Department of Biosystems and Agricultural Engineering
MICHIGAN STATE UNIVERSITY

BE 487 - Spring 2025
Biosystems Design Projects

Developing a Calculation Tool to Estimate Carbon Intensity of Renewable Natural Gas Production from Dairy Manure (Under NDA)

Jakob Harper, Ellen Mayes, Tushar Mukkatira, and Collin Neal
Client: Consumers Energy Faculty Advisor: Dr. Daniel Uyeh

Background

Consumers Energy is establishing additional partnerships with Michigan dairy farmers. Dairy manure can be used to generate renewable natural gas (RNG) through anaerobic digestion. Producing RNG from dairy manure can have significantly negative carbon intensity (CI) scores, which indicates a reduction in greenhouse gas emissions (GHG).

What is renewable natural gas?

RNG is gas produced from decomposing organic material that has been upgraded to a higher methane percentage. It is fully interchangeable with conventional natural gas infrastructure and machinery.

What is a carbon intensity score?

CI is a measure of GHG emissions associated with the production and burning of a fuel source, measured in gCO_2e/MJ.

Problem Statement:

Consumers Energy project strategists want a user-friendly calculator to estimate RNG production and associated CI score at dairy farms in Michigan. These values help them decide to pursue an RNG project (Figure 1). Previously, outside consultants were hired which was time consuming and costly.

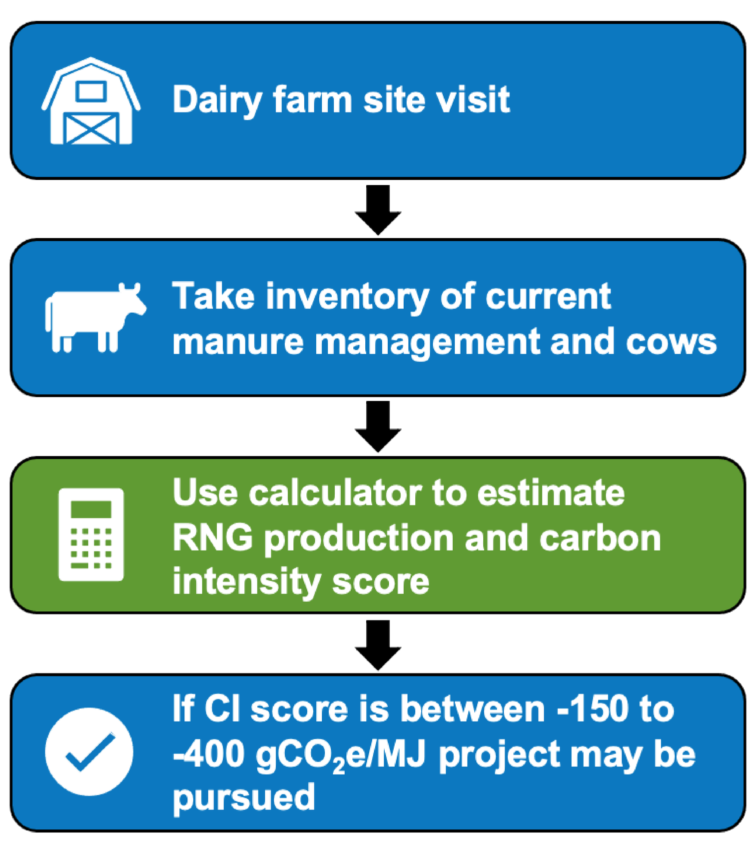

Figure 1: Updated Project Procurement Process.

Motivation:

- Net zero methane emissions by 2030
- Net zero GHG emissions by 2050
- Significant methane emissions from dairy farming, see Figure 2

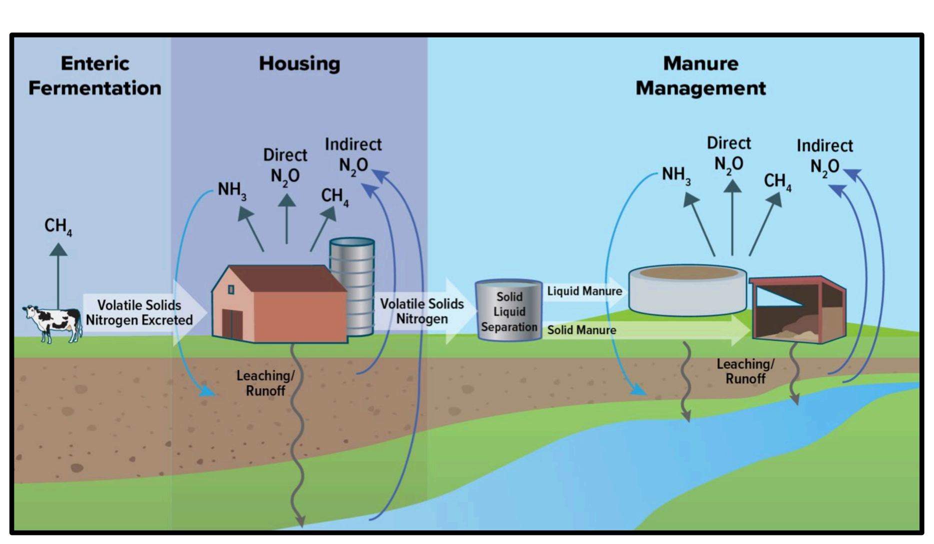

Figure 2: Methane Emission Sources on Dairy Farms [1].

Objectives

- Output RNG production in MMBTU and MJ and CI score in gCO_2e/MJ
- Survey Consumers Energy team to assess ease of use of calculator, continue iterative design until a minimum usability rating of 4/5 is achieved
- Provide user manual to aid future use and updates of reference data

Constraints

- Must utilize the GREET model
- Anaerobic digestion must be on-site in an enclosed vessel
- Feedstock type must be dairy manure
- Farms must have a minimum number of 3,500 cows/farm

Design Alternatives

I. Excel sheet modified with VBA (Selected)
II. App for data collection and Excel sheet for calculation
III. Website for data collection and calculation

Model

The model consists of 14 Excel sheets. Within these sheets the emissions for the business-as-usual (BAU) scenario and the new scenario are calculated. Emissions are calculated using equations from the USDA handbook and new methodology from the Mangino EPA report (Table 1). The avoided diesel emissions are calculated and added to the BAU emissions. The RNG production potential is calculated in the model using equations and reference data from the R&D GREET model (Table 1).

Table 1: Key Equations in the Model.

Key Equations	
Methane Emissions [1]	$CH_4 = VS \times (\frac{100\% - \%VS}{100}) \times B_O \times 0.67 \times \frac{MCF}{100}$
Van't Hoff Arrhenius [2]	$f = \exp[\frac{E(T_2 - T_1)}{RT_1T_2}]$
Renewable Natural Gas [3]	$RNG = (\frac{Raw\ Biogas \times lb2g}{p}) \times C \times BTU2mmBTU \times (\frac{100\% - L}{100\%})$
Carbon Intensity	$CI = \frac{New\ Scenario\ Emissions - Business\ as\ Usual\ Emissions}{RNG}$

User Interface

The user interface (UI) requires 9 inputs and is pre-filled with the average weight of each cow type (Figure 3). Help buttons provide more information behind each input. The solid-liquid separation system can be customized by inputting the separation efficiency in the event a new system becomes available. Each calculation's input and output is stored within a submission log. The CI output is guided by a color code in Table 2.

Table 2: CI Color Code Ranges.

CI Score Range	Color Code
0 to -29	Red (Undesirable)
-30 to -150	Yellow (Ok)
-151 to -400	Green (Ideal)
Above 0 or Less Than -400	Grey (Unrealistic)

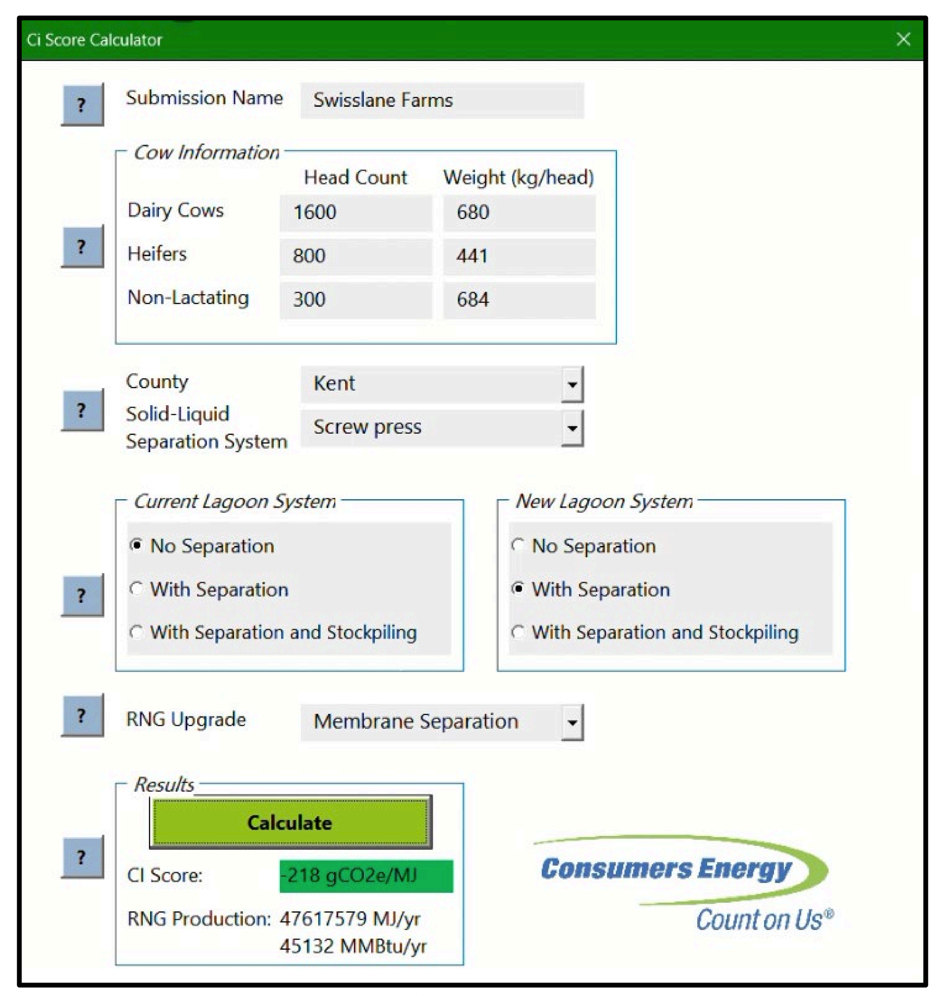

Figure 3: User Interface Input Form.

Case Study

To demonstrate the capabilities of the calculator a case study of the Swisslane/Alto Farm was performed. The input values are found in Figure 3.

To model emissions the business-as-usual scenario describes the current manure management practice at the farm. The new scenario details the new manure management strategy the farm will use when an anaerobic digester is installed. These management choices effect emissions. The scenarios for Swisslane/Alto Farm are shown in Figure 4.

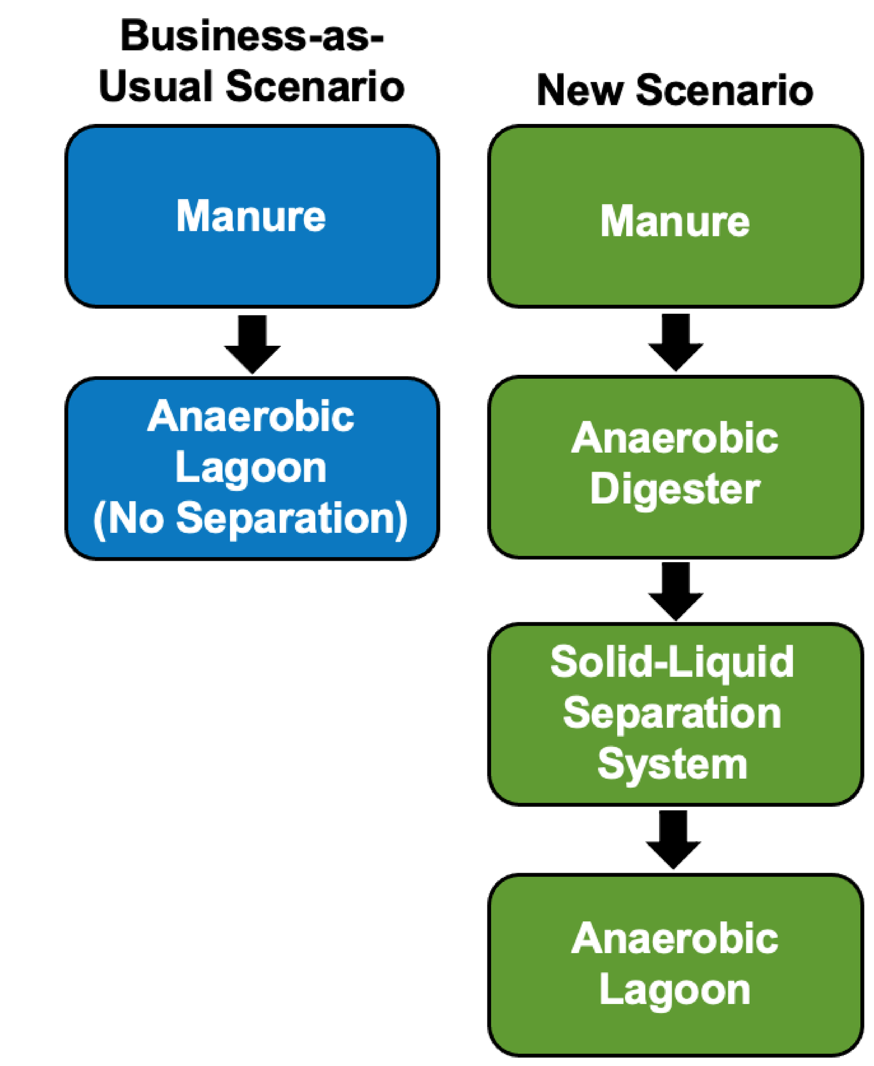

Figure 4: BAU and New Scenario for the Swisslane/Alto Farm.

Results

The comparison between our model's CI and RNG values and the consultants' values for 3 different farms are shown in Table 3.

Table 3: Comparison of Results.

Location	Our Results	Prior Results
Swisslane/Alto Farm	CI: -218 gCO_2e/MJ	CI: -384 gCO_2e/MJ
	RNG: 45,132 MMBTU/yr	RNG: 47,348 MMBTU/yr
Farm A	CI: -213 gCO_2e/MJ	CI: -244 gCO_2e/MJ
	RNG: 145,084 MMBTU/yr	RNG: 168,346 MMBTU/yr
Farm B	CI: -216 gCO_2e/MJ	CI: -399 gCO_2e/MJ
	RNG: 157,584 MMBTU/yr	RNG: 134,685 MMBTU/yr

The difference in values is a result of a difference in scope and calculation methodology. Our model calculates the VS rate on a daily basis. This means the manure in the lagoon at any given day within the model year is calculated. However, the report done by the consultants, utilized a common approach of using an estimated value of volatile solids for an entire year. This yearly method is less precise than the daily approach of our model. Our method also included the use of the Van't Hoff Arrhenius equation to account for changes in microbial activity due to temperature variations throughout the year.

Economics

Consumers Energy pays approximately \$20,000-\$25,000 every time they hire an outside consultant to provide estimates on a potential project. The calculator was estimated to cost \$3,847/year (Table 4).

Table 4: One Year Product Life-Cycle.

One Year Product Life-Cycle	
Rate of Pay	\$48.08/hr
Hours Worked	80 hours
Total Cost	\$3,847

The calculator can save Consumers Energy tens of thousands of dollars by helping them avoid hiring outside consultants, when the estimates from the calculator shows a potential project is clearly unfeasible.

Conclusion

The team created a calculator to aid the decision process to pursue RNG project for Consumers Energy project strategists. The calculated CI score can assist in ruling out projects that are not feasible and save money on outside consulting fees. Further research should be conducted to verify the next generation calculation model used in this design.

Acknowledgements

The team would like to thank Timothy Joyce, Andrew Stoops, Dustin Wood, Dr. Wei Liao, Dr. Daniel Uyeh, Dr. Luke Reese, and Dr. Sanghyup Jeong.

Select References

[1] Leytem, A.B., S. Archibeque, N.A. Cole, S. Gunter, A. Hristov, K.Johnson, E. Kebreab, R. Kohn, W. Liao, C. Toureene, J. Tricarico. (2024). Chapter 4: Quantifying greenhouse gas sources and sinks in animal production systems. U.S. Department of Agriculture. https://www.usda.gov/sites/default/files/documents/USDA-Methods-Report-Chapter- 4.pdf

[2] Mangino, J., Bartram, D., & Brazy, A., (2001). Development of a methane conversion factor to estimate emissions from animal waste lagoons. United States Environmental Protection Agency. https://www3.epa.gov/ttnchie1/conference/ei11/ammonia/mangino.pdf

[3] Wang, M., Elgowainy, A., Lu, Z., Baek, K., Balchandani, S., Benavides, P., Burnham, A., Cai, H., Chen, P., Gan, Y., Gracida-Alvarez, U., Hawkins, T., Huang, T., Iyer, R., Kar, S., Kelly, J., Kim, T., Kolodziej, C., Lee, K., ... Zhang, J. (2023). Greenhouse gases, regulated emissions, and energy use in technologies model ® (2023 .Net). USDOE Office of Energy Efficiency and Renewable Energy (EERE). https://doi.org/10.11578/GREET-Net-2023/dc.20230907.2