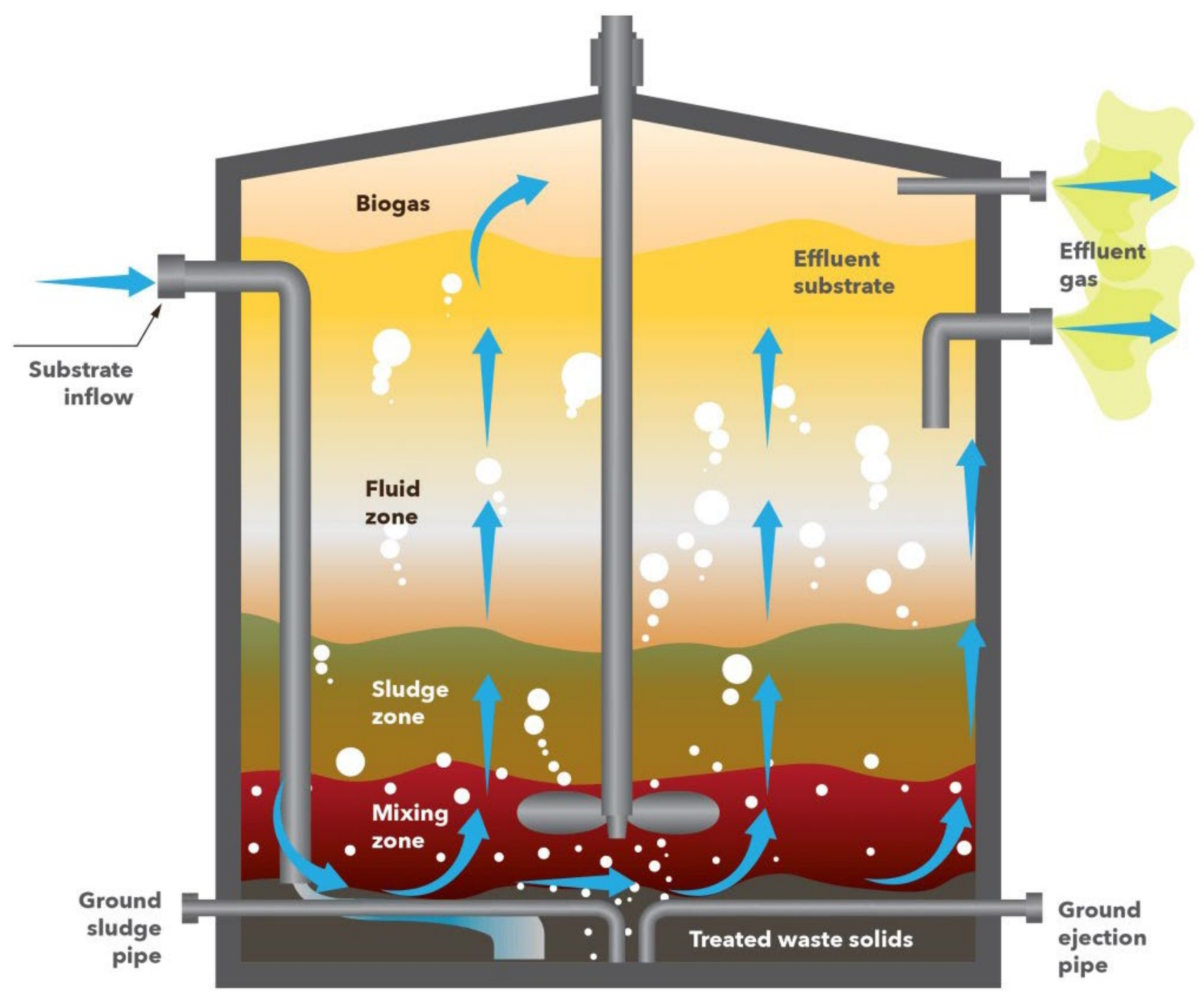

Fig 1. Anaerobic digestion process[2]

Feedstock for AD

- Current Consumers Energy AD site uses dairy manure as a feedstock
- Our project considers a 50-50 manure corn stover mixture as a feedstock
- Aims to increase biogas production and decrease carbon footprint

Corn stover

- Leftover residue after corn is harvested
- Composed of cellulose, hemicellulose, and lignin
- Difficult and time-consuming for bacteria to break down

Fig 2. Corn stover[4]

Problem Statement

There is a need for a technically and economically feasible method to convert excess corn stover in Michigan into renewable natural gas (RNG) while maximizing the profitability of its by-products.

Objectives

- Energy cost ≤ $50/MMBtu
- CO_2 equivalent emissions ≤ 0
- Return on investment (ROI) ≥ 10%

Constraints

- Site location ≤ 15 miles from Consumers Energy natural gas pipelines
- Methane yield ≥ XXX MMBtu/yr
- Temporal horizon = 25 years
- Project completed by May 2026
- Spend ≤ $1,000 for study

Site Location

The team decided on a site location that is North of Lansing about 0.5 miles from a Consumers Energy main pipeline. Figure 3 below shows the site on a Michigan map.

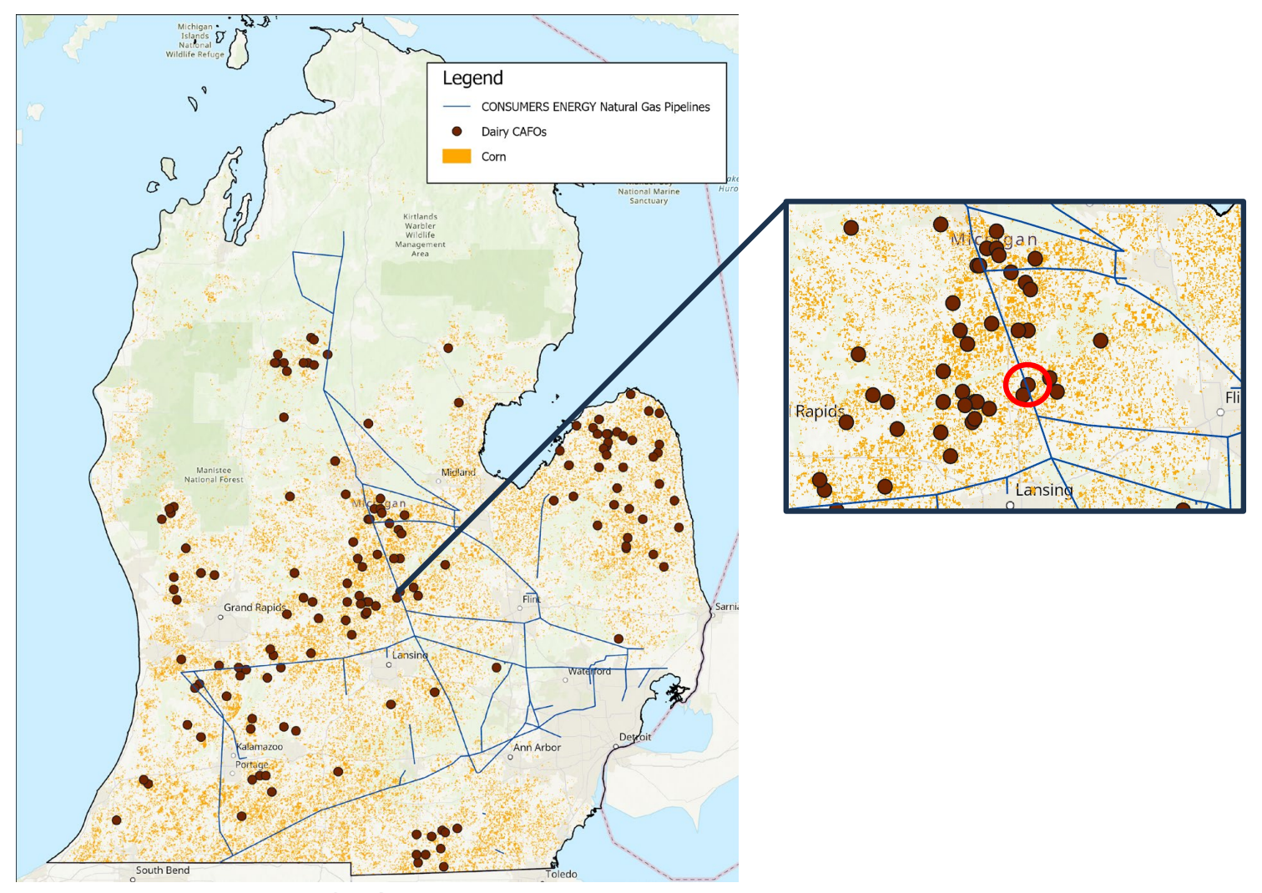

Fig 3. Map of Consumers Energy main pipelines, corn croplands, and dairy CAFOs in Michigan[1]

Lab Experimentation

Experimental Setup

- Bench-scale AD at MSU ADREC
- Manure vs. 50:50 manure-corn stover
- Mesophilic (~35°C), CSTR, 23-day HRT.

Fig 4. Reactor system setup

Data Collection & Analysis

- Daily biogas + CH_4 composition analyzed to determine methane fraction
- Methane production and CCE calculated

Key Findings

- Co-digestion increased biogas production (~410 vs. ~308 mL/day)
- Manure increased CH_4 (~60% vs. ~52%)
- CCE: 48.5% (manure) vs. 41.9% (mixed)
- Tradeoff: yield vs. efficiency

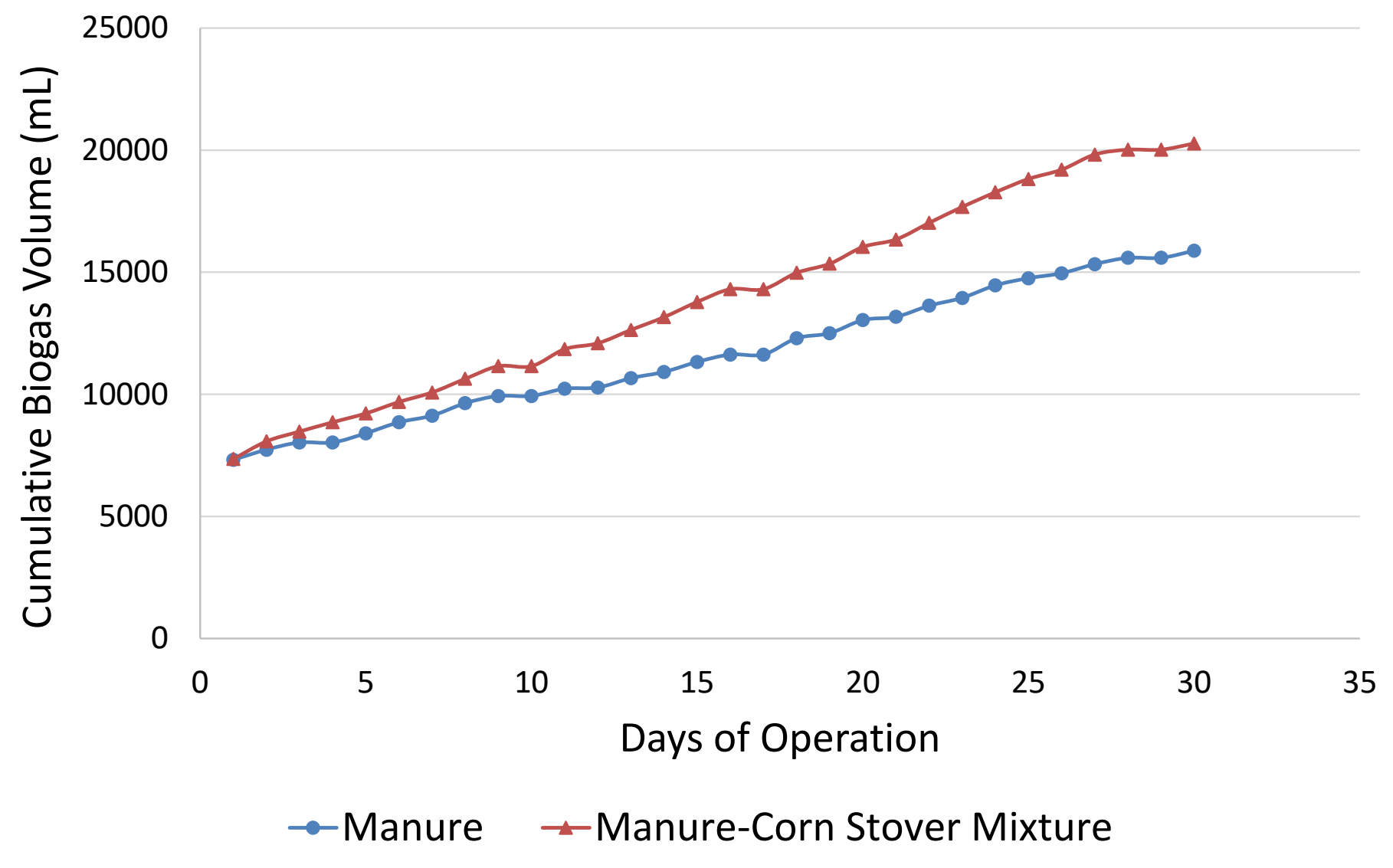

Fig 5. Cumulative biogas production for manure and manure-corn stover systems

Life Cycle Assessment

Process Flow Diagram

- The cradle-to-grave movements of mass flows in each digestion system is shown in Figure 6
- The green boxes indicate the additional steps necessary for the mixed digester compared to a manure-only digester
- The blue dashed line indicates the system boundary to where the greenhouse gas emissions were considered

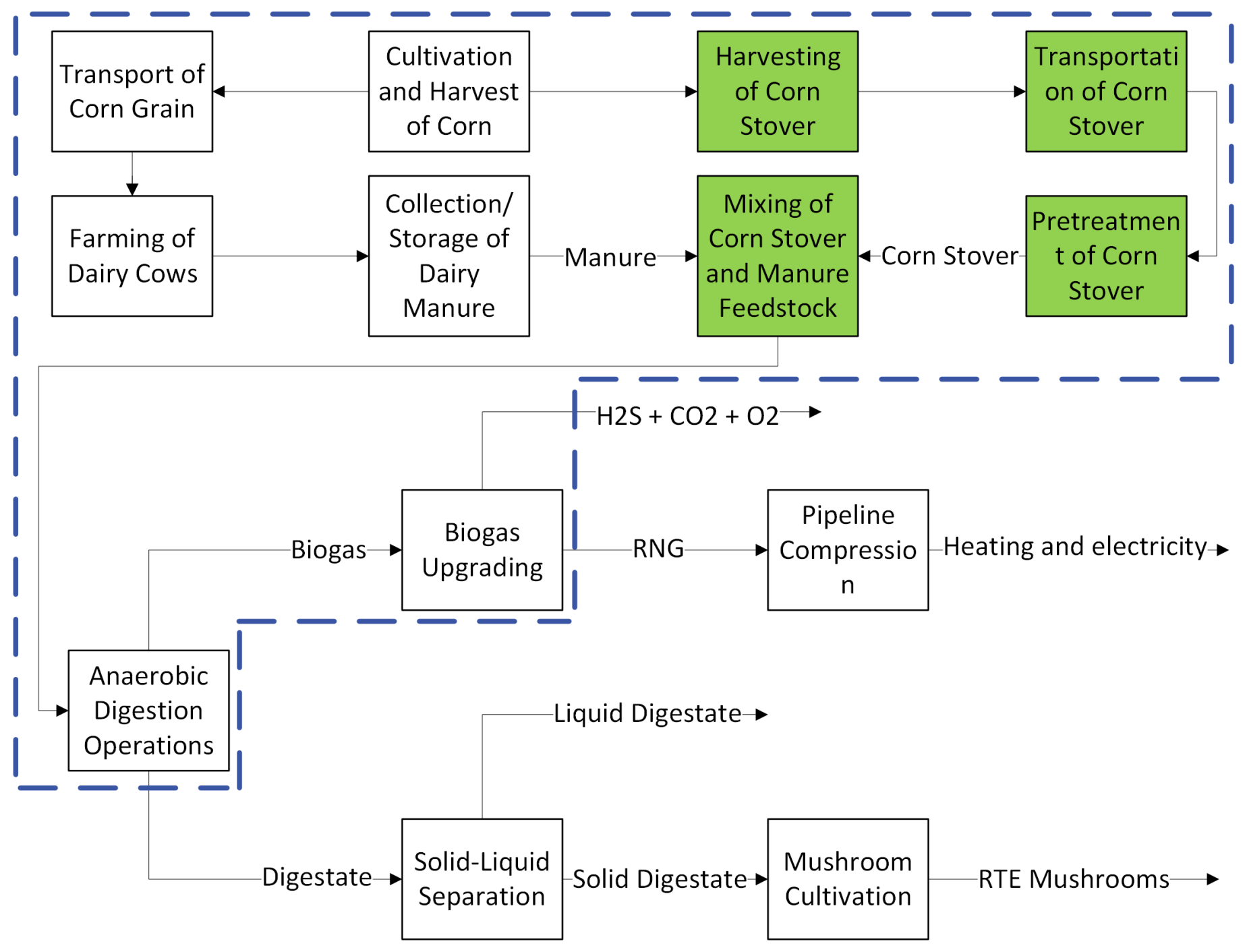

Fig 6. Process flow diagram showing cradle to grave movement of mass flows

Life Cycle Assessment (LCA)

- Shows where emissions are coming from in the RNG system
- Helps compare manure-only vs. manure-corn stover options
- Set dairy manure-only and dairy manure-corn stover systems equal in terms of RNG produced
- **Functional Unit:** MMBtu/yr

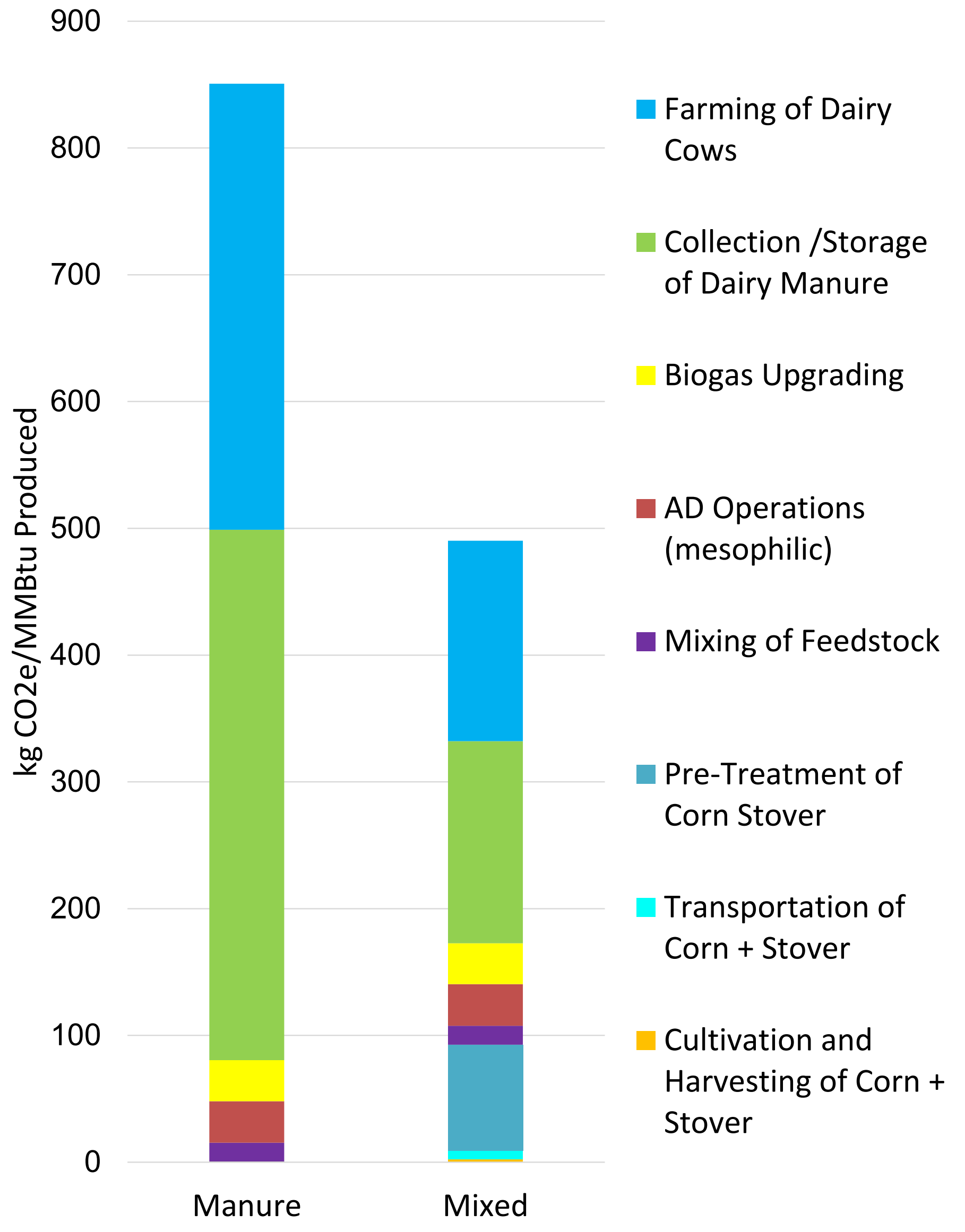

Fig 7. Global warming impact assessment between manure-only and mixed AD systems

Economic Analysis

- The total capital investment was determined from the cost of the capital equipment (Table 1)
- The annual production cost was projected based on the annual costs of raw materials, labor, and utilities (Table 1)

Table 1. Summary annual and investment costs

Metric	Corn Stover + Dairy Manure	Dairy Manure only
Capital Equipment Cost ($)	$21,706,250	$21,615,520
Total Capital Investment ($)	$65,362,947	$65,089,737
Annual Raw Materials, Labor, and Utilities ($)	$5,960,660	$2,624,040
Annual Production Cost ($)	$11,422,300	$8,963,581
Annual Production Cost after Green Credits Applied ($)	$7,021,106	$5,518,136

- In Table 2 the main economic indicators were calculated by setting the internal rate of return of each system equal to 10%
- The following assumptions were made:
  - Time Horizon = 10 years
  - IRR = 10%
  - Discount Rate = 8%

Table 2. Summary economic indicators calculated from the techno-economic assessment

Metric	Corn Stover + Dairy Manure	Dairy Manure only
NPV ($)	$10,735,577	$10,690,671
ROI (%)	9.83%	9.83%
Payback Period (years)	8.3	8.3
Energy Selling Price ($/MMBtu)	$158	$143

By-Product Designs

These were considered for future work:

1. Fertilizer
   - Digestate is rich in N, P, and K to support crop growth
   - Widely adopted in agriculture
2. Fiber bedding
   - Solid digestate dried for cattle bedding
   - Already in practice at Consumer's Energy AD sites
3. Liquid CO_2
   - Capture liquid CO_2 during biogas upgrading and purify to food-grade
   - Technology is still developing, not market-ready
4. Substrate for mushrooms
   - Solid digestate supports mushroom growth
   - High value food product

Selected Design

Table 3. Decision matrix for potential profitable by-product designs

Factor	Profit	GHG Emissions	Tech readiness	Market readiness	Safety	Total
Weight of factor (%)	30	25	20	15	10	100
Fertilizer	7	4	10	10	8	7.40
Fiber bedding	2	4	10	9	8	5.75
Liquid CO_2	7	8	8	6	3	7.30
Mushrooms	9	10	6	7	7	8.15

Based off the decision matrix in Table 3, the team selected **Mushrooms** as the most profitable by-product design.

- Solid digestate is rich in nitrogen and phosphorus
- Requires specialized processing and pathogen control to convert to substrate
- High-value food product: ~$20/lb

Converting digestate to mushroom substrate:

1. Solid digestate must be filtered to remove large debris
2. Add water to obtain a humidity content ~75%
3. Pasteurization: 72-74 °C steam treatment
4. Cooling though High Efficiency Particle Air (HEPA) filters
5. Inoculation with *P. ostreatus*

Fig 8. Full-scale mushroom cultivation[5]

Mushrooms can be further processed into fungal meat, an alternative to beef products that can reduce GHG by 98% compared to beef (42.7 kg CO_2e/kg vs 0.73 kg CO_2e/kg)[3]

Select References

[1] Michigan Public Service Commission. (2025). *Natural Gas Pipelines* [Photograph]. Arcgis.com. https://data-michiganpsc.hub.arcgis.com/pages/f2243010ee27403c9f66aef98bb99dc3

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[3] Putman, B., Rotz, A., & Thoma, G. (2023). A comprehensive environmental assessment of beef production and consumption in the United States. *Journal of Cleaner Production, 412*, 137002. https://doi.org/10.1016/j.jclepro.2023.136766

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[5] Zuffi, V., Puliga, F., Zambonelli, A., Trincone, L., Sanchez-Cortes, S., & Ornella Francioso. (2023). Sustainable Management of Anaerobic Digestate: From Biogas Plant to Full-Scale Cultivation of Pleurotus ostreatus. *Agronomy*, *13*(4). https://doi.org/10.3390/agronomy13040950