Anaerobic Digestion Implementation at Dairies in Colorado

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Summary of Findings

Anaerobic digestion (AD) of animal manure to produce biogas (methane) fuel has a wide variety of environmental benefits to air and water quality in addition to reducing greenhouse gas (GHG) emissions. In addition, the resulting biogas fuel and digestate products can help meet the energy needs and provide revenue to the farm. This case study explores the potential benefits and drawbacks of implementing an AD system at the Aurora Organic Dairy (AOD) High Plains Dairy Farms in Gill, Colorado. The project is envisioned as a digester located at the AOD High Plains Dairy Farms with a feed stream of manure from the Farms. The project would be implemented by a third-party contractor who would build and operate the system and pay the dairy a fraction of the profits, in addition to providing by-products such as digestate solids and liquids for fertilizer.

Snapshot

- Across the United States in 2019, methane emissions from livestock manure management accounted for an estimated 62.4 MMT CO_2 equivalent (CO_2eq.) or 9.5% of total anthropogenic methane emissions in the United States, with beef and dairy cattle emitting more methane than any other domestic animal type (US EPA 2021).
- Manure storage and treatment methods that produce anaerobic conditions, including liquid or slurry storage in lagoons and ponds, tend to produce more methane.
- 173,560 MMBtu/year of biogas derived methane (CH_4) would be produced by the modeled induced blanket reactor (IBR) system. If upgraded to pure renewable natural gas (RNG), this amount would be equivalent to 1.34 million gallons of gasoline.
- A combined heat and power (CHP) system operating on the biogas would produce 58,800 kWh/day (2.4 MW) of electricity and 200 MMBtu (equivalent to about 216,000 gallons of water heated to 170°F) of recoverable heat per day. After meeting the electricity demands for the dairies and digester operations, between 1.1 (summer) and 1.9 (winter) MW of electricity could be exported to the grid.[1]
- If upgraded to RNG and substituted for gasoline, the system output would avoid 12,000 MT CO_2eq/year of emissions from gasoline (EPA 2014)[2] and approximately 5,700 MT CO_2eq/year of avoided emissions from manure management in liquid lagoons. Fueling the dairies' milk truck fleet would require less than 7% of the output RNG.

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[1] Evaluation of restrictions and incentives for RNG and renewable electricity generation and export are beyond the scope of this case study. A summary of the potentially applicable programs is given at the end of the case study.

[2] Calculation does not account for emissions from RNG used as fuel.

Introduction

The Aurora Organic Dairy (AOD) consists of four dairy farms: High Meadow, Little Calf Ranch, High Plains, and High Ridge, with a total of about 13,000 cows, 80% of which are producing milk at any given time. The dairies are all located within about a mile and a half of each other. In total, the dairies encompass roughly 6,000 acres, including pasture where the cows graze during the summer (Figure 1). Milk produced at the dairies is chilled on-site and then trucked to the AOD processing and packaging facility about 40 miles away in Platteville, Colorado.

Third party contractors conducted an energy audit for the High Plains dairy in 2015 and a solar feasibility study for the High Meadow and Little Calf Ranch farms in 2021. Recommendations from the energy audit included efficiency improvements to lighting and water heating and in-floor heating systems for the milking parlors and offices. These improvements would augment the measures already implemented for the milk collection and chilling systems.

AOD is interested in finding additional opportunities for efficiency improvements and renewable energy generation. AOD explored anaerobic digestion (AD) of the farm's manure several years ago. However, the potential for use of the renewable methane in compressed natural gas (CNG) vehicles, as well as the sustainability and greenhouse gas (GHG) reduction potential, make revisiting AD worthwhile.

About Anaerobic Digestion

Microorganisms naturally break down organic matter such as animal manure and food waste. AD occurs when specific types of microorganisms break down organic matter in the absence of oxygen, producing biogas, which in the

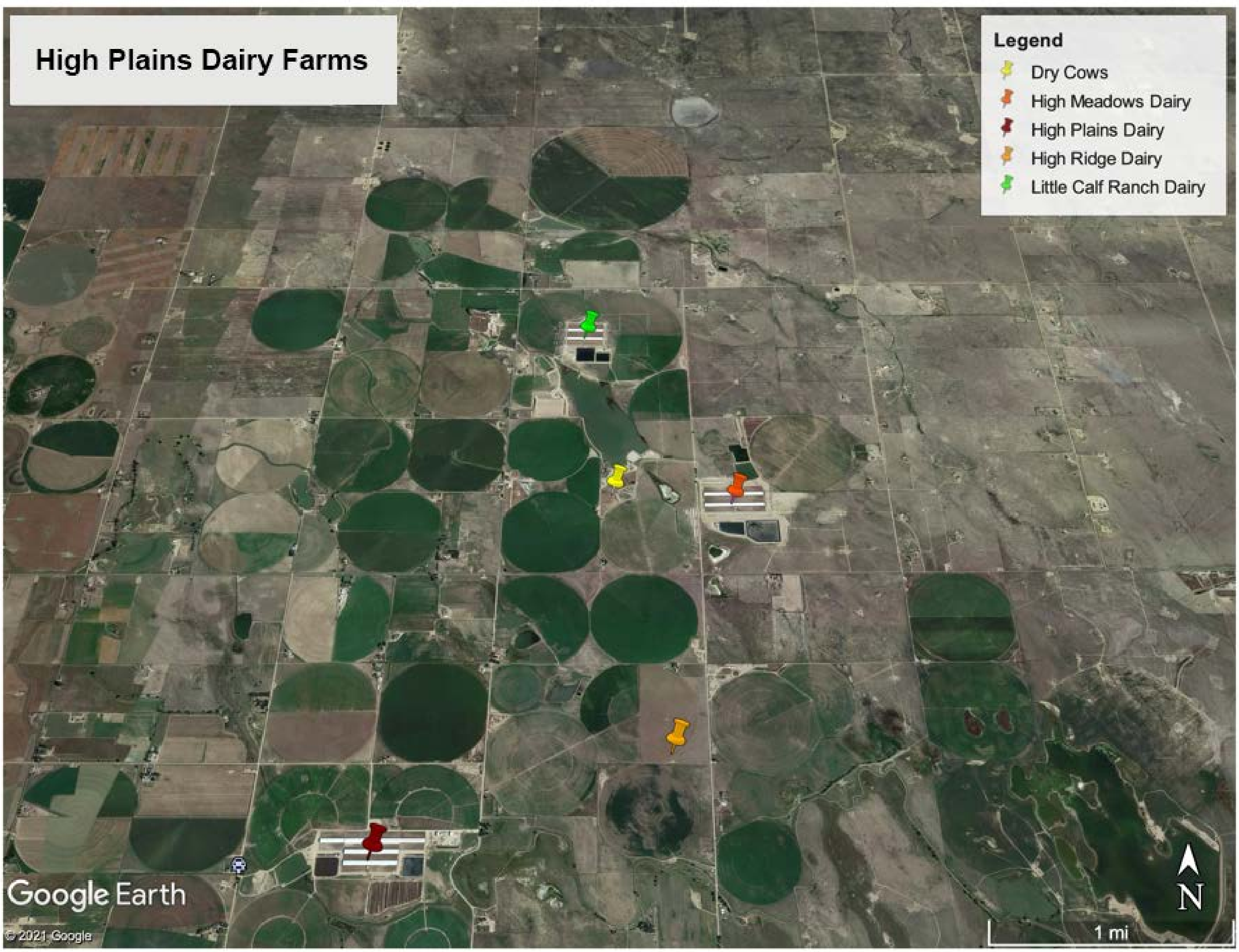


Figure 1. AOD High Plains Dairy Farms near Gill, Colorado. The dairies are located within a mile and a half of each other. Source: Candice Stacey, AOD. The number of cows at each dairy are: High Meadow, ~3,000, High Plains, ~4,000, Little Calf Ranch, ~2,000, and High Ridge Dairy, ~2,000. For this case study, the "dry cows" that are not producing milk are assumed to be evenly distributed among the dairies for calculation of biogas production and electricity and heat demand.

case of dairy manure biogas consists of about 60% methane (CH_4), 39% carbon dioxide (CO_2) and small amounts of other gases such as hydrogen sulfide (H_2S), and water vapor (Matthew Tomich and Marianne Mintz 2017).

Methane is a potent greenhouse gas, which has a near-term global warming potential climate impact 28–36 times greater than CO_2.[3] It is also an excellent fuel, releasing about 1,011 Btu per cubic ft (37,669 kJ/m3) when burned.[4] Capturing the methane produced by AD helps mitigate global warming by reducing atmospheric releases of methane and by replacing non-renewable fuels. Figure 2 illustrates the wide variety of benefits that can be derived from AD.

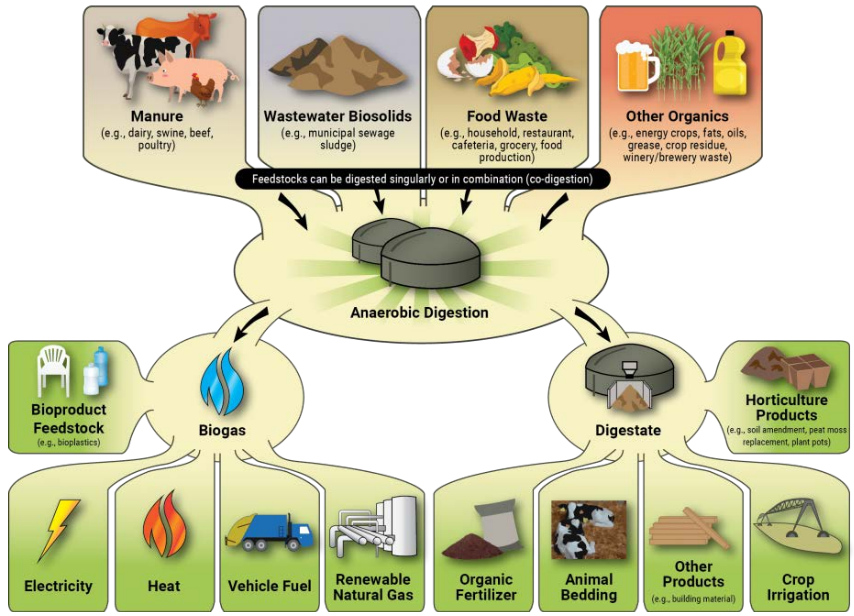


Figure 2. Basic AD/biogas system flow diagram (EPA 2020)

Economic and Environmental Benefits of AD

For the AOD dairies, diverting manure from current manure management practices to an anaerobic digester could result in a number of economic, environmental, and energy benefits. An estimated 10% of manure from Aurora Dairy facilities is flushed to lagoons, resulting in approximately 5,700 MT CO_2 eq. of methane emissions each year (AOD; Owen and Silver 2015). By capturing this methane and releasing CO_2 instead, the farm's liquid manure management GHG impact could be reduced by 90%.

For the remaining 90% of manure that is currently composted or applied directly to fields, diverting some or all of the manure to a biodigester could also have GHG benefits. While aerobically composted manure is expected to produce little or no methane, direct N_2O emissions are

High Plains Dairy Farms near Gill, Colorado. Photo courtesy of Candice Stacey, AOD

[3] https://www.epa.gov/ghgemissions/understanding-global-warming-potentials. US EPA, OAR. 2016. "Understanding Global Warming Potentials." Overviews and Factsheets. US EPA. January 12, 2016.

[4] https://www.engineeringtoolbox.com/heating-values-fuel-gases-d_823.html. Engineering ToolBox, (2005). *Fuel Gases Heating Values*.

Freestall barns being vacuumed at AOD High Plains Dairy Farms near Gill, Colorado. Photo courtesy of Candice Stacey, AOD

more likely, and indirect N_2O emissions due to volatilization or runoff and leaching can also be a concern (EPA 2021). N_2O has a global warming potential 265–298 times that of CO_2 and roughly 10 times that of CH_4, therefore the benefits of aerobically composted manure should be weighed against its potential GHG impacts. GHG reductions for biogas produced by digesters operating on dairy manure equal about 7.44 tons (6.75 MT) CO_2eq/cow/year (US EPA 2014). For the AOD High Plains Dairy Farms, this would amount to a total of about 93,750 tons (85,000 MT) CO_2eq/year; including the avoided emissions from eliminating the lagoons.

Beyond the direct climate benefits of avoided GHG emissions, diverting manure to biodigesters can protect local air quality, water quality, and land resources. Anaerobic digesters, particularly heated digesters, destroy more than 90% of pathogens present in the manure and concentrates nutrients, including nitrogen and phosphorus, in the solid digestate byproduct, preventing these pollutants from leaching into surface and groundwaters. With some additional post-processing technology, nutrients in the solids and liquid portion of the digestate can be further concentrated and used or sold as fertilizer, offering a safe and clean alternative to petroleum-derived fertilizers and a sustainable way to increase soil organic matter and alleviate soil compaction (EPA 2018).

Biogas has the potential to be used on-farm for thermal energy or electrical power or refined to RNG for use in vehicles or sale through natural gas pipelines. RNG from biogas can improve on-farm energy independence, reduce energy costs and emissions, and generate economic revenue from biogas sales. The use and/or sale of digestate and digestate-derived products for fertilizer, livestock bedding, soil amendments, or other bioproducts can significantly reduce costs and diversify farm income streams (EPA 2018).

Types of Anaerobic Digestor Technologies

There are a variety of digester technologies, ranging from large lagoons with a simple covering that allows for the collection of naturally generated biogas to digester bioreactors with carefully controlled conditions. A brief tabulation of key attributes of various digester designs is given in Table 1. The concentration

Table 1. Types and Main Characteristics of Common AD Digester Technologies

Digester Type	Tech Level	Percentage Total Solids	Hydraulic Retention Time (Days)	Best Location	Co-Digestion	Approx. Yield from Dairy Waste (MMBtu CH_4/cow/year)*	Heated?
Complete Mix	Med	3 to 10%	15+ days	All climates	Yes	18	yes
Covered Lagoon	Low	0.5 to 5%	30+ to 60+ days	Temperate and warm climates	Not optimal	7	no
Dry Digester	Low	>25%	20-30 days	All climates	Yes	N/A	yes
Horizontal Plug Flow	Low	12 to 15%	20+ days	All climates	Not optimal	17	yes
Induced Blanket Reactor (IBR)	High	6 to 12%	5 days or less**	All climates	Yes	11 (AgStar, one dairy farm), 16 for modeled digester	yes
Upflow Anaerobic Sludge Blanket (UASB).	High	< 3%	5 days or less**	All climates	Yes	N/A	yes
Mixed Plug Flow	Low	12 to 15%	20+ days	All climates	Not optimal	24	yes

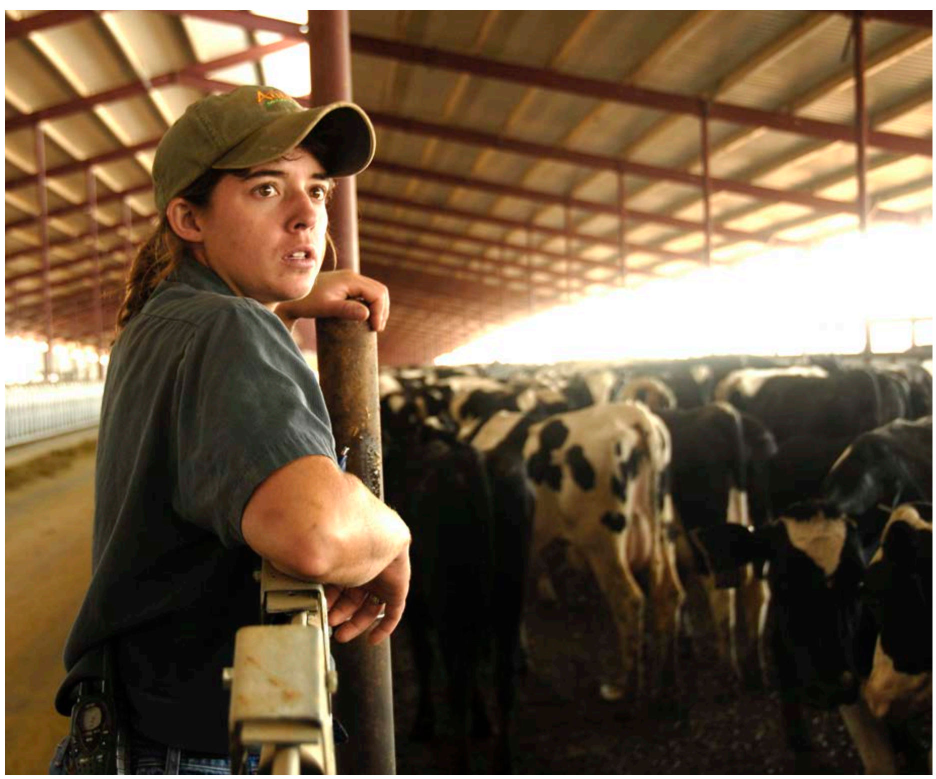
Source: (US EPA 2020)

N/A Not used for any dairy manure waste in the AgStar database.

*Derived from the AgStar database for digesters used for dairy manure digestion without co-digestion (https://www.epa.gov/agstar/livestock-anaerobic-digester-database)

** Microbes are suspended in a constant upward flow of liquid. Allows for short hydraulic retention time.

of solids in the waste stream should be matched to the appropriate technology. Technologies that work well with low solids-content waste (<5%) are often not suitable for colder climates where heating of the digester is needed to speed microbial growth because heating of a large volume of water is not economically feasible. A related attribute of digester designs is the hydraulic retention time, or the time in days that the waste must remain in the digester for complete conversion of the volatile solids to biogas. Low technology digester designs often require longer retention times because they do not actively manage the digestion process so it is slower. Longer retention times require bigger digesters that can hold many days of waste.



AOD High Plains Dairy Farms near Gill, Colorado. Photo courtesy of Candice Stacey, AOD

AOD High Plains Dairy Farms near Gill, Colorado. Photo courtesy of Candice Stacey, AOD

Dairy manure yields less biogas than other feedstocks (US EPA 2020). However, dairy farms often have manure management systems that are liquid- or slurry-based, which simplifies preparation of the digester feedstock stream. Dairy manure is also a homogeneous waste stream that already contains methane-producing bacteria from the animal's digestive tract. These two attributes lend stability to the digestion process, making it less susceptible to upsets.

For the AOD High Plains Dairy Farms, manure is collected from the free stall barns, milking parlors, and exercise pens. A vacuum system is used for the majority of the manure collection (about 70%), and the remaining manure is scraped from the exercise pens. Only a small fraction (about 10%) is flushed with water from the milking parlors. As a result, the manure stream is a little less than 10% solids, which is ideal for the Induced Blanket Reactor (IBR) digester modeled for this brief case study. Table 2 summarizes the main assumptions for the system.

Table 3 summarizes the yearly total and daily average output from the modeled digester system. Over 173,000 MMBtu of raw biogas would be produced per year. If the biogas were purified to RNG, a small fraction of the methane would

Operational and under-construction dairy manure digesters in the United States are shown in Figure 3. These digesters represent a potential RNG generation of over 8,000 giga Btus per year. According to the American Biogas Council (American Biogas Council 2021), 11.6 billion cu ft of biogas could be produced from dairies and swine operations in Colorado.

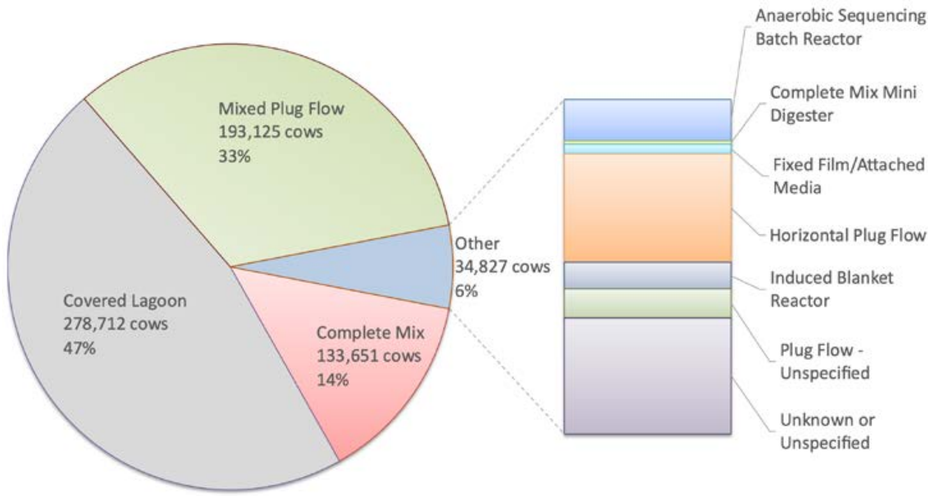


Figure 3. Percentages of cows associated with operating or under-construction dairy manure anaerobic digesters in the United States. Covered lagoon digesters are generally only appropriate for warm climates. Source: https://www.epa.gov/agstar/livestock-anaerobic-digester-database.

be lost during the purification process. The digestate liquids and solids could be used as high-quality fertilizer and as a soil amendment. The solids could also be used to replace the sand bedding currently used at the AOD High Plains Dairy Farms.[5]

Potential Uses for Biogas

In general, there are two primary routes for utilizing the biogas. Biogas can be used directly for electricity generation, and if there is a nearby heat demand, the waste heat from the electricity generation can also be used. Such Combined Heat and Power (CHP) applications can reach efficiencies of over 90%.[6] Alternatively, the methane in the biogas can be purified (i.e., CO_2 and other constituents are removed to produce almost pure CH_4) to meet RNG standards and injected into natural gas pipelines or used as a fuel for vehicles.[7]

For the AOD High Plains Dairy Farms, milk is chilled at the dairies and then trucked to the processing facility in Platteville, Colorado. Some of the biogas product from the digesters would have to be upgraded to RNG to make it acceptable to fuel the milk trucks. For the 14 milk trucks per day, about 31.5 MMBtu/day of RNG (less than 7% of the daily average energy output) would be required (equivalent to about 214 gallons of diesel). Excess RNG could be used for vehicle fuel through development of a CNG station in partnership with the milk transport contractor or via transport of the RNG to one of the nearby (CNG) fueling

Table 2. AOD High Plains Dairy Farms Digester Model Primary Assumptions

Value	Description
Digester	IBR reactor model provided by Brandon Julian of Pure Energy Group, Park City, Utah.
Hydraulic Retention Time	5 days
Bacteria	Mesophilic, requiring an operating temperature of 33°C (91°F)
Yield	0.043 MMBtu/cow/day
Number of Digesters	A total of 39 32,000 gal. digesters would be needed for the four-dairy complex.
Seasonal Variation	Cows are pastured between 8 and 24 hours per day during the summer. Eight hours is assumed for the case study. Manure is not collected from the pasture, therefore the feed flowrate to the digesters during the summer is about 33% less than the flowrate during the winter. The number of digesters and other equipment are sized for the winter (higher) flowrate. Electricity use, heat requirements, and other variable operating costs are scaled to account for the lower feed rate during the summer. In total, biogas production is reduced about 12% per year from the baseline of full operations at the winter flowrate.

[5] https://farm-energy.extension.org/uses-of-solids-and-by-products-of-anaerobic-digestion/

[6] https://www.clarke-energy.com/2012/using-biogas-for-combined-heat-and-power/

[7] See https://afdc.energy.gov/fuels/natural_gas_cng_stations.html.

stations (see Figure 4). Upgrading the biogas and transporting it to an existing CNG station would increase the equipment cost for the system by up to 20%. However, RNG is eligible for significant incentives and can be used in any application where natural gas is currently used.

Upgrading the biogas requires additional energy, and some of the methane is lost during the process (as shown in Figure 5).

For CHP applications to be effective, applications that use the heat are necessary. The AOD High Plains Dairy Farms digester has several potential heat demands that could be satisfied with the waste heat from a CHP system. The digester itself requires a significant amount of heat, as shown in Figure 5. The dairies also use a large amount of hot water and require heating for buildings and the milking parlors in the

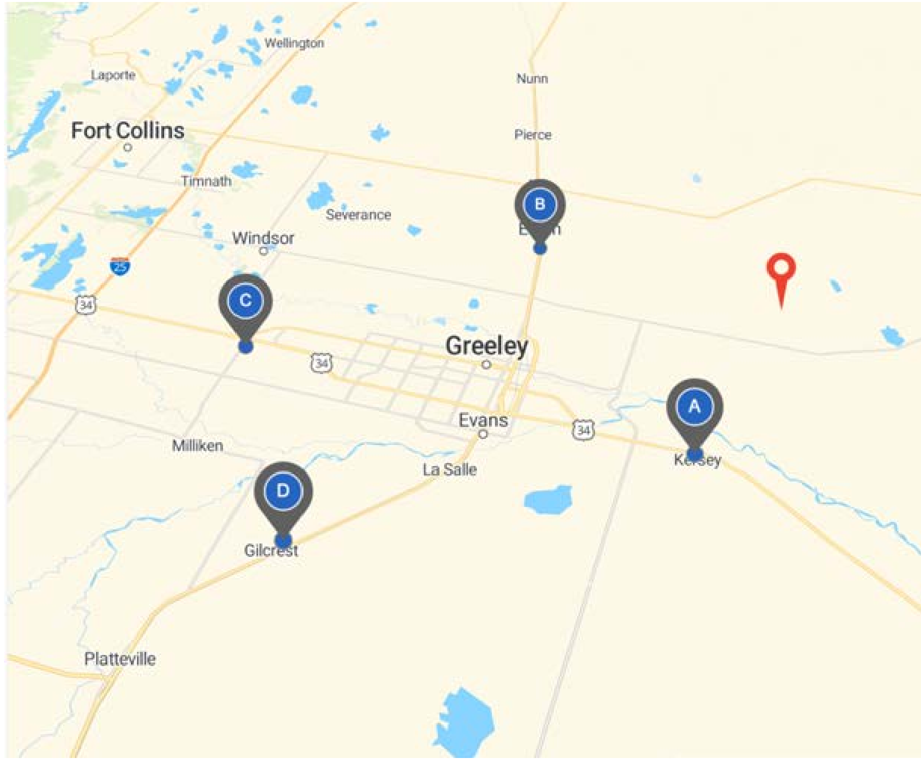


Figure 4. CNG stations near route from dairy farms to processing plant in Platteville, CO. Source: (https://afdc.energy.gov/stations/#/find/nearest?location=Aurora%20Organic%20Dairy,%2025520%20CO%20rd%2072,%20Gill,%20CO%2080624&fuel=CNG). The station in Gilcrest is a full-service fast-fill station capable of fueling large trucks.

Table 3. Yearly and Average Daily Outputs for the Modeled Digester System

Biogas	173,563 MMBtu/year	476 MMBtu/day
RNG (if all biogas upgraded)*	170,322 MMBtu/year	467 MMBtu/day
Solids	27,219 tons/year	149,144 lb/day
Solids (N)	0.79 tons/year	4 lb/day
Solids (P)	581 tons/year	3,183 lb/day
Solids (K)	861 tons/year	4,720 lb/day
Liquids	66 million gal/year	181,694 gal/day
Liquids (N)	658 tons/year	3,607 lb/day
Liquids (ammonia)	646 tons/year	3,537 lb/day
Liquids (P)	5.5 tons/year	30 lb/day
Liquids (K)	8.1 tons/year	44 lb/day

- The values shown in the table are based on the final fuel product being either biogas or RNG, not both.

Relaxed cow at AOD High Plains Farms near Gill, Colorado. Photo courtesy of Candice Stacey, AOD

AOD High Plains Dairy Farms near Gill, Colorado. Photo from Candice Stacey, AOD.

winter. CHP systems have the potential to replace the heat currently generated using propane, further reducing emissions and mitigating propane supply instability in Colorado that currently affects the farms.

While some heating needs are steady throughout the year, a large fraction of the heat demand is seasonal. Fortunately, the biogas production from the modeled system is also seasonal, with an output that is lower in summer when heat demand is also lower. Figure 6 plots the daily average biogas availability, electricity and heat production potential, and heat and electricity demands for the case study system. The hypothetical CHP system's heat output is very closely matched by the demand, especially if some of the biogas were upgraded for the milk trucks. CHP heat could also be used for

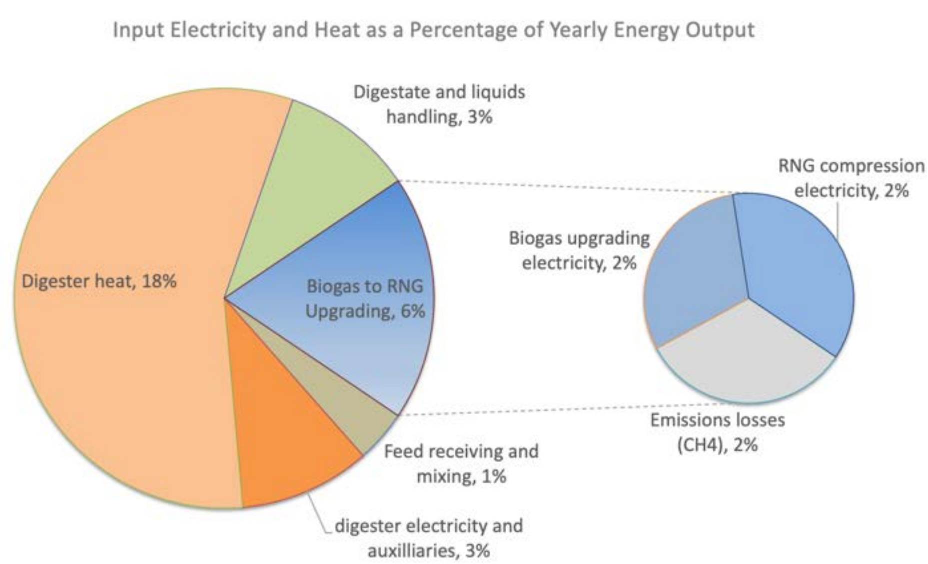


Figure 5. Digester and RNG process energy use as a percentage of the total energy output of the system. For this process, input energy is equal to about 31% of the output energy.

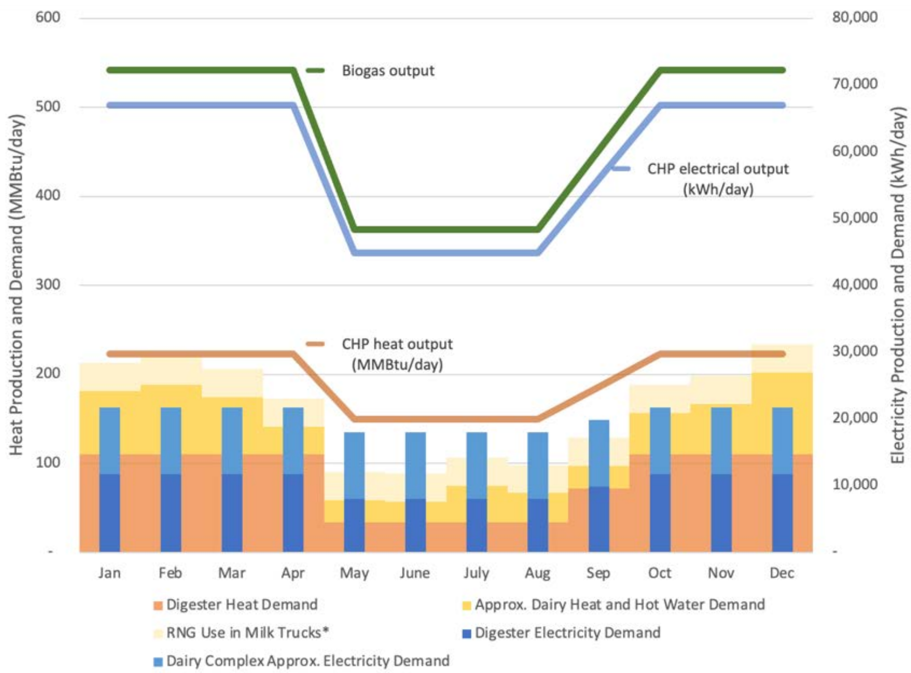


Figure 6. Daily average biogas availability, electricity and heat production potential, and heat and electricity demands for the case study system

Table 4. Summary of financial incentives and programs potentially applicable to AD projects in Colorado

Description	Further Reading
HB14-1159 Anaerobic Digester Sales Tax Exemption	https://programs.dsireusa.org/system/program/detail/133
Investment tax credits; in general, set to 10% of the project's capital expenditures.	https://programs.dsireusa.org/system/program/co
Rural Energy for America Program. Federal program funds renewable energy efficiency projects in rural areas that provides up to 25% of the project's costs as grants and up to 75% of a project's costs as loans.	https://www.rd.usda.gov/programs-services/rural-energy-america-program-renewable-energy-systems-energy-efficiency
Environmental Quality Improvement Program. Federal-level program providing financial and technical assistance to agricultural producers.	https://www.nrcs.usda.gov/wps/portal/nrcs/main/co/programs/
Conservation Innovation Grants. Conservation Innovation Grants are meant to stimulate development and adoption of conservation approaches while leveraging federal investments.	https://www.nrcs.usda.gov/wps/portal/nrcs/main/co/programs/
Conservation Security Program Production Incentive; voluntary program that provides financial and technical assistance that helps agricultural producers maintain and improve their existing conservation systems and adopt additional conservation approaches.	https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/alphabetical/csp/
Interconnection Standards: Colorado public utility commission adopted standards for net metering and interconnection and also relaxed some of the insurance requirements for interconnection.	https://openei.org/wiki/Interconnection_Standards_(Colorado)
Renewable Identification Numbers under the Renewable Fuel Standard Program: requires renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil or jet fuel. Renewable Identification Numbers function like renewable energy credits. They are tradeable commodities.	https://cdmsmith.com/en/Client-Solutions/Insights/RINs-Renewable-Gas-as-a-Revenue-Source https://www.epa.gov/renewable-fuel-standard-program/renewable-identification-numbers-rins-under-renewable-fuel-standard
Example Programs in Other States	
California FiT. The California Renewable Market Adjusting Tariff Feed-in-Tariff was designed to offer standard contracts to small renewable energy producers of up to 3-MW systems.	https://www.cpuc.ca.gov/feedintariff/
Vermont voluntary payment for on-farm AD with Green Mountain Power: "Cow Power" program. Participants receive $0.04/kWh produced, in addition to Vermont Standard Offer Program rates.	https://greenmountainpower.com/help/cow-power/ https://chptap.lbl.gov/profile/89/VermontGreenPower-profile1.pdf

chilling the milk via an absorption chiller if additional heat demand were needed. Excess electricity, between 1.1 (summer) and 1.9 (winter) MW, could also supply the grid.[8]

Financial and regulatory incentives would be important to the economic feasibility of the project. A cost-benefit analysis would be required to weigh the advantages and disadvantages of options for utilizing the biogas and other products. Table 4 lists incentive programs that may be applicable to an AD system at the AOD High Plains Dairy Farms. Colorado is moving forward in creating additional credits and incentives for the implementation of AD.

Conclusion

AD of animal manure to produce biogas fuel has a wide variety of environmental benefits to air and water quality in addition to reducing GHG emissions. Resulting biogas fuel and digestate products can also help to meet the energy needs and provide revenue streams for the farm. This case study explores the potential benefits and drawbacks of implementing an AD system at the AOD High Plains Dairy Farms in Gill, Colorado.

Bio Gas Installation. Photo from iStock 542697156

[8] Evaluation of restrictions and incentives for RNG and renewable electricity generation and export are beyond the scope of this case study. A brief summary of the potentially applicable programs is given at the end of the case study.

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Acknowledgments

The authors are grateful for the invaluable assistance of Brandon Julian of Pure Energy Group, Park City, Utah, who generously shared his time and extensive expertise with the NREL team. Candice Stacey of Aurora Organic Dairy (AOD) also generously shared her knowledge of the dairies' operations and provided the photographs used in the case study. Any errors are the sole responsibility of the authors.

This work was authored by the Joint Institute for Strategic Energy Analysis (JISEA), operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by Colorado Dept of Agriculture and Colorado Energy Office. The views expressed herein do not necessarily represent the views of the DOE, the U.S. Government, or sponsors.

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NREL/BR-6A50-80381 • Revised July 2021

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