Economic Feasibility of Co-Digestion of Manure and Food Waste on a Northern NY Dairy:

Scenario II Case Study

December 2022

Contents

Scenario II Overview

Scenario II of the Co-Digestion of Manure and Food Waste on a Northern NY Dairy Case Study focuses on the anaerobic digestion (AD) of manure and food waste using a 50:50 percent by volume ratio. This case study provides an economic feasibility analysis of adding a new anaerobic digester system to a dairy farm processing the dairy's manure with an equal amount of food waste from local sources and producing renewable natural gas (RNG) from the biogas. The annual benefits are compared to the capital and operating costs of the project and the net present value (NPV) calculated for a 15-year term.

Farm System

Scenario II is modeled using a hypothetical farm with the same herd size and location in Northern New York as Scenario I, but with no existing anaerobic digester to analyze the economic impact of installing a new manure and food waste co-digestion system. The farm's lactating cows and replacement heifers equal approximately 1,860 lactating cow equivalents (LCE) on a mass of volatile solids (VS) basis. It is assumed that the farm beds with sawdust/wood shavings and stores the scraped manure from the barns in multiple long-term storage pits for field application in the spring and fall. The farm operates over 3,500 acres of land used for growing both corn and forages.

Anaerobic Digester System

The anaerobic digester is a complete mix, mesophilic system with a flexible membrane cover. The digester volume is approximately 1.7 million gallons to process the 31,280 gallons per day of manure with an equal amount by volume of total mixed food waste, using a design hydraulic retention time (HRT) of 25 days.

The biogas produced by the digester is converted to RNG by the onsite biogas purification equipment that removes hydrogen sulfide (H_2S), water vapor, carbon dioxide (CO_2), and other impurities, resulting in concentrated methane suitable for pipeline injection. The RNG is inserted into the gas pipeline at the digester site, which is possible due to an existing natural gas pipeline adjacent to the farm. The digester is heated using a biogas boiler system that heats a closed water loop and maintains the digester temperature at 100 degrees Fahrenheit.

Co-digesting food waste with manure has been known to improve digester organism performance, resulting in more complete digestion of the contents that leads to decreased solids recovery of the effluent. We assumed that there would not be enough solids post-digestion to separate for bedding with the co-digestion of large volumes of food waste that equal the manure volume. For this reason, we did not include solid-liquid separation as a part of the digester system and assumed the farm would continue to purchase bedding. Table 1 provides a summary of the key information about the farm and the anaerobic digester system.

Table 1. Farm and anaerobic digester system information.

Number of cows	1,860 lactating cow equivalents
Digester type	Complete mix
Digester volume	1.7 million gallons
Digester temperature	100 degrees F
Influent	Raw manure, milking parlor wash water, food waste
Stall bedding material	Sawdust / wood shavings
Solid-liquid separation	None
Biogas utilization	Upgraded to renewable natural gas (RNG)

Food Waste Sources, Selection, and Equipment

Food waste sources were identified in part by utilizing the New York State Pollution Prevention Institute's Organic Resource Locator[1], a web-based tool to aid organic waste producers in connecting with potential organic waste recyclers. The filter tool provided by the Organic Resource Locator was used to show only organic waste from food and beverage manufacturers located in the Northern NY region and within a reasonable radius of the case farm to minimize contaminants that are common in post-consumer food waste.

After applying the location and food waste type filters, we determined that cheese whey, bakery waste, and meat waste were three available waste types to model. In the food waste selection, packaged food waste was avoided so that de-packaging equipment would not be needed. De-packaging equipment is a significant capital and operating expense that needs careful assessment for the potentially higher tipping fee value that accepting packaged food waste can bring.

A previous assessment of a local cheese plant by Clarkson University[2] determined that the daily volume of cheese whey available is 8,700 gallons. The bakery waste and meat waste were then estimated in equal amounts to achieve a 50:50 manure to total food waste ratio. The daily amounts of each feedstock added to the digester are shown below in Table 2.

Table 2. Daily digester feedstock volumes and mass.

Digester feedstock[a]	Daily volume (gal)	Daily mass (kg)
Manure	31,280	118,400
Wash water	5,010	18,960
Cheese whey	8,700	32,930
Bakery waste	11,290	42,740
Meat waste	11,290	42,740
Daily total	**67,570**	**255,770**

The food waste is delivered every day by trucks to the farm. There are two 5,000 cu-ft (37,400 gal) inground reception tanks to hold the food waste until it is pumped into the digester at a prescribed rate. The bakery waste and meat waste are expected to have higher solids content requiring use of a macerator after reception and prior to entering the digester. Each of the reception tanks contains a 15-hp mixer to agitate the contents and a 10-hp pump to transfer the contents to the digester. Approximately 380 ft of piping from the reception pits to the digester is included in the cost analysis. Drive over truck scales and a new 500 ft access road are included to measure the weight of the food waste on each truck load and allow for unloading to the reception tanks.

Biogas Production and Energy Generation

The Cornell Manure-based Anaerobic Digester Simulation Tool (herein referred to as the *Cornell AD Tool*) was used to estimate biogas production from the selected digester feedstocks for scenario II. The Cornell AD Tool contains a library of organic wastes and the estimated biogas yield associated with each, based on the volatile solids (VS) content and either a typical laboratory analysis or use of the Buswell equation. Biogas production estimates were made by adding the individual feedstock biogas yield values, assuming the anaerobic digester is operating at steady state with an HRT of about 25 days (Table 3). Interactions between the various feedstocks may impact the actual biogas and methane yields from anaerobic digestion. Potential for increased biogas above the sum of each individual feedstock is likely in a co-digestion system[3].

[a] Manure volumes estimated using ASABE Standard. Milking center wash water volume estimated by owner of a similarly sized and operated farm.

Table 3. Individual digester feedstock characteristics and estimated biogas production.

Digester feedstock	Dry matter / Total solids (%)	Volatile solids (%)	Biogas yield	Biogas production (cfm)
Dairy manure (with wash water)	L.C. 13.1, H. 16.8[4]	12.1[b]	79 cf/LCE[5]	102
Cheese whey	5.7	5.1	8 cf/LCE, for 10% VS ratio w/ manure[5]	10
Meat waste	18.2[c]	17.5	972 L/kg VS	178
Bakery waste	44.1[c]	43.3	791 L/kg VS	358
Total	**N/A**	**N/A**	**N/A**	**648**

The biogas produced by the anaerobic digester is used in part to fuel a hot water boiler that provides the digester heating required for operation at 100 degrees F. The heat load was computed using the Cornell AD Tool that includes both the influent heating and maintenance heating loads of the system. Several design inputs are required for this calculation that are summarized in Table 4. The average hourly heating load per month was summarized, with the corresponding biogas input to the boiler and net biogas remaining for upgrading to renewable natural gas (RNG).

Table 4. Design inputs used for anaerobic digester heating requirements.

Parameter	Units	Value
Digester diameter	ft	100
Digester height (above ground)	ft	30
Digester wall and cover insulation R-value	h ft^2 deg F/BTU	18
Influent temp (T)		Ambient T, minimum > 32 deg F
Biogas boiler efficiency	%	80

It is assumed that the produced biogas has an average methane content of 60% (i.e., higher heating value was taken as 600 BTU/cf). A 2% biogas loss was included to account for potential leaks from the digester through the biogas cleaning and RNG upgrading system. The biogas cleaning and RNG upgrading system includes iron sponge H_2S removal, moisture removal using a glycol chiller, gas compression to 250 psig, and CO_2 removal using a multiple pass membrane technology with a 98% methane recovery efficiency[6]. The system also includes a flare used to burn off biogas during down times. Table 5 reports the monthly average heating load, biogas input to the heating boiler, net RNG production, and percentage of biogas used for digester heating. The total RNG that can be injected into the pipeline for sale is estimated to be 185,000 million BTU (MMBTU) per year, accounting for an assumed system downtime of 2% due to maintenance.

[b] Computed VS content of combined lactating cow and heifer manure using ASABE Standard.
[c] Dry matter content in reference was multiplied by 50% to account for expected dilution with the food manufacturer's wash water.

Table 5. Monthly digester heating and net RNG production estimated. MMBTU is million BTU.

Month	Avg digester heat load (MMBTU/hr)	Biogas input rate to boiler (MMBTU/hr)	Net RNG production (MMBTU)	Percent (%) of biogas used for digester heat
Jan	0.899	1.124	15,849	7
Feb	0.895	1.119	14,319	7
Mar	0.862	1.078	15,883	7
Apr	0.777	0.971	15,446	6
May	0.649	0.811	16,077	5
Jun	0.541	0.676	15,654	5
Jul	0.491	0.613	16,222	5
Aug	0.510	0.637	16,204	5
Sep	0.646	0.807	15,561	5
Oct	0.770	0.962	15,967	6
Nov	0.841	1.051	15,389	7
Dec	0.889	1.111	15,859	7
Total Annual			**188,430**	

The electricity usage of the added systems to the farm was also estimated to determine the cost of purchasing additional utility grid electricity. The largest use of electric power is the biogas cleaning and RNG upgrading system, estimated at 0.45 kW/cfm. This equates to approximately 2,550,000 kWh per year of electricity usage. Note that the farm's electricity usage prior to adding the AD to RNG system is estimated at 1,400,000 kWh/yr. In addition to the biogas cleaning and RNG upgrading parasitic electricity, there is also added electricity required for the food waste reception tank pumps, mixers, and macerator. These were estimated to use approximately 140,000 kWh/yr based on a 30% average runtime. Finally, there is also electricity usage of the digester itself for internal mixing (25,000 kWh/yr) and pumping the effluent (50,000 kWh/yr).

Nutrient Management and Storage Impacts

The farm operates over 3,500 acres of land and applies raw manure in their pre-digester management to all but 495 acres at an average rate of 7,000 gallons per acre for forage ground and between 8,000 and 10,000 gallons per acre for corn ground. The 495 acres that do not receive on farm nutrients receive purchased urea fertilizer at an average rate of 122 pounds of nitrogen per acre. The nitrogen, phosphorus, and potassium values of the 50:50 manure and food waste digested effluent were calculated using values provided by previous Cornell PRO-DAIRY fact sheets for cheese whey[7] and dairy manure[8], and references for bakery waste[9] and meat processing waste[10]. Table 6 shows the total nutrient contents in pounds per 1000 gallons of effluent.

Table 6. Anaerobic digester effluent nutrient contents.

Nutrient	Lbs/1000 gallons of effluent
Total Nitrogen	38.42
Phosphorus as P_2O_5	8.19
Potassium as K_2O	16.08

Based on the values in Table 6, the volume of effluent needed to reach the nitrogen requirements of 122 pounds of nitrogen per acre was calculated to be 3,175 gallons per acre. Therefore, the additional volume provided by the food waste co-digested with the farm's manure would cover the 495 acres that received purchased fertilizer, as well as 3,100 additional acres.

The farm has roughly nine million gallons of on-farm manure storage, with five million gallons of additional remote storage. The existing storage does not have enough capacity to hold the additional volume that would be produced from the food waste, therefore a new on-farm storage was designed and included in the capital costs. The new storage was designed using the downloadable Animal Waste Management (AWM) created by the NRCS[11]. The tool considers manually entered information on animal numbers and weights, bedding types and other waste additions, as well as precipitation data for the climate and region selected in the tool to calculate the storage dimensions and volume. The AWM tool also takes withdrawal events into account, which we assumed would happen twice per year, once in May and again in October. The AWM tool estimated a storage measuring 136 ft by 893 ft with a depth of 14 ft. The volume of the new storage is roughly 1.2 million cu-ft, which is approximately 8.6 million gallons. A 2,080 ft fence is included around the new storage. We also assumed 1,300 ft of piping and a pump would be needed to transfer a portion of the digester effluent to the new storage, while the existing storage capacity would also be utilized.

Economics

Capital Costs

The capital costs of the installed infrastructure and equipment needed to take in the food waste and for the digester system are shown in Table 7. The capital costs for several of the system components were calculated using the USDA Environmental Quality Incentives Program cost list for New York State[12]. The list provides the average cost per unit for many services and materials used in various agriculture systems.

Table 7. Capital costs of new co-digestion system.

Capital costs	Cost ($)
reception tank system	$142,550
truck scales and access road	$135,120
solids macerator system	$200,000
anaerobic digester system	$4,535,000
biogas cleaning and upgrading	$2,500,000
pipeline injection point	$1,000,000
pipes and pumps for new storage	$47,875
new storage	$290,000
Total investment	**$8,850,545**

The reception tank system includes the two reception tanks as well as the associated agitators, pumps, and piping to the digester. The USDA cost list gave a price of $10/cu-ft for inground concrete reception pits, $9,930 for each of the reception pit agitators, $4,050 for each of the pumps, and $20/ft for 380 feet of piping running from the reception pits to the digester. We assumed an installation cost of $6,990 for the mixers and pumps associated with the reception tank system. The new 500 ft access road for the truck scales was priced at $30/ft for a constructed road with a heavy stone base and geotextile. The USDA cost list did not have a price for drive-over truck scales, so we estimated the cost to be $100,000 with $20,000 in installation costs. The USDA cost list did not have a price for a solids grinder or macerator pump, so we estimated the installed price to be $200,000 for this system.

The anaerobic digester system includes construction of the anaerobic digester vessel itself with the mixing and heating components, as well as the boiler used to heat the digester. The estimated cost for the anaerobic digester system is $4,535,000 based on discussions with developers and farmers and recent articles[13]. These resources also led us to an estimated cost of $2,500,000 for the biogas cleaning and upgrading to RNG equipment, and an assumed $1,000,000 for the gas pipeline injection point.

The additional pipes and pump for the new manure storage were priced at $20/ft for 1300 ft of piping, $12,300 for a 10-40 horsepower pump using the USDA cost list, with an additional $9,575 in estimated installation costs. The USDA cost list gave a cost of $0.25/cu-ft for the new storage, which includes construction costs. The fence to enclose the new storage was priced at $1.00/ft for a 2,080 ft fence.

Operating Costs

Additional operating costs and changes to existing farm operating costs are expected with the new digester system and are shown below in Table 8.

Table 8. Operating costs.

Annual operating costs	Cost ($)
additional spreading	$328,157
system O&M and management	$308,240
system electricity usage	$277,297
Total	**$913,694**

Additional spreading costs were calculated using $0.02/gallon for the stored effluent needed to cover the 495 acres of remaining land that the farm operates (approximately 3.6 million gallons per year), and $0.03/gallon for the additional land that would be needed to spread the remaining effluent from storage (approximately 8.5 million gal/year) that we assumed would be farther away than the farm's current operated acreage. The operating costs for spreading include fuel costs for equipment as well as additional labor. Digester system operations and management (O&M) costs include the maintenance and labor required for the new digester to RNG system and managing the food waste contracts. We included a cost of $250,000 per year for the system O&M including maintenance labor based on discussions with developers. Additional labor required to manage the food waste and system operations would cost $58,240 per year. The new digester to RNG system including the equipment needed to take in the food waste will increase the farm's electricity usage by an estimated 2,770,000 kWh annually and the farm's recent average utility cost of $0.10/kWh (inclusive of delivery and supply charges) was applied.

Annual Benefits

The benefits for scenario II include revenue from food waste tipping fees, revenue from RNG sales, and savings from reduced fertilizer purchases by the farm. The breakdown of the benefits for scenario II are shown in Table 9.

Table 9. Annual benefits.

Annual benefits	Benefit ($)
Tipping fees	$1,932,527
RNG sales	$1,850,000
Fertilizer savings	$21,137
Total	**$3,803,663**

Payment for taking in food waste is made by the food waste producer in the form of tipping fees, the same type of payment that landfills would receive for taking food waste. The value of food waste tipping fees depends on the type of food waste and the region of the food waste disposal. In this case study, a tipping fee of $0.07/gallon was used for the cheese whey, which is an estimated tipping fee for liquid food waste in New York State. A tipping fee of $50/US ton was used for the bakery and meat waste that are expected to have a higher solids content requiring the maceration pre-processing.

The fertilizer savings were determined by applying the average price of $700/ton for nitrogen fertilizer[14] to the 495 acres under the farm's current operation that would no longer require purchased fertilizer, saving the farm roughly 30 tons of fertilizer per year. No savings or value was included for the additional nutrients that would be spread from the digester effluent on 3,100 acres of land outside the farm's current operation.

We assumed that the RNG produced from the digester biogas could be sold at a rate of $10/MMBTU on the voluntary market. This value is equal to the Oct 2021 to Sep 2022 average natural gas price for industrial and commercial customers in New York State[15]. With the co-digestion operation, the farm should be able to sell 185,000 MMBTUs of RNG annually, leading to $1,850,000 in added revenue.

Economic Analysis

An economic analysis was performed to determine the gross profitability of the new co-digestion system over the course of fifteen years, considering the initial capital costs, annual operating costs, annual benefits, and the tax-related benefits[d] of accelerated depreciation and investment tax credit (Table 10). The US Inflation Reduction Act of 2022 introduced a 30% investment tax credit for anaerobic digester and biogas upgrading equipment[16]. This was applied to the anaerobic digester system and biogas cleaning and

[d] Consult a tax professional for advice on accelerated depreciation and investment tax credit opportunities.

upgrading costs of $7 million combined. Depreciation was included using a modified accelerated cost recovery system (MACRS) 10-year schedule (half-year convention).

Year 0 can be considered the installation and transition period, where the system is being paid for and installed. For a system of this size and complexity, this may take more than one calendar year. Year one and forward are the years that the digester system is fully operating. Operating costs and benefits are included for these years as the system is actively co-digesting food waste and the farm's manure and impacting the farm's operations and income. The net annual benefit row in Table 10 shows the net benefit for each of the years starting at the installation period.

The net present value (NPV) and discounted benefit to cost ratio for scenario II were calculated to be $19,922,594 and 2.1 respectively, assuming a discount rate of 8%. The NPV is a measure that evaluates the current value of future cash flows generated by a project or investment. A NPV of $19,922,594 indicates that the investment will have a positive return and the benefit to cost ratio greater than 1.0 is required for a good return on investment. No escalation of the operating costs or benefits are included for simplicity and because it is difficult to anticipate what these may be.

Table 10. Fifteen-year cash flow (undiscounted).

Year	0	1	2	3	4	5	6	7	8	9	10
Investment	($8,850,545)										
Investment tax credit	$2,110,500										
Operating cost		($913,694)	($913,694)	($913,694)	($913,694)	($913,694)	($913,694)	($913,694)	($913,694)	($913,694)	($913,694)
Benefit		$3,803,663	$3,803,663	$3,803,663	$3,803,663	$3,803,663	$3,803,663	$3,803,663	$3,803,663	$3,803,663	$3,803,663
Depreciation tax benefit		$272,835	$491,104	$392,883	$314,306	$251,554	$201,080	$178,707	$178,707	$178,980	$178,707
Net annual benefit	($6,740,045)	$3,162,805	$3,381,073	$3,282,852	$3,204,276	$3,141,524	$3,091,049	$3,068,677	$3,068,677	$3,068,949	$3,068,677

Year	11	12	13	14	15
Investment					
Investment tax credit					
Operating cost	($913,694)	($913,694)	($913,694)	($913,694)	($913,694)
Benefit	$3,803,663	$3,803,663	$3,803,663	$3,803,663	$3,803,663
Depreciation tax benefit	$89,490	$0	$0	$0	$0
Net annual benefit	$2,979,459	$2,889,969	$2,889,969	$2,889,969	$2,889,969

Other Considerations

There are additional considerations that we took into account when planning scenario II of the case study, such as food waste contracts, contamination, and quality assurance. A food waste contract is a contract between the food waste supplier and the digester operator stating the terms and conditions of the food waste agreement. Food waste contracts have become increasingly important considering the sizeable income that food waste can provide as well as the growing competition for food waste. Food waste contracts can vary in length, typically ranging from 1 to up to 7 years though shorter terms are most common. Thus, it is very likely that a co-digestion operation will need to secure several food waste contracts and expect to shift to new types and sources and withstand periods of unsteady volumes.

Food waste contracts can also help ensure the quality of the food waste and prevent serious contaminants that could potentially harm the digester system and reduce biogas production. Contaminants may include post-consumer items (e.g., eating utensils, plates, cookware, etc.) or unknown food wastes that contain elevated levels of elements that may cause digester upset, such as excessive salts or vitamins.

Authors

Angela George	ag2292@cornell.edu
Lauren Ray	ler25@cornell.edu
Peter Wright	pew2@cornell.edu

[1] New York State Pollution Prevention Institute. https://www.rit.edu/affiliate/nysp2i/organic-resource-locator.
[2] Personal communication with Stephan Grimberg, Clarkson University.
[3] Labatut, R.A., L.T. Angenent, and N.R. Scott. (2011). Biochemical methane potential and biodegradability of complex organic substrates. Bioresource Tech. 102:2255–2264. https://doi.org/10.1016/j.biortech.2010.10.035.
[4] ASABE D384.2 MAR2005 (R2010) Manure Production and Characteristics ASABE, 2950 Niles Road, St. Joseph, MI 49085-9659, USA.
[5] Shelford, T., C. Gooch, A. Choudhury, and S. Lansing. (2019). A Technical Reference Guide for Dairy-Derived Biogas Production, Treatment, and Utilization. Cornell PRO-DAIRY Dairy Environmental Systems. https://hdl.handle.net/1813/60803.2.
[6] US EPA. (2020). An Overview of Renewable Natural Gas from Biogas. EPA 456-R-20-001.
[7] Cornell University Nutrient Management Spear Program. http://nmsp.cals.cornell.edu/publications/factsheets/factsheet96.pdf.
[8] Cornell University Nutrient Management Spear Program. http://nmsp.cals.cornell.edu/publications/factsheets/factsheet61.pdf.
[9] Govindaraju, M., K.V. Sathasivam and K. Marimuthu. 2021. Waste to Wealth: Value Recovery from Bakery Wastes. Sustainability 2021, 13(5), 2835. https://doi.org/10.3390/su13052835.
[10] Bustillo-Lecompte, C. and M. Mehrvar. 2017. Slaughterhouse Wastewater: Treatment, Management and Resource Recovery. Physico-Chemical Wastewater Treatment and Resource Recovery. https://www.intechopen.com/chapters/52474.
[11] Natural Resource Conservation Service. https://www.nrcs.usda.gov/resources/tech-tools/usda-animal-waste-management-version-241.
[12] New York EQIP Cost List. https://www.nrcs.usda.gov/sites/default/files/2022-11/New-York-EQIP-23-payment-rates.pdf. *The 2022 cost list used for this case study has since been updated to 2023 and is no longer available.*
[13] M.J. Bradley & Associates, LLC. 2019. Renewable Natural Gas Project Economics. Renewable Natural Gas Issue Brief, Part IV. https://www.mjbradley.com/sites/default/files/RNGEconomics07152019.pdf.
[14] DTN. https://www.dtnpf.com/agriculture/web/ag/crops/article/2022/07/20/fertilizer-prices-press-lower-taking.
[15] NYSERDA. https://www.nyserda.ny.gov/researchers-and-policymakers/energy-prices/natural-gas.
[16] BioCycle. 2022. The IRA Revolutionizes AD Tax Credits. https://www.biocycle.net/the-ira-revolutionizes-ad-tax-credits/.

Grant Funding for the Project was provided by the farmer-driven Northern New York Agricultural Development Program is a research and technical assistance program serving the diverse agricultural sectors in Clinton, Essex, Franklin, Jefferson, Lewis, and St. Lawrence counties.