CALIFORNIA ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Construction and Operation of the ABEC #2 Covered Lagoon Digester and Electricity Generating 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 #2 Covered Lagoon Digester and Electricity Generating System is the final report for the ABEC #2 Digester Project, Contract Number EPC-14-029 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

The purpose of this project was to document the construction and operation for one year of the American Biogas Electric Company #2 LLC (ABEC #2) covered lagoon digester. This project advanced digester design by building and demonstrating an innovative, double-cell covered lagoon digester and 1-megawatt (MW) generation system. The system converted dairy manure into biogas and stored the biogas above the primary and secondary lagoons under an inflatable cover. The biogas was converted into renewable electricity and sold for export to the Pacific Gas & Electric Company distribution grid. Further, dairy biogas systems qualified for participation in the CPUC's Assembly Bill 2514 electricity storage program. In a future phase, the biogas system may compete for an energy storage contract.

The project consisted of two covered lagoon cells with volumes of 22.2 million gallons (cell 1) and 9.9 million gallons (cell 2) along with a 1-megawatt engine-generator. Construction was completed in 2017 along with start-up and commissioning using the flushed manure from 5,783 manure equivalent milkers, or MEMs, as influent. One MEM represents 100 percent of the manure from a Holstein cow weighing 1,360 pounds. Full operation commenced on February 13, 2018. Through December 31, 2018, ABEC #2 averaged 586,000 cubic feet per day of biogas containing 60 percent methane, more than 100 cubic feet per MEM per day. The facility vented approximately 90,000 cubic feet of excess biogas and used 496,000 cubic feet of biogas per day to generate electricity. The monthly gross electrical production averaged 696,000 kilowatt-hours (kWh) for 699 hours of operation (out of a possible 720 hours), averaging 995 kilowatts of capacity. The parasitic load was 37 kilowatts or 3.7 percent, and the net power sold to Pacific Gas & Electric Company was approximately 664,000 kWh per month. Average monthly income was $126,500. Based on a total installed capital cost of $8.9 million and average monthly operating costs of $34,500, the projected simple payback for the project is 8.1 years. Another project benefit was the production of fiber bedding fertilizer averaging 132 tons per day.

Environmental benefits of this project included the reduction of more than 15,000 metric tons of carbon dioxide equivalent greenhouse gas, principally methane, along with holding exhaust emissions to 1.8 parts per million (ppm) of oxides of nitrogen (NO_x) and 13.8 ppm carbon monoxide (CO), both of which are well under the California Air Resources Board's limits of 11 ppm NO_x and 210 ppm CO. Progress has been made in limiting hydrogen sulfide (H_2S) emissions and thus prolonging the life of the engine-generator. The levels of H_2S dropped from more than 4,000 ppm at the beginning of operation to less than 500 ppm in September while using only the air injection system. A final iron sponge scrubbing resulted in H_2S levels at 7 ppm going into the engine-generator.

Keywords: Methane, dairy manure, anaerobic digestion, energy

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EXECUTIVE SUMMARY

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, a substantial quantity of energy can be produced. 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

This project advances digester design by building and demonstrating an innovative, double-cell covered lagoon digester and 1-megawatt (MW) generation system. The system converts dairy manure into biogas and stores the biogas above the primary and secondary lagoons under an inflatable cover. The biogas is converted into renewable electricity and sold for export to the Pacific Gas & Electric (PG&E) distribution grid. Further, dairy biogas systems qualify for participation in the California Public Utility Commission's electricity storage program (Assembly Bill 2514). In a future phase, the biogas system may compete for an energy storage contract. The project will also improve groundwater protection by reducing the leaching of manure into groundwater.

This project provides concrete 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) #2 digester and engine-generator system at the West Star Dairy, and provided performance data over 12 months. This provides 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 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 data from the various instruments, collected 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 #2 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, US 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 #2 digester equaled or exceeded expected monthly production by as much as 28 percent during 2018. The annual electrical production was found to be approximately 1,268 kilowatt hours per milk cow equivalent, which is a measure of manure equivalent to that produced by a Holstein cow weighing 1360 pounds. The greenhouse gas emission reductions totaled 2.7 metric tons of carbon dioxide equivalent per milk cow equivalent per year. With its extensive and comprehensive data collection and analysis, this study provided the knowledge and data needed when considering adoption of more aggressive energy standards. As a result, the analysis identified the data in terms of electrical production 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 #2 digester and engine-generator system provided a comprehensive amount of data that could be valuable in using the digester technology. Having this data about how digesters perform helps planners in determining the technical feasibility of new digester projects. Additional research is still 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 generations via anaerobic digestion.

The demonstrated success of the ABEC #2 digester will stimulate growth in the 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 #2 digester facility, as well as at two other digester facilities (ABEC #3 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 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 also 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 995 kilowatts of electricity over 12 months in 2018 and reduced greenhouse gas emissions by 15,535 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

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 #2.

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 types of digester.

This project included the ABEC #2 digester project located at the West Star Dairy, along with two other Energy Commission-funded digester projects, ABEC #3 and ABEC #4, which are similar sized dairies (4,000 to 6,000 cows) with similar housing (freestalls) and similar digester types (covered lagoons). However, there were some key differences between the projects: 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 this project were to:

- Build a precommercial, storage-ready covered lagoon digester.
- Operate the system for 12 months.
- Accept approximately 400 tons of excreted manure in a flush volume of 1 million gallons per day into the system.
- Produce approximately 280 standard cubic feet per minute (scfm) of biogas 24/7 or 150 million standard cubic feet (scf) of biogas per year of operation.
- Export approximately 8.3 million kilowatt-hours (kWh) of electricity annually to Pacific Gas and Electric Company (PG&E), with the electricity potentially used by the dairy through a net energy metering arrangement.
- Demonstrate that the enclosed area above the primary covered lagoon digester is capable of storing approximately a three-day supply of biogas in preparation for the planned phase-2 expansion.
- Measure the composition of the manure effluent including improvements in plant absorbable nitrogen to help the farmer benefit from the advancement.

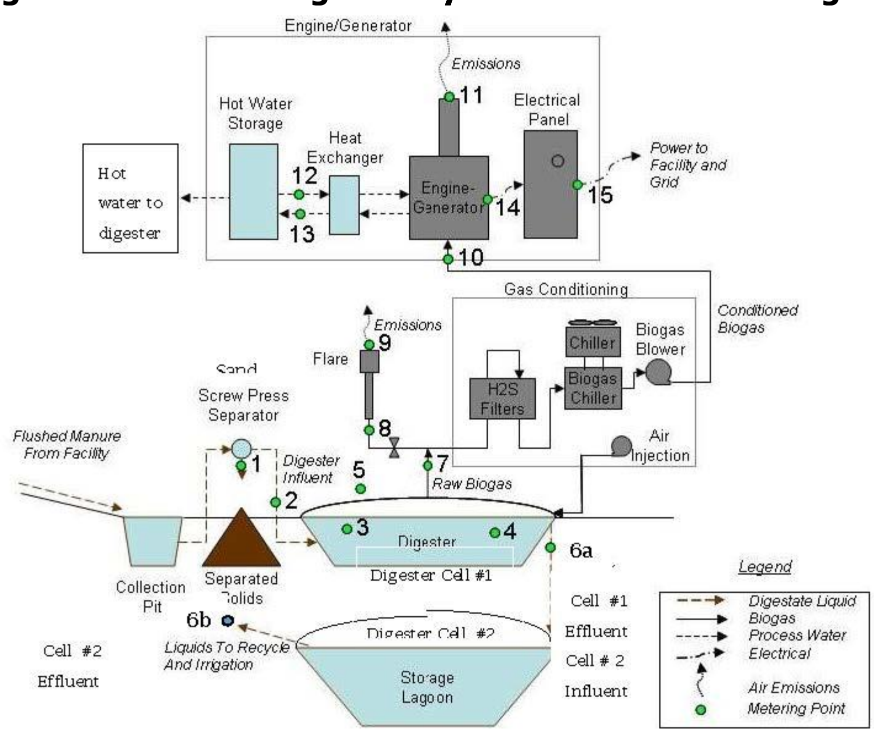
1 *An Economic Analysis of Six Dairy Digester Systems in California*, California Energy Commission, March 2013, CEC-500-2014-001-V2, https://www.energy.ca.gov/2014publications/CEC-500-2014-001/CEC-500-2014-001-V2.pdf.

- Share knowledge gained through the demonstration project with dairy farmers and other biogas electricity project developers throughout California through webinars, signage, publications, and other outreach.

Digester Construction, Startup, and Commissioning

The covered lagoon digester system at West Star dairy consists of two rectangular in-ground double-lined lagoon cells. Cell 1 is 300 feet wide by 600 feet long at the top, with a depth of 21 feet and a 2:1 side slope. Cell 2 is 300 feet wide by 300 feet long, 21 feet deep and has 2:1 side slopes. The total volume of Cell 1 is 23.5 million gallons with an operational liquid volume of 22.2 million gallons (1-foot freeboard). Cell 2 has a total volume of 10.9 million gallons with an operational volume of 10.2 million gallons (1-foot freeboard). The total digester volume is therefore 32.4 million gallons. The digester is loaded with the manure from 6,000 lactating cows, 600 dry cows, and 1,800 heifers housed in the milking parlor holding area, freestall barns, and open corrals flushed with fresh and recycled water, amounting to approximately 700,000 gallons per day. There were 5,783 manure equivalent milkers (MEM) contributing to this waste stream, with manure losses occurring because of the 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 #2 digester system; Table 1 describes each process point within the figure.

Figure 1: ABEC #2 Digester System Process Flow Diagram



Source: California Bioenergy

Table 1: Process Points in Figure 1 for ABEC #2 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
6a	Flow of Effluent from Digester Cell #1
6b	Flow of Effluent from Digester Cell #2
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 (Figure 2) system, and filling with a half-and-half mixture of fresh manure and stored aged manure.

Figure 2: ABEC #2 Digester Liner under Construction

Source: California Bioenergy

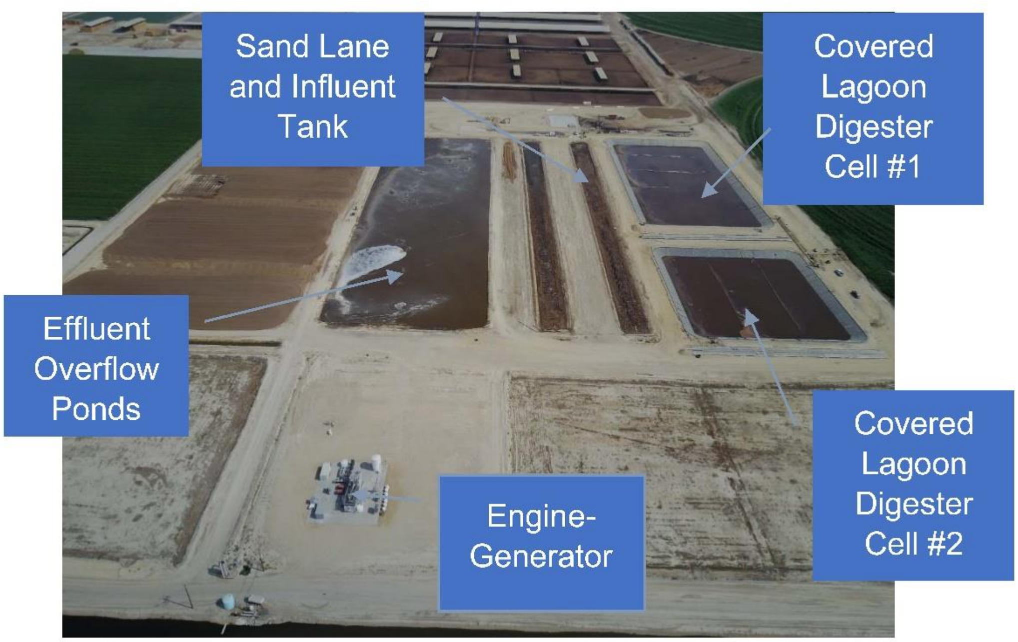
The digester cover was then pulled over the liquid digester contents, attached at the perimeter, and the mixer and air injection systems installed (Figure 3).

Figure 3: ABEC #2 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, 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 #2 Overview of Digester System



Source: California Bioenergy

CHAPTER 2: Project Approach

This chapter includes descriptions of the data collection process for all the digester systems listed as follows:

- 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 use
- Financial performance parameters

Data Collection and Analysis

The research team collected data during monthly visits to the ABEC #2 digester as well as weekly visits by California Bioenergy (CalBio) personnel to sample the influent and effluent and check the status of the SCADA system on the digester. CalBio, the parent company for the ABEC #2 project, contributed emissions and greenhouse gas data and compiled digester engine and monthly financial data. The complete matrix of data collected for the ABEC #2 digester is in Appendix A.

Dairy Cow Manure Production and Collection

The count of dairy cows was provided by staff at the West Star North Dairy and used to calculate dairy manure production. The number 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 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. The daily volume of solids was estimated based on the number of truckloads removed and the weight of each truckload.

Digester Influent and Effluent

After removal of the manure fibers, the liquids were pumped through a sand lane (Figure 6) in which heavier inert sand and dirt settles 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. The effluent (the material leaving the digester) exits at the opposite corner of the digester via an overflow sump where samples were also collected for analysis (Figure 7). Influent and effluent samples were also taken and analyzed for temperature and pH using portable instruments.

Figure 5: ABEC #2 Manure Solids Screen Separators and Weighing Wagon

Source: California Bioenergy

Figure 6: ABEC #2 Sand Lane and Influent Sampling Point

Source: California Bioenergy

Figure 7: ABEC #2 Effluent Overflow Sump and Sampling Point

Source: California Bioenergy

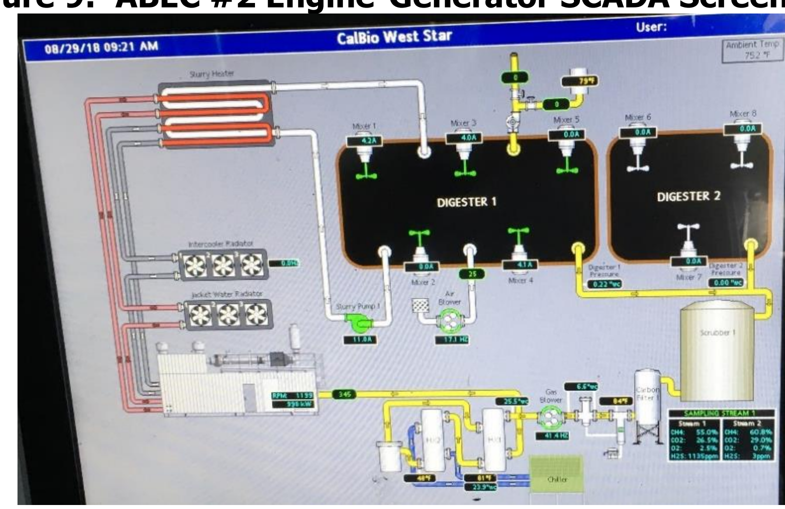
Digester Biogas Production Quantity and Quality

Meters built into the engine generator system and meters at the flare and vent measured digester biogas production. Figure 8 shows Cell #1 and Cell #2 of the digester. For the data collected in 2018, only Cell #1 was used; Cell #2 was bypassed and the effluent from Cell #1 was discharged directly into the overflow lagoon. 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 examples 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 8: ABEC #2 Digester Cell #1 and Cell #2

Source: California Bioenergy

Figure 9: ABEC #2 Engine-Generator SCADA Screenshot



Source: California Bioenergy

Engine-Generator Gross and Net Production

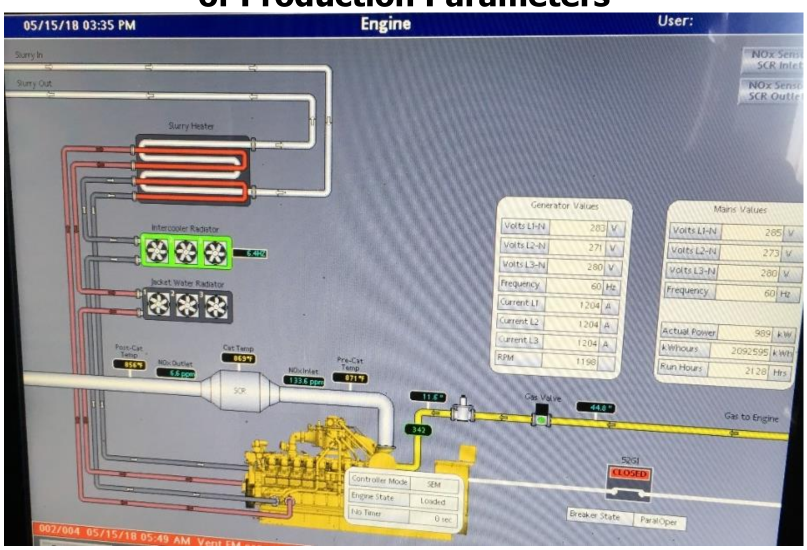
Engine generator gross electrical production was recorded by the Martin Energy SCADA and recovered each month from https://martinenergygroup.websupervisor.net/#/login.

The net energy production was also recorded by the engine-generator SCADA and downloaded into data files 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 #2 engine generator system; Figure 11 is a screen shot of the engine generator's instantaneous output.

Figure 10: ABEC #2 Engine-Generator System

Source: California Bioenergy

Figure 11: ABEC #2 Engine-Generator SCADA Screenshot 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; however, it was estimated that additional heat could have been utilized from the engine for such purposes as absorption cooling of the milk, as was practiced at one of the other CalBio digester projects, ABEC #4.

Financial Performance Parameters

The CalBio Office, 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, the total capital cost of the ABEC #2 digester and engine-generator systems, and the monthly operating cost of the ABEC#2 digester system including the costs of management, consultants, administration, insurance, digester operation 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 include NOx, SOx, CO, volatile organic compounds (VOC) 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. Note that Figure 12 is actually the testing at the ABEC #3 project but is representative of the stacks used in this project.

Figure 12: Stack Emission Testing at ABEC #2 Engine Generator

Source: California Bioenergy

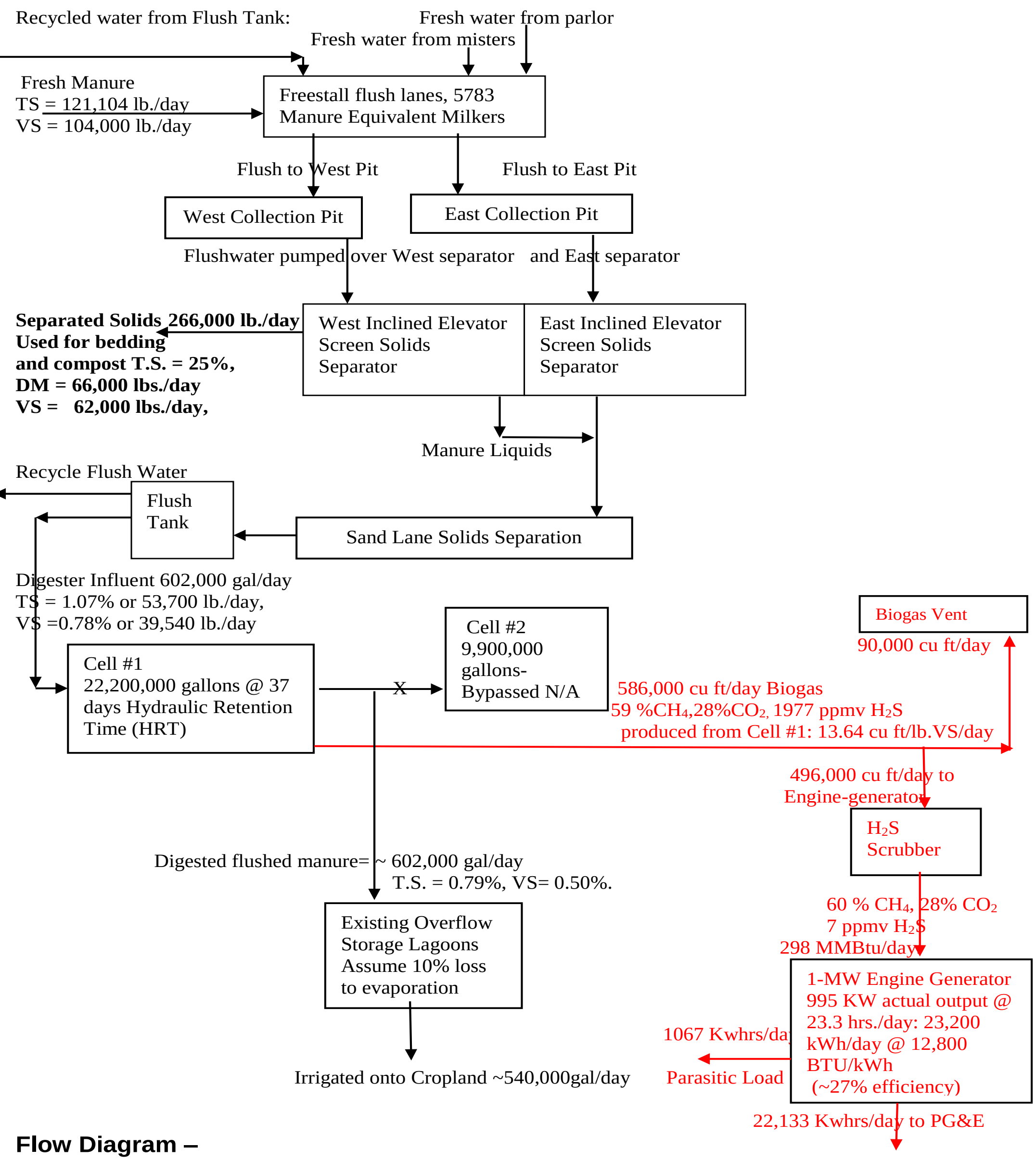
Greenhouse Gas Emission Reductions

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 (CH_4). Using the CARB conversion factor of 25 MT of carbon dioxide equivalent ($MTCO_2e$) per $MTCH_4$, 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 #2 West Star digester system. Figure 13 shows a mass and energy flow diagram of ABEC #2 with average daily quantities of the various inputs and outputs.

Figure 13: ABEC #2 Mass and Energy Flow Diagram



Flow Diagram –
West Star Covered Lagoon Digester System- Average daily flows in 2018

Source: California Bioenergy

Dairy Cow Manure Production and Collection

ABEC #2 had an average of 6,000 lactating cows, 600 dry cows, and 1,800 heifers housed in the milking parlor holding area, freestall barns, and open corrals. After losses based on the percent of time spent on concrete surfaces and flush recycling, there were 5,783 MEMs contributing to this waste stream (one MEM is 100 percent of the manure from a Holstein cow weighing 1,360 pounds). Based on ASABE standards, the daily manure collected on concrete surfaces and flushed to pretreatment prior to digestion amounted to 121,400 pounds per day of total solids (TS) and 104,000 pounds per day of volatile solids (VS). The fresh manure quantity was just over 800,000 pounds per day containing 15 percent total solids.

Flushed Manure Pretreatment and Solids Separation

The remaining flushed manure available to the slope screen separator system ranged from approximately 500,000 gallons per day in the cooler winter and spring months to almost 800,000 gallons per day during the warm months of summer and fall due to the added water from cooling misters in the freeestalls. The fiber separated by the screen separators was estimated to be approximately 266,000 pounds per day consisting of 25 percent total solids (66,000 pounds) of which 93 percent (62,000 pounds) was 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

The average digester influent volumes and characteristics for 2018 are shown in Table 2.

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

Flow/Characteristic	Data Source	Result
Flow of Manure, Influent to Digester	Inline Flowmeter	602,000 gal./day
Temperature of Manure, Influent to Digester	Type-K TC, 6 in probe	71°F
Composition of Manure, Influent to Digester	Monthly samples, 24h	8.05 pH
		10,700 mg/l TS
		7,800 mg/l VS
Total Solids in Influent	Flow X TS	53,700 Lb. /Day
Volatile solids in Influent	Flow X VS	39,540 Lb./day
Digester Volume	Measurement	22,200,000 gal.
Hydraulic Retention Time	Volume/influent/day	37 days
Volatile Solids Loading Rate	LB VS/digester volume	13 Lb. VS/1000 cu ft/day

Source: California Bioenergy

The average digester effluent volumes and characteristics for 2018 are shown in Table 3. Cell #2 was bypassed for most of the year, so only data for cell #1 is shown in the results.

Table 3: ABEC #2 Daily Effluent flows and Characteristics, Average for 2018

Flow/Characteristic	Data Source	Result
Flow of Effluent from Digester Cell #1	Estimated from influent flow	602,000 gal./day
Average Ambient Temperature	United States climate data 2018	65°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,	7.17 pH
		7,900 mg/l TS
		5,000 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 39,540 pounds of VS per day shown in Table 2), the digester performance in terms of biogas produced per unit of VS is 14.8 cubic feet per pound VS, much higher than the original estimation of 8.4 cu ft/pound VS.

Table 4: ABEC #2 Daily Biogas Flows and Characteristics, Average for 2018

Flow/Characteristic	Data Source	Result
Flow of Gas Total (Raw Biogas)	Mass flow meter	409 scfm
		586,000 cu ft/day
Composition of Gas Total (Raw Biogas)	Monthly analysis	59% CH_4 by vol.
		28% CO_2 by vol.
		1,977 ppm H_2S
		1.4% O2 by vol.
Flow of Gas to Flare/Vent (Raw Biogas)	Mass flow meter	90,000 scf/day
Flow of Gas to Engine-Generator	Mass flow meter	354 scfm
		496,000 scf/day
Composition of Gas to Generator	Monthly analysis	60% CH_4 by vol.
		28% CO_2 by vol.
		7 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.

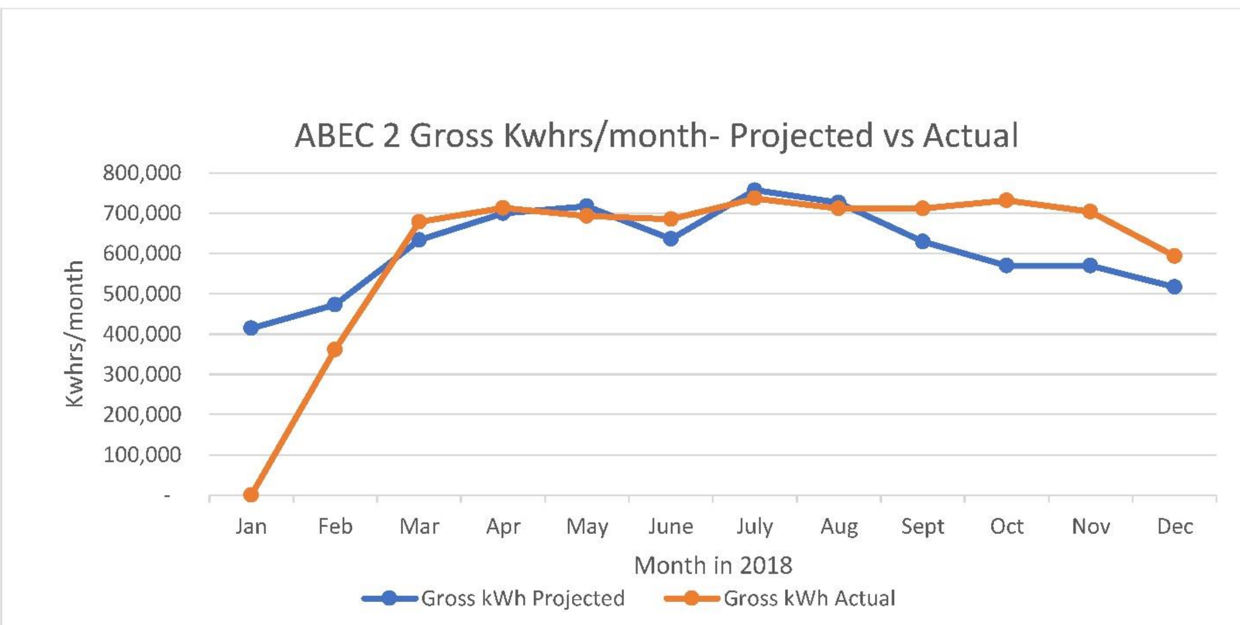
Table 5: ABEC #2 Engine-Generator Average Monthly Electrical Production in 2018

Electrical Production	Data Source	Result
Average Gross Generator Power Output	Generator power meter	995 kW
Generator hours	Generator power meter	699 hrs./mo.
Total Gross Generated Electrical Production	Generator power meter	696,000 kWhrs/mo.
Net Power sold to PG&E (after Parasitic Loads)	Utility meter - pulse	958 kW
Total electrical energy sold to PG&E	Utility meter - pulse	664,000 kWhrs/month
Parasitic Load	Gross – Net power	37 kW

Source: California Bioenergy

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

Figure 14: ABEC #2 Monthly Electrical Production in 2018, Actual versus Projected



Source: California Bioenergy

Cogenerated Heat Use

The engine heat was used for digester heating via the heat exchanger shown in Figure 10. Data was not recorded for the quantity of heat used; however, it was estimated that additional heat could have been utilized from the engine for such purposes as absorption cooling of the milk, as was practiced at one of the other CalBio digester projects, ABEC #4.

Financial Performance Parameters

ABEC #2 digester system financial performance parameters are shown in Table 6.

Table 6: ABEC #2 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	$8,920,623
OPEX: Monthly Operating Expenditures	Cal Bio Financial Records	$34,600/mo.
PB: Payback period on all relevant investments	CAPEX (NTIX-OPEX)/12	8.08 yrs.

Source: California Bioenergy

Environmental Quality Data

Criteria Pollutant Parameters

ABEC #2 engine generator criteria air quality parameters are shown in Table 7

Table 7: ABEC #2 Engine Generator Average Criteria Air Quality Parameters 2018

Parameter	Data Source	Result
Criteria Emissions from Engine: NOx CO	Monthly analysis using Tester; Annual 2-day stack test	NOx ppm @ 15% O2: 1.845 ppm CO ppm @ 15% O2: 13.82 ppm (Limits 11 ppm NOx, 210 ppm CO)

Source: California Bioenergy

Greenhouse Gas Reductions

ABEC #2 digester system greenhouse gas reductions are shown in Table 8.

Table 8: ABEC #2 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)	2087 grams of CO_2e/ kWh 15,535 Total tons of CO_2e

Source: California Bioenergy

Hydrogen Sulfide Removal

While untreated biogas can have H_2S contents of 4,000 to 5,000 ppm, the ABEC #2 digester reduced the H_2S to less than 500 ppm while using an air injection system. A final iron sponge scrubbing resulted in H_2S levels of 7 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 #2 digester project.

- Conducted community outreach meetings at the Kern Farm Bureau on June 13, 2017 and January 16, 2018.
- Open house for West Star Digester Commissioning for general public, February 2, 2018.
- On April 12, 2018, Neil Black and Roy Dowd from CalBio and Stuart Heisler from Anacapa (a company working with CalBio on future digester projects) 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 session. Topics included: California's GHG (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' 6th grade class at the Linwood School in Visalia. More visits are planned. A substantial number of the students, reflecting the area's demographics, are likely from disadvantaged communities, and the Linwood School program serves 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 to the BioResource and Agricultural Engineering class at Cal Poly on November 16, 2018 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 the US Biogas 2018 Conference in San Diego, California on November 6, 2018.
- CalBio presented at the 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 generations via anaerobic digestion.

Economic and Environmental Consequences of Technology Adaptation

There are currently approximately 1.7 million dairy cows in California. At an estimated 200 kW of electric capacity per 1,000 cows, the dairy market could represent as much as 340 megawatts of renewable energy generating capacity.

Technical Advisory Committee

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

California Energy Commission

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

Agencies/Nonprofits

- Dan Weller, California Air Resources Board
- Stephen Klein, California 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 5,783 MEMs as influent, ABEC #2 averaged 586,000 cubic feet per day of biogas containing 60 percent methane, which is approximately 100 cubic feet per cow per day. Of this total gas production, 90,000 cubic feet excess biogas was vented, and 496,000 cubic feet per day were used for electrical generation. Based on the organic loading rate of 39,540 pounds of VS per day, the digester performance averaged 14.8 cubic feet per pound VS, much higher than the original estimation of 8.4 cu ft/pound VS. This production was achieved from cell #1 (cell #2 was bypassed) of the covered lagoon digester system with a volume of 22.2 million gallons and having an average 37 days HRT(hydraulic retention time), average temperature of 74˚F and average organic loading rate of 13 pounds VS/1,000 cubic feet/day.

Engine-Generator Technical Performance

The monthly gross electrical production over the project period averaged 696,000 kWh for 699 hours of operation (out of a possible 720 hours), averaging 995 KW. The parasitic load was 37 kW or 3.7 percent, and the net monthly energy sold to PG&E averaged 664,000 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 $127,000. Based on a total installed cost of $8.9 million and average monthly operating costs of $34,500, the projected simple payback for the project is approximately 8 years. For all of 2018, the annualized income was more than $1.5 million, or $265 per cow. Based on recent milk prices of ~$15 per 100 pounds and the 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% to the dairy's per-cow income.

Environmental Quality Outcomes

The environmental benefits of this project include the reduction of more than 15,000 metric tons of CO_2e greenhouse gas, principally methane. This CO_2e reduction is equivalent to taking 3,260 cars off the road according to USEPA. Engine exhaust emissions were held to 1.8 ppm of NOx and 13.8 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, storage-ready covered lagoon digester was built. (objective completed)
- The system was operated for 12 months. (objective completed)
- The system accepted approximately 400 tons of excreted manure in a flush volume averaging 600,000 gallons per day into the system. (objective was 1 million gallons/day)
- The system produced an average of 409 scfm of biogas or 215 million standard cubic feet of biogas per year of operation. (objective was 280 scfm of biogas on a 24 x 7 basis or 150 million scf of biogas per year of operation)
- The system exported at an annual rate of approximately 8 million kWh of electricity to PG&E. (objective was 8.3 million kWh)
- The enclosed area above the primary covered lagoon digester was capable of storing an approximately three-day supply of biogas in preparation for the planned phase-2 expansion. (objective completed)
- The composition of the manure effluent was measured including improvements in plant absorbable nitrogen to help the farmer benefit from the advancement. (objective completed)
- 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 produced the following benefits to California's electricity 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 # 2 produced 995 kW and reduced greenhouse gas emissions by 15,000 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 the cost of meeting that increased demand low.
- This research sets the groundwork 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, ABEC #2 digester reduced the H_2S to less than 500 ppm while using an air injection system. A final iron sponge scrubbing resulted in H_2S levels of 7 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/Acronym	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/Acronym	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, Matthew; Doug Williams. (Summers Consulting, LLC). 2013. *An Economic Analysis of Six Dairy Digester Systems in California*. California Energy Commission. Publication number: CEC-500-2014-001-V1.

APPENDIX A:
Data Matrix for ABEC#2 Digester

A1. 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	274000	274000	274000	274000	274000	257,143	257,143	257,143	257,143	257,143	257,143	257,143
		Tons/month	Monthly weight estimate	4247	3836	4247	4110	4247	3,857	3,986	3,986	3,857.14	3,985.71	3,857.14	3,985.71
CMS	Composition of Manure Solids	% TS by wt.	Quarterly samples	N/A	N/A	27.7%	N/A	N/A	30%	N/A	N/A	30%	N/A	26%	22%
FMI	Flow of Manure, Influent to Digester	Gal/day	Inline Flowmeter	550,000	625,000	598,000	525,000	525,000	609,000	766,000	700,000	700,000	576,000	524,000	524,000
TMI	Temperature of Manure, Influent to Digester	°F	Type-K TC, 6 in probe	62.6	66.0	65.7	69.8	70.9	79.7	82.6	81.1	76.5	70.3	65.1	63.5
CMI	Composition of Manure, Influent to Digester	pH	Monthly samples, 24h	8.2	8.41	8.05	7.96	8.04	8.05	7.94	7.84	7.98	8.14	7.99	8.01
		mg/l TS		5800	8300	10000	11000	13100	13900	6600	10000	8000	23000	9400	9300
		mg/l VS		2600	5200	6700	7600	9400	10100	4450	8700	6300	18000	7600	6900
TD1	Temperature of Digester at Vent Valve 1	°F	Type-K TC, 72 in depth	63.5	63.66	67.46	72.68	78.62	81.14	86.9	86.72	80.96	69.44	65.84	66.56
TD2	Temperature of Digester at Vent Valve 2	°F	Type-K TC, 72 in depth	63.5	63.66	67.46	72.68	78.62	81.14	86.9	86.72	80.96	69.44	65.84	66.56
TAO	Temperature of Ambient Out	°F	US Climate data 2018	47	53	58	64	71	78	83	83	77	67	56	48
FME1	Flow of Manure, Effluent from Digester Cell #1, cell #2 is bypaSSED	Gal/day	Estimated from FMI	550000	625000	598,000	525000	525000	609,000	766,000	700,000	700,000	576,000	524,000	524,000
TME1	Temperature of Manure, Effluent from Digester Cell #1	°F	Type-K TC, 6 in probe	63.5	63.66	67.46	72.68	78.62	81.14	86.9	86.72	80.96	69.44	65.84	66.56
CME1	Composition of Manure, Effluent from	pH	Monthly samples, 24h	7.15	7.42	7.24	7.18	7.05	7.02	7.05	7.03	7.08	7.36	7.25	7.22
	Digester Cell #1	mg/l TS		4100	5500	7700	11000	7700	9500	6100	5000	3900	16000	10000	8800
		mg/l VS		1400	3000	4300	7000	4900	5900	3625	2900	2200	12000	7100	6000
FME2	Flow of Manure, Effluent from Digester Cell #2	Gal/day	Estimated from FMI	#REF!	#REF!	#REF!	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed
TME2	Temperature of Manure, Effluent from Cell #2	°F	Type-K TC, 6 in probe	63.5	63.66	67.46	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed
CME2	Composition of Manure, Effluent from Cell #2	pH	Monthly samples, 24h	7.08	7.42	7.24	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed
		mg/l TS		4000	4600	7000	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed
		mg/l VS		1400	2200	3800	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed	N/A - Cell 2 is being bypassed

A2. Digester Outputs: Biogas:

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
FGT	Flow of Gas Total (Raw Biogas)	scfm	Estimated from FGE &FGF	362	374	352	449	362	338	434	472	437	450	438	392
		cu ft/day		N/A	539,963	470,090	646,690	520,962	487,158	624,715	679,629.00	629,951.03	648,539.19	631,436	564,079
CGT	Composition of Gas Total (Raw Biogas)	CH4% by vol.	Monthly analysis	61%	60.35%	59.5%	59.5%	59.5%	60.0%	58.0%	55.0%	60.0%	60.5%	58.0%	59.0%
		CO2 %by vol.		25%	25.1%	28%	28%	28%	29%	28%	27%	29%	29%	28%	27%
		H2S ppm		4500	3806	4420	1840	1771	2238	803	573	457	1768	2603	1470
		O2 % by vol.			2%	2%	2%	<2%	<1.7%	1.40%	2.50%	1.00%	1.00%	1.50%	1.70%
FGF	Flow of Gas to Flare/Vent (Raw Biogas)	SCF/day	Mass Flow meter	0	0	0	119,618	15,194	7,457	115,266	194,117	125,051	136,575	95,689	178,465
CGF	Composition of Gas to Flare/Vent (Raw Biogas)	% by vol.	Monthly analysis	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Same as CGT	Same as CGT	Same as CGT	Same as CGT	Same as CGT
FEF	Flow of Emissions from Flare	SCF/day	Estimated from FGF	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CEF	Composition of Emissions from Flare	% or ppm	Monthly analysis	NA	NA	NA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FGE	Flow of Gas to Engine (Conditioned Biogas)	scfm	Mass Flow meter	362	374	352	366	351	333	354	349	352	356	372	335
CGE	Composition of Gas to Engine (Conditioned)	CH4% by vol.	Monthly analysis	61%	60%	59.5%	59.5%	59.0%	61.0%	62.0%	61.0%	60.5%	60.5%	60.0%	62.0%
		CO2 %by vol.		25%	25%	28%	28%	29%	30%	29%	29%	29%	29%	29%	28%
		H2S ppm		1	10	1	1	2	5	0	3	4	0	35	18
		O2 % by vol.		1.50%	2.15%	2%	2%	<2%	<1%	0.4%	0.7%	<1%	<1%	<1%	0.1%

A3. Engine Outputs: Electrical Generation and Emissions

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
CEE	Criteria Emissions from Engine:NOx, SOx, CO, Volatile Organic Compounds (VOC's),	% or ppm	Monthly analysis using Tester; Annual 2-day stack test	N/A	NOx ppm @ 15% O2: 1.390 ppm CO ppm @ 15% O2: 6.629 ppm	NOx ppm @ 15% O2: 0.95 ppm CO ppm @ 15% O2: 6.653 ppm		N/A data not available	NOx ppm @ 15% O2: 1.4 ppm CO ppm @ 15% O2: 9.254 ppm	N/A testing not done	NOx ppm @ 15% O2: 3.983 ppm CO ppm @ 15% O2: 11.128 ppm	NOx ppm @ 15% O2: 2.965 ppm CO ppm @ 15% O2: 17.827 ppm	NOx ppm @ 15% O2: 1.5 ppm CO ppm @ 15% O2: 19.35 ppm	NOx ppm @ 15% O2: 1.434 ppm CO ppm @ 15% O2: 24.392 ppm	NOx ppm @ 15% O2: 1.14 ppm CO ppm @ 15% O2: 15.339 ppm
GHG	Greenhouse gas Reductions: avoided methane	Grams of CO2e/ kwhr;	Biogas meter plus CARB GHG protocol (1 gr CH4 = 25	5,962.15	614.72	624.86	3,830	5,350	6,950	4,084	1,451	78.66	(416)	(156)	-
		Tons of CO2e		N/A	234	424.00	2,729	3,705	4,762	3,007	1,032	56	(304)	(110)	-
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			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	(Between Jacket and Exhaust)	°F	Type-K TC, 6 in probe	Temp	Temp										
WGO	Average Kilowatts of Generator Power Output	kW	Generator power meter	993	989	983	992	1029	994	996	989	993	996	987	999
	Generator hours	hrs./mo.	Generator power meter	0	385	690	718	673	689	739	719	717	734	713	595
	Total Generated Kilowatt-hours/month	kwhrs/month	Generator power meter		380662	678548	712515	692473	685133	736316	711214	711969	730961	703592	594108
WNT	Kilowatts of Net Total sold to PG&E (Power after Parasitic Loads)	kW	Utility meter - pulse	957	751	955	958	951	960	954	953	964	970	972	974
	Total Kilowatt-hours sold to PG&E		Utility meter - pulse		289250	658839	687884	640206	661112	705001	684864	690961	712244	692782	579534
	Parasitic Load:	kW	WGO-WNT	36	237	29	34	78	35	42	37	29	25	15	24

A4. 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	$ 54,958	$ 138,638	$ 113,427	$ 106,812	$ 109,853	$ 138,404	$ 134,889	$ 135,796	$ 143,921	$ 139,946	$ 117,014
CAPEX	Total Capital Expenditures	$	Cal Bio Financial Records	N/A	N/A	$ 8,920,623	$ 8,920,623	$ 8,920,623	$ 8,920,623	$ 8,920,623	$ 8,920,623	$ 8,920,623	$ 8,920,623	$ 8,920,623	$ 8,920,623
OPEX	Annualized Operating Expenditures	$/month	Cal Bio Financial Records	N/A	N/A	$ 50,663	$ 39,048	$ 45,598	$ 39,671	$ 30,892	$ 73,450	$ 22,606	$ 27,939	$ 17,958	$ 32,309
PB	Payback period on all relevant investments	Years	CAPEX (NTIX-OPEX)/12	N/A	N/A	8.45	9.99	12.14	10.59	6.91	12.10	6.57	6.41	6.09	8.78
	System footprint, visual impact, ingress and egress requirements			N/A	N/A	See Narrative	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	16,684,200	14,175,000	14,647,500	16,443,000	21,371,400	19,530,000	18,900,000	15,552,000	14,148,000	14,148,000
	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)