Energy Research and Development Division
FINAL PROJECT REPORT

SMUD COMMUNITY RENEWABLE ENERGY DEPLOYMENT

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

SMUD Community Renewable Energy Deployment Final Report is the final report summarizing results for the four projects: Simply Solar, Sacramento Regional County Sanitation District (SRCSD) Biogas Enhancement, New Hope Dairy Anaerobic Digester, and Van Warmerdam Dairy Anaerobic Digester (contract number PIR-11-005) conducted by SMUD and its subcontractors. The information from this project contributes to Energy Research and Development Division's Renewable Energy Technologies Program.

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

ABSTRACT

This report summarizes the renewable energy projects supported by California Energy Commission, the US Department of Energy (DOE), and the Sacramento Municipal Utility District (SMUD) Community Renewable Energy Deployment (CRED) program.

The funding from the DOE and Energy Commission allowed CRED to complete three different renewable energy projects: (1) constructing a solar power system, (2) biogas generation from waste systems, and (3) anaerobic digestion systems at dairy facilities.

SMUD achieved these goals:

- Installed renewable energy facilities interconnected to SMUD's distribution grid.
- Contributed to SMUD's Renewable Portfolio Standard goal.
- Contributed to the Departments of Energy's goal of accelerating renewable deployment.
- Reduced greenhouse gas emissions through destruction of methane.
- Created jobs and spured local economic activity.
- Demonstrated economically viable installations of technologies that are not yet widely commercially deployed.
- Demonstrated the alignment of economic incentives to achieve socially and environmentally desirable goals.

In addition to reducing greenhouse gas emissions, deploying the CRED projects showed solar projects and anaerobic digesters can be successfully implemented under favorable economic conditions and business models and through partnerships. This work helps other communities learn how to assess, overcome barriers, utilize, and benefit from renewable resources for electricity generation in their region.

Keywords: community renewable energy deployment, solar, biogas, fats oils and greases (FOG), biodigester, dairy, methane

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Funding from the California Energy Commission, the US Department of Energy, and the Sacramento Municipal Utility District (SMUD) Community Renewable Energy Deployment (CRED) program supported construction of a solar power system, biogas generation from waste systems, and anaerobic digestion systems at dairy facilities for electricity generation and delivery to SMUD's distribution system. The projects will allow SMUD to meet their renewable energy goals for 2020.

Project Purpose

The goal of the CRED program was to develop and demonstrate renewable energy technologies within SMUD's service territory. These technology installations were intended to bring several benefits to SMUD's customers and the local community:

- Generate renewable electricity locally to displace the use of fossil fuels, increase the distribution system's efficiency, and help to alleviate transmission constraints.
- Contribute to SMUD's and the state's RPS programs.
- Reduce GHG (chiefly, methane) emissions.
- Add tax revenue for the county and extra revenue to farmers from lease payments.
- Create jobs.
- Mitigate the problematic treatment and disposal of animal manure and food wastes.
- Turn problematic wastes into energy resources, reducing odor and flies.
- Provide farmers with facilities and equipment that improve dairy operations and reduce odors and flies.
- Co-produce value-added products such as fertilizers (solid and liquid).

Project Process

Simply Solar Project

Researchers installed solar facilities on top of a carport structure, dog park shade structures, and a ground mount facility at the City of Sacramento's Sutter's Landing's Regional Park. All three structures have a total nameplate capacity of 1,498 kilowatts of direct current. Researchers were able to successfully install a PV facility with a 1.5 MW nameplate rating within the park.

SRCSD Biogas Enhancement

Researchers designed and built a fats, oils, and grease (FOG) receiving facility with the ability to receive 42,000 gallons of FOG and food processing waste (FPW) per day. The facility consists of two storage tanks, two off-loading stations, pumps, odor control, strainers, rock traps, grinders, flowmeters, and valves, along with two heated pipes from the offloading facility to the digesters. FOG material is continuously mixed and chopped by the pumps and grinders to generate biogas.

New Hope Dairy Digester

The 1,200 milk cow New Hope Dairy uses a system that continuously scrapes manure from the stalls and moves it to the complete stirred tank reactor digester at mesophilic temperatures. The manure is diluted with water and kept in the tank digester for thirty to forty days; biogas is gradually formed as the manure decomposes. The gas is then collected, cleaned and sent to a 450 kW engine generator.

Van Warmerdam Dairy Digester

The covered anaerobic digester was installed on the 1,000 cow Vanwarmerdam Dairy with an earthen pond and a total operational fluid volume of about eight million gallons. The pond is covered with a high density polyethylene membrane to store biogas which allows the engine to run during peak power periods when prices paid for electricity are highest and store gas when prices are lower. The 600 kilowatt generator is connected to SMUD’s distribution feeder.

Results

Table 1 shows the numerical results of the four projects:

Table 1: CRED Project Results Summary

Parameter	Simply Solar	SRCSD	New Hope Dairy	Van Warmerdam Dairy
Nominal Electric Capacity (kW)	1,498	1,000 - 3,000	450	600
Capacity Factor (%)	18	95	45	36
Annual Energy Production (MWh)	2,423	13,747	1,569	1,612
CO_2 equivalent Reduction (MT/yr)	1,842	10,616	2,697	7,839
LCOE (dollars/MWh) with tax credits and grants 2014 Nominal $	97.0	<100	140	78.5
kW = kilowatt gpd = gallons per day MWh = megawatt-hour CO_2 = carbon dioxide				

MT/yr = metric tons per year LCOE = levelized cost of energy

Simply Solar:

The Simply Solar project resulted in significant additional photovoltaic (PV) generation in SMUD territory, achieving community education goals and increasing public awareness about solar energy through three different solar configurations in a public park location. The project addresses the challenges of installing solar technology on brownfield landfill sites and in environmentally difficult conditions.

SRCSD Biogas Enhancement:

This project resulted in implementing grease and liquid food processing waste co-digestion at the SRCSD Elk Grove Wastewater Treatment Plant. Long-term benefits include the capacity for increased waste diversion from landfills, a decrease in associated transportation costs, and a significant increase in renewable energy generation from biogas.

New Hope and Van Warmerdam Dairy Digesters:

Installing the two dairy digester projects resulted in 10,536 metric tons/year in avoided carbon dioxide (CO_2) equivalent emissions and helped meet or exceed the California Air Resources Board oxides of nitrogen (NO_x) requirements. These systems also mitigated odor, flies, and water contamination issues for the dairy facilities.

Benefits to California

The four renewable projects had numerous short-term economic benefits including 30-80 full/part time construction jobs and all used US manufactured goods. Additional benefits included institutional capacity-building and advancing the renewable energy industry in the Sacramento region, allowing project replication and higher efficiencies for future projects.

The projects are an example of how small and distributed generation of renewable energy can be developed and deployed when appropriate business models and economic incentives are provided. SMUD believes the successful distribution of these CRED projects can inspire others to develop similar projects in California, nationally, and internationally, bringing immediate benefits to communities.

CHAPTER 1: Introduction

1.1 About the CRED Program

To help the Sacramento Municipal Utility District (SMUD) achieve its aggressive renewable energy goal, the US Department of Energy (DOE) provided more than $5 million in funding for several SMUD Community Renewable Energy Deployment (CRED) projects. This funding, combined with $500,000 from the California Energy Commission, supported constructing four projects: a solar power system, a biogas enhancement facility at a regional wastewater treatment plant, and anaerobic digestion systems at two dairy facilities, all for electricity generation and delivery to SMUD's distribution system. The CRED projects are the Simply Solar, Sacramento Regional County Sanitation District (SRCSD) Biogas Enhancement, New Hope Dairy Digester, and Van Warmerdam Dairy Digester projects, both in the Galt area.

1.2 CRED Objectives

The activities helped accelerate deployment and market penetration of the SMUD community's indigenous renewable resources, making use of otherwise overlooked resources. The biogas projects are used for combined heat and power (CHP) application. The environmental benefits of using biogas for CHP are substantial, since this technological application concurrently prevents release of biogas to the atmosphere and displaces the demand for an equivalent amount of fossil fuel, in addition to using waste heat. These projects also help meet SMUD's 2020 renewable energy goal and the Office of Energy Efficiency and Renewable Energy's (EERE's) goal of accelerating market adoption of renewable energy technologies.

1.3 CRED Approach

The CRED project approach installed and integrated renewable distributed generation into the system grid by proactively working with community, industrial, and regulatory partners. As the host utility, SMUD addressed interconnection requirements and issues. In addition, SMUD leveraged working relationships with regulatory and permitting entities (e.g., California Air Resources Board, air quality boards, and the city and county of Sacramento). Through SMUD's power purchase agreements (PPAs) and feed-in-tariff (FIT) mechanisms and partnerships, implementation and deployment of renewable distributed generation was streamlined and accelerated relative to historic business models.

The following is a brief summary of the projects:

- Simply Solar: The Simply Solar project resulted in significant additional photovoltaic (PV) generation in SMUD territory, while also achieving community education goals and increasing public awareness about solar energy through three different solar configurations in a public park location. The project helps move the industry forward by addressing challenges of installing solar technology on brownfield landfill sites and in environmentally challenging conditions.

- SRCSD Biogas Enhancement: This project resulted in the implementation of grease and liquid food processing waste co-digestion at the SRCSD Elk Grove Wastewater Treatment Plant. Long-term benefits include the capacity for increased waste diversion from landfills, a decrease in associated transportation costs, and a significant increase in renewable energy generation from biogas.
- New Hope and Van Warmerdam Dairy Digesters: Implementing the two dairy digester projects resulted in avoided carbon dioxide (CO_2) equivalent (CO_2e) emissions of 10,536 MT/yr and helped meet or exceed the California Air Resources Board (CARB) oxides of nitrogen (NO_x) requirements. These systems also mitigate odor, flies, and water contamination issues for the dairy facilities where they are installed.

The following sections of this report provide additional details for each project.

CHAPTER 2:
Simply Solar

2.1 Project Description

Solar facilities were installed in the City of Sacramento's Sutter's Landing Regional Park. There are three solar configurations in the Sutter's Landing installation: a carport shade structure, dog park shade structures, and a ground-mount facility. All three facilities occupy the same general vicinity in the park. A general layout is provided on Figure 1.

Figure 1: Layout of Three Solar Photovoltaic Configurations at the Simply Solar Facility

2.1.1 Carport System

The carport system has a nameplate capacity of 371 kilowatts of direct current (kWdc), and it covers about 200 parking spots. The system uses the following equipment: Sharp 250W PV modules, SMA Sunny Central 500 kilowatt (kW) inverters, The New IEM switchgear, ABB transformers, Draker and Shark 100 Meter monitoring and reporting systems, and Capital Iron Works mounting structures.

2.1.2 Tree-Style Shade Structures

There are 10 tree-style shade structures installed in the dog run area of the park. These structures have an aggregate nameplate capacity of 35 kWdc. Equipment manufacturers are almost the same as those listed in Subsection 2.1.1.

2.1.3 Ground-Mount System

The ground-mount system has a nameplate capacity of 1,092 kWdc. This is the largest and most cost-effective of the three configurations on the site. It is a stationary structure with panels tilted at approximately five degrees for optimal sun exposure throughout the year.

2.1.4 Project Partners and Timeline

Project partners included Conergy and Washington Gas.

A general timeline is as follows:

- Fall 2011: Engineering design began.
- Spring 2012: SMUD completes competitive solicitation and awards project grant funds to Conergy.
- Spring 2013: Sacramento City Council approves project California Environmental Quality Act (CEQA) document, landfill post-closure amendment, and lease agreement with Conergy.
- Fall 2013: Grant Subrecipient Agreement completed.
- Winter 2014: Sitework and construction begins.
- Fall 2014: Work completed.

2.2 Project Implementation and Testing Goals

Goals included reducing greenhouse gas (GHG) emissions, demonstrating new applications of solar energy, and providing educational value for both the industry and the general public.

2.3 Project Outcomes

2.3.1 Solar Energy System Performance

The solar system installation is complete. The system is generating 2,423 megawatt-hours per year (MWh/yr). The installation is providing educational value for accelerating renewable energy deployment in new applications and reaching a broad public audience through its strategic location.

2.3.2 Greenhouse Gas Benefit Analysis

The electricity generated is equivalent to 1,842 MT of CO_2e per year.

2.3.3 Job Creation Analysis

During the design and construction of the project, many jobs were created and retained. For Conergy, there were approximately six people working on the project before and during construction. In addition, there were many subcontractors and suppliers involved with the project. Approximately 10 contractors were on-site, with one to eight employees, for approximately 10 weeks of construction.

2.3.4 Project Economic Analysis

In 2012, Conergy's original project budget estimate was slightly in excess of $5.7 million dollars. The project experienced delays in construction because of a complex design process and a lengthy CEQA study and project approval phase. These delays increased some costs but also allowed the project to benefit from reduced solar panel and other equipment costs. After changes in the system design and equipment specifications from the original proposal, the preliminary budget was set in early October 2013 for the constructed system. The final project cost was $4,074,255. There were several partners and funding sources for this project, including DOE through a grant, California Energy Commission and SMUD through match and project funding, and Conergy. The California Energy Commission provided $125,000 in cost share, while the DOE CRED grant funded a $1,632,800 contribution toward the modules and a portion of the electrical installation. SMUD contributed $224,000 toward one of the project inverters and also provided project cost share and grant administration. Conergy covered $2,092,455 of the remaining costs, which were for racking, installation, a portion of the modules, and the balance of system for the project to be completed.

2.3.4.1 Levelized Cost of Energy

Using the above cost and performance data, the levelized cost of electricity (LCOE) using the revenue requirement approach was calculated for solar PV. The results of different LCOE cases and other assumptions such as taxes and other technical and financing assumptions are shown in Table 2.

The LCOE of generating electricity from solar PV depends primarily on capital and operating expenses.

- **Case 1.** This scenario assumes the capital cost = $4,469,662, operating expenses = $20/kW-yr (kilowatt-year), with no investment tax credit (ITC), no CO_2 payment, no grants, 60 percent debt ratio, cost of debt = 8 percent, debt term = 20 years, return on equity = 12.5 percent, and economic life = 20 years. The LCOE in this scenario is equal to 21.99 cents/kWh (kilowatt-hour) (nominal $2014).
- **Case 2.** This scenario assumes the capital cost = $4,469,662, operating expenses = $20/kW-yr, with no ITC, no CO_2 payment, no grants, 100 percent debt ratio, cost of debt = 8 percent, debt term = 20 years, no return on equity, and economic life = 20 years. The LCOE in this scenario is equal to 15.52 cents/kWh (nominal $2014).
- **Case 3.** This scenario assumes the capital cost = $4,469,662, 30 percent ITC, $10/MT CO_2 payment, grants from DOE and Energy Commission = $1,825,328, total equity invested = ($4,469,662-$1,825,328) = $2,644,334, debt ratio = 60 percent, cost of debt = 8 percent, debt term = 20 years, return on equity = 12.5 percent, and economic life = 20 years. The LCOE in this scenario is equal to 5.25 cents/kWh (nominal $2014).
- **Case 4.** This scenario assumes the capital cost = $4,469,662, 30 percent ITC, $10/MT CO_2 payment, grants from DOE and Energy Commission = $1,825,328, total equity invested = ($4,469,662-$1,825,328) = 2,644,334, equity = 100 percent, no cost of debt, no debt term, return on equity = 12.5 percent, and economic life = 20 years. The LCOE in this scenario is equal to 9.76 cents/kWh (nominal $2014). This Case 4 mimics the actual case for Conergy.

Table 2: Simply Solar LCOE Calculations

Cases	Case 1	Case 2	Case 3	Case 4
Technical Entries				
Total Facility Capital Cost ($)	$ 4,469,662	$ 4,469,662	$ 4,469,662	$ 4,469,662
Grants	$ -	$ -	$ 1,825,328	$ 1,825,328
Electric- base year				
Net Electrical Capacity (kWe)	1.5	1.5	1.5	1.5
Capacity Factor (%)	18	18	18	18
Carbon Offset (tons CO2e)				
Expenses-base year				
O&M ($/kW-yr)	20	20	20	20
Federal Tax Rate (%)	34	34	34	34
State Tax Rate (%)	6.65	6.65	6.65	6.65
Combined Tax Rate (%)	38.389	38.389	38.389	38.389
Investement Tax Credit (% of Total Capital Cost)	0	0	30	30
Income other than Energy				
Carbon Payment ($/tons)	0	0	10	10
Escalation/Inflation				
General Inflation (%/y)	2.8	2.8	2.8	2.8
Escalation-for all parameters (%/y)	2	2	2	2
Financing				
Debt Ratio (%)	60	100	60	0
Equity Ratio (%)	40	0	40	100
Interest Rate on Debt (%/y)	8	8	8	8
Life of loan or debt term (y)	20	20	20	20
Economic Life (y)	20	20	20	20
Return of Equity (%/y)	12.5	0	12.5	12.5
Cost of Money (%/y)	9.8	8	9.8	12.5
Depreciation Schedule	MACRS 5-YR	MACRS 5-YR	MACRS 5-YR	MACRS 5-YR
Current $ LCOE (cents/kWh) 2014	21.99	15.52	5.25	9.76
Constant $ LCOE ($/kWh) 2014	17.65	12.29	4.21	7.99

LCOE is particularly sensitive to capital cost, operating expense, capacity factor, return on equity, debt ratio, and price of carbon, which are illustrated in Figure 2. This figure shows the full LCOE as each parameter is varied over the indicative relative range, all other values held constant at their reference or base case values (in this case LCOE = 5.25 cents/kWh [nominal $2014] Case 3). If the debt ratio is 0 percent or 100 percent equity, LCOE = 9.76 cents/kWh (Case 4). As capacity factor increases, LCOE decreases and as price of carbon increases, LCOE decreases.

Figure 2: Sensitivity of LCOE (2014 Current $/kWh) to Technical and Financial Factors for PV Solar Field at Conergy PV Site

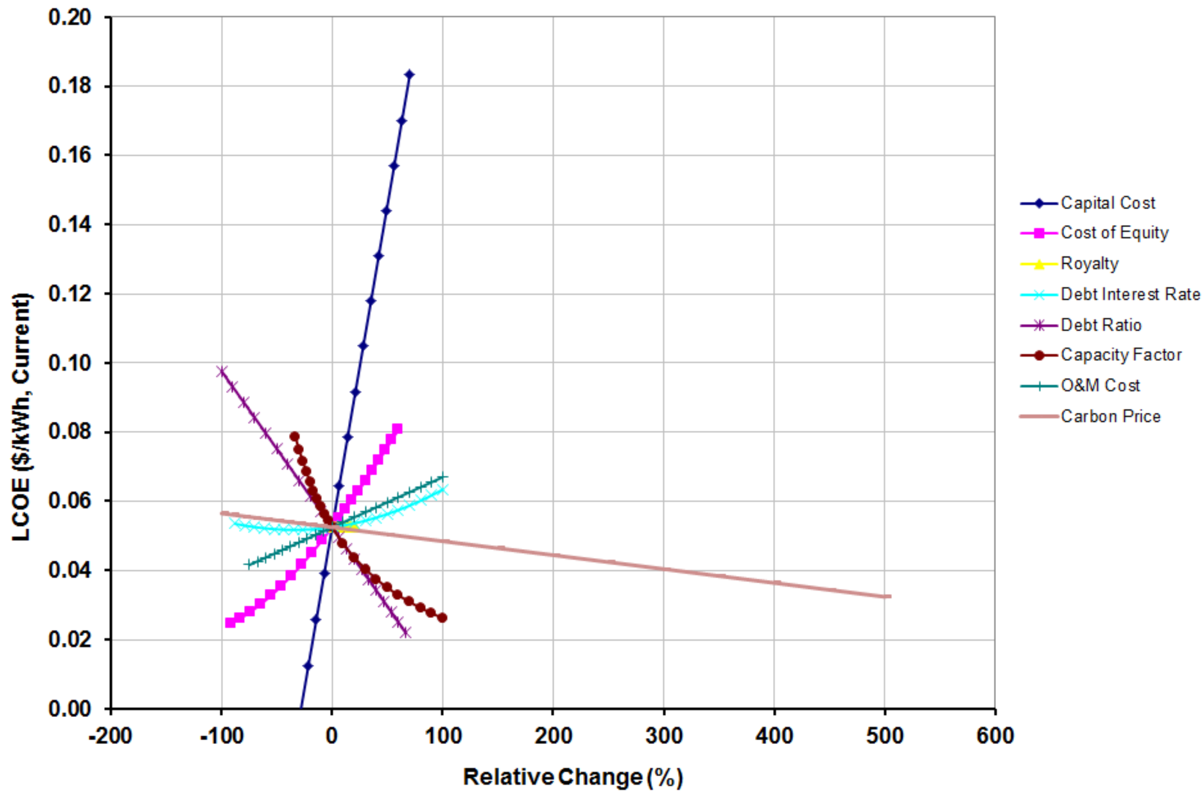


Figure 2 is based on the assumptions shown in Table 3.

Table 3: Input Assumptions for Simply Solar LCOE Calculations (2014 Nominal $)

Capital Cost = $ 4,469,662	Operating Expenses = $20/kW-yr	ITC = 30%
Price of Carbon = $ 10/MT	Debt Ratio = 0%	Grants Total = $1,825,328
Debt Term = 20 years	Cost of Equity = 12.50%/yr	Economic Life = 20 years
MACRS Depreciation = 5 years	General Inflation = 2.80%	Federal Tax Rate = 34%
State Tax Rate = 6.65 %	Net Plant Capacity = 1,500 kW	Capacity Factor = 18%

The significant drivers for economic sustainability of a large PV field deployment include the following:

- Reduction in capital cost.
- Reduction in operations and maintenance (O&M) cost.
- Increased carbon value.

2.4 Conclusions

The Simply Solar project advanced science and technology and overcame the following barriers:

- Achievements:
  - Solar structures were installed in three configurations: a carport shade structure, dog park shade structures, and a ground-mount facility at Sutter's Landing Regional Park in the City of Sacramento.
- Challenges:
  - Installing solar on a closed, pre-regulation landfill.
  - Working through CEQA issues (Swainson's hawk, Hackberry bush), which resulted in project downsizing and redesign.
  - The bankruptcy of a major equipment manufacturer, which eliminated grant funding for one of the inverters and required that a new funding source be found.
  - Contractor financing issues and parent company insolvency proceeding.
  - Tribal monitoring.
  - New city design requirement for explosionproof fittings.
  - Easement conflict with local residential development.
  - Hazardous waste disposal requirement for a portion of excavated soils.
- Lessons learned:
  - Additional project costs should be anticipated for solar PV projects sited on capped landfills, both for foundation design and other types of environmental mitigation.
  - Solar electricity generation can provide GHG emissions reductions and other associated benefits to the community.
  - Project delays are not necessarily always detrimental; in this case, they resulted in lower priced PV modules, as increased manufacturing achieves economies of scale.

In summary, the Simply Solar project successfully installed a PV facility with a 1.5 MW nameplate rating. The system is delivering electricity to SMUD (2,423 kWh/yr) at an LCOE of $97/MWh, and it is achieving 1,842 MT CO_2e per year GHG emissions reductions.

CHAPTER 3: Sacramento Regional County Sanitation District Biogas Enhancement

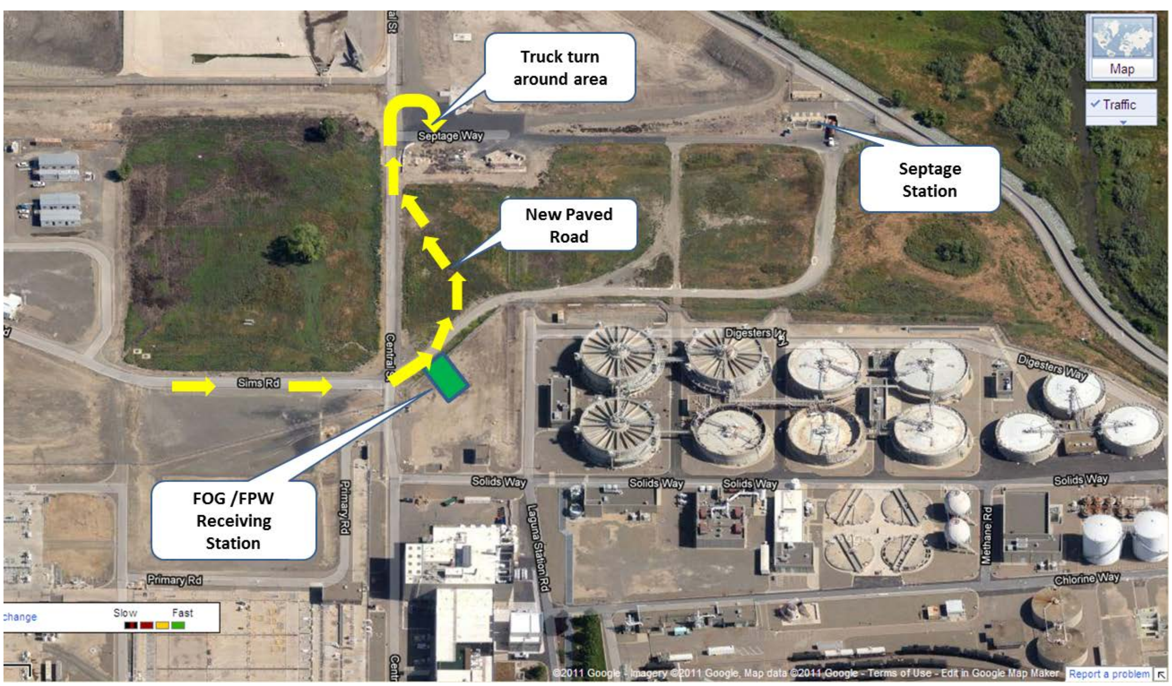
3.1 Project Description

A new process at the SRCSD wastewater treatment facility co-digests fats, oils, and grease (FOG) and food processing waste (FPW), such as off-specification soda pop, with sewage to generate biogas. During 2009, SRCSD and SMUD conducted a biogas enhancement pilot test to evaluate the feasibility of using FOG and FPW. This study confirmed that FOG and FPW used in the anaerobic digesters improved overall biogas production and would provide more electricity from the green energy source. Design and construction of the new biogas enhancement project (BEP) was completed in 2012, and the facility is currently operational. This project is estimated to provide renewable energy to power between 1,000 and 3,000 homes, eliminate GHG emissions and saving money for local businesses. These businesses might otherwise have paid a higher tipping fee to dispose of this waste, in a less GHG-efficient manner.

3.1.1 FOG Receiving System

The project consisted of designing and building a FOG receiving station sized to receive 42,000 gallons per day (gpd) of material. An aerial view of the facility can be seen on Figure 3.

Figure 3: New Biogas Enhancement Project (BEP) Overview at Sacramento Regional County Sanitation District

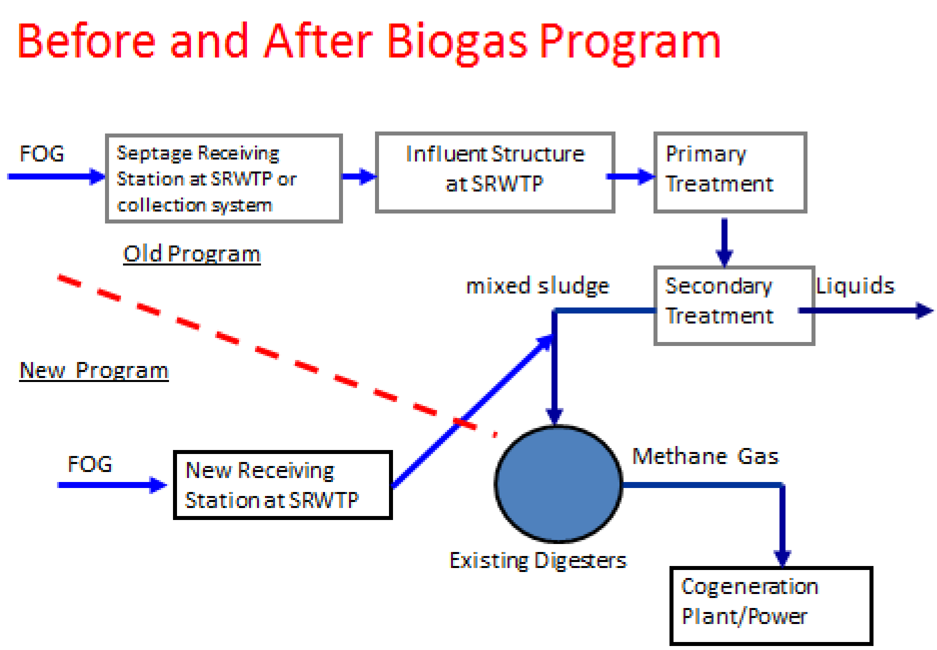


The BEP is located at the Sacramento Regional Wastewater Treatment Plant (SRWTP). The BEP was designed to handle up to 42,000 gpd of feedstock material that includes FOG and FPW, such as soda pop waste. The estimated 42,000 gpd includes 30,000 gpd of FOG and 12,000 gpd of FPW materials. The BEP facility allows these materials to bypass the primary and secondary treatment processes at the SRWTP. The material is injected into the anaerobic digester to enhance the generation of biogas, which SMUD uses to produce renewable energy at the adjacent Carson Energy Cogeneration Plant.

The FOG receiving facility consists of two storage tanks, two off-loading stations, pumps, odor control, strainers, rock traps, grinders, flowmeters, and valves, along with two heated pipes from the offloading facility to the digesters. When the facility is not receiving FOG, the mixing mode is in effect, and FOG material is continuously mixed and chopped by the pumps and grinders. Each FOG tank has a variable frequency drive (VFD) pump that can vary the feed rate to the process downstream of the mixed sludge tanks.

A general layout is provided on Figure 4.

Figure 4: Layout of the SRCSD Biogas Enhancement Project



3.1.2 Project Partners and Timeline

Project partners included SRWTP, Carollo Engineers, Western Water Constructors (WWC), Kleinfelder Engineering, and Swabe.

The project timeline is summarized as follows:

- May 25, 2011: Design phase commenced.
- January 11, 2012: Project awarded to WWC.
- January 23, 2012: Construction phase commenced.
- December 31, 2012: Substantial completion achieved.
- January 31, 2013: Activation work commenced.
- June 12, 2013: Final project acceptance at SRCSD board meeting.
- July 2013: Initial operational phase (FOG only). Daily discharge averaging 4,500 gpd, resulting in nine percent increase in biogas production.

3.2 Project Implementation and Testing Goals

The goal was shaped by the following feasibility studies that had been completed previously:

- SRWTP Biogas Enhancement Feasibility Study Phase I (January 2006).
- Phase II Technical Feasibility (May 2007).
- Phase III Economic Feasibility (August 2007).
- Pilot Study (January 2008–December 2009).
- FOG Receiving Facility Request for Proposal (RFP) (March 2011).

These prior studies had established that the BEP could leverage existing infrastructure at the SRWTP to provide a solution for problem waste streams such as FOG, while also providing new revenue streams for SRCSD, using excess SRWTP plant capacity, reducing cost and emissions of FOG waste disposal, and providing renewable fuel to the adjacent Carson Energy Cogeneration Plant. In return, the Carson plant provides steam to the SRWTP to meet its heating needs. Beyond improving plant operations, the feasibility studies also indicated that the project could contribute to SMUD's renewable energy goals.

3.3 Project Outcomes

3.3.1 FOG Receiving System Performance

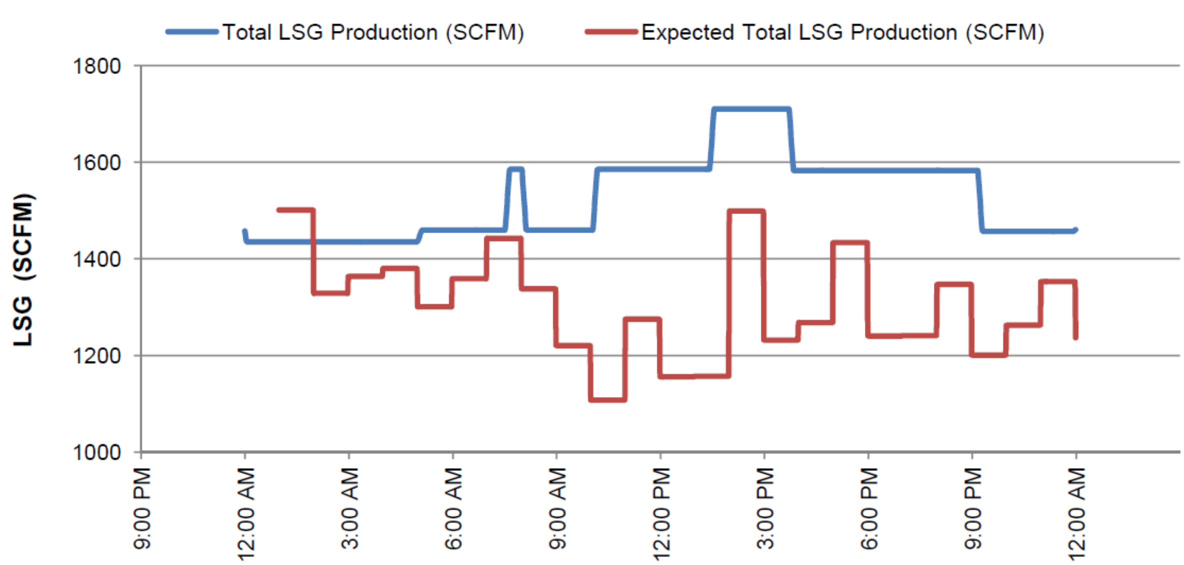
The SRCSD BEP was designed to handle up to 42,000 gpd of feedstock material that includes FOG and liquid FPWs, such as soda pop waste. The BEP began operational testing in January 2013 and became functional in June 2013. The system can reduce GHG emissions and can provide efficiency and operational benefits to the wastewater plant operators; however, SRCSD has experienced significant operational issues since the system was commissioned. In the first few months, FOG deliveries were limited to about 1,500 gpd to allow SRCSD an opportunity to gain operational experience, avoid digester upsets, resolve operational issues, and ensure system stability before gradually increasing feedstock deliveries.

The BEP operated from May 2013 to May 2014 using only the FOG feedstock. The BEP experienced valve and pump failures in May 2014 and has been out of service since that time. Upon inspection, it was determined that the internal linings of valves and pumps failed because of swelling and delaminating of the rubber sealing surfaces. SRCSD directed its design consultant to evaluate causes of failure and propose corrective measures. The evaluation included extensive research of similar facilities and visiting multiple BEPs in California and throughout the US to determine if other BEPs had experienced similar issues. O&M, as well as the characteristics of the FOG material, was highly variable, which presented challenges in developing suitable corrective measures.

SRCSD staff has identified a preferred alternative to resolve the operational issues and is preparing to make significant modifications and improvements to the BEP. Corrective actions are expected to take 6 months and will include a competitive bidding process and lead time for equipment, construction, and commissioning. Details of the operational problems and research into solutions are attached as Appendix B3.

Figure 5 shows an example of low-pressure sludge gas (LSG) flow, on a high feed day in July. The total LSG production (in standard cubic feet per minute [scfm]) was higher than expected for this day. During the initial operational period, there was a general trend toward more biogas than expected during FOG feeding. FOG deliveries were, however, below peak design delivery rates during this period. Until more regular and substantial FOG and FPW feeds are received, it will likely be difficult to measure and confirm the ultimate increase in biogas production attributable to the BEP, as distinct from other contributing factors.

Figure 5: Low-Pressure Sludge Gas on High-Feed July Day at SRCSD Facility



The methane and energy content of the LSG was found to be stable.

SRCSD will continue to monitor its measuring methods and monitor the biogas production to better determine the amount of additional biogas that is being produced by the BEP. The production of biogas will increase as operational issues are resolved and system stability is ensured.

Pending implementation of proposed design changes, the project can contribute renewable energy toward SMUD's RPS goals and provide educational value for accelerating renewable energy deployment in new applications.

3.3.2 Greenhouse Gas Benefit Analysis

The electricity generated will be equivalent to 10,616 MT CO_2e per year.

3.3.3 Job Creation Analysis

During the design and construction of the project, many jobs were created and retained. Job creation includes employees of the SRWTP, Carollo Engineers, WWC, Kleinfelder Engineering, and Swabe.

3.3.4 Project Economic Analysis

The budget for this project was $3,520,000. The following funding was provided: $100,000 from the Energy Commission, plus $1,455,800 from DOE, for a total of $1,555,800.

3.3.4.1 Construction Costs

Budgeted construction costs were $2,263,897. The full amount was expended as of May 23, 2014.

3.3.4.2 Operational Costs

Typical operational costs for such a plant are about $60,000/yr.

3.3.4.3 Revenues

Revenue streams come from both tipping fees and avoided electricity.

With assumed average electricity cost of about $100/MWh, and annual electricity production of about 13,747 MWh, this gives electricity cost savings of $1,374,700.

Tipping fees may be an additional source of revenue, which have not been incorporated into this analysis, in order to give a conversative estimate of net benefits.

3.3.4.4 Levelized Cost of Energy

At assumed full scale operation of SRCSD FOG receiving station and using the above cost and performance data, the levelized cost of electricity (LCOE) was calculated. The results of different LCOE cases and other assumptions such as Net Electrical Capacity and other technical and financing assumptions are shown in Table 4 below.

The LCOE of generating electricity from anaerobic digestion of dairy wastes depends mainly on capital and operating expenses

Case 1 Using the capital cost = $ 3,194,500, Net Electrical Capacity = 3 MW, no grants, no taxes, 100 % debt ratio, economic life = 20 years, cost of debt = 5%, debt term = 10 years. The LCOE in this scenario is equal to 5.47 cents/kWh (nominal 2014).

Case 2 Using the capital cost = $ 3,194,500, Net Electrical Capacity = 1 MW, no grants, no taxes, 100 % debt ratio, economic life = 20 years, cost of debt = 5 %, debt term = 10 years. The LCOE in this scenario is equal to 16.42 cents/kWh (nominal 2014).

Case 3 With grants from DOE and Energy Commission = $1,555,800, the capital cost is about $1,638,700, Net Electrical Capacity = 1 MW, no taxes, no debt since the rest will be covered by SRCSD, Equity ratio = 100 %, economic life = 20 years. The LCOE in this scenario is 4.95cents/kWh (nominal 2014).

Case 4 With grants from DOE and Energy Commission = $1,555,800, the capital cost is about $1,638,700, Net Electrical Capacity = 1 MW, no taxes, no debt since the rest will be covered by SRCSD Equity ratio = 100 %, economic life = 20 years. The LCOE in this scenario is 14.84 cents/kWh (nominal 2014).

Table 4: LCOE Cases for SRCSD

SRCSD				
Case:	Case 1	Case 2	Case 3	Case 4
Technical Entries			With grants = $1,555,800	With grants = $1,555,800
Total Facility Capital Cost ($)	$3,194,500	$3,194,500	$1,638,700	$1,638,700
Electrical and Biogas Fuel--base year				
Gross Electrical Capacity (kWe)	3,300	3,300	3,300	3,300
Net Electrical Capacity (kWe)	3,000	1,000	3,000	1,000
Capacity Factor (%)	95	95	95	95
Net Efficiency--Biogas to Electricity (%)	50	50	50	50
Methane Concentration in Biogas (% by volume)	60	60	60	60
Heat--base year				
Total heat production rate (kwth)	2,700	2,700	2,700	2,700
Aggregated fraction of heat recovered (%)	50	50	50	50
Recovered heat (kWth)	1,350	1,350	1,350	1,350
Overall CHP Efficiency--Gross (%)	77.5	77.5	77.5	77.5
Overall CHP Efficiency--Net(%)	72.5	72.5	72.5	72.5
Taxes				
Federal Tax Rate (%)	0	0	0	0
State Tax Rate (%)	0	0	0	0
Combined Tax Rate (%)	0	0	0	0
Escalation/Inflation				
General Inflation (%/y)	2.80	2.80	2.80	2.80
Escalation-- for all parameters (%/y)	2.80	2.80	2.80	2.80
Financing				
Debt Ratio (%)	100	100	0	0
Equity Ratio (%)	0	0	100	100
Interest Rate on Debt (%/y)	5	5	5	5
Life of loan or debt term (y)	10	10	10	10
Economic Life (y)	20	20	20	20
Cost of Equity (%/y)	5	5	5	5
Cost of Money (%/y)	5	5	5	5
Depreciation Schedule	MACRS 5-yr	MACRS 5-yr	MACRS 5-yr	MACRS 5-yr
Current $ LCOE ($/kWh) 2014	0.05472	0.16416	0.04945	0.14836
Constant $ LCOE ($/kWh) 2014	0.04227	0.12681	0.03820	0.11460

LCOE is particularly sensitive to capital cost, operating expense, capacity factor and net plant capacity. If the debt ratio is 0 percent or 100 percent equity, with at net plant capacity of 3,000 kW, LCOE = 4.94 cents/kWh [nominal $ 2014] Case 3).

The critical factors for economic sustainability of co-digestion facility at SRCSD includes:

- Reduction in capital cost.
- Reduction in operation and maintenance (O&M) cost.
- Plant Capacity
- Tipping Fees

3.4 Conclusions

The SRCSD BEP advanced science and technology and overcame the following barriers as follows:

- Achievements:
  - Completed 5 month design within budget.
  - Provided satisfactory connection point at which to feed FOG.
  - Used proactive approach to minimize change orders.
  - Met "Buy American" requirements.
  - Leveraged existing infrastructure at the SRWTP to provide an environmentally friendly disposal solution for problem waste streams such as FOG.
  - Utilized excess SRWTP plant capacity.
  - Reduced cost and emissions of FOG waste disposal.
  - Provided renewable fuel to the adjacent Carson Energy Cogeneration Plant.
- Challenges:
  - Tight schedule, expedited design.
  - Unclear specification of liquidated damages.
  - Short operational testing period (96 hours).
  - Significant effort of reporting for grant funding.
  - Late identification of pump component design flaw led to system outages.
- Lessons Learned:
  - Enforce accountability.
  - Work closely with responsible engineer for timely resolution of issues.

In summary, the SRCSD BEP successfully installed a FOG receiving facility capable of receiving 42,000 gpd. The system is capable of delivering up to 13,747 MWh/yr of electricity to SMUD, and achieving 10,616 MT CO_2e per year GHG emissions reductions.

CHAPTER 4:
New Hope Dairy Digester

A team led by California Bioenergy LLC (CalBio), through its special purpose company ABEC New Hope LLC, developed and demonstrated an anaerobic digester and engine-generator system at a 1,200 milk cow dairy farm, New Hope Dairy LLC, located west of Galt in the southern part of Sacramento County.

4.1 Project Description

New Hope uses a manure collection system to scrape manure from most stalls and deliver it to the complete stirred tank reactor (CSTR) digester that operates at mesophilic temperatures. The collected manure, along with some dilution water, is retained in the tank digester for 30 to 40 days. As the manure decomposes, biogas is produced and accumulates in the tank. The gas is then collected, cleaned, and sent to a 450 kW engine-generator.

4.1.1 Manure Collection System

New Hope Dairy installed a new automatic manure scraping system to collect manure from most of the stalls and deliver it to the anaerobic digesters. This system continuously scrapes the fresh manure from three free-stall barns into two slurry collection tanks with influent pumps.

4.1.2 Digester System

The tank digester (Figure 6) is a reinforced concrete structure 85 feet in diameter and 26 feet deep. This digester is heated using the water jacket and exhaust heat from a 2G CENERGY engine-generator.

In order to collect the produced biogas, the tank is equipped with a flexible double membrane roof. The outer cover is a protective cover that is held up through air inflation. The inner membrane can move freely between the top of the tank and the outer membrane, allowing for gas storage capacity. The effluent from the digester is pumped to a storage pond for solids separation and is afterward used for crop irrigation as a liquid fertilizer.

Figure 6: New Hope Tank Digester

4.1.3 Engine-Generator System

As shown in Figure 7, the engine-generator, made by 2G CENERGY using a MAN core engine, is a CHP package with a rated capacity of 450 kW; it uses a selective catalytic reduction (SCR) emissions control system.

Figure 7: New Hope 450 kW Engine-Generator

4.1.4 Project Partners and Timeline

CalBio, through its special purpose company ABEC New Hope LLC, is the developer of the New Hope Dairy Digester. MT-Energie, through its special purpose company RECM, LLC, completed the design in 2011; construction started in December 2012 and was completed in the first quarter of 2013. Commissioning was completed in the second and third quarters of 2013.

4.2 Project Implementation and Testing Goals

The main goal of this task was to implement the installation of an anaerobic digestion system at New Hope Dairy in Galt, California, which has over 1,200 dairy cows. The design strategy for the New Hope Dairy Digester included selecting an engine based on its suitability for biogas, its efficiency, and its emissions capabilities. The engine size was chosen to fit with the digester output to optimize power generation during peak hours.

4.3 Project Outcomes

4.3.1 CHP Engine Testing

The CHP engine-generator was subjected to yearlong continuous testing of its electrical output according to the biogas energy input as well as the thermal heat output and overall efficiency. The testing utilized the data collection system included as part of the engine-generator installation, which continuously collects the important engine and generator data, and results of influent and effluent lab analyses at several sampling times.

The overall efficiency of the CHP engine-generator is 67 percent, including both the electrical production and utilized thermal energy for digester heating. The available manure generates gas of consistent methane composition (55 percent average) and generates sufficient gas to produce 1,774,000 kWh/yr. The net load exported by the project is 1,570,926 kWh/yr, approximately 90 percent of the generated energy. These production levels are achieved at a 45 percent capacity factor; the generator operates twice per day as needed to burn the accumulated biogas, and the programming optimizes generation to occur as much as possible during hours when the SMUD rates are on-peak.

4.3.2 Greenhouse Gas Benefit Analysis

Actual and projected GHG benefits related to the system’s ability to capture and combust methane emissions from the dairy manure were calculated using the Climate Action Reserve protocols. The estimated GHG credits for the actual 12 month period of operation considered were 2,697 MT of CO_2e per year.

4.3.3 Emissions Exhaust Analysis

Exhaust emissions from the engine-generator were tested in June 2013 while it was operating at 73 percent to 100 percent load, and the measured levels were compared to the allowable limits for the various pollutants. Air Science Technologies, Inc., conducted the testing, and the results are shown in Table 5.

Table 5: New Hope Generator Exhaust Emissions Testing Results

Pollutant	Emissions Limit	Results	Corrected to 15% O_2
CO (ppmvd)	329.6*	24.6**	8.1
NO_x (ppmvd)	24.1*	11.2**	3.7
VOC (ppmvd)	79.1*	13.0**	4.3
NH_3 (ppmvd)	10*	0.06**	0.020
PM (lb/day)	9.6	0.08	0.026
H_2S (ppmvd, fuel)	350	0.06	0.020

* at 15 percent O_2.
** at 3 percent O_2.

Notes:
CO = carbon monoxide
NO_x = oxides of nitrogen
VOC = volatile organic compound
NH_3 = ammonia
PM = particulate matter
H_2S = hydrogen sulfide
ppmvd = parts per million volumetric dry
lb/day = pounds per day

4.3.4 Job Creation Analysis and Impact to Local Economy

Job creation during construction and actual operation of the digester was determined. The calculation was based on the number of hours worked divided by 2,040 hours/year (full-time employee status). During construction, 6.1 full-time equivalent (FTE) jobs were created, and 0.86 FTE jobs were created for ongoing operations. Almost $230,000 was added to the local economy in terms of direct wages and additional indirect benefits of materials purchased.

4.3.5 Project Economic Analysis

Project financial and performance information were used as inputs to perform cash flow economic calculations and levelized cost analysis for the project.

4.3.5.1 Capital Costs

Capital costs to construct and commission the project amounted to $3.9 million. This figure includes design, procurement, and construction of the system; permitting; grid interconnection agreement; power and CO_2 purchasing agreement; financing costs; construction loan; commissioning; monitoring; developer fees; and other direct project costs. The total is exclusive of one-time costs related to training subcontractors on the use and deployment of the concrete slip-forming technology used to pour the CSTR tank digester.

DOE ($125,000), Energy Commission ($250,000), and United States Department of Agriculture/Environmental Quality Incentives Program (USDA/EQIP) ($250,000) grants provided $1.177 million of the total cost. After achieving commercial operation, the project was successful in receiving an American Recovery and Reinvestment Act (ARRA) Treasury 1603 Grant in the amount of $1.24 million. The balance of the project cost was provided by CalBio and MT-Energie USA, Inc., as project equity and from a secured bank loan in the amount of approximately $400,000.

4.3.5.2 Operational Costs

As shown in Table 6 total fixed costs were determined to be $121,954, which included state property taxes, property insurance, administrative expenses, and a portion of the digester O&M expenses. The variable operating costs were determined to be $107,303, which included farmer feedstock and lease and O&M expenses related to the generator and digester. Based on an annual estimated energy production of 1,774 MWh, the annual operational cost is $0.1292 per kWh. The levered annual operational cost is $0.1247 per kWh.

Table 6: New Hope Operational Cost Estimate

Parameter	Value
Annual Total Fixed Costs ($)	121,954
Annual Variable Operating Costs ($)	107, 303
Annual Estimated Production (MWh)	1,774
Annual Operational Cost ($/kWh)	0.1292
Annual Interest Expense ($)	31,982
Levered Annual Operational Cost ($/kWh)	0.1247

4.3.5.3 Revenues

Based on the net energy production of 1,570,925 kWh/yr, and the average distribution of production by rate period (off-peak: 18.7 percent, on-peak: 40.4 percent, and super-peak: 40.9 percent), the annual average project revenue is expected to be $0.1414 per kWh, generating $222,116.38 per year in electricity sales.

4.3.5.4 Levelized Cost of Energy

The LCOE was calculated using the model developed by Black & Veatch[1] and often referenced by the Energy Commission. The LCOE was calculated for the following four cases:

- **Case 1 (current economics).** Manure only, low capacity factor was assumed. This case assumes there is no 30 percent ITC, i.e., the ITC remains unavailable for biogas projects. Under this scenario, the LCOE = 41.2 cents per kWh (nominal 2014$).
- **Case 2 (economics of manure plus co-digestion).** Co-digestion of a farm friendly substrate that generates additional biogas sufficient to fully utilize the plant at a 95 percent capacity factor was assumed. This case assumes that the substrate generates a $10 per wet ton tipping fee, is 25 percent dry matter, and generates gas at 9,500 standard cubic feet (scf) of methane (CH_4) per dry matter ton. Similar to Case 1, it was assumed that the 30 percent ITC remains unavailable for biogas projects. The LCOE = 21.1 cents per kWh (nominal 2014$).
- **Case 3.** Same as Case 2, but it was assumed that the federal government adopts the Energy Policy Extension Act, or equivalent, and that the 30 percent ITC is reinstated for biogas projects to give them treatment similar to that of solar projects. The LCOE = 14.0 cents per kWh (nominal 2014$).
- **Case 4.** Same as Case 3, but it was assumed that the New Hope farmers would be willing to sell the fiber solids output of 112 tons per day x 8 percent dry matter or screw-pressed to 30,000 pounds per day at 70 percent dry matter. It was assumed that the project could net, after processing and drying costs, $10 per ton dry matter or $32,589 per year, approximately $90 per day. With this additional revenue, the LCOE = 12.8 cents per kWh (nominal 2014$).

Assuming higher prices of carbon offsets (in the regulatory and voluntary markets) lower O&M costs per kWh, and lower capital cost per MW, LCOEs around 10 cents per kWh or lower are possible. Possible higher market value of carbon offsets is likely the most viable economic factor to help in deployment of biomass-to-energy projects.

4.4 Conclusions

The overall project objective of implementing an anaerobic digestion system at New Hope Dairy was successfully achieved. Performance and financial conclusions of the first year of operation are summarized as follows:

- The CHP engine-generator operates with an overall (electrical and thermal) efficiency of 67 percent.

[1] http://www.cpuc.ca.gov/NR/rdonlyres/69848D0B-9EA3-466B-8B8F-CE1E0EEF1894/0/PublicDRAFTLCOEModelCPUCSB1122.xlsx.

- The project currently operates at a capacity factor of 45 percent. The project exports a net energy production of 1,570,925 kWh to the grid (90 percent of the generated kWh) annually. Both can be increased by extending the operational period of the generator.
- During construction, 6.1 FTE jobs were created, and 0.86 FTE jobs were created for ongoing operations. Most of the job creation was realized during the construction phase. Almost $230,000 was added to the local economy.
- The generator emissions were lower than the allowable limits in all measured categories, demonstrating the effectiveness of the engine's SCR emissions control system installed in meeting stringent air emissions standards in California.
- The estimated GHG credits for the actual 12 month period of operation considered were 2,697 metric tons of CO_2e for the year.
- The project generates an estimated $222,116 in annual electricity sales.
- Using current project economics generates an LCOE of $0.412 per kWh, which could decrease to as little as $0.128 per kWh, assuming higher capacity factor, adoption of the Energy Policy Extension Act and extension of the 30 percent ITC, and sales of fiber solids and dry matter.

In addition to producing renewable energy, the facility also reduces significant GHG emissions by destroying methane. GHG benefits from the project are generated by the avoided methane emissions component. This benefit is unique to digester projects versus other renewables such as solar or wind.

Project revenues were maximized by optimizing generator production with SMUD peak rate periods. This is a critical strategy for the financial viability of the project. Of additional importance is the ability for biogas to regain tax parity with solar on the ITC. This has a significant impact on the LCOE. The performance of the system during the 12 month period of this review indicates that by optimizing the operations strategy, the New Hope Dairy Digester can produce high value, predictable, and reliable electricity at a competitive price.

CHAPTER 5:
Van Warmerdam Dairy Digester

The Van Warmerdam Dairy Digester is a covered lagoon anaerobic digester, which was installed on a 1,000 cow dairy farm near Galt, California, in 2012 to 2013. The project is privately developed, owned, and operated by Maas Energy Works, Inc., with significant financial and development support from SMUD, which also purchases the power generated by the facility.

5.1 Project Description

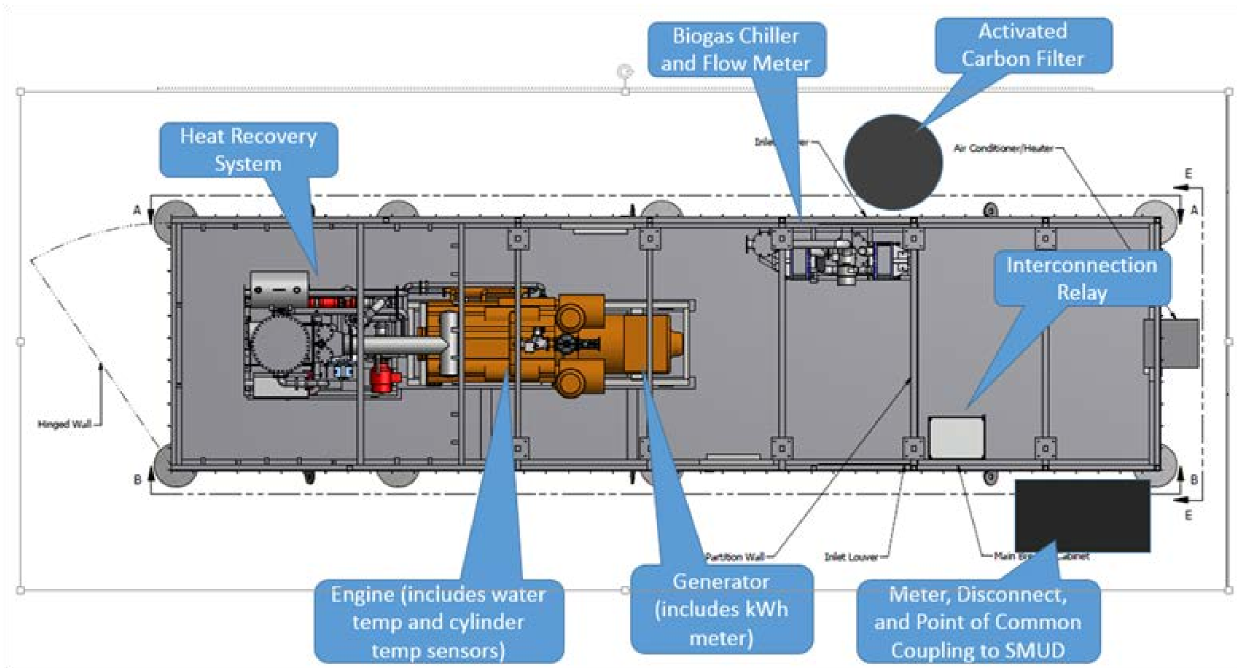
The facility operates solely on manure collected from the Van Warmerdam Dairy. Biogas from the covered lagoon anaerobic digester is routed to a containerized internal combustion engine capable of generating 600 kW of electricity for delivery back onto the SMUD distribution grid.

5.1.1 Digester System

The digester is an earthen pond approximately 525 feet by 125 feet, with a total operational fluid volume of about 8,000,000 gallons. The pond is covered with an 80/1,000 inch high density polyethylene (HDPE) membrane to contain the biogas. The cover is designed to allow directional flow through the digester to ensure retention time; mixers in the digester improve biogas production. The digester operates at ambient temperatures and is supplemented by engine waste heat. The digester’s flexible cover enables biogas storage, allowing the engine to run during peak power periods when prices paid for electricity are highest and store gas when prices are lower. The effluent from the digester is used as a liquid fertilizer for crop irrigation. The biogas is conveyed underground to the engine-generator system.

A schematic of the engine-generator set depicting the filtration system, engine, generator, and heat recovery system is shown in Figure 8.

Figure 8: Van Warmerdarm Engine-Generator Set Schematic



5.1.2 Engine-Generator System

The project's power plant is a 600 kW engine-generator made by Martin Machinery. The engine is a Guascor SFGLD 560, 1,800 revolutions per minute (rpm), 12 cylinder internal combustion engine rated at over 900 horsepower and operating on biogas fuel from the co-located covered lagoon anaerobic manure digester. The engine is mated to a Stamford HCI 534F 600 kW synchronous generator, generating at 480 volts, which is connected to SMUD's distribution feeder via a 750 kilovolt-ampere interconnection transformer.

5.1.3 Heat Recovery System

The generator recovers heat from three sources. The engine block's jacket water is pumped out via the engine water pump. Additionally, the exhaust from the engine is routed through a series of parallel pipes where a heat exchanger extracts energy from the exhaust in the form of more hot water. Finally, the engine's intercooler loop coolant is pumped out to catch more hot water. Together, these three sources allow the system to recover hot water for a total well in excess of 40 percent of the engine's energy input. After collection, the hot water is transferred to a pipe-in-pipe heat exchanger where the heat is transferred to manure pumped from the covered lagoon. With its large volume, the lagoon can supply essentially unlimited cooling potential to the engine. The heated manure in the heat exchanger is then dumped back into the lagoon to increase the overall lagoon temperature and improve biogas production.

5.1.4 Project Partners and Timeline

In addition to Maas EnergyWorks, Inc as the project owner, Martin Machinery supplied the engine-generator set and ancillary equipment. Environmental Fabrics, Inc, supplied and installed the lagoon cover. MEW coordinated a small number of local contractors and suppliers for additional services.

An earlier version of this project was previously attempted by a different developer whose contract with SMUD was terminated. For that reason, the project plan included an additional objective of rapid, reliable execution in order meet the summer 2013 sunset date for grant funds awarded to this effort. The grant agreement between MEW and SMUD was signed in December 2011, and permitting applications commenced in 2012. Construction began in January 2013, and the SMUD-approved commercial operations date was May 28, 2013. The total time from initial concept to commercial operations was 17.7 months.

5.2 Project Implementation and Testing Goals

The main goal of this task was to implement the installation of an advanced anaerobic digester system (AADS) at the Van Warmerdam Dairy. The effort will offset the use of grid energy the dairy requires and provide energy benefits and revenues through SMUD's FIT. This dairy farm has 1,100 lactating dairy cows and is located in Elk Gove, California.

The procedure used was a design-build-operate model headed by MEW. MEW designed the project using reliable technologies common to the digester industry, including a lean burn piston engine and covered lagoon digester. This approach promised the most amount of energy and economic benefit for the smallest capital investment in the shortest possible time with the highest degree of reliability. The overall approach to the project involved a simplified management structure at MEW, with only two main fixed-price, design-build contracts.

5.3 Project Outcomes

5.3.1 CHP Engine Performance

SMUD's monthly statements of power generation were used to create a record of net power delivered by the project. This information was broken down into off-peak, on-peak, and super-peak portions. MEW used its own ComAp InteliMonitor metering equipment to audit the SMUD monthly statements. Electrical consumption was calculated by subtracting the net power metered by SMUD from the gross power generation logged on the ComAp InteliMonitor; the difference was assumed to be site load.

The overall gross efficiency of the CHP engine-generator is 70.5 percent, including both the electrical production and utilized thermal energy for digester heating. The available manure generated gas of consistent methane composition (58.2 percent average) and 1,691,774 kWh during the first complete 12 months of operation. The net load exported by the project was approximately 1,612,294 kWh/yr, over 95 percent of the generated energy. These production levels are achieved at a 36 percent capacity factor. The generator is frequently started up/shut down to optimize generation to occur as much as possible during hours when the SMUD rates are on-peak.

5.3.2 Greenhouse Gas Benefit Analysis

GHG benefits were calculated using the Climate Action Reserve Livestock Protocol Tool Version 3.0 for avoided methane emissions. The estimated total annual GHG reduction was 7,839 metric tons of CO_2e.

5.3.3 Emissions Exhaust Analysis

Exhaust emissions from the engine-generator were tested on August 22, 2013, while it was operating at full load, and the measured levels were compared to the allowable limits for the various pollutants. MEW contracted a licensed third-party emissions tester to check for air permit compliance. The results of the testing are shown in Table 7.

Table 7: Van Warmerdam Exhaust Emissions Testing Results

Pollutant	Emissions Limit	Results
CO (ppmvd at 15% O_2)	236.2	34.5
NO_x (ppmvd at 15% O_2)	12	8.8
VOC (ppmvd at 15% O_2)	45.9	11.2
NH_3 (ppmvd at 15% O_2)	10	6.8

5.3.4 Job Creation Analysis

Project financial records were used to estimate total spending on manufactured equipment during construction and also to calculate hours of labor billed by MEW and other contractors. Estimates of operational purchases and labor were generated on the basis of expected O&M schedules. During construction, 8.2 FTE jobs were created, and 1.3 FTE jobs were created for ongoing operations.

5.3.5 Project Economic Analysis

Project financial and performance information were used as inputs to perform cash flow economic calculations and levelized cost analyses for the project.

5.3.5.1 Construction Costs

The initial budget for the project was set at $1,700,000. This amount does not include certain development, insurance, rent, and financing costs that were not eligible for inclusion in the SMUD project cost basis. The project was awarded a total of $880,852 in funding from SMUD, including $125,000 from the Energy Commission and $755,852 from the DOE. In addition to these funds, the project secured a $900,000 construction loan from New Resource Bank. The project working capital and other funds were supplied out of company cash.

The total construction-related costs for this project amounted to $1,470,988, which includes lease agreement, interconnection and permitting, engineering, procurement, construction, grid connection, commissioning, labor, subcontractors, and other direct expenses. Inclusion of the non-SMUD-eligible costs brings the total project cost to slightly over $1,600,000, which is less than the initially budgeted amount.

5.3.5.2 Operational Costs

MEW staff tracked operational costs by summing the labor, rents, taxes, insurance, consumables, and other costs incurred during operations. In many cases, these costs had to be estimated since the project has not operated long enough to establish clear, steady-state operational cost trends. The annual operating costs totaled $166,974. Dividing by an estimated annual average production value of 1,800 MWh results in an annual operational cost per kWh of $0.0927. Costs are shown in Table 8.

Table 8: Van Warmerdam Operational Cost Estimate

Parameter	Value
Annual Total Operating Cost ($)	166,794
Annual Estimated Production (MWh)	1,800
Annual Operational Cost ($/kWh)	**0.0927**

5.3.5.3 Revenues

The project's electrical production revenue was estimated using historical production rates and estimated winter temperature impacts. For this calculation, total estimated power was set to 1,800 MWh. Revenues from electricity were calculated at the estimated levelized Power Purchase Agreement (PPA) price of $146.45/MWh on the basis of estimated seasonal and time of day power generation. The carbon revenue was estimated on the basis of a predicted market price of $9 per MT CO_2e. Total annual revenues were calculated as $317,610.

Without access to peak pricing, the effective PPA price received by the project would be significantly lower, and the project would not be economically feasible as designed.

5.3.5.4 Levelized Cost of Energy

Using the above cost and performance data, the LCOE using the revenue requirement approach was calculated for the Van Warmerdam Dairy Digester. The results of five different LCOE cases and other assumptions such as taxes and other technical and financing assumptions shown in Table 9 are described as follows:

- **Case 1.** This scenario assumes the capital cost = $1.8 million, operating expenses = $166,794, with no ITC, no CO_2 payment, no grants, 50 percent debt ratio, cost of debt = 6 percent, debt term = 10 years, return on equity = 15 percent, and economic life = 20 years. The LCOE in this scenario is equal to 25.59 cents/kWh (nominal $2014).
- **Case 2.** This scenario assumes the capital cost = $1.8 million, operating expenses = $166,794, with 30 percent ITC, with $9/MT CO_2 payment, no grants, 50 percent debt ratio, cost of debt = 6 percent, debt term = 10 years, return on equity = 15 percent, economic life = 20 years. The LCOE is equal to 19.28 cents/kWh (nominal $2014).
- **Case 3.** This scenario assumes 30 percent ITC, with $9/MT CO_2 payment, grants from DOE and Energy Commission = $880,852, 50 percent debt ratio, cost of debt = 6 percent,

debt term = 10 years, return on equity = 15 percent, economic life = 20 years. The LCOE is equal to 9.29 cents/kWh (nominal $2014).

- **Case 4.** This scenario mimics the real case for MEW with 30 percent ITC, $9/MT CO_2 payment, grants from DOE and Energy Commission = $880,852, capital cost of $919,148 (or about $900,000), 94 percent debt ratio, cost of debt = 6 percent, debt term = 10 years, 6 percent equity contribution, return on equity = 15 percent, economic life = 20 years. The LCOE is equal to 7.85 cents/kWh (nominal $2014). The levelized PPA price is equal to $14.645, which is significantly higher than the LCOE in this scenario.
- **Case 5.** This scenario assumes 30 percent ITC, $9/MT CO_2 payment, grants from DOE and Energy Commission = $880,852, 100 percent debt ratio, cost of debt = 6 percent, debt term = 10 years, return on equity = 15 percent, economic life = 20 years. The LCOE is equal to 7.67 cents/kWh (nominal $2014).

Table 9: LCOE Cases for Warmerdam Dairy Digester

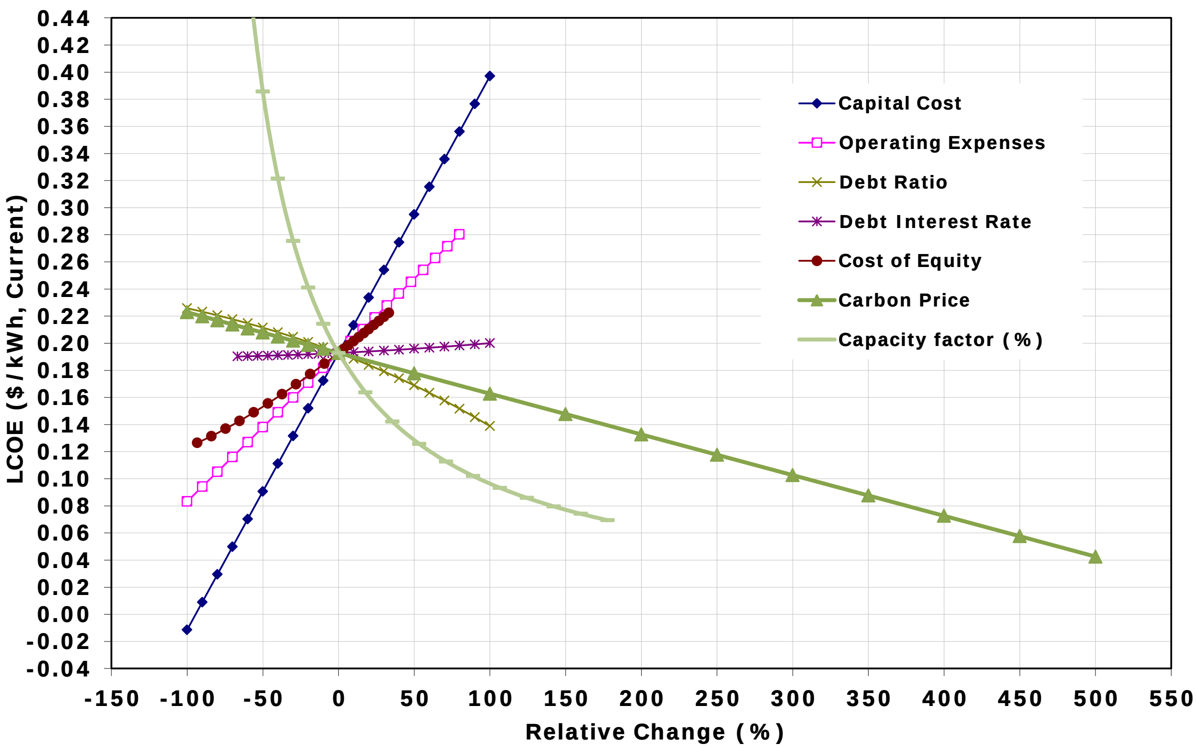
Warmerdam Dairy Digester

Case:	Case 1	Case 2	Case 3	Case 4	Case 5
Technical Entries			With grants = $880,852	With grants = $880,852	With grants = $880,852
Total Facility Capital Cost ($)	1,800,000	1,800,000	919,148	919,148	919,148
Electrical and Biogas Fuel--base year					
Gross Electrical Capacity (kWe)	600	600	600	600	600
Net Electrical Capacity (kWe)	570	570	570	570	570
Capacity Factor (%)	36	36	36	36	36
Net Efficiency--Biogas to Electricity (%)	38.9	38.9	38.9	38.9	38.9
Methane Concentration in Biogas (% by volume)	59.0	59.0	59.0	59.0	59.0
Heat--base year					
Total heat production rate (kWth)	865	865	865	865	865
Aggregate fraction of heat recovered (%)	50	50	50	50	50
Recovered heat (kWth)	433	433	433	433	433
Overall CHP Efficiency--Gross (%)	70.5	70.5	70.5	70.5	70.5
Overall CHP Efficiency--Net (%)	68.4	68.4	68.4	68.4	68.4
Carbon Offset (tons CO2e)	6,000	6,000	6,000	6,000	6,000
Expenses--base year					
Operating Expenses ($)	166,794	166,794	166,794	166,794	166,794
Taxes					
Federal Tax Rate (%)	34.00	34.00	34.00	34.00	34.00
State Tax Rate (%)	6.65	6.65	6.65	6.65	6.65
IvestmentTax Credit (% of Total Capital Cost)	0.000	0.300	0.300	0.300	0.300
Combined Tax Rate (%)	38.39	38.39	38.39	38.39	38.39
Income other than energy					
Carbon Payment ($/tons)	0	9	9	9	9
Sales price for solids ($/t)	0.00	0.00	0.00	0.00	0.00
Escalation/Inflation					
General Inflation (%/y)	2.50	2.50	2.50	2.50	2.50
Escalation--for all parameters (%/y)	2.50	2.50	2.50	2.50	2.50
Financing					
Debt ratio (%)	50.00	50.00	50.00	96.00	100.00
Equity ratio (%)	50.00	50.00	50.00	4.00	0.00
Interest Rate on Debt (%/y)	6.00	6.00	6.00	6.00	6.00
Life of loan or debt term (y)	10	10	10	10	10
Economic Life (y)	20	20	20	20	20
Cost of equity (%/y)	15.00	15.00	15.00	15.00	15.00

5.3.5.5. Sensitivity Analysis:

LCOE is particularly sensitive to capital cost, operating expenses, capacity factor, return on equity, and price of carbon. Sensitivity to these and other factors is illustrated on Figure 9, which shows the full LCOE as each parameter is varied over the indicative relative range and all other values held constant at their reference or basecase values (in this case LCOE = 19.28 cents/kWh [nominal $2014]). If capital cost is lowered by 50 percent (or with grants of about $900,000), LCOE is reduced to about 9 cents/kWh (nominal $2014) similar to the LCOE in Case 3 above. Lowering operating expenses by 50 percent reduces LCOE to 14 cents/kWh. Increasing the capacity factor by 50 percent reduces LCOE to about 13 cents/kWh. In addition, as the price of carbon increases, LCOE decreases.

Figure 9: Van Warmerdam LCOE Sensitivity Analysis (2014 Nominal $/kWh) Assumptions as shown:



Capital cost = $1.8 Million	Operating expenses = $166,794/year	ITC = 30%
Price of Carbon = $9/MT	Debt ratio = 50%	Cost of debt = 6%/year
Debt term = 10 years	Return on equity = 15% /year	Economic life = 20 years
MACRS Depreciation = 5-year	General Inflation = 2.5%	Federal tax Rate = 34%
State Tax rate = 6.65%	Gross electrical capacity = 600 kW	Capacity Factor = 36%

5.3 Conclusions

The anaerobic digestion system at Van Warmerdam Dairy was successfully installed and operated. Performance and financial conclusions of the first full year of operation are summarized as follows:

- The overall gross efficiency of the CHP engine-generator is 70.5 percent including both the electrical production and utilized thermal energy for digester heating.
- The project operates at a capacity factor of 36 percent. The net load exported by the project was approximately 1,612,294 per year, over 95 percent of the generated energy.
- During construction, 8.2 FTE jobs were created, and 1.3 FTE jobs were created for ongoing operations. As with most renewable energy facilities, the project created most of its jobs during construction.
- Generator exhaust emissions were lower than the allowed limits in all measured categories. These results prove the effectiveness of the engine's lean burn control systems, as well as the effectiveness of the SCR emissions control system installed on the engine.
- The estimated total annual GHG reduction was 7,839 MT of CO_2e.
- The project generates an estimated $317,610 in annual electricity sales.
- Using current project economics generates an LCOE of 7.85 cents per kWh, which could decrease to as little as 7.67 cents per kWh assuming a higher debt ratio.

In addition to producing renewable energy, the facility also reduces significant GHG emissions by destroying methane. Nearly all of the GHG benefits from the project are generated by the avoided methane emissions component. This benefit is unique to digester projects compared to other renewables such as solar or wind.

The engine is oversized to allow the facility to generate most of its power during peak demand periods. Without access to peak pricing, the effective PPA price received by the project would be significantly lower, and the project would not be economically feasible as designed. The significant drivers for economic sustainability of covered lagoon digesters for widespread deployment include the following:

- Increased carbon value from methane destruction.
- Reduction in capital cost.
- Reduction in operating expenses.

Co-digestion can boost biogas production and increase revenues with minimal capital investment. Where feasible, this technique should be employed.

The project's overall financial approach was to reduce project cost and complexity as a means of reducing financial risk. The project achieved a low installation cost both in terms of capital expense and manpower expended. This structure enabled a simplified financial package whereby a single owner and a single bank, together with SMUD, financed the project. Many other projects require additional grants, loans, or investors, which slows down project development, increases costs, and reduces the likelihood of successful project replication.

CHAPTER 6: Conclusions and SMUD's Lessons Learned

When SMUD was awarded the grant for the CRED effort, five projects were planned including the Garden Highway Foods Anaerobic Digestion project with RealEnergy as the developer. Soon after the grant was awarded, Garden Highway Foods decided not to participate in the project. RealEnergy started discussions to locate the project at the Sacramento Recycling Transfer Station. After prolonged discussions, RealEnergy could not secure this site. The SMUD team with DOE approval decided to terminate the project and was able to reallocate the DOE funding to the remaining four projects.

For the Van Warmerdam Dairy Digester project, SMUD contracted first with Innate Energy California, LLC (Innate). Unfortunately, Innate was not able to comply with the DOE's grant disbursement requirements and was not able to secure financing for the project. Because of these issues and the limited time left to implement the CRED, SMUD and Innate mutually decided to terminate the partnership and allow SMUD to find a substitute developer/partner to implement the Van Warmerdam Dairy Digester project. Through a competitive solicitation, MEW was selected to implement the project.

For the CRED solar project, SMUD initially intended to team with CalTrans and SolFocus to deploy the Sacramento Solar Highways effort. SMUD released a solicitation for a developer for the Solar Highways effort and did not receive an economically viable submittal. Because of this, SMUD terminated the Solar Highways project with DOE approval. SMUD then released a solicitation and teamed up with Conergy to develop the Simply Solar project.

In addition to overcoming the challenges described, the following overall goals of the SMUD CRED program were still achieved:

- Installing renewable energy facilities interconnected to SMUD's distribution grid.
- Contributing toward SMUD's RPS goal.
- Contributing to DOE's goal of accelerating renewable deployment.
- Reducing GHG emissions through destruction of methane.
- Creating jobs and spurring local economic activity.
- Demonstrating economically viable installations of technologies that are not yet widely commercially deployed.
- Demonstrating the alignment of economic incentives to achieve socially and environmentally desirable goals.
- Providing lessons learned for all participants (engineers, developers, public agencies, site hosts, interconnecting utility, contractors, financiers, permitting agencies, and the public).

In addition to reducing GHG emissions, the projects also demonstrate that solar projects and anaerobic digesters can be readily implemented through collaborative partnerships. This work helps other communities learn how to assess, overcome barriers, utilize, and benefit from renewable resources for electricity generation in their region.

GLOSSARY

Below is a summary of terms and definitions used in this report.

Term	Definition
AADS	Advanced Anaerobic Digester System
ARRA	American Recovery and Reinvestment Act
BEP	Biogas Enhancement Project
Biogas	Gaseous fuel, especially methane, produced by the fermentation of organic matter
CalBio	California Bioenergy LLC
CARB	California Air Resources Board
CCO	California Climate Offsets
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CH_4	Methane
CHP	Combined Heat and Power
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
CRED	Community Renewable Energy Deployment
CSTR	Complete Stirred Tank Reactor
DOE	Department of Energy
EERE	Energy Efficiency and Renewable Energy
EQIP	Environmental Quality Incentives Program
FIT	Feed-in-Tariff
FOG	Fats, Oils, and Greases
FTE	Full-time Equivalent
FWP	Food Processing Waste

GHG	Greenhouse Gas Emissions
gpd	Gallons per Day
H_2S	Hydrogen Sulfide
HDPE	High Density Polyethylene
ITC	Investment Tax Credit
kW	Kilowatt
kWdc	Kilowatts of Direct Current
kWh	Kilowatt-hour
kW-yr	Kilowatt-year
lb/day	Pounds per Day
LCOE	Levelized Cost of Energy
LSG	Low-Pressure Sludge Gas
MACRS	Modified Accelerated Cost Recovery System
MEW	Maas Energy Works
MT/yr	Metric Tons per Year
MWh	Megawatt-hour
NH_3	Ammonia
NO_x	Oxides of Nitrogen
O&M	Operations and Maintenance
PM	Particulate Matter
PPA	Power Purchase Agreement
ppmvd	Parts per Million Volumetric Dry
RD&D	Research, Development, and Demonstration
RFP	Request for Proposal
RPS	Renewable Portfolio Standard
scf	Standard Cubic Feet
scfm	Standard Cubic Feet per Minute

SCR	Selective Catalytic Reduction
SMUD	Sacramento Municipal Utility District
SRCSD	Sacramento Regional County Sanitation District
SRWTP	Sacramento Regional Wastewater Treatment Plant
USDA	United States Department of Agriculture
VOC	Volatile Organic Compound
WWC	Western Water Constructors

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APPENDICES

The following appendices are available as a separate publication, publication number: CEC-500-2017-004-APA-D

APPENDIX A: Simply Solar Report

APPENDIX B1: SRCSD Biogas Enhancement Report

APPENDIX B2: SRCSD Supplemental Operational Data Report

APPENDIX B3: SRCSD Supplemental Review of Biogas Enhancement Project

APPENDIX C: New Hope Dairy Digester Report

APPENDIX D: Van Warmerdam Dairy Digester Report