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Energy Research and Development Division

FINAL PROJECT REPORT

Construction and Operation of the ABEC #3 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 #3 Covered Lagoon Digester and Electrical Generation System is the final report for the ABEC #3 Digester project, Contract Number EPC-14-022, conducted by California Bioenergy LLC. 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

ABEC #3 LLC, DBA Lakeview Farms Dairy Biogas installed and demonstrated an innovative covered lagoon digester system that processes dairy manure into biogas to generate renewable electricity for export to the electricity distribution grid.

This project documented the construction and one year of operation of the ABEC #3 LLC (ABEC #3) covered lagoon digester, which has a volume of 18.5 million gallons, along with a 1-megawatt engine-generator. Construction of the digester was completed in 2017 along with start-up and commissioning using flushed manure from 4,168 "manure equivalent milkers" as influent (one manure equivalent milker 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 #3 averaged 374,000 cubic feet per day of biogas containing 61 percent methane, approximately 90 cubic feet of biogas per cow per day. The monthly gross electrical production over this period averaged 607,000 kilowatt-hours for 614 hours of operation (out of a possible 720 hours), averaging 985 kilowatts. The parasitic load was 43 kilowatts or 4.3 percent, and the net monthly energy sold to Pacific Gas and Electric Company averaged 580,000 kilowatt-hours.

The average monthly income for the project was approximately $116,000, with a simple payback of 7.5 years based on $7.925 million total installed capital cost and average monthly operating costs of $27,500. The project provided the additional benefit of producing an average of 99 tons per day of fiber bedding and fertilizer.

The environmental benefits of the project included reduction of nearly 11,000 metric tons of carbon dioxide equivalent greenhouse gases, principally methane, along with keeping exhaust emissions at 2.3 parts per million (ppm) of oxides of nitrogen and 10 ppm carbon monoxide, well under California Air Resources Board limits. Progress was made in limiting hydrogen sulfide emissions, thus prolonging the life of the engine-generator. Levels ranged from a high of 1,000 ppm to a low of 193 ppm, averaging 582 ppm for the year while using only the air injection system, and a final iron sponge scrubbing resulted in hydrogen sulfide levels of 5 ppm going into the engine-generator.

Keywords: Methane, dairy manure, anaerobic digestion, energy

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EXECUTIVE SUMMARY

Introduction

California has been the nation's 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 electricity and natural gas for their operations and, according to the California Air Resources Board (CARB), 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 CARB 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, which consists of methane, carbon dioxide, and small amounts of water and other compounds. The methane can then be burned to generate electricity or heat. 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 for a 12-month operating period for covered lagoon digester systems that produce electricity.

Converting the manure from California dairy cows to methane and subsequently to electricity can produce a substantial quantity of energy. These renewable energy resources generate electricity with little or no pollution and also contribute to California's goal of lowering greenhouse gas emissions to reduce the effects of climate change. Biomethane from dairy manure digestion has the added benefit of being able to produce electricity around the clock, unlike solar and wind technologies, and can also be scheduled to generate during periods of high electricity demand.

Project Purpose

American Biogas Electric Company (ABEC) #3 LLC, DBA Lakeview Farms Dairy Biogas, has installed and demonstrated an innovative covered lagoon digester system that will process dairy manure into biogas to generate renewable electricity for export to the electricity distribution grid. This particular project is located near 11 other dairies and will help launch the state's first "hub-and-spoke" dairy digester cluster by preparing the 1 megawatt (MW) generator platform to accept 2 MWs of future capacity potentially using biogas from neighboring dairies and providing a means to off-take gas for vehicle fuel use. This hub-and-spoke approach was initially proposed in a case study prepared for the United States Department of Agriculture on the economic feasibility of dairy digester clusters in California. The idea is to allow dairies to benefit from the aggregation of capital investment and reduce operation and management costs by centrally locating the generators and associated electrical equipment.

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 ABEC #3 digester and engine-generator system and provided performance data over 12 months. The results provide a comprehensive report on how electricity can be cost-effectively 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 that included a Supervisory Control and Data Acquisition (SCADA) system 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, Chief Executive Officer, and Controller, as well as the onsite operator and consultant researchers for the project. The key stakeholder was the farm owner at the ABEC #3 dairy whose staff were very helpful in the data gathering effort.

The project team formed a technical advisory committee consisting of representatives from the California Energy Commission (CEC), various non-profits and governmental agencies (CARB, 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 #3 digester equaled or exceeded expected monthly production by as much as 32 percent during 2018. Annual electrical production was more than 1,500 kilowatt-hours per milk cow equivalent (a measure of manure equivalent to that produced by a Holstein cow weighing 1,360 pounds). Greenhouse gas emission reductions totaled 2.6 metric tons of carbon dioxide equivalent per milk cow equivalent per year. Because of the extensive and comprehensive data collection and analysis, this study provided the knowledge and data to inform efforts to adopt proper energy standards. As a result, the analysis identified electrical production data from dairy manure digesters that 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 #3 digester and engine-generator system effectively provided results that could be valuable in using the digester technology. Additional research is necessary on how to improve hydrogen sulfide scrubbing to enable 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, presentations, and an open house for the completed Lakeview 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 generation via anaerobic digestion.

The demonstrated success of the ABEC #3 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 #3 digester facility, as well as at two other digester facilities (ABEC #2 and ABEC #4) 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 energy technology.

Members of the technical advisory committee, including California government and regulatory officials as well as university and industry representatives, reported that their organizations are 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 gases. 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 997 kilowatts of electricity capacity over 12 months in 2018 and reduced greenhouse gas emissions by 11,000 metric tons of carbon dioxide equivalent. If all of California’s dairies adopted this digester technology, they could potentially provide 340 megawatts of electricity, 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 is needed, 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.
- One of the other projects funded by the CEC, ABEC #4, used an absorption chiller to use waste heat from the generators. The benefit of this technology is utilization of otherwise wasted thermal energy from the engine, to reduce the energy to cool milk. Therefore, the researchers recommend further expansion of the on-farm use of the waste heat from the generators, such as the absorption chiller that was utilized at ABEC #4. This could also be done at ABEC #3.

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 12-month study looked at 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 studied in this report were quite different in terms of the number of cows (300 to 5,000), types of cow housing (free stall and dry lot), and type 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 that is the subject of this report, the ABEC #2 project at the West Star North Dairy, and the ABEC #4 project at the Carlos Echeverria & Sons 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 #3 project were to:

- Build a pre-commercial, covered lagoon digester located at a dairy.
- Operate the system for 12 months.
- Accept approximately 785,000 pounds of dairy manure into the system per day.
- Produce approximately 360,000 standard cubic feet (scf) per day of biogas or 130 million scf of biogas per year of operation.
- Export approximately 6.7 million kilowatt-hours (kWh) of electricity to the Pacific Gas and Electric Company (PG&E) distribution grid (or use the electricity in a net energy metering arrangement).
- Build the infrastructure foundation and plan for the future phase-2 diversion of 25 percent to 33 percent of the biogas to produce renewable compressed natural gas to be used as a transportation fuel.
- Prepare a system for possible codigestion of substrates with a planned test of biodiesel wash-water from Crimson Renewable Energy.[2]

[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.

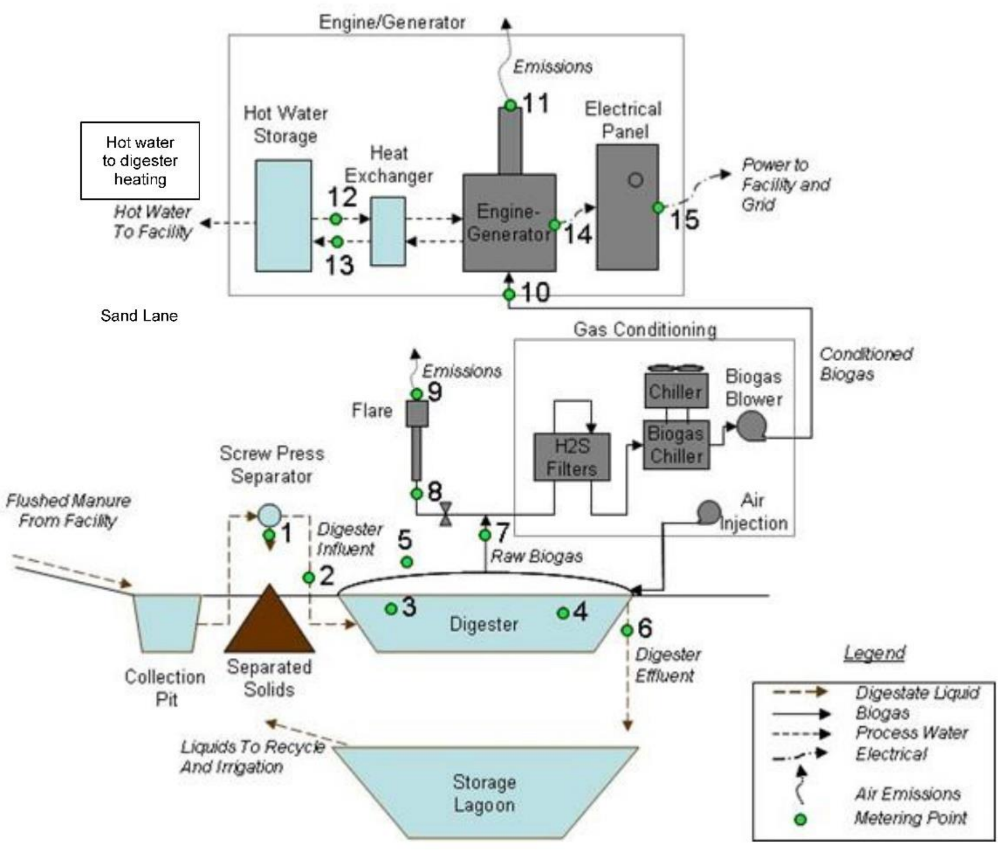
[2] Crimson Renewable Energy, located in Bakersfield, is California's largest producer of ultra-low carbon biodiesel.

- Pump about 250 million gallons/year of nutrient-rich water into irrigation pipes.
- Share knowledge gained through the demonstration project with dairy farmers throughout California through webinars, signage, publications, and other outreach.

Digester Construction, Startup, and Commissioning

The covered lagoon digester at Lakeview dairy is a rectangular in-ground double-lined lagoon that is 331 feet wide by 518 feet long and 20 feet deep with a 2:1 side slope. Total liquid volume is about 18.5 million gallons with 1.5 feet freeboard. The digester is loaded with the manure from 4,450 lactating cows housed in the milking parlor holding area, free stall barns, and open corrals flushed with fresh and recycled water, amounting to approximately 600,000 gallons per day. An average of 4,168 manure equivalent milkers (MEMs)[3] contributed 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 over two sloped screen separators where fibrous solids are separated for bedding. The manure liquid from this screen then passes through a sand lane where dirt and sand particles settle out, and the resulting influent finally flows into the digester. Figure 1 shows a process flow diagram of the ABEC #3 digester system; Table 1 describes each process point within the figure.

Figure 1: ABEC #3 Digester System Process Flow Diagram



Source: California Bioenergy

[3] 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 #3 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 #3 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 #3 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 engine-generator, and flare and vent systems (Figure 4). Finally, the electrical systems were installed and utility approvals obtained followed by successful production of electricity and official tie-in with PG&E in February 2018.

Figure 4: ABEC #3 Overview of Digester System

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 #3 digester along with weekly visits by CalBio personnel to sample the influent and effluent and check the status of the digester's SCADA system. CalBio, the parent company for the ABEC #3 project, contributed emissions and greenhouse gas emissions data and compiled digester engine energy data and monthly financial data. The complete matrix of data collected for the ABEC #3 digester is in Appendix A.

Dairy Cow Manure Production and Collection

Staff at Lakeview Dairy provided the count of dairy cows that was then used to calculate 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 concrete manure collection areas versus dry lot areas.

Flushed Manure Pretreatment and Solids Separation

The manure was flushed with recycled water into a sump and then pumped over two sloped screen separators (Figure 5). The resulting fibers were collected and used for bedding and soil amendments. Daily volume of solids was estimated based on the volume of each stack of manure accumulated over a typical 24-hour day, then using the density of the manure solids to calculate the weight of the manure solids in the two stacks of manure. This number was then confirmed with the staff at Lakeview Dairy.

Digester Influent and Effluent

After removal of the fibers, the liquids were pumped through a sand lane (Figure 6), where heavier inert sand and dirt settled out. The resulting liquid is metered and enters the digester as influent. The influent was sampled monthly and sent to laboratories for analysis of total solids, volatile solids, and sulfates.

Figure 5: ABEC #3 Manure Solids Screen Separators and Resulting Fiber Stacks

Source: California Bioenergy

Figure 6: ABEC #3 Sand Lane and Influent Sampling Point

Source: California Bioenergy

The effluent (material leaving the digester) exits at the opposite corner of the digester via an overflow sump where samples were collected for analysis (Figure 7). Influent and effluent samples were also taken and analyzed for temperature and pH using portable instruments.

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 8 shows the ABEC #3 digester and the biogas offtake pipe. The biogas quality was continuously monitored by sensors built into the engine generator SCADA system, a screenshot of which is shown in Figure 9. Weekly biogas samples were also taken using a portable analyzer. The quantity parameters were cubic feet per minute (cfm) and cubic feet per month for engine-generator input and flare/vent output, for which the total biogas was the sum of the engine-generator and flare/vent flows. Biogas quality parameters included percentages of methane (CH_4), carbon dioxide (CO_2), oxygen (O_2) and parts per million of hydrogen sulfide (H_2S). Also monitored was the air injection rate in cfm, used for H_2S reduction under the digester cover.

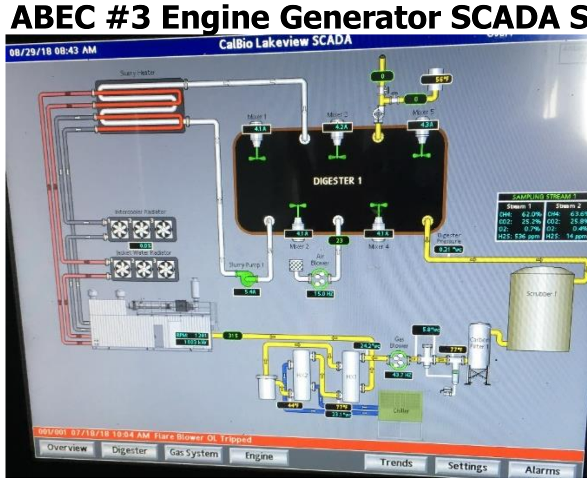
Figure 7: ABEC #3 Effluent Overflow Sump and Sampling Point

Source: California Bioenergy

Figure 8: ABEC #3 Digester

Source: California Bioenergy

Figure 9: ABEC #3 Engine Generator SCADA Screenshot

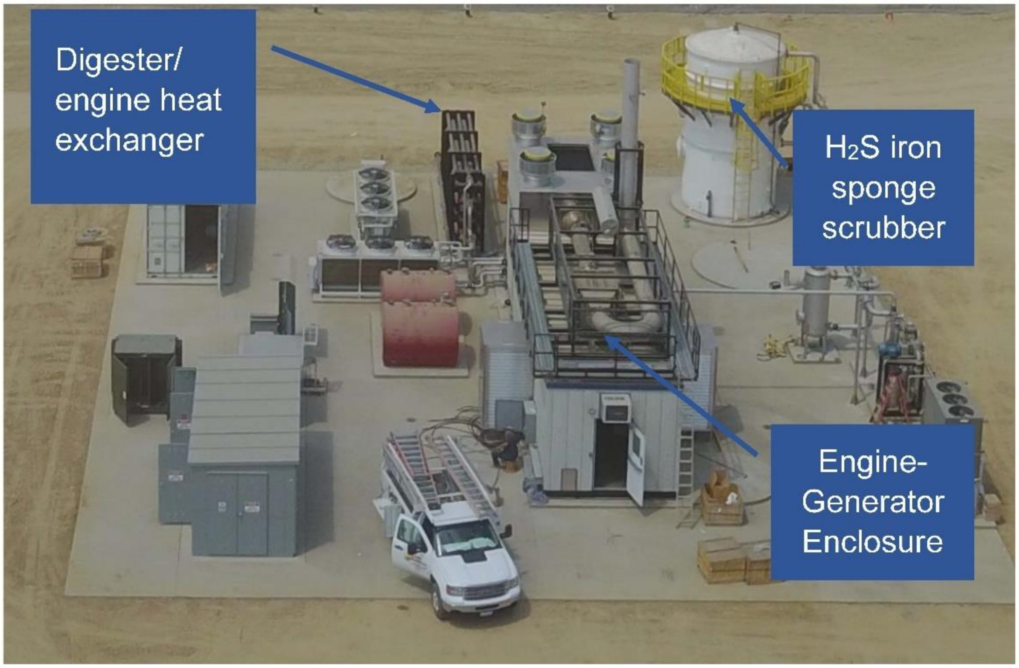


Source: California Bioenergy

Engine Generator Gross and Net Production

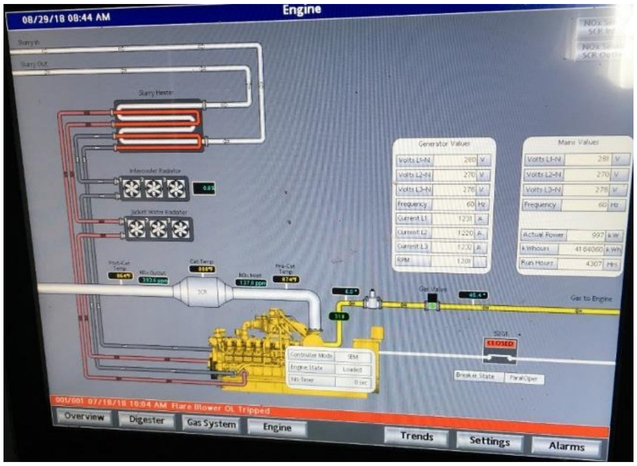
Engine-generator gross electrical production was recorded by the Martin Energy SCADA and was recovered each month from: https://martinenergygroup.websupervisor.net/#/login. The net energy production was also recorded by the engine generator SCADA and downloaded by CalBio each month. The average kilowatt (kW) output was then determined by dividing the total monthly kilowatt-hours by the total monthly hours of the generator , and the parasitic load (internal electrical demand consumed during operations) was the difference between the gross and net electrical power. Figure 10 shows the ABEC #3 engine-generator system; Figure 11 is a screen shot of the engine-generator's instantaneous output in August.

Figure 10: ABEC #3 Engine-Generator System



Source: California Bioenergy

Figure 11: ABEC #3 Engine Generator SCADA Screen Shot of Production Parameters



Source: California Bioenergy

Cogenerated Heat Use

The engine heat is used for digester heating via the heat exchanger shown in Figure 10. Data was not recorded for the quantity of heat used.

Financial Performance Parameters

CalBio, where all financial data was accumulated for the project, recorded financial performance parameters each month. Data collected included the net electricity produced by the engine-generator that was sold to PG&E each month, total capital cost of the ABEC #3 digester and engine-generator systems, and monthly operating cost of the ABEC#3 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 the United States Environmental Protection Agency (USEPA) to set National Ambient Air Quality Standards (NAAQS) for six common air pollutants: ozone, particulates, lead, carbon monoxide (CO), sulfur oxides (SOx), and oxides of nitrogen (NOx). The criteria emissions in the engine exhaust addressed in this report 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 12 shows the apparatus used for this testing at ABEC #3.

Figure 12: Stack Emission Testing at ABEC #3 Engine-generator

Source: California Bioenergy

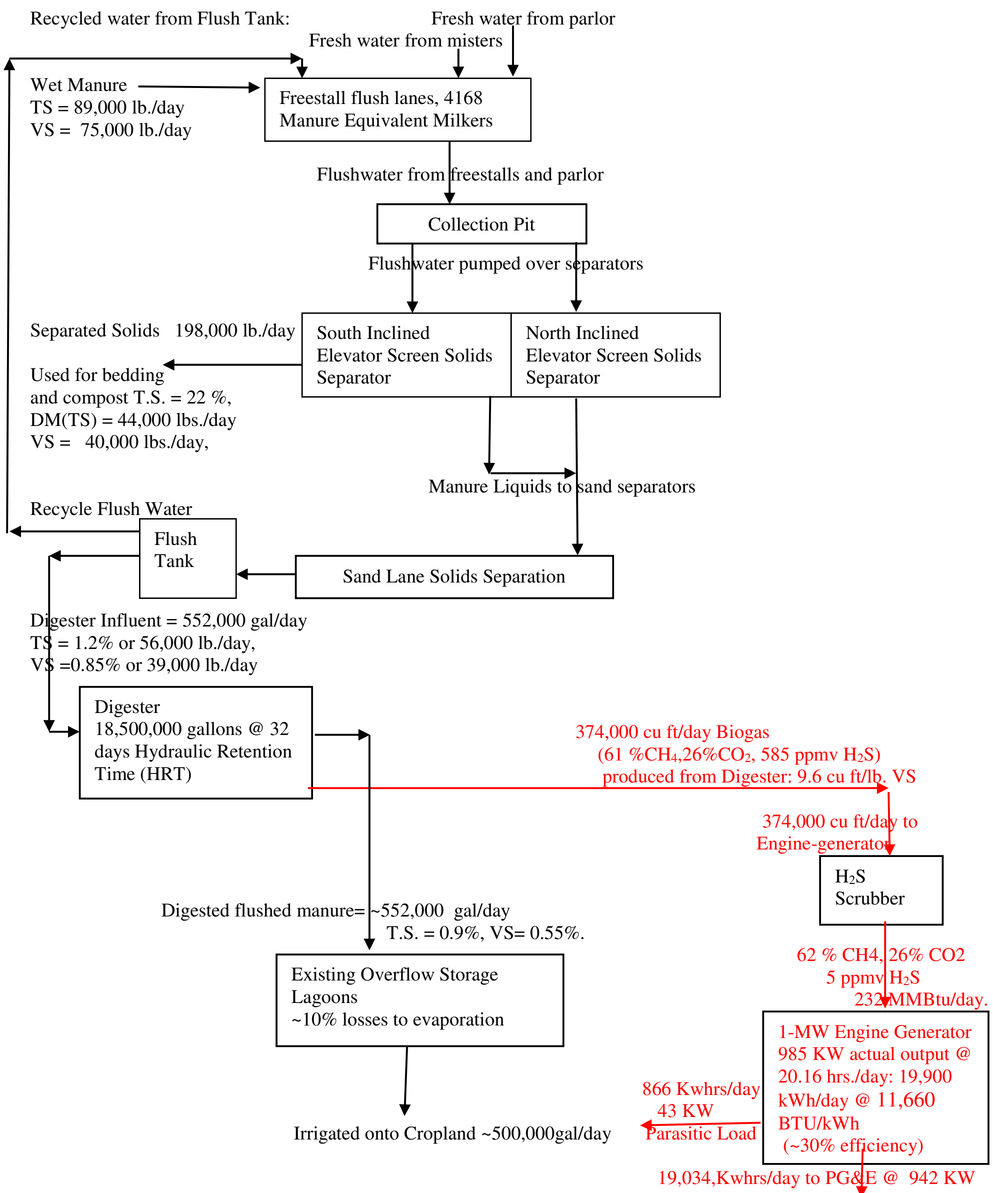
Greenhouse Gas Emission Reductions

Greenhouse gas emission reductions were determined 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. Using the CARB conversion factor of 25 MT of carbon dioxide equivalent ($MTCO_2e$) $MTCH_4$, the estimated reduction in $MTCO_2e$ was then determined.

CHAPTER 3:
Project Results

This chapter summarizes the results of the 12-month data collection effort for the ABEC #3 Lakeview digester system. Figure 13 shows a mass and energy flow diagram of ABEC #3 with average daily quantities of the various inputs and outputs.

Figure 13: ABEC #3 Mass and Energy Flow Diagram



Flow Diagram –
Lakeview Covered Lagoon Digester System – Typical Daily Flows

Source: California Bioenergy

Dairy Cow Manure Production and Collection

ABEC #3 had an average of 4,450 lactating cows 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 4,168 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 89,000 pounds per day of total solids (TS) and 75,000 pounds per day of volatile solids (VS).

Flushed Manure Pretreatment and Solids Separation

The remaining flushed manure available to the slope screen separator system ranged from approximately 400,000 gallons per day in the cooler winter and spring months to 700,000 gallons per day during the warm 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 198,000 pounds per day consisting of 22 % total solids (44,000 lb.) of which 93% was volatile solids (40,000 lb. VS). After passing through the sand lane for removal of inert sand and dirt, the resulting liquid then entered the digester.

Digester Influent and Effluent:

Table 2 shows the average digester influent volumes and characteristics for 2018.

Table 2: ABEC #3 Daily Influent Flows and Characteristics, Average for 2018

Flow/Characteristic	Data Source	Result
Flow of Manure, Influent to Digester	Inline Flowmeter	552,283 gal./day
Temperature of Manure, Influent to Digester	Type-K TC, 6 in probe	70.8°F
Composition of Manure, Influent to Digester	Monthly samples, 24h	• 7.8 pH • 12,135 mg/l TS • 8,450 mg/l VS
Total Solids in Influent	Flow X TS	55,864 Lb. /Day
Volatile solids in Influent	Flow X VS	38,921 Lb./day
Digester Volume	Measurement	18,500,000 gal.
Hydraulic Retention Time	Volume/influent/day	32 days
Volatile Solids Loading Rate	LB VS/digester volume	15.7 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 #3 Daily Effluent Flows and Characteristics, Average for 2018

Flow/Characteristic	Data Source	Result
Flow of Effluent from Digester Cell #1	Estimated from influent flow	552,283 gal./day
Average Ambient Temperature	United States climate data 2018	67°F
Temperature of Effluent from Digester Cell #1	Type-K TC, 6 in probe	74°F
Composition of Effluent from Digester Cell #1	Monthly samples	7.2 pH 9,004 mg/l TS 5,518 mg/l VS

Source: California Bioenergy

Digester Biogas Production Quantity and Quality

The daily digester biogas production volume and characteristics for 2018 are shown in Table 4. Based on the organic loading rate of 38,921 pounds of VS per day (Table 2), the digester performance in terms of biogas produced per unit of VS is 9.6 cubic feet per pound VS, higher than the original estimation of 8.4 cu ft/pound VS. There was no excess biogas above the engine-generator requirements.

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

Flow/Characteristic	Data Source	Result
Flow of Gas Total (Raw Biogas)	Mass flow meter	315 scfm 373,809 cu ft/day
Composition of Gas Total (Raw Biogas)	Monthly analysis	61% CH_4 by vol. 26% CO_2 by vol. 585 ppm H_2S <1% O_2 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	317 scfm 373,809 scf/day
Composition of Gas to Generator	Monthly analysis	62% CH_4 by vol. 26% CO_2 by vol. 5 ppm H_2S <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.

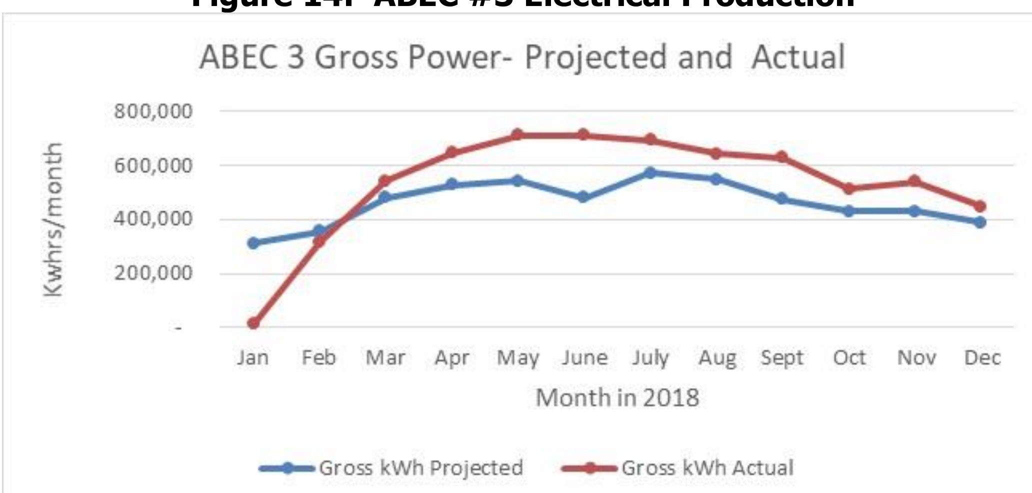
Table 5: ABEC #3 Engine-Generator Average Monthly Electrical Production in 2018

Electrical Production	Data Source	Result
Average Gross Generator Power Output	Generator power meter	985 kW
Generator hours	Generator power meter	614 hrs./mo.
Total Gross Generated Electrical Production	Generator power meter	606,515 kWhrs/mo.
Net Power sold to PG&E (after Parasitic Loads)	Utility meter - pulse	942 kW
Total electrical energy sold to PG&E	Utility meter - pulse	580,350 kWhrs/mo.
Parasitic Load	Gross – Net power	43 kW

Source: California Bioenergy

Figure 14 compares the actual gross monthly electrical production with the projected production estimated in the original project proposal.

Figure 14: ABEC #3 Electrical Production



Source: California Bioenergy

Cogenerated Heat Use

The engine heat is used for ABEC #3 digester heating via the heat exchanger shown in Figure 10. Data was not recorded for the quantity of heat used.

Financial Performance Parameters

ABEC #3 digester system financial performance parameters are shown in Table 6.

Table 6: ABEC #3 Digester System Financial Performance in 2018

Parameter	Data Source	Result
NTI: Net monthly income from electricity	Utility Statement	$115,615/mo.
CAPEX: Total Capital Expenditures	Cal Bio Financial Records	$7,924,693
OPEX: Monthly Operating Expenditures	Cal Bio Financial Records	$27,589/mo.
PB: Payback period on all relevant investments	CAPEX (NTIX-OPEX)/12	7.5 yrs.

Source: California Bioenergy

Environmental Quality Data

Criteria Pollutant Parameters

ABEC #3 engine generator criteria air quality parameters are shown in Table 7.

Table 7: ABEC #3 Engine Generator Average Criteria Pollutant 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: 2.31 ppm CO ppm @ 15% O2: 10.00 ppm (Limits 11 ppm NOx, 210 ppm CO)

Source: California Bioenergy

Greenhouse Gas Reductions

ABEC #3 digester system greenhouse gas reductions are shown in Table 8.

Table 8: ABEC #3 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)	1,519 grams of CO_2e/ kWh 10,973 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, the ABEC #3 digester reduced the H_2S to 582 ppm while using an air injection system. A final iron sponge scrubbing resulted in H_2S levels of 5 ppm going into the engine-generator.

CHAPTER 4: Technology and Market Adoption Activities

Meetings, Presentations, and Open House

The approach used to build market adoption included numerous meetings, presentations, and an open house for the completed ABEC #3 Lakeview Dairy digester project as outline below.

- Conducted community outreach meetings at the Kern Farm Bureau on June 13, 2017 and January 16, 2018.
- Held an open house for Lakeview 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 for the results of this project includes 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 generation via anaerobic digestion.

Economic and Environmental Consequences of Technology Adaptation

There are currently approximately 1.7 million dairy cows in California. The results of the digester and engine-generator system at ABEC #3 included the production of 1,500 kWh per cow, meaning the electrical production potential could be as much as 2.6 million megawatt-hours of renewable electricity generation per year.

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/Outcomes

Conclusions

Digester Technical Performance

Using the flushed manure from 4,168 MEMs as influent, ABEC #3 averaged 374,000 cubic feet per day of biogas containing 61 percent methane which is approximately 90 cubic feet per cow per day. Based on the organic loading rate of 38,921 pounds of VS per day, the digester performance averaged 9.6 cubic feet per pound VS, higher than the original estimation of 8.4 cubic feet per pound VS. This production was achieved from a covered lagoon digester with a volume of 18.5 million gallons and having an average 32 days hydraulic retention time, average temperature of 74˚F and average organic loading rate of 15.7 pounds VS/1,000 cubic feet/day.

Engine-Generator Technical Performance

The monthly gross electrical production over this period averaged 607,000 kWh for 614 hours of operation (out of a possible 720 hours), averaging 985 KW. The parasitic load was 43 kW or 4.3 percent, and the net monthly energy sold to PG&E averaged 556,000 kWh. For all of 2018, actual net electrical production exceeded the projected net production by 20 percent.

Financial Performance of Digester/Engine Generator System

The average monthly income from electricity sales to PG&E was approximately $116,000. B ased on a total installed cost of $7.925 million and average monthly operating costs of $27,500, the simple payback for the project is 7.5 years. For all of 2018 the annualized income was almost $1.4 million, or $334 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 15% to the dairy’s per-cow income.

Environmental Quality Outcomes

The environmental benefits of this project include the reduction of almost 11,000 metric tons of CO_2e greenhouse gases, principally methane. This CO_2e reduction is equivalent to taking 2,391 cars off the road according to USEPA. Engine exhaust emissions were held to 2.3 ppm of NOx and 10 ppm CO, both well under CARB limits of 11 ppm NOx and 210 ppm CO.

Recommendations

1. Further research on H_2S reductions in the digester should be carried out, especially regarding the use and optimization of the air injection system.
2. Improved solids separation methods that increase the yield of methane per cow should be explored.
3. One of the other projects funded by the Energy Commission, ABEC #4, used an absorption chiller to use waste heat from the generators. The benefit of this technology

is utilization of otherwise wasted thermal energy from the engine, to reduce the energy to cool milk. Therefore, this recommendation is to further expand the on-farm use of the waste heat from the generators, such as the absorption chiller that was utilized at ABEC #4. This could also be done at ABEC #3.

Outcomes Compared to Objectives

- A pre-commercial, covered lagoon digester located at Lakeview dairy was built. (objective completed)
- The system was operated for 12 months. (objective completed)
- The system accepted approximately 600,000 pounds of wet manure per day. (objective was approximately 785,000 pounds/day)
- The system produced 374,000 cubic feet per day or 136 million scf per year of biogas. (objective was approximately 360,000 scf per day or 130 million scf per year of operation)
- The system exported approximately 7 million kWh of electricity for 12 months to PG&E. (objective was to export approximately 6.7 million kWh to the distribution grid or use it in a net energy metering arrangement)
- Built the infrastructure foundation and developed a plan for the future phase-2 diversion of 25-33 percent of the biogas to produce renewable compressed natural gas for transportation. (objective completed)
- Prepared a system for possible codigestion of substrates with the planned test of biodiesel wash-water from Crimson Renewable Energy. (objective completed)
- Pumped 182 million gallons per year of nutrient rich irrigation water into irrigation pipes. (objective was 250 million gallons)
- The knowledge gained in this demonstration was shared with dairy farmers and other biogas electricity project developers throughout California through webinars, signage, publications, and other outreach. (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 drastically reducing the carbon footprint of the electricity generation. Ratepayers benefit from digester technology through the availability of economic electrical generation that also 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 #3 produced 985 kW and reduced greenhouse gas emissions by 11,000 metric tons of CO_2e per year. If all dairies adopted 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 the cost of meeting that increased demand low.

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 #3 digester reduced the H_2S to 582 ppm while using an air injection system. A final iron sponge scrubbing resulted in H_2S levels of 5 ppm going into the engine-generator. Since H_2S is both odorous and toxic, removing it from the atmosphere is of benefit to all citizens of the California region where these projects are located.

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)
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
kW	kilowatt

Term	Definition
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.

USEPA, 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#3 Digester

The following tables provide data for the digester and engine system inputs, outputs, and financial performance.

Table A-1: Digester Inputs

Data	Description	Eng. Units	Sensor or Instrument	MONTH	MONTH	MONTH	MONTH	MONTH	Month	Month	Month	Month	Month	Month	Month
Point				January	February	March	April	May	June	July	August	September	October	November	December
FMS	Flow of Manure Solids - Bedding	lb./day	Daily weight estimate	198000	198000	198000	198000	198000	198000	198000	198000	198000	198000	198000	198000
		Tons/day	Monthly weight estimate	3069	2772	3069	2970	3069	2970	3069	3069	2970	3069	2970	3069
CMS	Composition of Manure Solids	% TS by wt.	Quarterly samples	N/A	N/A	27%			25%			25%		22%	23%
FMI	Flow of Manure, Influent to	Gal/day	Inline Flowmeter	766342	425000	481000	531000	594000	729,439	551,266	708,587	674,527	559,387	463,951	356,951
TMI	Temperature of Manure, Influent to Digester	°F	Type-K TC, 6 in probe	61	63	62	69	71	78	83	80	77	73	63	60
CMI	Composition of Manure, Influent to Digester	pH	Monthly samples, 24h	7.84	8.15	8.18	7.8	7.65	7.72	7.42	7.53	7.84	7.95	8.01	7.93
		mg/l TS		7500	7400	7800		16000	12700	12650	14000	10000	18000	13000	9800
		mg/l VS		3500	4800	4900		10000	9100	9000	9800	8800	12000	9200	6900
TD1	Temperature of Digester at Vent Valve 1	°F	Type-K TC, 72 in depth	63	63	65	65	80	79	89	89	85	76	64	60
TD2	Temperature of Digester at Vent Valve 2	°F	Type-K TC, 72 in depth	63	63	65	65	80	79	89	89	85	76	64	60
TAO	Temperature of Ambient Out	°F	Weather Station Data	47	53	58	64	71	78	83	83	77	67	56	48
FME	Flow of Manure, Effluent from Digester	Gal/day	Estimated from FMI	766342	425000	481000	531000	594000	729,439	551,266	708,587	674,527	559,387	463,951	356,951
TME	Temperature of Manure, Effluent from Digester	°F	Type-K TC, 6 in probe	63	62	65	65	80	79	89	89	85	76	64	60
CME	Composition of Manure, Effluent from Digester	pH	Monthly samples, 24h	7.2	7.43	7.3	7.2	7.12	7.03	7.08	7.06	7.11	7.27	7.1	7.2
		mg/l TS		4400	5000	8600	10000	8500	8000	6550	7800	10000	4600	19000	11000
		mg/l VS		1500	2300	4800	6400	5500	4600	3500	4800	6800	3000	12000	7000

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 &FGF	298	298	292	325	322	316	306	329	326	334	324	296
		cu ft/day		N/A	303960	310,274	425,750	444,983	447,456	421,095	412,630	411,592	330,579	354,074	249,504
CGT	Composition of Gas Total (Raw Biogas)	CH4% by vol.	Monthly analysis	60%	63%	61%	60%	61%	59%	59%	62%	60%	60%	63%	63%
		CO2 %by vol.		25%	24%	25%	29%	27%	27%	25%	25%	29%	29%	23%	23%
		H2S ppm		300	958	861	883	1000	193	394	555	483	289	257	528
		O2 % by vol.			1.5%	1.5%	<2%	<2%	<1%	<1%	<1%	<1%	<1%	0.5%	1.0%
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	298	298	290	325	322	316	306	329	326	334	324	296
CGE	Composition of Gas to Engine (Conditioned)	CH4% by vol.	Monthly analysis	60%	63%	61%	60%	61%	60%	62%	64%	60%	60%	64%	64%
		CO2 %by vol.		25%	24%	25%	29%	27%	28%	26%	26%	29%	29%	23%	23%
		H2S ppm		1	2	1.50	1	3	4	23	14	2	0	2	2
		O2 % by vol.		1.50%	1.50%	1.50%	<2%	<2%	<1%	<1%	<1%	<1%	<1%	0.7%	1.0%

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
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	NOxppm @ 15% O_2: 1.434 ppm CO ppm @ 15% O_2: 3.550 ppm	NOxppm @ 15% O_2: 2.567 ppm CO ppm @ 15% O_2: 3.242 ppm	NOxppm @ 15% O_2: 2.964 ppm CO ppm @ 15% O_2: 4.075 ppm	N/A results not yet available	NOxppm @ 15% O_2: 1.23 ppm CO ppm @ 15% O_2: 8.28 ppm	NOxppm @ 15% O_2: 0.944 ppm CO ppm @ 15% O_2: 10.477 ppm	No testing this month	NOxppm @ 15% O_2: 1.415 ppm CO ppm @ 15% O_2: 13.144 ppm	NOxppm @ 15% O_2: 2.101 ppm CO ppm @ 15% O_2: 14.066 ppm	NOxppm @ 15% O_2: 1.278 ppm CO ppm @ 15% O_2: 12.016 ppm	NOxppm @ 15% O_2: 4.544 ppm CO ppm @ 15% O_2: 11.186 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)	N/A	628	1,548	2,644	3,138	3,989	3,062	1,924	(712)	156	191	136
		Tons of CO2e /month		N/A	199	839	1,710	2,229	2,837	2,128	1,235	(448)	80	103	61
TCI	Temperature of Coolant, Inlet to Engine,(Jacket and Exhaust Coolant)	°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, Outlet of Engine(Between Jacket and Exhaust)	°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
WGO	Kilowatts of Generator Power Output	kW	Generator power meter	1011	875	987	988	995	1005	978	991	998	1001	985	1029
	Generator hours	hrs./mo.	Generator power meter	0	362	549	655	714	708	711	648	631	512	547	435
	Total Generated Kilowatt-hours/month	kwhrs/month	Generator power meter		316691	541890	646825	710258	711273	695019	642015	629493	512,611	538,944	447,651
WNT	Kilowatts of Net Total (Power after Parasitic Loads)	kW	Utility meter - pulse	991	812	947	951	950	945	927	961	959	973	956	975
	Total Kilowatt-hours sold to PG&E		Utility meter - pulse		294,064	519,968	623,034	678,171	669,364	659,385	622,486	605,242	498,101	522,972	424,103
	Estimated Parasitic Load	kW	Electrical meters	20	24	40	36	45	59	50	30	38	28	29	54

Table A-4. Financial Performance of Digester System

Data	Description	Eng. Units	Sensor or Instrument	MONTH	MONTH	MONTH	MONTH	MONTH	Month	Month	Month	Month	Month	Month	Month
Point				January	February	March	April	May	June	July	August	September	October	November	December
NTI	Net total income from electricity	$/month	Utility Statement	N/A	$ 55,872.16	$ 109,493.00	$ 108,328	$ 114,279	$ 111,612	$ 130,645	$ 134,889	$ 121,967	$ 119,929	$ 113,855	$ 97,713
CAPEX	Total Capital Expenditures	$	Cal Bio Financial Records	N/A	$ 7,924,693	$ 7,924,693	$ 7,924,693	$ 7,924,693	$ 7,924,693	$ 7,924,693	$ 7,924,693	$ 7,924,693	$ 7,924,693	$ 7,924,693	$ 7,924,693
OPEX	Monthly Operating Expenditures	$/month	Cal Bio Financial Records	N/A	N/A	$ 31,776	$ 28,113	$ 29,458	$ 27,898	$ 27,417	$ 58,405	$ 14,374	$ 23,757	$ 6,831	$ 27,857
PB	Payback period on all relevant investments	Years	CAPEX/(NTIX-OPEX)/12	N/A	N/A	8.50	8.23	7.79	7.89	6.40	8.63	6.14	6.87	6.17	9.45
	System footprint, visual impact, ingress and egress requirements					See Narrative	See Narrative	See Narrative	See Narrative	See Narrative	See Narrative	See Narrative	See Narrative	See Narrative	
	Water consumption, Atmospheric emissions - see CEE and GHG above, no other waste products	Gal water/mo.	Calculated from influent flow meter(influent*90%= water added)	N/A	N/A	13,419,900	14,337,000	16,572,600	19,694,853	15,380,321	19,769,577	18,212,229	15,103,449	12,526,677	9,637,677
	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)