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FINAL PROJECT REPORT

Construction and Operation of the ABEC #4 Covered Lagoon Digester and Electrical Generation System

Gavin Newsom, Governor
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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Construction and Operation of the ABEC #4 Covered Lagoon Digester and Electrical Generation System is the final report for the ABEC #4 digester project, contract number EPC-14-084, conducted by California Bioenergy. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

This project used biogas derived from on-site dairy manure to generate low-carbon, renewable electricity and achieve high overall efficiency by capturing waste heat from the power generation system and using it to drive an absorption chiller. The absorption chiller is designed to convert waste heat into chilling capacity, which will be used to chill milk produced by the dairy cows.

The purpose of this project was to document the construction and operation for one year of the American Biogas Electric Company #4 LLC (ABEC #4) covered lagoon digester, with a volume of 25.6 million gallons, along with a 1-megawatt engine-generator. Construction, start-up, and commissioning of the digester was completed in 2017 using the flushed manure from 5,760 "manure equivalent milkers" as influent (one manure equivalent miler represents 100 percent of the manure from a Holstein cow weighing 1,360 pounds). Full operation commenced in February, 2018.

Through the end of December, 2018, ABEC #4 averaged 430,750 cubic feet per day of biogas containing 60 percent methane, approximately 75 cubic feet of biogas per cow per day. The average monthly gross electrical production during this period was 684,000 kilowatt-hours (kWh) for 701 hours of operation per month (out of a possible 720 hours), averaging 976 kilowatts of generating capacity. The parasitic load was 31 kilowatts or 3.1 percent, and the net energy sold to Pacific Gas and Electric Company averaged more than 662,000 kWh per month.

Average monthly income for the project was $127,000, with a simply payback of 6.8 years based on total installed capital cost of $7.63 million and average monthly operating costs of $34,000. The project provided the additional benefit of producing an average of 108 tons per day of fiber bedding/fertilizer.

Environmental benefits of this project include the reduction of more than 21,000 metric tons of carbon dioxide equivalent greenhouse gas, principally methane, along with holding exhaust emissions at 2.6 parts per million (ppm) of oxides of nitrogen (NOx) and 35 ppm carbon monoxide (CO), well under California Air Resources Board limits of 11 ppm NOx and 210 ppm CO. Progress was made in limiting hydrogen sulfide (H_2S) emissions, thus prolonging the life of the engine-generator. H_2S levels dropped from a high of 5,000 ppm to less than 100 ppm in June while using only the air injection system. A final iron sponge scrubbing resulted in H_2S levels averaging 12 ppm going into the engine-generator.

Keywords: Methane, dairy manure, anaerobic digestion, energy

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Introduction

California has been the leading milk-producing state since 1993. Dairy farming is the leading agricultural commodity in California, according to the California Department of Food and Agriculture, with dairies producing $6.5 billion in cash receipts from milk production in 2017. Dairies use large quantities of both electricity and natural gas for their operations and, according to the California Air Resources Board, account for about 60 percent of greenhouse gas emissions from the agricultural sector.

In 2016, Senate Bill 1383 (Lara, Chapter 395, Statutes of 2016) gave broad authority to the California Air Resources Board to set goals for reducing "short-lived climate pollutants," including reducing methane emissions from dairy manure management by 40 percent below 2013 levels by 2030. Although regulations to reduce dairy emissions cannot take effect until after January 1, 2024, many dairies are already exploring ways to comply with the regulations while keeping costs down.

Anaerobic digestion is a process to convert manure into biogas consisting of methane, carbon dioxide, and small amounts of water and other compounds. The methane can then be burned to generate electricity or heat. There have been few studies on the long-term performance of digesters in California. While there are a number of anaerobic digestion projects in California, few studies have been done on long-term performance of digesters. In particular, complete and accurate data has not been widely available over a 12-month period for covered lagoon digester systems that produce electricity.

By converting the manure from California dairy cows to methane and subsequently to electricity, anaerobic digesters can produce a substantial quantity of renewable energy with little or no pollution while contributing to California's goal of lowering greenhouse gas emissions. Biomethane from dairy manure digestion has the added benefit of being able to produce electricity around the clock, unlike solar and wind technologies, and it can also be scheduled to generate more during periods of high electricity demand.

Project Purpose

The project uses biogas derived from on-site dairy manure from approximately 5800 milk-cow equivalents (which is a measure of manure equivalent to that produced by a Holstein cow weighing 1360 pounds) to generate low-carbon, renewable electricity. The project achieves high overall efficiency by capturing waste heat from the power generation system, using it to drive an absorption chiller. The absorption chiller is designed to convert waste heat into chilling capacity, which will be used to chill milk produced by the dairy cows. Combining renewable generation with waste heat collection and cooling, the project increases energy efficiency of the existing dairy by up to 10%, while also reducing peak grid power demand.

This project provides concrete, documented data regarding the quantity of biomethane available per cow at California dairies as well as expected electrical production from that biomethane. This data can be used to predict the total statewide potential for the technology. The research team documented the construction, start-up, and operation of the American Biogas Electric Company (ABEC) #4 digester and engine-generator system, and provided performance data over 12 months. The results provide a comprehensive report on how economic electricity can be generated from dairy methane digesters. The audiences for this research include utility decision makers, universities, and dairy farmers considering digesters for their farms.

Project Approach

The project approach focused on monitoring the digester operation for 12 months. Prior to the data collection, the digester construction was completed and loaded with a mixture of fresh and stored dairy manure for startup, and the engine-generator was commissioned. The research team developed a comprehensive data collection plan using supervisory control and data acquisition (SCADA) systems on the engine-generator, made regular visits to the digester by California Bioenergy (CalBio) to record instrument data and collect liquid and gas samples for laboratory analysis, conducted interviews with dairy staff regarding digester operation, and compiled all data into an organized framework to better understand digester performance and problems. CalBio provided data on digester project costs, and both consultants and CalBio personnel compiled data on performance and technical characteristics by using the digester SCADA data collection system, onsite collection of gas and liquid samples, and laboratory analysis.

The research team addressed both technical and non-technical difficulties during the project; for example, incorrect testing results necessitated a switch in laboratories. Other challenges encountered during the project included faulty instruments and measurement devices, which required replacement.

The research team included CalBio's President, CEO, and Controller, as well as the on-site operator and consultant researchers for the project. The key stakeholder was the farm owner at the ABEC #4 dairy whose staff were very helpful in the data gathering effort. A technical advisory committee was formed consisting of representatives from the California Energy Commission, various non-profits and governmental agencies (California Air Resources Board, Sustainable Conservation, U.S. Environmental Protection Agency, and the University of California, Davis) and industry representatives (Milk Producers Council). The role of the committee was to advise and provide useful feedback on the direction of the research to ensure collection of the most relevant information.

Project Results

Electrical production at the ABEC #4 digester equaled or exceeded expected monthly production by as much as 27 percent during 2018. Annual electrical production was approximately 1250 kilowatt-hours per milk-cow equivalent; there were a total of over 5800 milk-cow equivalents at ABEC #4 dairy. Greenhouse gas emission reductions amounted to 4 metric tons of carbon dioxide equivalent per milk-cow equivalent per year. Because of its extensive and comprehensive data collection and analysis, this study provides the knowledge and data needed to inform efforts to adopt proper energy standards. As a result, the analysis identified electrical production data from dairy manure digesters that would minimize unintentional consequences of energy policy or planning decisions. This accurate electrical production data can help planners in formulating energy policies having to do with the future electrical production potential if additional dairy farms add digesters to their waste treatment systems.

One of the major lessons learned was that the SCADA data collection system built into the ABEC #4 digester and engine-generator system provided a comprehensive and complete set of information that could be valuable in using the digester technology. Additional research is still necessary on how to improve hydrogen sulfide scrubbing to enable the biogas produced by the digester to meet air quality standards.

Technology Transfer and Market Adoption

The approach used to build market adoption included numerous meetings and presentations, as well as multiple open houses, including one for the completed Carlos Echeverria & Sons Dairy digester project, that were well-received and generated a great deal of interest in the project. Presentations were conducted at various technical and public forums such as the Sustainable Dairy conference in Sacramento, California in November, 2018. The intended audiences included dairy farmers, government officials, universities, high schools, and technology providers and developers.

The near-term markets are other dairy farms; the mid-term and long-term target markets would be other agricultural and food industries that produce organic wastes that could be used for energy generations via anaerobic digestion.

The demonstrated success of the ABEC #4 digester will stimulate growth in the agricultural market. The main challenges for commercialization of the digester technology are financial and regulatory rather than technical. The success and replicability of the digester technology demonstrated at the ABEC #4 digester facility, as well as at two other digester facilities (ABEC #2 and ABEC #3) under separate EPIC-funded projects, will help inform public agency efforts to change policy, permitting, operations, and other regulatory requirements to help increase the use of the technology.

Members of the technical advisory committee, including California government and regulatory officials as well as university and industry representatives, reported that their organizations were very receptive to the digester technology.

Benefits to California

The results of this project benefit ratepayers by demonstrating that digester-generated electricity can compete with other forms of renewable baseload power generation in California and can contribute significant reductions in carbon emissions. This results in increased availability of economic electrical generation that reduces air pollution and greenhouse gas emissions. Furthermore, the technology could be adapted to other agricultural businesses that have sufficient organic waste products. Because the biogas fuel for the generator can be stored in the digester, electrical generation can be scheduled in response to incentives offered by utilities to deliver power to the grid at specific times of the day, which allows the technology to deliver electricity at times of peak demand and potential reduce the need for expensive and higher emission peaking power plants.

This project averaged 976 kilowatts of electricity capacity over 12 months in 2018 and reduced greenhouse gas emissions by 21,500 metric tons of carbon dioxide equivalent. If all of California’s dairies adopted this digester technology, they could provide 340 megawatts of electricity capacity while reducing greenhouse gas emissions by 12 million metric tons per year. This research also provides a foundation for other studies by making data on digester performance available that could then be used to verify or improve existing anaerobic digestion theoretical equations.

Recommendations

- Further research on hydrogen sulfide reductions in the digester should be carried out, especially regarding the use and optimization of the air injection system.
- Improved solids separation methods that increase the yield of methane per cow should be explored.
- Expand the on-farm use of the waste heat from the generators, such as that demonstrated in the absorption chiller at ABEC #4.

CHAPTER 1: Introduction

Background

Few studies have been done on long-term performance of digesters in California. One of the most comprehensive studies was done by Summers and Williams (2013) for the California Energy Commission.[1] That study evaluated six different types of digesters including covered lagoons, complete mixed, and plug flow and included biogas production, electrical energy production, and cogenerated heat production. The dairies that were part of the study that included the subject of this report, the ABEC #4 digester, were quite different in terms of the number of cows (300 to 5,000), the types of housing (free stall and dry lot), and the types of digester.

The study that includes this project is unique because it included three digester projects funded by the Energy Commission that are very similar in size (4,000-6,000 cows), housing type (free stalls), and digester type (covered lagoons): the ABEC #3 project at the Lakeview Dairy, the ABEC #2 project at the West Star North Dairy, and the ABEC #4 project at the Carlos Echeverria & Sons (CE&S) Dairy. However, there were some important differences: ABEC #2 had two lagoon cells as part of its digester system, and ABEC #4 used an absorption chilling system with the hot water from the engine as input.

Project Overview

The original objectives of the ABEC #4 project were to:

- Design, build, and operate a pre-commercial remotely controlled and managed biogas-fired engine-generator with combined heat and power (CHP) and an absorption chiller, and an associated covered lagoon digester, and operate the system for 12 months.
- Accept approximately 1,000,000 gallons of dairy manure into the system per day.
- Produce approximately 270,000 standard cubic feet (scf) of biogas per day of operation.
- Generate and distribute approximately 6.1 million kilowatt-hours (kWh) per year of electricity for use on the dairy under a net metering arrangement or for export to the local feeder line that also feeds all of the community's other meters.
- Produce approximately 100 tons of waste heat-fired cooling capacity to be used on site for milk chilling.
- Share knowledge gained in this demonstration with dairy farmers throughout California through webinars, publications, and appropriate organizations such as Agricultural Consumer Energy Association or the Bioenergy Association of California.
- Implement a utility-operated demand response program to help address peak power demand.

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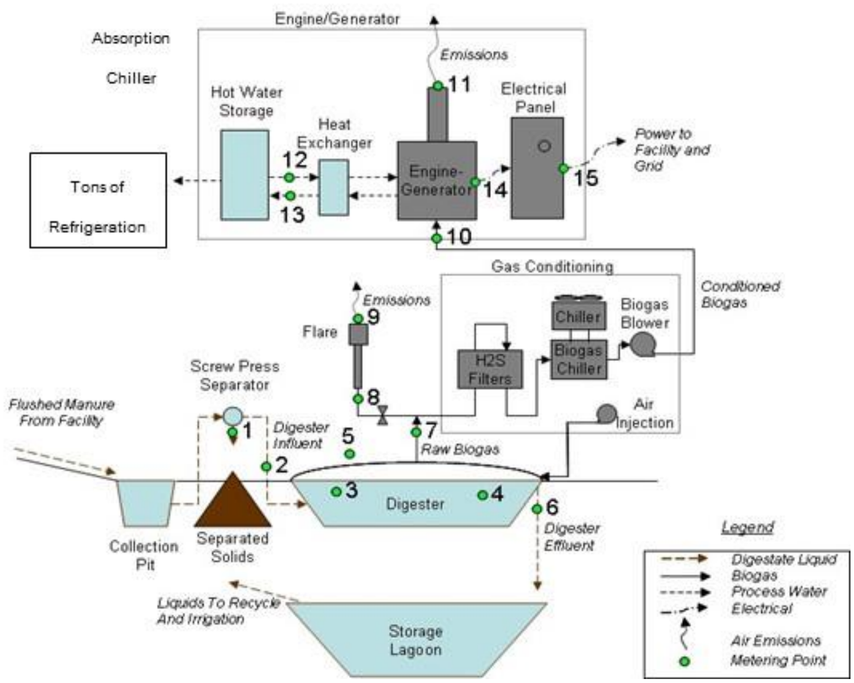
[1] Summers, Matthew; Sean Hurley. (Summers Consulting, LLC). 2013. *An Economic Analysis of Six Dairy Digester Systems in California*. California Energy Commission. Publication number: CEC-500-2014-001-V2.

Digester Construction, Startup, and Commissioning

The covered lagoon digester at Carlos Echeverria & Sons Dairy is a rectangular in-ground double-lined lagoon that is 381 feet wide by 550 feet long and 23.5 feet deep with a 2:1 side slope. The total volume of the digester is about 28 million gallons with an operating liquid volume of 25.6 million gallons (1.5 feet freeboard). The digester is loaded with approximately 400,000 gallons of manure per day from 5,776 lactating cows, 776 dry cows, and 1,825 heifers housed in the milking parlor holding area, free stall barns, and open corrals flushed with fresh and recycled water. There were 5,760 manure equivalent milkers (MEM)[2] contributing to this waste stream, with manure losses occurring because of time the cows spend in non-flushed areas of the corral. The flushed manure first passes through a solids settling tank where dirt and sand particles settle out, and the resulting liquids then are pumped over three sloped screen separators where fibrous solids are separated for bedding. The manure liquid influent from this screen then flows into the digester. Figure 1 shows a process flow diagram of the ABEC #4 digester system.

Figure 1: ABEC #4 Digester System Process Flow Diagram



Source: California Bioenergy

[2] One manure equivalent milker represents 100 percent of the manure from a Holstein cow weighing 1,360 pounds.

Table 1: Process Points in Figure 1 for ABEC #4 Digester System

#	Description
1	Flow of Manure Solids - Bedding
2	Flow of Manure, Influent to Digester
3	Temperature of Digester at Vent Valve 1
4	Temperature of Digester at Vent Valve 2
5	Temperature of Ambient Outside Air
6	Flow of Manure, Effluent from Digester
7	Flow of Gas Total (Raw Biogas)
8	Flow of Gas to Flare (Raw Biogas)
9	Flow of Emissions from Flare
10	Flow of Gas to Engine (Conditioned Biogas)
11	Flow of Emissions from Engine
12	Temperature of Coolant, Inlet to Engine, (Jacket and Exhaust Coolant)
13	Temperature of Coolant, Outlet of Engine (Between Jacket and Exhaust)
14	Kilowatts of Generator Power Output
15	Kilowatts of Net Total (Power after Parasitic Loads)

Source: California Bioenergy

Construction commenced in 2017 with excavation of the lagoon, installation of a double liner system (Figure 2), and filling with a half-and-half mixture of fresh and stored aged manure.

Figure 2: ABEC #4 Digester Under Construction

Source: California Bioenergy

The digester cover was then pulled over the liquid digester contents, attached at the perimeter, and the mixer and air injection systems installed (Figure 3).

Figure 3: ABEC #4 Digester Cover Installation

Source: California Bioenergy

Digester start-up commenced with monitoring the biogas production while the rest of the components were installed: biogas lines, 1,000-kilowatt (kW) engine-generator, and flare and vent systems (Figure 4 and Figure 5). Finally, the electrical systems were installed and utility approvals obtained followed by successful production of electricity and official tie-in with Pacific Gas and Electric Company (PG&E) in February 2018.

Figure 4: ABEC #4 Overview of Digester System

Source: California Bioenergy

Figure 5: ABEC #4 Engine-Generator

Source: California Bioenergy

CHAPTER 2
Project Approach

Data Collection and Analysis

This chapter describes the data collection process for the following digester systems:

- Dairy cow manure production and collection
- Flushed manure pretreatment and solids separation
- Digester influent and effluent
- Digester biogas production – quantity and quality
- Engine-generator production- gross and net
- Cogenerated heat utilization
- Financial performance parameters

The research team collected data during monthly visits to the ABEC #4 digester along with weekly visits by CalBio personnel to sample the influent and effluent and check the status of the digester's supervisory control and data acquisition (SCADA) system. CalBio, the parent company for the ABEC #4 project, contributed emissions and greenhouse gas data and compiled digester engine energy data and monthly financial data. The complete matrix of data for ABEC #4 digester is in Appendix A.

Dairy Cow Manure Production and Collection

Staff at CE&S Dairy provided the count of dairy cows that was then used to calculate the dairy manure production. The count included lactating cows, dry cows, and the heifers and calves. The daily manure production estimate was based on American Society of Agricultural and Biological Engineers (ASABE) manure production standards. The amount of actual manure collected was based on the percentage of time each animal category spent on the concrete manure collection areas versus the dry lot areas.

Digester Influent and Effluent

The manure was flushed with recycled water into a sump and a sand settling basin (Figure 6) where heavier inert sand and dirt was settled out.

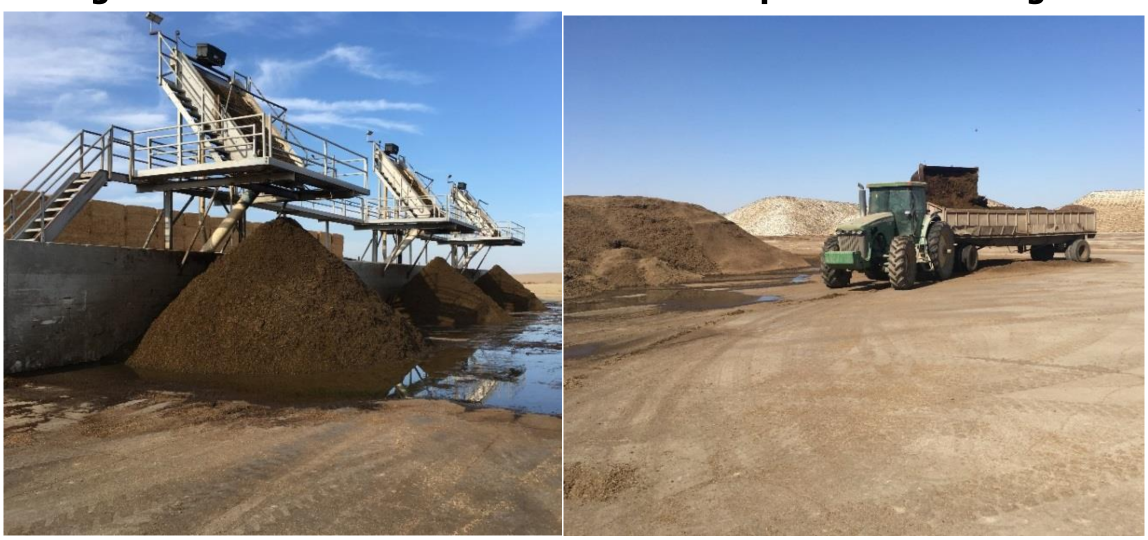
Flushed Manure Solids Separation

The manure was then pumped over three sloped screen separators (Figure 7). The resulting fibers were collected and used for bedding and soil amendments; daily volume was estimated by the number of truckloads removed and the weight of each truckload.

Figure 6: ABEC #4 Sand Settling Basin and Influent Sampling Point

Source: California Bioenergy

Figure 7: ABEC #4 Manure Solids Screen Separators and Wagon



Source: California Bioenergy

After the fibers were removed, the resulting liquid was metered and entered the digester as influent. While the influent was not sampled, some sampling of the flushed manure before screening was sent to laboratories for analysis of total solids, volatile solids, and sulfates. The effluent exited the digester at the opposite corner of the digester via an overflow sump where samples were collected for analysis (Figure 8). Influent and effluent samples were also analyzed for temperature and pH using portable instruments.

Figure 8: ABEC #4 Effluent Overflow Sump and Pipe into Storage Pond

Source: California Bioenergy

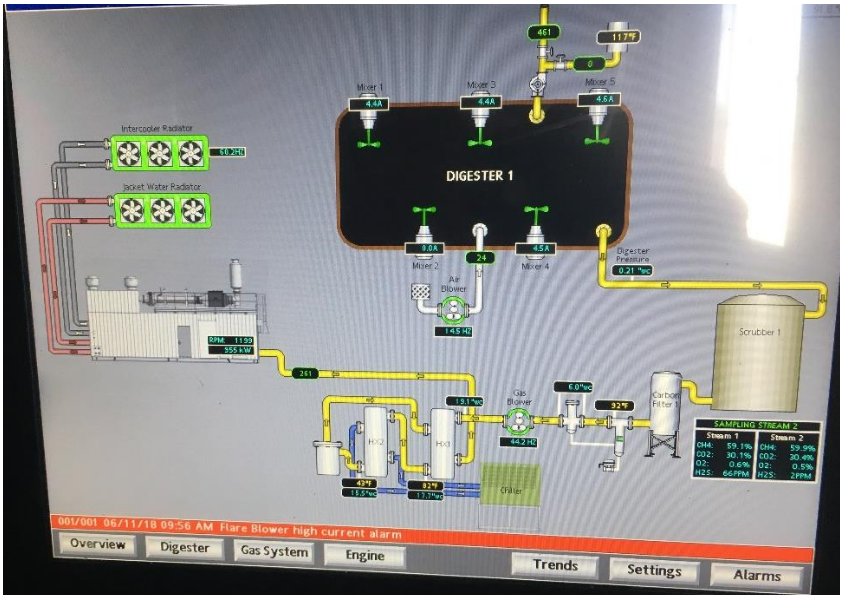
Digester Biogas Production Quantity and Quality

Digester biogas production was measured with meters built into the engine-generator system and meters at the flare and vent. Figure 9 shows a typical view of ABEC #4 digester cover. The biogas quality was continuously monitored by the sensors built into the engine-generator SCADA system (see screenshot in Figure 10). Weekly biogas samples were also taken using a portable analyzer. The parameters for measuring biogas quantity were cubic feet per minute (cfm) and cubic feet per month for engine-generator input and flare/vent output, with total biogas being the sum of the engine-generator and flare/vent flows. Biogas quality parameters included percentage of methane (CH_4), carbon dioxide (CO_2), oxygen (O_2) and parts per million (ppm) of hydrogen sulfide (H_2S). Also monitored was the air injection rate in cfm, used for H_2S reduction under the digester cover.

Figure 9: ABEC #4 Digester

Source: California Bioenergy

Figure 10: ABEC #4 Engine-Generator SCADA Screenshot



Source: California Bioenergy

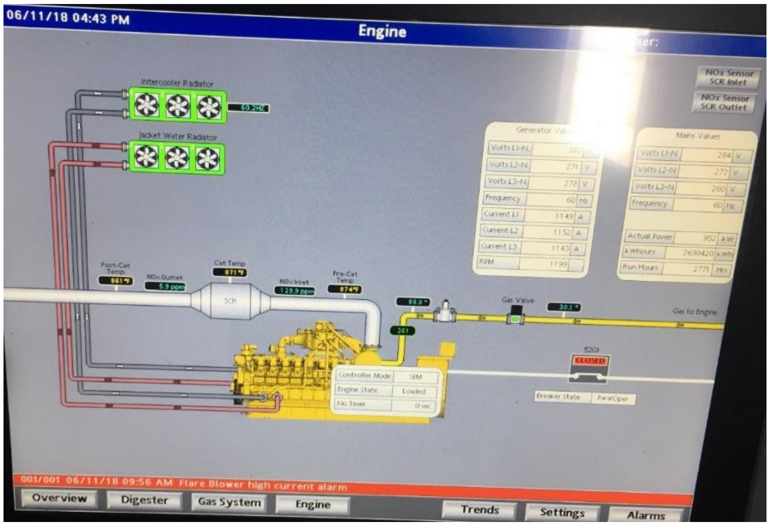
Engine-Generator Gross and Net Production

Engine-generator gross electrical production is recorded by the Martin Energy SCADA and was recovered each month from: https://martinenergygroup.websupervisor.net/#/login. The net energy production was also recorded by the engine-generator SCADA and downloaded by CalBio each month. The average kilowatt (kW) output was then determined by dividing the total monthly kilowatt-hours by the total monthly hours of the generator, and the parasitic load was the difference between the gross and net electrical power. Figure 11 shows the ABEC #4 engine-generator system and Figure 12 the screenshot of the engine-generator instantaneous output.

Figure 11: ABEC #4 Engine-Generator System

Source: California Bioenergy

Figure 12: ABEC #4 Engine-Generator SCADA Screenshot of Production Parameters



Source: California Bioenergy

Cogenerated Heat Use

For most of 2018, the waste heat from the engine was dispersed into the atmosphere via the radiators shown at the top left of Figure 12. The ultimate goal for using the cogenerated heat was to power an absorption chiller that provides refrigeration for milk cooling at the dairy parlor. Construction for installing the chiller was completed in September 2018 and included connecting the cooling water pipes from the engine to the absorption cooler located near the milking parlor (Figure 13 and Figure 14). The absorption chiller was commissioned in October 2017 and operated in November and December 2017.

Figure 13: ABEC #4 Engine-Generator Cooling Water Pipes for Absorption Chiller

Source: California Bioenergy

Figure 14: ABEC #4 Absorption Chiller Using Cogenerated Heat from Engine

Source: California Bioenergy

Financial Performance Parameters

CalBio collected and recorded financial performance data each month. Data collected included monthly net engine-generator production sold to PG&E, total capital cost of the ABEC #4 digester and engine-generator systems, and monthly operating costs of the digester system including management, consultants, administration, insurance, digester operations and maintenance (O&M), engine-generator O&M, gas handling, accounting, legal, taxes, and utilities.

Environmental Quality Data

Criteria Pollutant Parameters

The Clean Air Act requires United States Environmental Protection Agency (USEPA) to set National Ambient Air Quality Standards (NAAQS) for six common air pollutants: ozone, particulates, lead, carbon monoxide, sulfur oxides, and nitrogen oxides. The criteria emissions from the engine that were recorded included NOx, SOx, CO, volatile organic compounds (VOCs), and particulates. Levels of these pollutants were recorded monthly using a portable tester unit, and an annual source stack emission test was conducted by Montrose Environmental. This test was conducted over a two-day period in May 2018. Figure 15 shows the apparatus used for this testing. Note that Figure 15 actually shows the testing at the ABEC #3 project, but is representative of the stacks used in the ABEC #4 project.

Figure 15: Stack Emission Third Party Testing Apparatus

Source: California Bioenergy

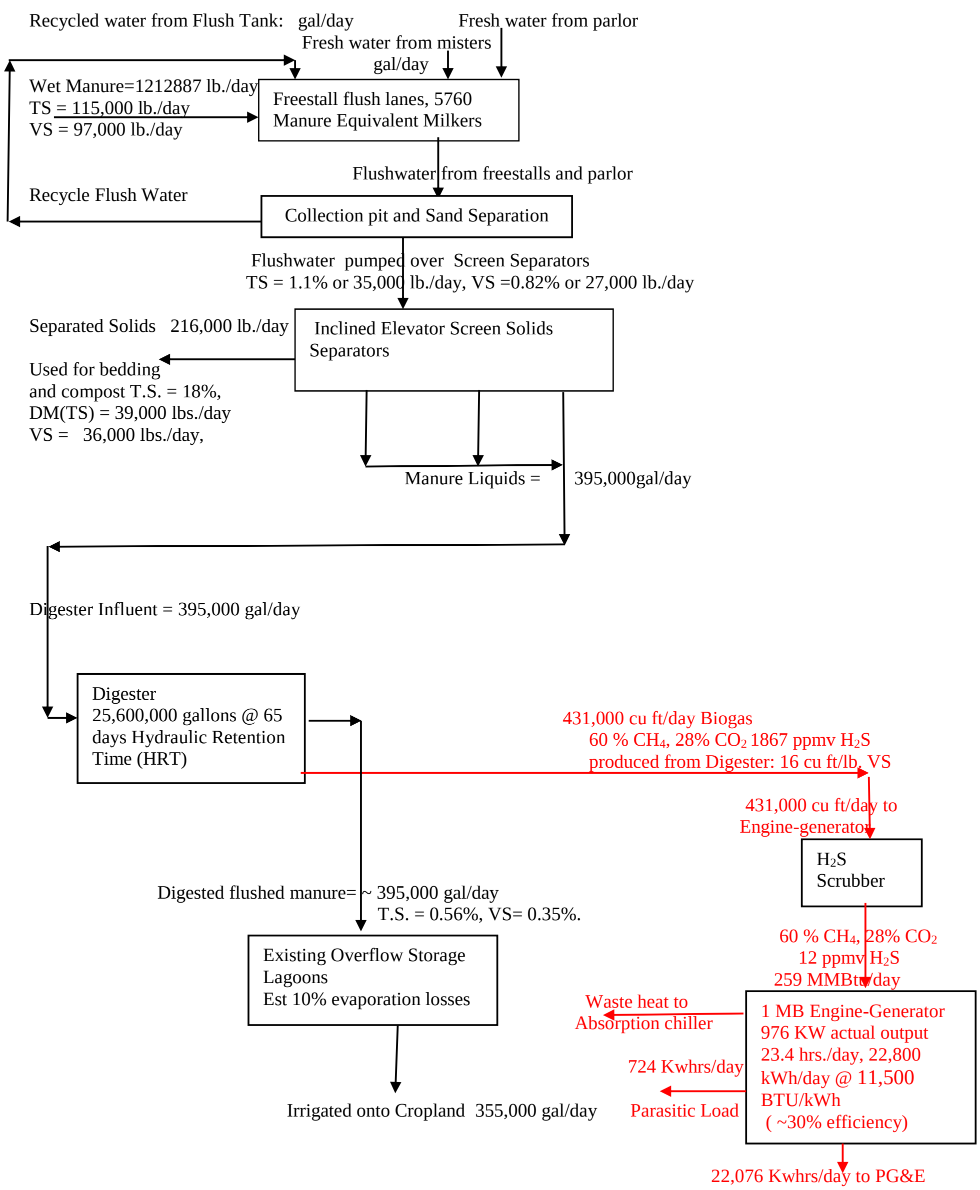
Greenhouse Gas Emission Reductions

The research team determined greenhouse gas emission reductions each month based on biogas production and baseline dairy manure parameters using the California Air Resources Board (CARB) Livestock Protocol in which the avoided methane is the standard cubic feet (scf) recorded monthly by the digester biogas meter, adjusted for methane content, with the density of methane then used to calculate metric tons (MT) of methane. The estimated reduction in $MTCO_2e$ was then determined using the CARB conversion factor of 25 MT of carbon dioxide equivalent ($MTCO_2e$) per $MTCH_4$.

CHAPTER 3: Project Results

This chapter summarizes the results of the 12-month data collection effort regarding the ABEC #4 CE&S digester system. Figure 16 shows a mass and energy flow diagram of ABEC #3 with average daily quantities of the various inputs and outputs.

Figure 16: ABEC #4 Mass and Energy Flow Diagram



Flow Diagram – CE&S Covered Lagoon Digester System- Typical Daily Flows

Source: California Bioenergy

Dairy Cow Manure Production and Collection

ABEC #4 had an average of 5,765 lactating cows, 776 dry cows, and 1,825 heifers housed in the milking parlor holding area, free stall barns, and open corrals. After losses based on the percentage of time spent on concrete surfaces and flush recycling, there were 5,760 MEMs contributing to this waste stream. Based on ASABE standards the daily manure collected on concrete surfaces and flushed to pretreatment prior to digestion was 115,000 pounds per day of total solids (TS) and 97,000 pounds per day of volatile solids (VS).

Flushed Manure Pretreatment and Solids Separation

After the flushed manure passed through a settling basin for removal of inert sand and dirt, the resulting liquid that was pumped over the slope screen separator system ranged from approximately 300,000 gallons per day in the cooler winter and spring months to 500,000 gallons per day during the warmer months of summer and fall due to the added water from cooling misters in the free stalls. The fiber separated by the screen separators was estimated to be approximately 216,000 pounds per day consisting of 18 percent total solids (39,000 pounds) of which 93 percent (36,000 pounds) was VS.

Digester Influent and Effluent

The actual digester influent was not sampled due to inaccessibility to the influent pipe. However, the volumes and characteristics of the influent prior to the sloped screen separator were measured; average daily values for 2018 are shown in Table 2.

Table 2: ABEC #4 Daily Influent (Prior to Screen) Flows and Characteristics, Average for 2018

Flow/Characteristic	Data Source	Result
Flow of Manure, Influent to Digester	Inline Flowmeter	395,000 gal./day
Temperature of Manure, Influent to Digester	Type-K TC, 6 in probe	(°F) N/A
Composition of Manure, Influent to Digester	Monthly samples, 24h	(pH) N/A 10,600 mg/l TS 8,200 mg/l VS
Total Solids in Influent	Flow X TS	35,000 Lb. /Day
Volatile solids in Influent	Flow X VS	27,000 Lb./day
Digester Volume	Measurement	25,600,000 gal.
Hydraulic Retention Time	Volume/influent/day	65 days
Volatile Solids Loading Rate	LB VS/digester volume	7.9 Lb. VS/1000 cu ft/day

Source: California Bioenergy

The average digester effluent volumes and characteristics for 2018 are shown in Table 3.

Table 3: ABEC #4 Daily Effluent Flows and Characteristics, Average for 2018

Flow/Characteristic	Data Source	Result
Flow of Effluent from Digester Cell #1	Estimated from influent flow	395,000 gal./day
Average Ambient Temperature	United States climate data 2018	65°F
Temperature of Effluent from Digester	Type-K TC, 6 in probe	71°F
Composition of Effluent from Digester	Monthly samples	7.1 pH 5,600 mg/l TS 3,500 mg/l VS

Source: California Bioenergy

The daily digester biogas production volume and characteristics for ABEC #4 in 2018 are shown in Table 4. Based on the organic loading rate of 27,000 pounds of VS per day (Table 2), the digester performance in terms of biogas produced per unit of VS is 15.95 cubic feet per pound VS, much higher than the original estimation of 8.4 cubic feet per pound VS. There was no excess biogas above the engine-generator requirements.

Table 4: ABEC #4 Daily Biogas Flows and Characteristics, Average for 2018

Flow/Characteristic	Data Source	Result
Flow of Gas Total (Raw Biogas)	Mass flow meter	312 scfm 430,725 cu ft/day
Composition of Gas Total (Raw Biogas)	Monthly analysis	60% CH_4 by vol. 28% CO_2 by vol. 1,867 ppm H_2S 1.07% O2 by vol.
Flow of Gas to Flare/Vent (Raw Biogas)	Mass flow meter	0 scf/day
Flow of Gas to Engine-Generator	Mass flow meter	312 scfm 430,725 scf/day
Composition of Gas to Generator	Monthly analysis	60% CH_4 by vol. 28% CO_2 by vol. 12 ppm H_2S 1.1% O_2 by vol.

Source: California Bioenergy

Engine-Generator Gross and Net Production

The monthly engine-generator gross and net electrical production are listed in Table 5.

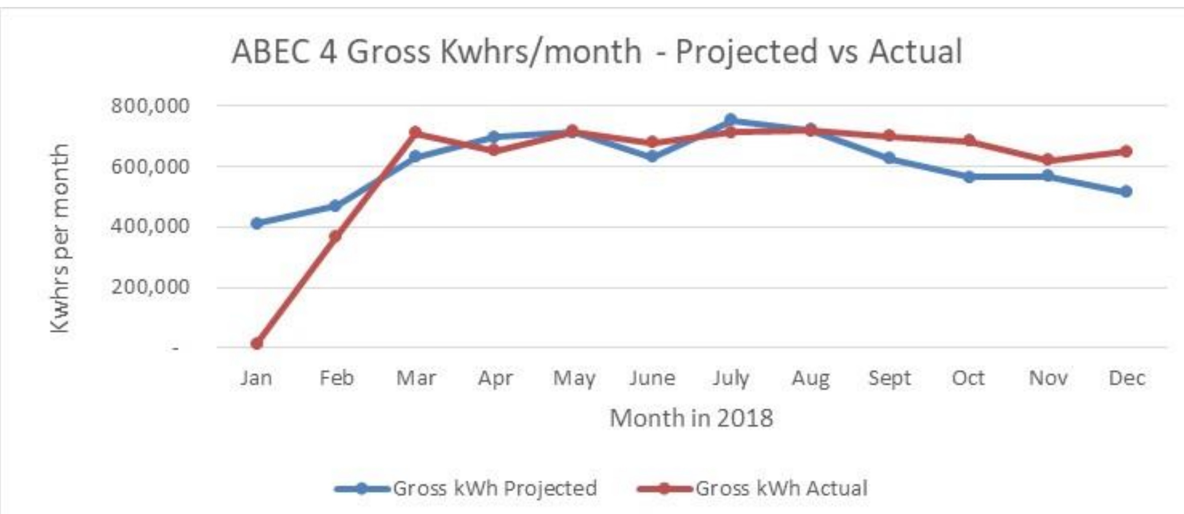
Table 5: ABEC #4 Engine-Generator Average Monthly Electrical Production in 2018

Electrical Production	Data Source	Result
Average Gross Generator Power Output	Generator power meter	976 kW
Generator hours	Generator power meter	701 hrs./mo.
Total Gross Generated Electrical Production	Generator power meter	683,882 kWhrs/month
Net Power sold to PG&E (after Parasitic Loads)	Utility meter - pulse	945 kW
Total electrical energy sold to PG&E	Utility meter - pulse	662,452 kWhrs/month
Parasitic Load	Gross – Net power	31 kW

Source: California Bioenergy

Figure 17 compares the actual gross monthly electrical production with the projected production estimated in the original proposal.

Figure 17: ABEC #4 Electrical Production



Source: California Bioenergy

Cogenerated Heat Use

The engine-generator at ABEC #4 provided hot water to an absorption chiller that starting in November helped cool the milk at the milking parlor. When the absorption chiller is operating, this causes one or more of the refrigeration compressors to go off-line, thus saving electrical energy. The research team estimates one to two compressors, 35 horsepower each, were offline due to the input of the absorption chiller. This saved an estimated 28,274 kWhs of electricity and provided the equivalent of 11 tons of refrigeration.

Financial Performance Parameters

ABEC #4 digester system financial performance parameters are shown in Table 6.

Table 6: ABEC #4 Digester System Financial Performance in 2018

Parameter	Data Source	Result
NTI: Net monthly income from electricity	Utility Statement	$127,000/mo.
CAPEX: Total Capital Expenditures	Cal Bio Financial Records	$7,627,147
OPEX: Monthly Operating Expenditures	Cal Bio Financial Records	$34,400/mo.
PB: Payback period on all relevant investments	CAPEX (NTIX-OPEX)/12	6.8 yrs.

Source: California Bioenergy

Environmental Quality Data

Criteria Air Quality Parameters

ABEC #4 Engine-generator criteria air quality parameters are shown in Table 7.

Table 7: ABEC #4 Engine-Generator Average Criteria Air Quality Parameters in 2018

Parameter	Data Source	Result
Criteria Emissions from Engine: NOx CO	Monthly analysis using Tester; Annual 2-day stack test	NOx ppm @ 15% O2: 2.64 ppm CO ppm @ 15% O2: 35 ppm (Limits 11 ppm NOx, 210 ppm CO)

Source: California Bioenergy

Greenhouse Gas Reductions

ABEC #4 digester system greenhouse gas reductions are shown in Table 8.

Table 8: ABEC #4 Digester System Greenhouse Gas Reductions in 2018

Greenhouse Gas Reduction	Data Source	Result
Avoided methane	Biogas meter plus CARB GHG protocol (1 gr CH_4 = 25 gr CO_2e)	2,885 grams of CO_2e/ kWh 21,524 total tons of CO_2e

Source: California Bioenergy

Hydrogen Sulfide Removal

While untreated biogas can have H_2S contents of 4,000-5,000 ppm, ABEC #4 digester reduced the H_2S to 1,867 ppm while using an air injection system. A final iron sponge scrubbing resulted in H_2S levels of 12 ppm going into the engine-generator.

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

Meetings, Presentations, and Open House

The approach used to build market adoption included numerous meetings and presentations and an open house for the completed ABEC #4 CE&S Dairy digester project.

- Conducted community outreach meetings at the Kern Farm Bureau on June 13, 2017 and January 16, 2018.
- Held an open house for the CE&S digester commissioning for the general public on February 2, 2018.
- On April 12, 2018, Neil Black and Roy Dowd from CalBio and Stuart Heisler from Anacapa (CalBio's lead process engineer on all four clusters; Anacapa is based in Bakersfield) spoke at an event to introduce CalBio to the California State University Bakersfield community. The hour-long program was coordinated by Dr. Kathleen Madden, Dean of Natural Sciences, Mathematics and Engineering. Roughly half a dozen faculty and 25 students attended the presentation and question and answer. Topics included: the state's greenhouse gas and Short-Lived Climate Pollutants reduction requirements; local environmental benefits; and the importance of academic training in biology and engineering to build digester projects. CalBio's internship and the hiring at Anacapa (in part to support the CalBio projects) were explained and resulted in significant interest.
- On April 20, 2018, at the invitation of Professor Karim Salehpoor, Roy Dowd presented to his Renewable Energy Production engineering class. The class was primarily introductory about dairy digesters and covered key elements of the biological processes, design/construction decisions, and operations and maintenance programs.
- School visit on April 24, 2018. Neil Black spoke to thirty-four lively students in Mrs. Julie Cates's 6^{th} grade class at the Linwood School in Visalia. More visits are planned. A substantial number of the students are likely from disadvantaged communities, reflecting the area's demographics, and the Linwood School program is aimed to serve as a platform for broader educational outreach in Tulare and Kings counties.
- In the fall of 2018, CalBio's digester consultant, Dr. Doug Williams, gave two presentations discussing CalBio's existing dairy digester projects and future plans up and down the San Joaquin Valley. The first presentation occurred on September 25, 2018 in the Agricultural Anatomy class at Delta High School in Clarksburg, California. The second presentation was on November 16, 2018 to the BioResource and Agricultural Engineering class at Cal Poly where Dr. Williams taught for many years. A significant portion of the next generation of California dairy farmers are educated at Cal Poly. Several students expressed interest in potentially working with CalBio and inquired about potential internships.
- CalBio presented at US Biogas 2018 in San Diego on November 6, 2018.

- CalBio presented at Sustainable Dairy Conference in Sacramento, California on November 27–28, 2018.

Intended Audience

- The intended audience included dairy farmers, government officials, universities, high schools, and technology providers and developers.

Technology advancements

- Near-term markets for the results of this research are dairy farms; the mid-term and long-term target markets would be other agricultural and food industries that produce organic wastes that could be used for energy generations via anaerobic digestion.

Economic and Environmental Consequences of Technology Adaptation

- There are currently approximately 1.7 million dairy cows in California. At 200 kW per 1,000 cows, electrical generating capacity could be as much as 340 megawatts of renewable energy.

Technical Advisory Committee

The technical advisory committee consisting of California government and regulatory officials, university and industry representatives then gave Cal Bio feedback that their organizations were very receptive to the digester technology. This committee consisted of the following individuals and their affiliations

- Rizaldo Aldas
- Gina Barkalow
- Le-Huy Nguyen
- Garry O'Neill

Agencies/Nonprofits

- Dan Weller, California Air Resources Board
- Stephen Klein, California State Regional Water Board
- Kevin Wing, San Joaquin Valley Air Pollution Control District
- Ryan Flaherty, Sustainable Conservation
- Rob Williams, University of California, Davis
- Trina Martynowicz, USEPA
- Robert Parkhurst, Environmental Defense Fund

Industry

- Kevin Abernathy, Milk Producers Council, Dairy Cares
- Michael Boccadoro, West Coast Advisors, Agricultural Energy Consumers Association, Dairy Cares

CHAPTER 5: Conclusions, Recommendations, and Outcomes

Conclusions

Digester Technical Performance

Using the flushed manure from 5,760 MEMs as influent, ABEC #4 averaged 431,000 cubic feet per day of biogas containing 60 percent methane, which is approximately 100 cubic feet per cow per day. Based on the organic loading rate of 27,000 pounds of VS per day, the digester performance averaged 16 cubic feet per pound VS, higher than the original estimate of 8.4 cubic feet per pound VS. This production was achieved from a covered lagoon digester with a volume of 25.6 million gallons and having an average 64 days hydraulic retention time, average temperature of 71˚F, and average organic loading rate of 8 pounds VS/1,000 cubic feet/day.

Engine-Generator Technical Performance

The monthly gross electrical production over this period averaged 684,000 kWh for 701 hours of operation (out of a possible 720 hours), averaging 976 KW. The parasitic load was 31 kW or 3.1 percent and the net monthly energy sold to PG&E averaged 662,000 kWh. For all of 2018, actual net electrical production exceeded the projected net production by 10 percent.

Financial Performance of Digester/Engine-Generator system

The average monthly income from electricity sales to PG&E was approximately $126,700. Based on a total installed cost of $7.6 million and average monthly operating costs of $34,400, the simple payback for the project is 6.8 years. For 2018 the annualized income was more than $1.5 million, or $264 per cow. Based on current milk prices of ~$15 per 100 pounds and average per cow production of 15,000 pounds of milk per year, annual milk income would be $2,250 per cow; the digester electrical production therefore adds around 12 percent to the dairy’s per-cow income.

Environmental Quality Outcomes

The environmental benefits of this project include the reduction of 21,524 $MTCO_2e$, principally methane. This reduction is equivalent to taking 4,679 cars off the road according to USEPA. Engine exhaust emissions were held to 2.64 ppm of NOx and 35 ppm CO, both well under CARB limits of 11 ppm NOx and 210 ppm CO.

Recommendations

1. Continue research on H_2S reductions in the digester, especially regarding the use and optimization of the air injection system.
2. Improve solids separation methods that increase the yield of methane per cow.
3. Expand the on-farm use of the waste heat from the generators, such as the absorption chiller that was utilized at ABEC #4.

Outcomes Compared to Objectives

- The project team designed, built, and operated for 12 months a pre-commercial remotely controlled and managed biogas-fired engine-generator with CHP and an absorption chiller, and an associated covered lagoon digester. (objective completed)
- The system accepted an average of 395,000 gallons per day of dairy manure (objective was approximately 1,000,000 gallons per day)
- The system produced an average of 431,000 scf of biogas per day of operation. (objective was approximately 270,000 scf/day)
- The system produced a net of 7.95 million kWh of electricity in a year (objective was to generate and distribute approximately 6.1 million kWh per year of electricity on the dairy under a net metering arrangement and/or export to the local feeder line that also feeds all of the community's other meters)
- The team installed and commissioned an absorption chiller in October 2018, with preliminary testing done and full operation expected in 2019. (objective was to produce approximately 100 tons of waste heat fired cooling capacity to be used on site for milk chilling)
- Shared knowledge gained in this demonstration with dairy farmers and other biogas electricity project developers throughout California through webinars, signage, publications, and other outreach. (objective completed)
- The project participated in a utility-operated demand response program to help address peak power demand by automatically turning the generator on or off based on (1) PG&E's time-of-day pricing schedule for that time of year and (2) the amount of biogas fuel available in the digester for the day. (objective completed. (objective completed)

CHAPTER 6: Benefits to Ratepayers

This project demonstrated that electricity generated using digester gas can be competitive with other forms of power generation in California, while also significantly reducing carbon emissions. Ratepayers benefit from the digester technology through the availability of economic electrical generation that reduces air pollution and greenhouse gas emissions.

The technology analyzed in this project could be adapted to other agricultural businesses that have sufficient organic waste products, providing additional benefits to ratepayers in the form of more clean energy.

ABEC # 4 produced 976 kW and reduced greenhouse gas emissions by 21,000 metric tons of CO_2e per year. If all dairies adapted this digester technology, the amount of energy possible is 340 megawatts of electricity, while reducing greenhouse gas emissions by 12 million metric tons per year. With electricity demand in California continuing to grow, adding to the state's electricity generating capacity benefits ratepayers by helping to keep costs low for meeting that increased demand.

This research provides a foundation for other studies by providing data on digester performance that can be used to verify or improve existing anaerobic digestion theoretical equations.

A significant environmental benefit is the reduction of H_2S. While untreated biogas can have H_2S contents of 4,000 to 5,000 ppm, the ABEC #4 digester reduced the H_2S to 1,867 ppm while using an air injection system. A final iron sponge scrubbing resulted in H_2S levels of 12 ppm going into the engine-generator.

Odor reduction was also a very significant societal benefit of the covered lagoon digester technology.

LIST OF ACRONYMS

Term	Definition
ABEC	American Biogas Electric Company
ASABE	American Society of Agricultural and Biological Engineers
CalBio	California Bioenergy
CAPEX	Total capital expenditures
CARB	California Air Resources Board
CEE	Criteria emissions from engine: NOx, SOx, CO, volatile organic compounds, particulates
CEF	Composition of emissions from flare
Cfm	Cubic feet per minute
CGF	Composition of gas to flare (raw biogas)
CGE	Composition of gas to engine (conditioned)
CGT	Composition of gas total (raw biogas)
CE&S	Carlos Echeverria and Sons
CH_4	Methane
CME	Composition of manure, effluent from digester
CMI	Composition of manure, influent to digester
CMS	Composition of manure solids
CO_2	Carbon dioxide
FC	Flow of coolant
FEF	Flow of emissions from flare
FGE	Flow of gas to engine (conditioned biogas)
FGF	Flow of gas to flare (raw biogas)
FGT	Flow of gas total (raw biogas)
FME	Flow of manure, effluent from digester
FMI	Flow of manure, influent to digester
FMS	Flow of manure solids - bedding
GHG	Greenhouse gas
H_2S	Hydrogen sulfide

Term	Definition
kW	kilowatt
kWh	Kilowatt-hour
MEM	Manure equivalent milkers
mg/l	milligrams per liter
MT	Metric tons
$MTCO_2e$	Metric tons of carbon dioxide equivalent
NTI	Net total income from electricity
O_2	Oxygen
O&M	Operation and maintenance
OPEX	Monthly operating expenditures
PB	Payback period on all relevant investments
PG&E	Pacific Gas & Electric Company
Ppm	Parts per million
SCADA	Supervisory Control and Data Acquisition
Scf	Standard cubic feet
Scfm	Standard cubic feet per minute
TAO	Temperature of ambient out
TCI	Temperature of coolant, inlet to engine, (jacket and exhaust coolant)
TCO	Temperature of coolant, outlet of engine (between jacket and exhaust)
TD1	Temperature of digester at vent valve 1
TD2	Temperature of digester at vent valve 2
TME	Temperature of manure, effluent from digester
TMI	Temperature of manure, influent to digester
TS	Total solids
USEPA	United States Environmental Protection Agency
VS	Volatile solids
WGO	Kilowatts of generator power output
WNT	Kilowatts of net total (power after parasitic loads)

REFERENCES

American Society of Agricultural and Biological Engineers (ASABE) Standards. ASABE D384.2 MAR2005, Manure Production and Characteristics. 2005.

CARB (California Air Resources Board). Compliance Offset Protocol Livestock Projects, https://www.arb.ca.gov/cc/capandtrade/protocols/livestock/livestock.htm

EPA, Greenhouse Gas Emissions from a Typical Passenger Vehicle. https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle

Summers, Matt and DW Williams, "Energy and Environmental Performance of Six Dairy Digester Systems in California", prepared for California Energy Commission, Sacramento, CA, January 2014. http://www.energy.ca.gov/2014publications/CEC-500-2014-001/CEC-500-2014-001-V1.pdf

APPENDIX A:
Data Matrix for ABEC #4 Digester

Table A-1: Digester Inputs

Data Point	Description	Eng. Units	Sensor or Instrument	MONTH January	MONTH February	MONTH March	MONTH April	MONTH May	MONTH June	MONTH July	MONTH August	MONTH September	MONTH October	Month November	Month December	Averages
FMS	Flow of Manure Solids - Bedding	lb./day	Daily weight estimate	216000	216000	216000	216000	216000	216000	216000	216000	216000	216000	216000	216000	216,000
		Tons/month	Monthly weight estim	3348	3024	3348	3240	3348	3240	3348	3348	3240	3348	3240	3348	3,285
CMS	Composition of Manure Solids	% TS by wt.	Quarterly samples	N/A	N/A	15%			19%			19%		20%	18%	18%
FMI	Flow of Manure,	Gal/day	Inline Flowmeter	425000	475000	392000	386000	329529	394558	480,141	437,482	438,698	349,218	317,414	316,934	395,165
TMI	Temperature of Manure, Influent to Digester	°F	Type-K TC, 6 in probe	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CMI	Composition of Manure, Influent to Digester	pH	Monthly grab samples and lab analysis	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		mg/l TS		N/A	N/A	N/A	N/A	9400	10000	10,100	12,000	8,200	14,000	11,000	9,800	10,563
		mg/l VS		N/A	N/A	N/A	N/A	7300	7600	7,750	9,400	6,500	11,000	8,600	7,300	8,181
TD1	Temperature of Digester at Vent Valve 1	°F	Estimated from TME	62	62	64	69	72	78	85	84	80	71	63	59	71
TD2	Temperature of Digester at Vent Valve 2	°F	Estimated from TME	62	62	64	69	72	78	85	84	80	71	63	59	71
TAO	Average Temperature of Ambient Out	°F	usclimatedata.com for Bakersfield, CA	47	53	58	64	71	78	83	83	77	67	56	48	65
FME	Flow of Manure, Effluent from Digester	Gal/day	Estimated from FMI	425000	475000	392000	386000	329529	394558	480141	437482	438698	349218	317414	316934	395,165
TME	Temperature of Manure, Effluent from Digester	°F	Type-K TC, 6 in probe	62	62	64	69	72	78	85	84	80	71	63	59	71
CME	Composition of Manure, Effluent from Digester	pH	Monthly samples, 24h	7.03	7.76	7.12	7.12	7.03	7.09	6.96	6.91	6.97	7.02	7.05	7.11	7.1
		mg/l TS		3600	3300	3800	7600	6600	5200	4475	3700	2800	5300	14000	7000	5,615
		mg/l VS		1400	1800	1900	4800	4000	2900	2700	2200	2000	3400	11000	4000	3,508

Source: California Bioenergy

Table A-2: Digester Outputs: Biogas

Data Point	Description	Eng. Units	Sensor or Instrument	MONTH January	MONTH February	MONTH March	MONTH April	MONTH May	MONTH June	MONTH July	MONTH August	MONTH September	MONTH October	Month November	Month December
FGT	Flow of Gas Total (Raw Biogas)	scfm	Estimated from FGE&F	300	339	322	279	292	279	279	300	320	336	346	343
		cu ft/day		N/A	488160	454955	377739	403525	397854	400140	427935	456997	448598	440078	441993
CGT	Composition of Gas Total (Raw Biogas)	CH4% by vol.	Monthly analysis	60%	60%	59%	65%	60%	59%	58%	59%	60%	60%	60%	60%
		CO2 %by vol.		25%	25%	27%	31%	29%	30%	30%	28%	29%	28%	28%	26%
		H2S ppm		300	3000	3213	4883	2023	94	173	952	542	239	1365	4050
		O2 % by vol.			2%	2%	0	1%	1%	0.6%	1.0%	1.0%	0.8%	1.0%	1.4%
FGF	Flow of Gas to Flare (Raw Biogas)	SCF/day	Mass Flow meter	0	0	0	0	0	0	0	0	0	0	0	0
CGF	Composition of Gas to Flare (Raw Biogas)	% by vol.	Monthly analysis	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FEF	Flow of Emissions from Flare	SCF/day	Estimated from FGF	0	0	0	0	0	0	0	0	0	0	0	0
CEF	Composition of Emissions from Flare	% or ppm	Monthly analysis	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
FGE	Flow of Gas to Engine (Conditioned Biogas)	scfm	Mass Flow meter	300	339	322	279	292	279	279	300	320	336	346	343
CGE	Composition of Gas to Engine (Conditioned)	CH4% by vol.	Monthly analysis	60%	60%	60%	60%	60%	60%	59%	58%	60%	61%	60%	61%
		CO2 %by vol.		25%	25%	25%	25%	30%	30%	30%	27%	29%	29%	28%	27%
		H2S ppm		1	12	25	1	2	2	2	36	1	3	29	32
		O2 % by vol.		1.50%	2.00%	1%	2%	1%	1%	0.4%	0.7%	1.0%	0.8%	0.9%	1.3%

Source: California Bioenergy

Table A-3: Engine Outputs: Electrical Generation and Emissions

Data Point	Description	Eng. Units	Sensor or Instrument	MONTH January	MONTH February	MONTH March	MONTH April	MONTH May	MONTH June	MONTH July	MONTH August	MONTH September	MONTH October	Month November	Month December
FEE	Flow of Emissions from Engine	SCF/day	CEF	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CEE	Criteria Emissions from Engine: NOx, SOx, CO, Volatile Organic Compounds (VOC's), particulates	% or ppm	Monthly analysis using Tester; Annual 2-day stack test	N/A	NOx ppm @ 15% O_2: 3.378 ppm CO ppm @ 15% O2: 4.495 ppm	NOx ppm @ 15% O_2: 4.065 ppm CO ppm @ 15% O2: 16.000 ppm	NOx ppm @ 15% O_2: 6.402 ppm CO ppm @ 15% O2: 11.428 ppm	N/A results not yet available	NOx ppm @ 15% O_2: 0.84 ppm CO ppm @ 15% O2: 14.4 ppm	NOx ppm @ 15% O_2: 1.853 ppm CO ppm @ 15% O2: 57.757 ppm	No testing this month	NOx ppm @ 15% O_2: 1.860 ppm CO ppm @ 15% O2: 73.343 ppm	NOx ppm @ 15% O_2: 2.706 ppm CO ppm @ 15% O2: 59.405 ppm	NOx ppm @ 15% O_2: 0.947 ppm CO ppm @ 15% O2: 39.870 ppm	NOx ppm @ 15% O_2: 1.699 ppm CO ppm @ 15% O2: 38.613 ppm
GHG	Greenhouse gas Reductions: avoided methane and hydrogen sulfide	Grams of CO2e/ kwhr;	Biogas meter plus CARB GHG protocol (1 gr CH4 = 25 gr CO2e)	4,745.31	1,419	1,865	3,862	5,238	6,826	5,157	3,010	2,122	844	785	609
		Metric Tons of CO2e /month		N/A	524	1324	2521	3745	4634	3672	2162	1483	577	486	396
TCI	Temperature of Coolant from Absorption Chiller, inlet to engine heat exchanger	°F	Type-K TC, 6 in probe	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FC	Flow of Coolant	GPM	Onicon Flowmeter	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TCO	Temperature of Coolant to Absorption Chiller, outlet from engine heat exchanger	°F	Type-K TC, 6 in probe	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TOR	Tons of Refrigeration to Milk cooler	Tons of refrigeration	Calculation based on 40 kw savings in refrigeration compressors	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	11.2	11.2
WGO	Generator Power Output	kW	Gen power meter	1017	988	973	966	1,001	952	961	974	980	992	974	976
	Generator hours	hrs./mo.	Gen power meter	0	374	730	676	714	713	741	737	713	689	636	666
	Kilowatt-hours generated per month	kWhrs/mo.			369371	710000	652852	715029	678828	712088	718189	698848	683415	619282	650212
WNT	Kilowatts of Net Total	kW	Utility meter - pulse	1001	928	957	938	969	920	920	936	945	962	960	954
	Net Kilowatt-hours/month	kwhrs/month			347143	698800	634304	692147	655855	681986	689731	673,613	662,596	610,702	635,366
	Parasitic Load: only radiator heat exchange. Digester loads are separate	kW	Electrical meters	16	16	15	27	32	32	41	39	35	30	13	22

Source: California Bioenergy

Table A-4: Financial Performance of Digester System

Data Point	Description	Eng. Units	Sensor or Instrument	MONTH January	MONTH February	MONTH March	MONTH April	MONTH May	MONTH June	MONTH July	MONTH August	MONTH September	MONTH October	Month November	Month December
NTI	Net total income from electricity, based on WNT X hours/month X $.19/kwhr	$/month	Utility Statement	N/A	$ 65,957	$ 147,041	$ 106,204	$ 114,127	$ 108,941	$ 134,141	$ 135,786	$ 132,625	$ 135,679	$ 125,912	$ 129,956
CAPEX	Total Capital Expenditures	$	Cal Bio Financial Reco	$	*	$ 7,627,147	$ 7,627,147	$ 7,627,147	$ 7,627,147	$ 7,627,147	$ 7,627,147	$ 7,627,147	$ 7,627,147	$ 7,627,147	$ 7,627,147
OPEX	Monthly Operating Expenditures	$/month	Cal Bio Financial Reco	N/A	*	$ 53,250	$ 43,700	$ 52,819	$ 38,125	$ 23,727	$ 59,586	$ 25,362	$ 26,550	$ 15,418	$ 39,975
PB	Payback period on all relevant investments	Years	CAPEX/(NTIX-OPEX)/1	N/A	*	6.78	10.17	10.37	8.98	5.76	8.34	5.93	5.82	5.75	7.06
	System footprint, visual impact, ingress and egress requirements			N/A	N/A	See Narrative and Summary	See Narrative and Summary	See Narrative and Summary	See Narrative and Summary	See Narrative and Summary	See Narrative and Summary	See Narrative and Summary	See Narrative and Summary	See Narrative and Summary	See Narrative and Summary
	Water consumption, Atmospheric emissions - see CEE and GHG above,	Gal water/mo.	Calculated from influent flow meter(influent*90%=	N/A	N/A	10,936,800	10,422,000	9,193,859	10,653,066	13,395,934	12,205,748	11,844,846	9,428,886	8,570,178	8,557,218
	Specific jobs and economic development resulting from this project		Cal Bio Financial Records	N/A	.33 FTE (Roy Dowd)	.33 FTE (Roy Dowd)	.33 FTE (Roy Dowd)	.33 FTE (Roy Dowd)	.33 FTE (Roy Dowd)	.33 FTE (Roy Dowd)	.33 FTE (Roy Dowd)	.33 FTE (Roy Dowd)	.33 FTE (Roy Dowd)	.33 FTE (Roy Dowd)	.33 FTE (Roy Dowd)

Source: California Bioenergy