CALIFORNIA ENERGY COMMISSION

Clean Transportation Program

FINAL PROJECT REPORT

Anaerobic Digestion of Rendering Waste to Make Compressed Natural Gas Vehicle Fuel

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Prepared by: North State Rendering

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance, and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual *Clean Transportation Program Investment Plan Update*. The CEC issued PON-09-604 to provide funding opportunities for the development of new, California-based biofuel production plants and to enhance the operation of existing ethanol production plants to increase statewide biofuel production and reduce greenhouse gas emissions. In response to PON-09-604, the recipient submitted an application that was proposed for funding in the CEC's notice of proposed awards on April 7, 2010. The agreement was executed as ARV-10-040 on August 4, 2011 in the amount of $5,456,149.

ABSTRACT

The Anaerobic Digestion of Rendering Waste to Make Compressed Natural Gas Vehicle Fuel report documents North State Rendering's efforts to process rendering waste into compressed bio-natural gas vehicle fuel. North State Rendering researched and installed waste reception technology, anaerobic digesters, biogas cleaning technologies, and compressed natural gas vehicle fuel technologies into an integrated whole within the rendering facility.

Rendering plants are a significant consumer of diesel truck fuel as they pick up their core business feedstocks. There is a compelling need and incentive for renderers to offset their diesel consumption with a self-made source of bio-natural gas.

The production of bio-natural gas via anaerobic digestion also enables renderers to dispose of rendering wastewater and difficult-to-render feedstocks such as grease trap waste, food waste, and liquefied animal carcasses.

The goal of ARV-10-040 was to construct an anaerobic digestion facility generating biogas as a vehicle fuel to a) prove the economic viability of the technology and promote broader adoption of waste-to-fuel systems; b) reduce air pollution from vehicles in the state of California, including carbon dioxide, nitrogen oxide, smog, particulate matter, etc.; and c) create an integrated waste-to-vehicle fuel system to produce California-sourced fuel technology.

The results of ARV-10-040 showed that biogas could be generated from rendering waste, that biogas can be effectively processed into bio-natural gas, and on-site fueling of waste hauling trucks is an economically sound proposition.

The rendering industry is an ideal example of how anaerobic digestion technologies can have multiplier effects on a core business: reducing operating costs, reducing fuel costs, reducing electricity costs, and managing problematic waste streams.

Keywords: Biogas, biomethane, anaerobic digestion, CNG, RNG, rendering.

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EXECUTIVE SUMMARY

North State Rendering, the principal applicant and owner of the waste-to-biomethane facility, is a third-generation family business based in Oroville that has served Northern California, Oregon, and Nevada for almost 100 years. The company processes the waste that is often ignored in the food production process: dead dairy cows, slaughterhouse waste, and food processing waste. North State has a fleet of 24 heavy-duty diesel trucks that pick up the waste from dairy farms, slaughterhouses, businesses and more. This fleet historically consumed 15,000 gallons of diesel per month.

Typical waste materials from the rendering process – wastewater, grease traps, food waste, etc. – have significant biogas production potential in the anaerobic digestion process. North State Rendering used CEC's grant funding to build an anaerobic digestion facility and biogas clean-up and compression system, to produce a renewable vehicle fuel for North State Rendering's fleet of heavy-duty diesel delivery trucks

Primary equipment for this project includes waste processing equipment, anaerobic digesters, gas cleaning equipment, gas compression system, fueling station, switchgear/transformers, and post-digestion waste processing systems. The output of the system is 75 cubic feet per minute, which extrapolates to 108,000 cubic feet per day, 3,240,000 standard cubic feet per month and 38,880,000 standard cubic feet per year of pipeline quality biomethane. The biomethane is stored in on-site fueling station tanks and dispensed daily after North State Rendering trucks offload their waste feedstocks at the rendering plant. The trucks then re-fuel at the compressed natural gas refueling station prior to beginning another round of pick-ups.

The project has multiple benefits for the rendering facility:

- Reduce truck fuel costs.
- Creates significant carbon credits.
- Enables expansion of waste disposal capacity.

The project has multiple benefits for the state:

- Reduce diesel consumption in fleet trucks.
- Provide data for future biomethane-to-vehicle-fuel projects.
- Improve air quality from trucks.
- Tax revenue.
- Increased employment.

Project Goals

The goal of this project is to construct an anaerobic digestion facility that generates biogas as a vehicle fuel. The project will: a) prove the economic viability of the technology and promote broader adoption of waste-to-fuel systems; b) reduce air pollution from heavy-duty diesel trucks in California, including Carbon Dioxide (CO_2), nitrogen oxide, smog, particulate matter, etc.; and c) create an integrated waste-to-vehicle fuel system to produce California-sourced renewable fuels. The long-term goal is to create a replicable model that will proliferate the technology and services to various industries and locations across California.

Project Objectives

The objectives of the project are to

1. Engineer and install an anaerobic digestion system.
2. Operate the anaerobic digester 24 hours per day, seven days per week with scheduled maintenance.
3. Make bio-compressed natural gas at the site to supply customer vehicle fleet.
4. Convert company trucks to dual fuel vehicles and supply with compressed natural gas biomethane.
5. Analyze the economic and environmental attributes of the anaerobic digestion system.
6. Study the process to replicate it at other facilities.
7. Expand the system as the model is proven, adding more feedstock, and continuing to process rendering waste under California rendering regulations.

Project Conclusions

Some of the conclusions drawn from the research analysis are:

- Rendering waste is a suitable feedstock for anaerobic digestion.
- Constant monitoring of the biogas biology is necessary to avoid problems in the digester.
- Anaerobic digestion biology for high-energy value feedstock must be maintained with addition of nutrients when required.
- Balancing of digester feedstock is critical to maintaining anaerobic digestion.
- It is imperative to work closely with the local utility on interconnection issues for any electricity being produced on site.

Project Economics

Adding anaerobic digestion capacity to North State’s existing rendering operations proved to be efficient and generated positive revenues. The infrastructure and delivery fleet used for rendering were already capitalized, meaning that no additional equipment or infrastructure was needed to manage incoming renewable natural gas feedstocks.

Biogas Energy, North State’s energy consultant, calculated biogas monetary values for each of the three potential end-markets for North State’s biogas. The calculations revealed the following results (normalized to one million British Thermal Units):

- 1 one million British Thermal Units = $23.80 as a vehicle fuel
- 1 one million British Thermal Units = $8.80 as electricity sold to utility
- 1 one million British Thermal Units = $15.84 as electricity used on site

North State's biogas yields the highest value when sold into the fuels market. At $23.80 per one million British Thermal Units, sales to the vehicle fuels market generates three times the value of sales to a utility for electricity generation and 50 percent higher than the value of the electricity used on site. For both end uses, the value for fuel or on-site power would be realized as the avoided costs to procure fuel or power.

Biogas Energy developed a simple pro forma financial model for the project with transportation fuel as the assumed end use. Estimated annual revenues were calculated as "earnings before interest tax depreciation & amortization" and was estimated at $1.3 million.

The project cost including only technology and construction costs (omitting land costs, project management costs, consulting costs, etc.) totaled $7.7 million.

With an annual earnings before interest tax depreciation & amortization of $1,324,000, a payback period of five years is required, or a 20 percent return on capital. The finished product of the project is shown below in Figure ES-1.

Figure ES-1: North State Rendering's Completed Anaerobic Digestion Project with Renewable Natural Gas Fueling Station (lower left)

Source: Biogas Energy

CHAPTER 1: Goals, Objectives, and Approach

Problem Summary

The rendering industry consists of two basic types of renderer: small, local, family-owned operations; and large publicly traded companies. The core business for both is the collection and disposal of used oils and grease traps from restaurants and other food processors. The other main product of rendering is the disposal of animal carcasses and slaughterhouse waste. This service is a critical one for the health and viability of our nation's food processing industry, as the disposal options are otherwise limited.

The rendering business model is to collect the dead animals/slaughterhouse waste, and to process it into animal feed or pet food or other value-added byproducts.

The rendering process is extremely energy intensive:

- Vehicle fuel (diesel) to collect the waste feedstocks and transport them to the rendering plant.
- Vehicle fuel (diesel) to bring the rendering products to their intended customers.
- Natural gas to cook the waste into the rendering products.
- Electricity to run grinders, pumps, etc.

In addition, the types of waste processed also add costs to the rendering process.

- Food waste is difficult to render due to its high-water content and low protein and fat content.
- Grease trap waste requires significant pre-processing in the form of decanting to get the fats for rendering. In addition, the wastewater from the decanting is foul smelling and must be processed.
- The rendering process itself has significant wastewater to process. The cooking process produces vapors that must be condensed into a wastewater, and from there stored for evaporation.

However, the problems of energy and fuel costs are not limited to the rendering industry. Any waste hauling company can tell you the significant costs associated with diesel consumption, from the cost of the diesel to the regulatory requirements of emissions controls on the trucks. There is a significant problem and opportunity to produce biomethane from waste feedstocks in the organic waste processing industry. As California mandates diversion from organics, the landfill under Assembly Bill 1826[1] and Assembly Bill 1594[2], more and more of this material will become available for exploitation and value creation. Without significant experience in real-life operations of these biogas systems however, adoption by the rendering industry will remain limited in the state.

With rising costs and lower waste disposal fees squeezing the industry, renderers are looking for a way to cut costs and streamline operations. Converting rendering waste into biogas solves many issues faced by the industry:

- Biogas production can be used for multiple direct benefit purposes in rendering:
  - Feed raw biogas directly to the rendering boiler to offset natural gas consumption.
  - Feed biogas to an on-site electrical generator to produce electricity for the entire facility.
  - Convert biogas into biomethane and use it as compressed natural gas (CNG) for vehicle fuel.
- The anaerobic digestion process improves the rendering process:
  - The anaerobic digester can be a wastewater treatment plant, reducing biological oxygen demand and chemical oxygen demand of the water coming out of the rendering plant.
  - By simply feeding grease trap waste[3] directly to the digester, the decanting process is no longer needed because a higher value is extracted from the grease trap waste (generating energy rather than a relatively small amount of yellow grease).
  - The renderer can leverage existing infrastructure and assets to secure more feedstocks like food waste, green waste, or other materials that have value for disposal.

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1 Bill Text - AB-1826 Solid waste: organic waste.
http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB1826

2 Bill Text - AB-1594 Firearms: civil suits.
https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB1594

3 Grease traps are plumbing wastewater devices designed to prevent greases and other soldis from entering the sewer systems and are typically found in restaurants and kitchens. Grease trap waste is periodically pumped by vacuum truck from the grease traps and must be disposed of in an environmentally sound way. The contents of the grease trap waste can vary significantly, containing waste oils, food particles, contaminants (forks, napkins, etc.) and water.

Approach

The approach for ARV-10-040 anaerobic digestion project was to fully integrate anaerobic digestion into the rendering process by diverting rendering waste to the biogas production process and re-introducing the anaerobic digestion byproducts into the rendering facility. The integration points are as follows:

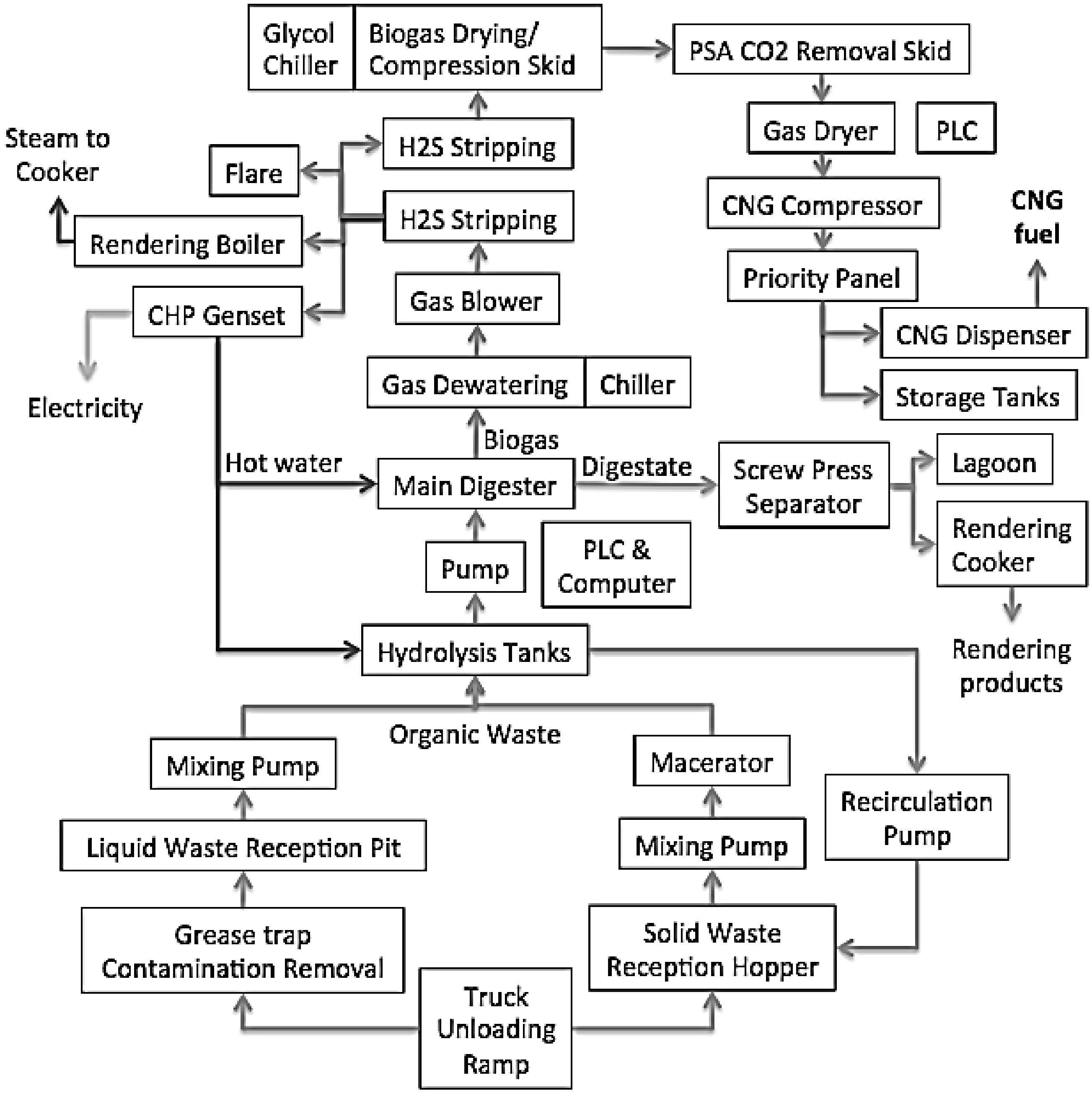
1. Divert difficult to render wastes to the anaerobic digestion system, including greasetrap waste and food waste.
2. Feed rendering waste product (wastewater from the cooker condensers) to the anaerobic digestion system.
3. Generate electricity from biogas produced in the anaerobic digestion system to power the rendering plant. The plant is shown below in Figure 1.
4. Produce Renewable CNG to fuel the trucks that deliver waste to the rendering plant and anaerobic digestion system.

Figure 1: North State Rendering Anaerobic Digestion Facility

Source: Biogas Energy

The following diagram shown in Figure 2 the flow of material through the facility and the elements of the facility separated by function.

Figure 2: Process Flow Diagram



Source: Biogas Energy

Anaerobic Digestion Facility

The Anaerobic Digestion process cultivates several strains of bacteria that process food material in an oxygen-free environment with the result being a biogas gas comprised of 50-65 percent methane, 35-48 percent CO_2, and small amounts of hydrogen sulfide, nitrogen, oxygen.

Waste Reception

The sequence of converting raw waste material to biogas output involves a complex integrated and automated system of technologies, from waste reception to gas usage.

The anaerobic digestion system designed for North State Rendering took into account the intermittent, heterogeneous feedstock supply expected to be delivered to the project by constructing two waste reception methods; a high-solids hopper with macerator, and a low-solids pit with mixing pump. High solids feedstock includes food waste from kitchens, agricultural waste from food processors, and green waste (yard clippings etc). Low solids feedstock includes greasetrap waste from restaurants, wine production waste, and wastewater from the rendering process.

The high-solids reception system (shown in Figure 3) is comprised of a truck reception ramp where the trucks back up in order to deliver the load; a reception hopper including level sensors and an auger system; a mixing pump; and a macerator. The truck driver unloads the material and presses a button at the hopper to turn on the feeding process. The digester computer is programmed to automatically process the waste by adding recycled liquid from the digesters, auger the material to the mixing pump, opening valves, and running the macerator. A flow meter measures the material going into the digesters and records the volume.

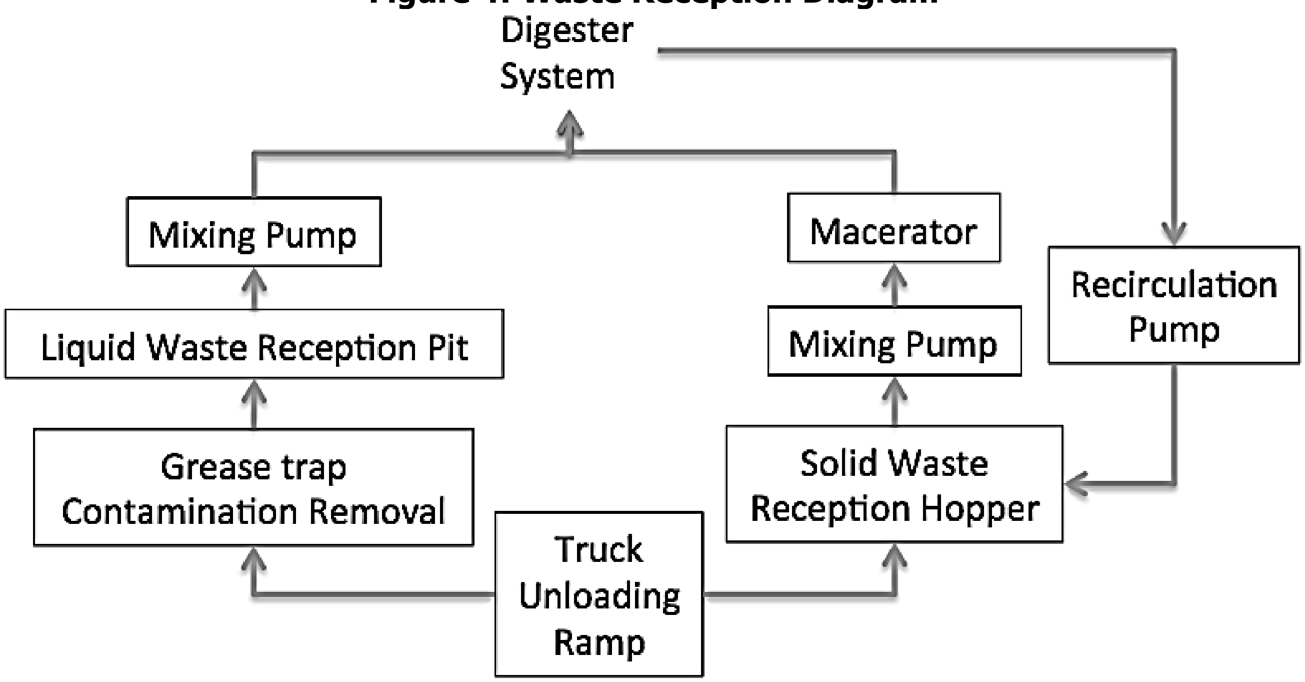
Figure 3: High Solids Reception Hopper

Source: Biogas Energy

The low-solids reception system is comprised of a contaminant-removal auger, a reception pit, a mixing pump, level sensors, and pneumatic valves. The truck driver pipes the liquid from the tank through the contaminant removal auger, which removes foreign objects like cutlery, napkins, etc. The liquid then flows into the pit, which fills to a pre-programmed point. When that level is reached, the digester's programmable logic controller automatically triggers the mixing pump. The material is agitated for a predetermined time, and then pneumatic valves automatically open to pump the material into the digester facility. A flow meter monitors and records the amount of liquid going into the anaerobic digestion system.

Figure 4 below focuses on the waste reception portion of the facility. Note the ability of the high solids reception to receive recirculated digestate to liquefy the material an enable pumping into the digesters. This flexibility in feedstock supply is a critical element for successful management of the disparate types of waste that the facility can accept.

Figure 4: Waste Reception Diagram



Source: Biogas Energy

Anaerobic Digesters

The anaerobic digestion technology selected for the North State project is designed to maximize biogas production from heterogeneous feedstocks on a minimal footprint. Three tanks were constructed of reinforced concrete and lined with an epoxy.

- Two 40' diameter, 25' tall hydrolysis tanks. These tanks are identical mirror designs of each other and serve to homogenize the feedstock, heat it to the correct temperature, and foster bacteria that perform the first phase of the biogas production process: hydrolysis. In these tanks, an acidic level is attained through acidogenic bacteria, which break down the feedstock into volatile fatty acids; a feedstock for the next strain of bacteria to come. The tanks are equipped with propeller agitators, heating coils, over/under pressure valves, windows, a gas-holding roofing structure, level & temperature sensors, and gas volume & pressure sensors. Material from the reception system is pumped directly into one or the other hydrolysis tanks as dictated by the plant operator's configuration of the computer controls.

- One 40' diameter, 64' tall anaerobic digester. This tank is agitated with two pumps that circulate material in the tank and spray down the surface of the liquid inside to prevent foam formation. The tank is equipped with heating coils, over/under pressure valves, windows, a gas holding roof structure, level and temperature sensors, and gas volume and pressure sensors. While any gas produced in the hydrolysis tanks is piped to this digester, nearly all of the biogas output from the system is produced in this digester tank.

Digestate Processing

The level of the material in the digester is maintained within a range of 5': if the level reaches a predetermined maximum height in the tank, a valve opens to drain the tank down to a predetermined minimum height. For example, with the tank total height of 64', the maximum level is 61', at which point the sensor will trigger the drain valve to open. Once the minimum height of 56' is reached, the system closes the drain valve, and the digester (shown in Figure 5) starts to fill up again from the hydrolysis tank. This process enables batch feeding from the reception into the hydrolysis tanks, but continuous feeding from the hydrolysis tanks to the digester, which is the most stable and supportive method for maintaining biogas production biology.

The liquid from the digester flows to a buffer tank with level sensors in it. When the buffer tank is full, the screw press comes on and accepts the material. The liquid squeezed from the screw press flows via gravity to storage lagoons where it is evaporated off during the course of the year, and the solids from the screw press drop into a bunker where they can be picked up with a front loader and delivered to the rendering process.

Figure 5: Digestate Separation System

Source: Biogas Energy

Biogas Processing

Biogas produced in the digester must be dried and stripped of hydrogen sulfide prior to use in other technologies. First, the biogas is put through a dryer, which is cooled with a glycol chiller to condense water vapour from the gas. Then the gas flows through a hydrogen sulfide scrubber tank filled with carbon media. By the time the gas is prepared for use, the hydrogen sulfide level is under 50 parts per million. Further stripping is required at the CNG system;

however, the 50 parts per million is sufficient for using the biogas in the combined heat and power generator genset or boiler.

For gas going to the CNG system, an additional carbon filtration hydrogen sulfide stripping system reduces hydrogen sulfide to under five parts per million: the specification for the CNG equipment. Figure 6 and Figure 7 shows the before and after of the project from satellite view.

Figure 6: Project Site Prior To Project Start

Source: Bing.com

Figure 7: Project Satellite View

Source: Google

Combined Heat and Power Unit

After the biogas has been dewatered and stripped of hydrogen sulfide, it is piped to a combined heat and power generator, such as the one shown in Figure 8. The gas feeds an internal combustion engine which generates heat that is used to heat the digesters. The internal combustion engine powers a generator which is rated at 710 kilowatt (kW) electrical output. The electricity feeds a switchgear that distributes the power on-site, to provide electricity to the biogas plant, the CNG system, and the rendering plant. Surplus power will be Net Metered back to the utility to balance out electricity brought in as backup power supply from Pacific Gas and Electric (PG&E).

The genset is housed in a weatherproof and sound diminishing container. Cooling systems on the roof of the container will dissipate any surplus heat, but by capturing heat to warm the digesters to about 100 degrees Fahrenheit, the efficiency of the use of the biogas increases.

The generator will produce 100 percent of the power needed for the entire facility during normal operations. This has been a real benefit to the project, because the CNG system's compressors and equipment have a significant electrical generation requirement. By providing "free" electricity to the project, the financials of the CNG production improve drastically.

Figure 8: Combined Heat and Power Generator Unit

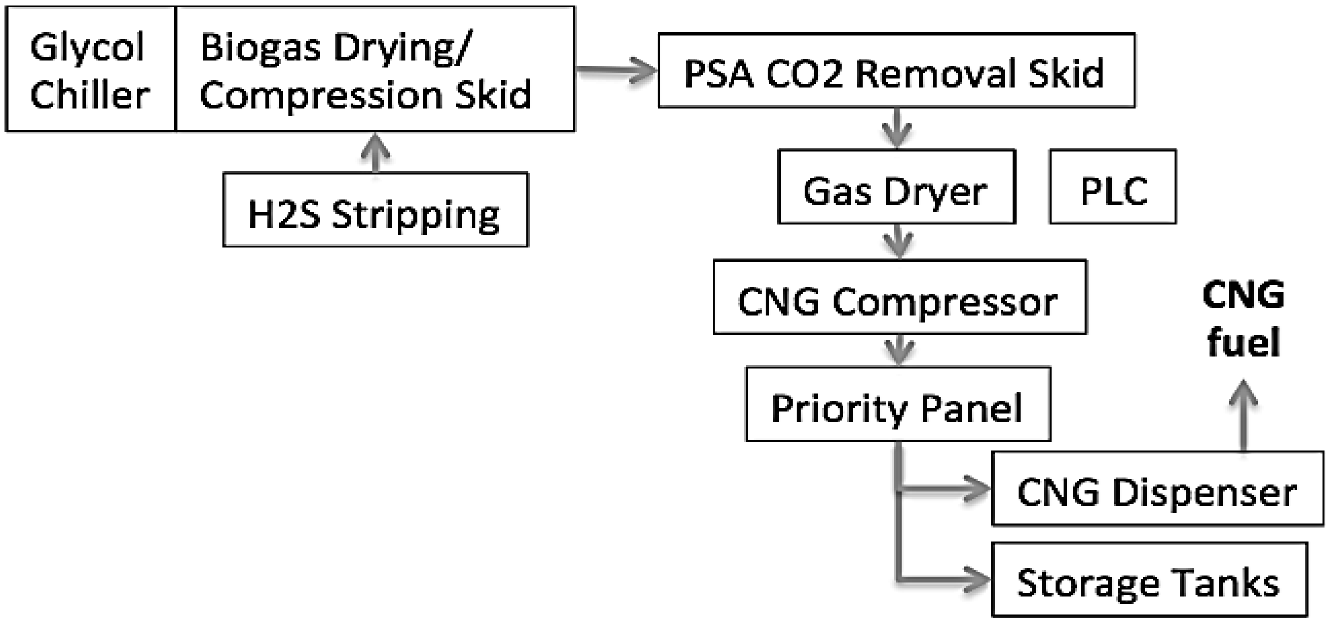
Source: Biogas Energy

The combined head and power genset include a selective catalytic reduction system that reduces nitrogen oxide emissions to air board quality standards. Using urea as a catalyst the selective catalytic reduction system meets the nine parts per million limit for nitrogen oxide as set by the Butte Count Air Quality Control District's authority to construct permit no NSR-11-03-AC.

Bio-CNG production

The following diagram (Figure 9) displays the configuration of the Bio-CNG system.

Figure 9: CNG Production Diagram



Source: Biogas Energy

Biogas produced by the anaerobic digester is not suitable for use as a transportation fuel in vehicles because it contains CO_2 and hydrogen sulfide; therefore, the gas must be cleaned to remove those gasses. Hydrogen sulfide is reduced to less than five parts per million in the gas using a carbon media. By having two stages of hydrogen sulfide stripping; first for the raw biogas directly out of the digester which reduces hydrogen sulfide to 50 parts per million, and second at the CNG system, media replacement costs are minimized. The biogas going to combined heat and power generator for electricity production has a specification of 50 parts per million, and therefore is not cost effective to reduce that biogas to five parts per million. Instead, only that biogas going to CNG production is refined further to under five parts per million. While there was additional cost for the stripping equipment, the ongoing operational cost avoidance of carbon media replacement will justify the initial capital expenditure. Periodically the carbon media must be replaced, and this is triggered by a rising hydrogen sulfide level in the biogas. Once a predetermined hydrogen sulfide level is met (above five parts per million), the carbon media is replaced.

The carbon dioxide is removed with a pressure swing absorption (PSA) system provided by Unison Solutions. The Unison system is composed of a gas chiller/dryer (including glycol chiller), PSA system, and system controls. The PSA system runs automatically when “go” signals are provided by both the digester and the CNG fueling station, the PSA system is ready to provide and accept gas. Therefore, the PSA system is always operating either in standby mode or in production mode. A system such as the one discussed above is shown in Figure 10.

Figure 10: CNG dryer and PSA Skid

Source: Biogas Energy

Carbon dioxide is separated from the biogas stream using a process that involves two pressurized tanks filled with a carbon media that acts as the absorbent under high-pressure conditions. Biogas fills one vessel and is pressurized, causing the CO_2 to adhere to the carbon material, and allowing the methane to pass through. Once the methane has been extracted, the high-pressure vessel is released to low pressure, thereby releasing the CO_2 into the tail gas stream.

The upgraded biomethane has a methane content of 97-99 percent, which meets or exceeds pipeline gas specification for use in vehicles. The tail gas is predominantly carbon dioxide (approximately 80-90 percent); however, there is some methane in it. The tail gas is then either recirculated back to the digesters for combustion with biogas in the combined heat and power generator genset or flared off.

The Unison system is controlled with programmable logic controllers that automate operations and are configured using a touch screen on the cabinet. All operations are displayed in a graphic user interface for easy configuration, and all faults and notifications are recorded and coded.

Finished product gas from the Unison PSA system is routed to a CNG fueling station provided by ANGI Energy Systems LLC. The station can be seen below in Figure 11.

Figure 11: ANGI Energy Systems LLC Drying Skid and Compressor

Source: Biogas Energy

The ANGI Energy Systems LLC system is typically deployed at conventional pipeline CNG gas stations, but this equipment has been applied to biomethane-to-CNG fueling successfully without undue configuration changes.

The biomethane is first dewatered to remove all moisture and meet the specification required for operation in trucks. It will be noted that along with the digester dewatering and the PSA dewatering this is the third time the biogas is dewatered before going to vehicle fueling.

Next, the biomethane is fed to a compressor that takes the pressure up to 3800 pounds per square inch. The compressor is enclosed within a container with easy access for maintenance.

The compressor feeds biomethane to a priority panel which regulates and directs the gas to either storage or the dispenser. The storage consists of three tanks with a capacity of 15,000scf @ 4500 pounds per square inch gauge at 70 degrees Fahrenheit and makes the gas available to the dispenser as needed. These CNG storage tanks can be seen in Figure 12.

Figure 12: CNG Storage Tanks

Source: Biogas Energy

The final stage of the process is the dispenser that fuels the trucks at the site. It should be noted that the dispenser is not available to the public and remains in use only for the purpose of North State Rendering's fleet of CNG trucks. Limiting usage to only in-house vehicles avoids complications involved in dispensing fuel to the public and eliminates the need for card readers or other forms of payment.

The dispenser is a dual-hose configuration enabling trucks to fuel up on either side of the dispenser. The entire system including the CNG dispenser and anaerobic digestion equipment is pictured in Figure 13. The dispenser is fast fill, enabling full refueling of trucks in a matter of minutes, as opposed to slow fill stations that require several hours. For example, Chris Ottone of North State Rendering is pictured fueling CNG. This was necessary for this application due to the sporadic ability for trucks to refill, and the quick turnaround time required to get trucks back out on their routes. The dispenser displays the amount of gas provided and communicates to the ANGI Energy Systems LLC controller to allocate when to compress more gas.

The entire CNG system is located for convenient truck access and grouped together for ease of maintenance.

Figure 13: CNG Dispenser and Anaerobic Digestion Equipment

Source: Biogas Energy

Figure 14: Chris Ottone of North State Rendering Fueling CNG

Source: Biogas Energy

CHAPTER 2: Activities and Results

Observations

Anaerobic Digestion

North State Rendering and Biogas Energy successfully constructed a biogas plant that operates with rendering waste and various other feedstocks. Biogas Energy built the biogas plant, pouring three concrete tanks for the digester system and installing all of the equipment; sensors, agitators, pumps, heating systems, gas handling & cleaning equipment, etc.

Ease of operation was of paramount importance since the project must be integrated into existing rendering operations, so the design of the system encompassed automated elements as far as practicable. A computer with operations software is programmed with the biogas production parameters, so the entire facility can be run with minimal personnel. Regular maintenance of the system is required, however.

The biogas plant was successful at generating significant energy from the rendering feedstocks. However, electricity could not be generated due to delays with the utility gas pipeline interconnection; the gas was consumed either in a flare or in a boiler at the rendering plant, and ultimately in the Bio-CNG production system.

Construction of the facility was completed on schedule and on budget. Commissioning the digesters required three months of feeding the digester wastewater from the local wastewater treatment plant and manure from a local dairy to stabilize the anaerobic digestion process. Once that feedstock was stabilized, other material like food waste and greasetrap waste were added carefully until the biogas production started to rise. By gradually increasing the amount of feedstock material, the bacteria culture was supported until the input volume reached 40 tons per day of material. At that point, the feeding was limited at 40-50 tons per day since there was no use of the biogas during that time. Even with only half the targeted feedstock input, the gas production was strong, maxing out the flare's capacity.

Laboratory analysis was performed to monitor biology and determine effects on biogas production rates. The analysis of the acid spectrum of the digestate showed a high level of propionic acid and acetic acid, which indicates the lack of essential nutrients in the biological process. The most important insufficiencies of nutrients/trace elements were identified as nickel and cobalt, which were then added to the feedstock. Other elements like selenium might also be required. When dealing with imbalances in nutrients and trace elements, the first step is to reduce further input into the digester to minimize damage to the biology and to add micronutrients and trace elements on an ongoing basis. Further investigations are recommended and advised.

In addition, tests were done on samples of feedstocks. The rendering wastewater sample showed very good results for gas production rates. Thirty five metric tons of wastewater would produce 8790 Nm3/d of biogas with 68.9 percent of methane. At 35 metric tons per day, it would be enough gas to generate one megawatt electricity continuously.

Further tests are recommended to determinate on how much this waste stream varies over time and on an ongoing basis.

Bio-CNG Production

The Biogas-to-CNG processing system requires the seamless integration of the two biogas and biomethane processing systems with the anaerobic digestion facility.

By implementing two PSA towers for the removal of CO_2, a steady stream of biogas can be processed; the resulting biogas from the PSA system creates a steady stream of biomethane for the fueling station.

Integration planning was critical prior to fabrication of the equipment and controls, so it is imperative that the manufacturers work closely with each other as well as with the digester developer.

Since the PSA and fueling station systems are passive, they require minimal human interaction. When the ANGI Energy Systems LLC system needs more gas, it sends a signal to the Unison PSA system. Simultaneously, the digester is sending information on available gas. When both the ANGI Energy Systems LLC system and the digesters are sending "go" signals, the Unison system automatically starts and generates biomethane from biogas.

Ultimately, pipeline injection of the biomethane will be a valuable addition to the fueling station functionality since that frees the owner to sell to buyers in other parts of the state. North State Rendering is preparing to apply for pipeline injection of their biomethane and has been working with PG&E on the interconnection agreement.

Projections

Mass and Energy Balance

Upon full operation of the biogas plant, the system will accept 100 tons of waste per day:

- 40 tons/day food waste (kitchen waste, brewery waste and food processing waste)
- 20 tons/day greasetrap waste
- 40 tons/day rendering waste

The amounts of each feedstock can vary so that if more revenue can be earned from food waste tipping fees, then it would be possible to decrease rendering waste and increase food waste supply. In addition, the 100 tons/day total is not a hard limit. The total can decrease or increase as needed for temporary spikes or valleys in feedstock supply. However, the total of 100 tons/day is the designed capacity, taking into account the time needed for stable biological digestion.

Output from the digesters in the form of digestate will be run through a screw press separator. Solid material will be fed back to the rendering process and liquids will go to the lagoon for evaporation.

Projections of the biogas output: 300 standard cubic feet per minute with an energy value of 10.5 MMBtu per hour.

Use of the biogas:

- 120-150 standard cubic feet per minute to combined heat and power generator unit to generate 500kW electricity & heat for digesters
- 150 standard cubic feet per minute to CNG production to generate 750 DGE per day, or 273,864 DGE per year

Electricity generation will be used on site under a Net Metering interconnection tariff.

CNG production will be used on-site by the NSR truck fleet. In addition, NSR will apply for the ability to inject the gas into the PG&E natural gas pipeline under Assembly Bill 1900[4], which allows for biomethane injection into natural gas pipelines. The California Public Utility Commission has yet to announce its decision to address cost allocation and interconnection issues, however North State Rendering will begin the interconnection application process in the coming months with PG&E, with interconnection coinciding with the California Public Utility Commission's guideline publication. The ability to inject the biomethane into the pipeline will enable North State Rendering to monetize surplus biogas above what can be consumed in their fleet of trucks on site. North State Rendering is currently in discussions with potential CNG fuel purchasers, who would extract the biomethane-CNG at fueling stations throughout the state of California. In this way, North State Rendering will benefit from producing the CNG but avoid the issues associated with selling CNG retail to the public.

The original grant proposal anticipated production of 370,000 Diesel Gallon Equivalent (DGE) per year, however the projected annual CNG production is expected to be 273,800 DGE. The lower DGE production is due to the diversion of biogas to produce the electricity necessary to operate the anaerobic digestion system and the CNG production equipment. Without diverting biogas to generate electricity on site, North State Rendering faced the issue of paying retail electrical rates to operate the new equipment installed with the project. The added electrical load of the project would have significantly increased electricity costs at the site. In addition, it was counterintuitive to import energy in the form of electricity generated remotely to produce a "renewable" fuel while all the necessary renewable energy could be generated on site. By diverting biogas to electricity production, the operational costs of the project are driven down, and the carbon intensity of the CNG is reduced to zero. No outside energy is used to make the bio-CNG in the current scenario, and that provides a significant improvement over the original proposal's carbon footprint.

For those times when the CNG and/or combined heat and power generator systems are down, biogas will be fed to a boiler at the rendering plant to generate hot water for the digesters and for the rendering process. The intent is to avoid flaring the gas, and instead give it a

4 Assembly Bill 1900 http://www.leginfo.ca.gov/pub/11-12/bill/asm/ab_1851-1900/ab_1900_bill_20120927_chaptered.html

monetized use. The boiler's energy value is not as significant as the combined heat and power generator genset or the CNG system. However, if surplus gas can be consumed in the boiler it makes it more useful than simply flaring it off.

CHAPTER 3: Advancements in Technology and Assessment of Project Success

Achievement of Goals and Objectives

North State Rendering achieved its goal to construct an anaerobic digestion facility that produces renewable natural gas (RNG) vehicle fuel at a rendering facility.

The technology has successfully processed food waste, grease trap waste and rendering waste into biogas, which was then cleaned to pipeline quality grade CNG and used as a vehicle fuel in the host company's trucks.

The project budget was completed within budget.

The goal of the project was to generate RNG to fuel North State Rendering's fleet of delivery trucks using anaerobic digestion of waste feedstocks.

The project has successfully generated a track record of biogas production over the course of months that proves that the anaerobic digestion technology is successfully performing as intended. Feedstock fed to the system via both the liquid and solid waste reception systems has been successfully processed and used to generate biogas.

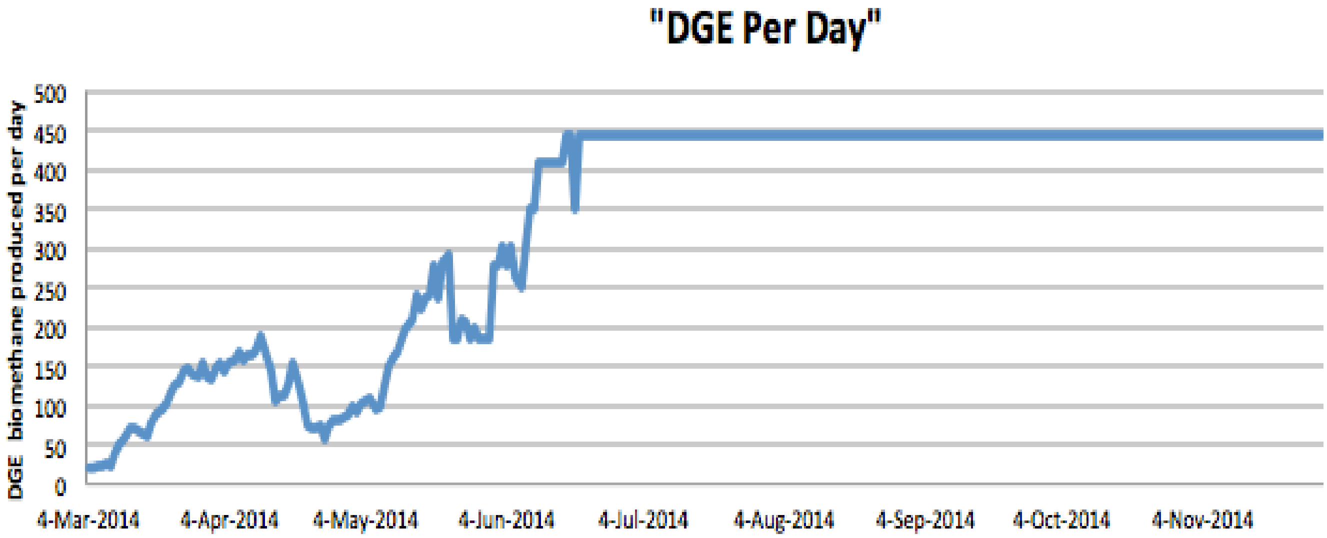
Goals Measured and Analyzed

RNG production is the goal of the project. Since the vendor delivery of the CO_2 removal system and CNG fueling station was delayed, the anaerobic digestion facility had months of operational history to record with biogas production rates and throughput monitoring.

Biogas production data from the anaerobic digestion system was recorded continuously by monitoring the operation of the flare, which consumed the biogas produced and metered the biogas throughput. The chart below (Figure 15) displays the biogas production rate of the anaerobic digestion system prior to the CNG system coming online, and it should be noted that the flare has a maximum throughput rate of 45 cubic feet per minute per day. Therefore, the anaerobic digester has been generating a minimum of 45 cubic feet per minute since July 2014, which, if converted to Diesel Gallon Equivalent (DGE), comes out to 444 DGE per day. The flare was operating 24 hours per day, seven days per week.

As the plant becomes fully operational and the electricity production comes online, the flare will only be used as backup and the CNG production and combined heat and power generator genset operation will consume 100 percent of the biogas produced.

Figure 15: Biogas Production Represented in DGE



Source: Biogas Energy

Project Accomplishments and Performance

The project has succeeded in meeting all criteria specified in the project scope of work. The anaerobic digestion equipment is performing as specified and is configured to enable operations by North State Rendering staff. The anaerobic digestion system is computer controlled and automated, requiring minimal oversight or operations on a day-to-day level. Daily, weekly, monthly, quarterly and annual tasks are assigned to NSR staff that performs all operations and maintenance on the facility.

Moving forward, NSR will continue with feedstock acquisition to bring in the maximum revenue from tipping fees[5] possible. Since the digester has flexible feedstock management capabilities, NSR has the ability to select feedstocks that earn the best revenue, while balancing the biology in the anaerobic digestion process. For example, if one feedstock earns $10/ton tipping fee while another earns $50/ton, NSR will prioritize the $50/ton feedstock and seek to secure as much of that material as possible. Tests done on the feedstocks for biomethane production potential will enable NSR to calculate which feedstocks to prioritize from a biogas production standpoint as well. For example, a $50/ton feedstock that generates minimal biogas may not be as compelling as a $20/ton feedstock that generates significant biogas.

With 100 ton/day capacity, NSR has the flexibility to secure multiple feedstock suppliers while maximizing tipping fees and stabilizing anaerobic digestion biology. Since NSR has a readily-available source of biogas-rich feedstock in the form of rendering wastewater, they can be

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5 Tipping fees are the fees that waste generators pay to operators of waste disposal facilities to take their waste materials.

selective and aggressive about feedstock acquisition. The on-site wastewater has proven to be a significant source of biogas and doesn't have any acquisition (trucking) costs; however, it doesn't bring a tipping fee. With that readily available "backup" feedstock, NSR can be more aggressive with its tipping fee structure.

RNG production will continue, and NSR will replace its diesel fleet with CNG or dual fuel trucks in the coming years as financials permit. The regular replacement of trucks will be done with CNG consumption at the forefront in order to increase the diesel replacement benefits of the RNG system on site. NSR plans to apply for state funding to help with CNG vehicle acquisition since the conversion away from conventional diesel usage is incentivized by the state. Ultimately, NSR intends to convert its entire fleet to CNG or dual fuel.

NSR will also apply to PG&E to inject gas into the natural gas pipeline. Any surplus gas produced can be a source of income to NSR if they can sell it to truck fleets around the state. The pipeline injection process is not expected to require significant changes to the existing configuration at the site: the CO_2 and hydrogen sulfide removal systems are in place and all that is needed is the PG&E required equipment: flow meter, biogas analyzer (in place already), compressor to 40 pounds per square inch (the current compressor is overkill, going up to 4000 pounds per square inch) and pipe interconnection.

Stakeholder Feedback

This project is unique in that 100 percent of the inputs to the system and 100 percent of the outputs from the system are controlled and benefit North State Rendering. NSR acquires the feedstock, processes it in the anaerobic digestion system, generates electricity for their own use, and consumes all of the RNG they produce. Unlike other projects which deliver products to other customers (electricity to the grid, RNG to the public, etc.), North State Rendering are the exclusive beneficiaries of the project's products.

North State Rendering's rendering operation has improved dramatically with the co-location of the anaerobic digestion facility. The digester enables NSR to route messy, wet feedstocks away from the rendering process and over to the biogas process. This reduces energy use at the rendering plant since less water needs to be cooked off. It also frees up rendering throughput capacity so more high-value material can be processed into rendering by-products. Finally, it reduces labor requirements at the rendering plant since less wet feedstock means less labor in managing wet feedstock.

RNG production has improved NSR's bottom line by reducing the cost of diesel in their fleet of trucks. Diesel is a significant operations expense for the company, since they rely on their fleet to deliver the feedstock to the rendering facility. The reduction of diesel consumption can either come from reduced trucking routes which would bring about the reduction of feedstock acquisition, or it can come from RNG fuel. As described in the "cost of fuel" section of this document, the case can be made that the RNG fuel has no cost, or even a revenue attached to it, making RNG a significant alternative to conventional diesel consumption. NSR has been using the RNG as fuel with no adverse effects on the operations of the trucks. The location of the fueling station within the rendering property has proven extremely convenient and efficient for drivers to pull up and refuel between delivery routes. Since the fueling dispenser is fast fill, the 20 minutes typically required for refuelling has proven to be fast enough for rapid turnaround time.

North State Rendering has been able to secure new sources of feedstocks and revenues with waste disposal contracts from waste suppliers who have not typically delivered waste to the rendering process. For example, a local fruit processing company delivers rejected fruit to the project. And a local composting company routes green waste to the digesters. A local brewery delivers spent grains to the project. All of these feedstocks bring tipping fee revenue to NSR, but more importantly provide a balanced diet of nutrients to the bacteria, which require different complementary feedstocks to augment high fat feedstocks like grease trap waste or rendering plant wastewater.

CHAPTER 4: Observations, Conclusions and Recommendations

Observations

Electrical Interconnection Issues

The project ran into one major hurdle that could have been avoided with the benefit of hindsight. Specifically, the interconnection of the electric power production with the utility proved to be a significant obstacle to the project's timing and viability. The initial effort was to interconnect and sell all the power produced to the utility under a Wholesale Distribution Tariff; all of the power generated would be put onto the grid and sold to the utility. This process had significant engineering application costs associated with it, and ultimately resulted in the identification of significant utility network upgrade requirements to take the power generated onto the grid (710 kW). The utility gave an estimate of the costs at $2,500,000 which the applicant (North State Rendering) would need to pay. This was impossible, so North State Rendering re-applied for interconnection under Net Energy Metering rules. This application is still underway, but the expectation is that since the power will be used onsite, the costs associated with interconnection will not be the same. In retrospect, the Net Energy Metering application should have been undertaken at the outset.

Feedstock Acquisition

Projects such as this one has a significant requirement for feedstock. For this project, this requirement is 100 tons per day. Fortunately, for the project owner, their existing waste contracts and rendering waste material can supply that feedstock while enabling them to go out and secure new profitable feedstocks as well. However, new projects have the challenge of securing feedstock supplies prior to having the project built: but they cannot attain financing to build the project until they have secured feedstock supply contracts. This catch-22 must be addressed if the projects are to succeed. One option is to do what this project did: co-locate at an existing waste processing facility and leverage existing waste supplies and truck fleets that can easily attain more feedstock supplies. Another option is to co-locate at a facility that generates organic waste that is currently exported from the site, and would also have a significant energy footprint that the biogas plant could accommodate. Eligible candidates would be food processors, breweries, agricultural processors, etc. Finally, with the requirement to divert all organics from landfill in California, the opportunity to generate biogas with anaerobic digestion is only going to increase. This is a significant target market for CNG production for pipeline injection, which would then make RNG available to fueling stations around the state.

Feedstock Management

The importance of feedstock management is paramount, since the anaerobic digestion biology depends upon it. Along with the technological handling of the feedstock, the constitution and variability of the feedstock itself is the most decisive factor for a healthy methanogenic bacteria culture. Constant monitoring of the biological process is required, including the tracking of trace element and nutrients that the bacteria require.

Conclusions

Suitability of Anaerobic Digestion for Rendering Plants

Integration of biogas production into rendering facilities is an ideal pairing. The rendering facility is able to leverage its unexploited assets to diversify revenue and virtually eliminate energy costs.

- Diesel consumption is reduced and potentially eliminated
- Electricity consumption is potentially eliminated
- Natural gas consumption in the rendering boilers can be reduced and even eliminated with adequate biogas production

Existing assets make rendering plants ideal candidates for anaerobic digestion:

- Permits are in place to accept and process waste materials
- Renderers either have a fleet of trucks to utilize the RNG or they have visiting trucks that can fuel up when dropping off waste
- Since renderers already have odor emissions, any odors generated by the additional waste processing are minor and fall under existing odor control exemptions
- Renderers are significant consumers of electricity, making Net Energy Metering the ideal form of interconnection and thereby avoiding significant interconnection costs.

An article about the project appeared in the international rendering industry trade publication Render[6] and another was published in the international anaerobic digestion trade publication Bioenergy Insight.

Interconnection with Electric Utility

When North State Rendering applied for a Wholesale Distribution Tariff interconnection, NSR was faced with a $2,500,000 estimate from PG&E for network upgrades and other costs. Under the Wholesale Distribution Tariff, the electrical generator is responsible for all costs associated with upgrading the network to be able to accept the electrical supply. This cost was impossible for NSR to cover so an alternative was sought.

Due to the fact that NSR was adding significant electrical demand to their facility in the form of the anaerobic digestion facility and the CNG production facility, it became clear that all of the power generated at the site would be able to cover the on-site power requirement. This meant that NSR was eligible to apply for Net Energy Metering interconnection. The Net Energy Metering tariff enables utility customers to generate only enough electricity to cover their historical electrical load plus any additional load the project was incurring. Interconnection

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6 RendererMeetsAD.pdf (d10k7k7mywg42z.cloudfront.net)
https://d10k7k7mywg42z.cloudfront.net/assets/52fadedd4f720a4df4000650/RendererMeetsAD.pdf

costs and network upgrade costs are borne by the utility and not the customer, and therefore NSR could avoid the $2,500,000 cost under the Wholesale Distribution Tariff. In addition, whereas NSR could sell its electricity under the Wholesale Distribution Tariff for a maximum of $0.11/kilowatt hour (kWh) while still paying for all the electricity it was consuming at an average cost of $0.18/kWh; Net Energy Metering will enable them to simply eliminate their electric bill. Surplus power sold to the grid will earn $0.04/kWh; however, the genset will be operated to meet the daily demand of electricity consumption and no significant surplus of power is expected to be generated.

Given the challenges of interconnecting small to medium-size projects to the electrical grid (250kW-1 megawatt) and the high costs involved, this project concludes that the power supply should be sized to take advantage of Net Energy Metering rules.

The CNG production is a significant electrical load, and power production should be a part of any biogas-to-CNG project for that reason. If the project is forced to purchase electricity to power the CNG production process at retail utility rates, the returns on investment are significantly affected. By producing the electricity from surplus biogas to operate the facility *but not producing more electricity than is needed onsite*, the anaerobic digestion project maximizes efficiency and cost-effectiveness with the Net Energy Metering power interconnection.

Diversification of Biogas Use

Anaerobic digestion produces a uniquely flexible output: biogas. Historically, it has been used primarily to generate electricity in a combined heat and power generator genset; this is logical since heat is required for the digesters and that heat is collected from the combined heat and power generator genset.

Renewable electricity production has been heavily subsidized in the markets where anaerobic digestion gained the most popularity: Europe and significantly Germany. Electricity production was and is the predominant use of biogas. However, the North State rendering project proved that there are other uses for the gas that have equal or greater value; production of biomethane for vehicle fuel or for pipeline injection.

Biogas Economics

The benefits of making biomethane in the US market are significant. Unlike Germany, where electricity from biogas would earn US$0.30/kWh, projects in California would earn $0.10/kWh. Therefore, there must be an alternative to exclusive use of the biogas in electricity generation.

<u>Vehicle fuel from biogas has the following value:</u>

- 1DGE = $3.50
- 1DGE = 0.15MMBtu; 1MMBtu = 6.8DGE
- 1MMBtu = $23.80 as a vehicle fuel

<u>Electricity sold to utility has the following value:</u>

- 1MMBtu = 293kW total energy
- efficiency of combined heat and power generator genset = 35%

- 1MMBtu converted to electricity = 293kW * 35% = 88kW el
- 1kWh = $0.10
- 1MMBtu = 88kW * $0.10/kWh = $8.80 as electricity sold to utility

<u>Electricity used on-site has the following value:</u>

- 1kWh = $0.18
- 88kW * $0.18/kWh = $15.84 as electricity used on site

It should be noted that electricity production is advisable for the on-site power consumption load, since heat is required for the digesters anyway, and combined heat and power generator application maximizes the energy value of the biogas going towards heating the digesters. That said, there is a compelling case to be made for conversion of the biogas into CNG, either for on-site vehicle fuel or for pipeline injection for sale to remote CNG fueling users.

Diversification of Feedstocks

The healthy maintenance of the biology of a biogas plant requires suitable feedstock material. In the case of dairy manure digesters, this is not an issue since the methanogenic bacteria are adequately fed with manure alone. However, for those projects that do not have manure or that are trying to maximize biogas production by introducing co-digestion feedstocks, the diversification of feedstock is paramount to the project's success.

Test results performed on the project's feedstocks showed significant variability in biogas potential, ranging from extremely favorable (rendering wastewater) to negligible (fruit processing wastewater).

North State rendering has ample energy supply in the two most common and available feedstocks: rendering wastewater and greasetrap waste. However, even though these feedstocks have significant biogas potential, they require additional feedstocks to buffer their effect on the biology in the digester. They are high fat – content substrates, so other feedstocks with carbohydrates and proteins are required to round out the nutrient requirements of the bacteria. In this project's case, additional suitable feedstocks were secured from prison kitchens, food processors, and a local brewery. In addition, green waste from a local composting company is fed to the digester.

It is highly advisable that any anaerobic digestion system under consideration be equipped with the ability to test potential substrates for their biomethane potential, and for their effect on the overall biology of the other feedstocks.

Recommendations: Technology Transfer and Production Readiness Plan

The objective of this project was to produce RNG from rendering waste, and to integrate the operations into an existing rendering facility. This was accomplished by fully integrating the operation of the anaerobic digestion plant into existing rendering infrastructure, both from a waste processing perspective and from an energy production perspective. While there are specific rendering integration points, there are also integration points that apply regardless of the host site.

Critical Processes, Systems and Personnel

Integration of the rendering plant with the anaerobic digestion technology requires critical processes:

- Reception facilities that can accept multiple feedstocks, including high solids material and high liquid material. Due to the varying types of feedstocks supplied to the site, the reception facility must be equipped to manage all types of waste. The installed system successfully processes liquid greasetrap waste and high solids foodwaste equally well.
- Biogas processing equipment that reduces hydrogen sulfide and H_2O is critical to the effective operation and maintenance of the biogas energy production systems; the combined heat and power generator genset and the CNG production system. The installed system reduces hydrogen sulfide and H_2O to target levels for the final use, thereby lengthening the operations of the biogas equipment.
- Backup boiler technology to heat digesters when combined heat and power generator genset is down. This is critical for the ongoing operation of the system since combined heat and power generator downtime is not only probable but necessary (for oil changes and maintenance, etc.).
- Anaerobic Digestion system user interface and operational instructions must be comprehensive and easy to operate. The installed system has a computer user interface that monitors and controls all elements of the digester facility and enables remote operation of all systems.
- Full-time staff is required to monitor biology and operations of the anaerobic digestion system including
  - pH level, hydrogen sulfide level, methane level, and bicarbonate production of digester material.
  - Feedstock type and volume.
  - Temperature of digester.
  - Physical attributes of operations including inspection for foaming, agitation, separator operation
  - On-call remote monitoring and troubleshooting for problems that arise
  - Regular maintenance on anaerobic digestion equipment, CNG equipment and combined heat and power generator genset
- Staffing of the system is a critical component of successful operation of the facility and is often the cause of success or failure of the equipment. Without regular monitoring and maintenance of all systems, the biology in the digester will suffer and cause larger issues.
- Supply of waste from rendering plant: liquid waste supply via pipeline from condensers or solid waste supply from rendering reception.
- Transfer of digested solids from digester to rendering plant for processing. Unlike typical anaerobic digestion systems that may require composting for solids disposal, the rendering/anaerobic digestion integration means the ability to transfer digested solids to the rendering process.

Supplier Technology Capacity Constraints and Design Critical Elements

The anaerobic digestion system was designed and built by Biogas Energy with site-specific requirements and operations. The challenge of processing varying feedstock was addressed by the waste reception design and the configuration of two hydrolysis tanks as the first step of anaerobic digestion. The hydrolysis tanks enable the homogenization of multiple feedstocks prior to feeding the main digester; thereby maximizing biogas production from what otherwise would be a difficult feedstock profile to manage in the anaerobic digestion process. The biogas producing bacteria thrive when fed with a consistent feedstock measured in temperature, solids content, pH, and energy value. Variabilities in any of those parameters create stress for the bacteria resulting in decreased biogas production.

All materials used in the production process are compostable or recyclable, including the carbon gas filtration media and engine oil. The only other consumables used at the site are iron chloride, which is dosed into the digester to reduce hydrogen sulfide and is thereby consumed totally, and urea for the selective catalytic reduction in the combined heat and power generator engine, which is totally consumed there.

Pro Forma Financial Model for the Project

Integrating the anaerobic digestion plant into an existing business (rendering plant) creates cost savings for the host business which are not adequately addressed by a simple income statement. It is necessary to incorporate the profit and loss financials from the host business into the anaerobic digestion project's financials in order to come to a clearer picture of the effects of the biogas plant's benefits. The benefit of the electricity production and the CNG production are not in revenue since those products are not sold; they are consumed in-house as cost savings. Therefore, the biggest benefits from the project are not income, but cost savings.

In a stand-alone anaerobic digestion project, the financial modeling is more straightforward and outlined below as a hybrid savings/income financial statement. This model assumes that the customer will be able to monetize all of the electricity produced and all of the CNG produced, which is possible with the co-located project at a rendering plant as well. The financial model is explained below in Tables 1 through 3.

Table 1: Pro Forma Income Financial Model

Category	Annual Amount	Price Earned	Annual Income
Tipping fees	100 tpd * 300dpy =30,000 ton	$12 per ton	$360,000
Renewable Identification Number s]Sales	160,000 DGE/yr	$0.50	$80,000
Carbon credits	12,000 tons	$3 per ton	$36,000
Protein meal	500 tons	$350	$175,000
Total			**$651,000**

Source: Biogas Energy

Table 2: Project Pro-forma Cost Savings Financial Model

Category	Annual Amount	Price Saved	Annual Savings
Diesel	146,000DGE	$3.00	$438,000
Electricity	500kW * 8000hr/yr = 4,000,000kWh	$0.16	$640,000
Rendering Capacity Freed Up	15,000 ton	$12 per ton	$180,000
Total			**$1,258,000**
Total Annual Income and Cost Savings			**$1,909,000**

Source: Biogas Energy

Table 3: Project Operating Expenses

Digester Operations	$142,000
CNG Maintenance	$150,000
Combined Hand Power Generator O&M	$165,000
Labor	$48,000
Insurance	$80,000
Total:	**$585,000**
Earnings Before Interest Tax Depreciation & Amortization	**$1,324,000**

Source: Biogas Energy

Projected Cost of Fuel When in Production

The analysis required to determine the cost of fuel must be made with several assumptions in order to adequately allocate revenues and costs associated with the project. In other words, unlike conventional fuels or even renewable biodiesel, RNG from this anaerobic digestion project has no costs associated with feedstock acquisition, with energy consumption, or even with labor when factoring in operations and maintenance costs that can be associated with other revenue streams put out by the project. The only reasonable cost associated with the production of RNG is the financing charge, which itself can be allocated to other operations in the project.

The fact that RNG can be produced with a feedstock that earns multiple other revenues such as a tipping/disposal fee, carbon credits, RINs, digester solids income, etc., means that the fuel output itself has no cost other than the CNG equipment.

In contrast to ethanol fuel, RNG does not pay for its feedstock (for example, ethanol must purchase corn as its feedstock). Biodiesel also incurs cost for feedstock acquisition (used vegetable oil or palm oil). Both ethanol and biodiesel fuel production require significant energy for their processes in the form of heat and electricity. In distinction, RNG's feedstock earns money in the form of tipping fees for the waste disposal, and the energy required to run the equipment is supplied by a co-located power generator.

RNG's feedstock is organic waste that is converted into biogas and then upgraded to biomethane (RNG). The organic waste can be derived from material diverted from landfill, or it can be agricultural waste, both of which can contribute to greenhouse gas emissions. By diverting this waste to the production of RNG, that source of greenhouse gas emissions is diverted to a useful purpose: vehicle fuel. As California diverts its organics from landfill, that material is an ideal feedstock for the production of RNG and converts what is otherwise a simple plan to avoid Greenhouse Gas emissions into a multiplier effect: producing RNG that displaces diesel in trucks. There are significant opportunities for domestic renewable fuel production that directly reduce air emissions in California if this project's model can be widely adopted.

The bottom line is a net *negative cost* (or net *income*) for the RNG when factoring in all the ancillary benefits to the technology. With RINs alone generating $0.50 per DGE, the RNG production is a net revenue initiative.

Expected Investment Threshold to Launch Commercial Product

The project cost, including technology and construction costs (omitting land costs, project management costs, consulting costs, etc.) totaled $7,773,750.

With an annual EBITDA of $1,324,000, a payback period of five years is required, or a 20 percent return on capital.

As the first project of its kind to be built, it is now possible to reduce those costs as the biogas plant is no longer a one-off and can instead leverage economies of scale when building new projects. For example, a re-design of the digester into a hybrid tank/lagoon system could reduce the tank costs by 20-35 percent.

Ultimately the commercial viability of the anaerobic digestion product will depend on a developer’s ability to finance the project under acceptable terms and secure the volumes of feedstock necessary to make it all work. Co-location with a significant energy consumer has distinct advantages over a pure energy export play, particularly on the electricity side. Electricity that can be consumed in-house will (a) be more valuable since one is replacing retail rates for power supply, and (b) work on Net Metering which has no interconnection or network upgrade costs associated with it. When power is exported to the utility, significant engineering studies and interconnection costs apply, and the price earned for the power can be 40-60 percent lower than offset retail electricity.

Biogas plants are not standard pieces of equipment and instead have to be custom designed for each application. One facility’s reception configuration may need to be altered significantly for another project. However, the core functionality of the system remains constant, and the experience gained from this project will reap significant cost savings and design improvements that will benefit future installations of the technology.

GLOSSARY

CALIFORNIA ENERGY COMMISSION (CEC)—The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The CEC's five major areas of responsibilities are:

- Forecasting future statewide energy needs.
- Licensing power plants sufficient to meet those needs.
- Promoting energy conservation and efficiency measures.
- Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels.
- Planning for and directing state response to energy emergencies.

Funding for the CEC's activities comes from the Energy Resources Program Account, Federal Petroleum Violation Escrow Account, and other sources.

CARBON DIOXIDE (CO2)—A colorless, odorless, nonpoisonous gas that is a normal part of the air. Carbon dioxide is exhaled by humans and animals and is absorbed by green growing things and by the sea. CO2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO2 also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalent).

COMPRESSED NATURAL GAS (CNG)—Natural gas that has been compressed under high pressure, typically between 2,000 and 3,600 pounds per square inch, held in a container. The gas expands when released for use as a fuel.

DIESEL GALLON-EQUIVALENT (DGE)—is the amount of alternative fuel it takes to equal the energy content of one liquid gallon of diesel gasoline.

KILOWATT (kW)—One thousand watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon, a typical home—with central air conditioning and other equipment in use—might have a demand of 4 kW each hour.

KILOWATT-HOUR (kWh)—The most used unit of measure telling the amount of electricity consumed over time, means one kilowatt of electricity supplied for one hour. In 1989, a typical California household consumed 534 kWh in an average month.

MMBtu—One million (10^6) British thermal units.[7]

NEW SOURCE REVIEW (NSR)—Congress established the New Source Review (NSR) Permitting program as part of the 1977 Clean Air Act Amendments.[8]

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7 U.S. Energy Information Administration https://www.eia.gov/tools/glossary/
8 New Source Review (NSR) Permitting US EPA https://www.epa.gov/nsr

PRESSURE SWING ADSORPTION (PSA)—a well-established gas separation technique in air separation, gas drying, and hydrogen purification separation. Recently, PSA technology has been applied in other areas like methane purification from natural and biogas and has a tremendous potential to expand its utilization.[9]

RENEWABLE NATURAL GAS (RNG)—A gaseous mixture of carbon dioxide and methane produced by the anaerobic digestion of organic matter.

9 Carlos Grande. "Advances in Pressure Swing Adsorption for Gas Separation." *International Scholarly Research Notices*. 2012. https://www.hindawi.com/journals/isrn/2012/982934/