Denali Emerging Energy Technology Grant:

"Improving Cold Region Biogas Digester Efficiency"

Final Report – September 20, 2011

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Summary

Energy is a high cost, imported commodity to most Alaskan utilities. Biogas digester systems, which take organic material into an air-tight tank, where microbes break down the material under anaerobic conditions and release methane-rich biogas, may offer an alternative energy solution. Biogas can be burned as a fuel for cooking, heating, generating electricity and powering lights; and the liquid effluent can be used as organic compost. While small-scale biogas digesters are being used by thousands of households in India, Egypt, Costa Rica, and other warm-climate countries, seasonal limitation to biogas production is experienced in colder climates due to the shut-down of mesophilic (warm loving) microbial communities in winter. This project set out to improve the efficiency of biogas digesters under cold climate regimes by inoculating digesters with active-methane-producing psychrophiles (cold-tolerant microbes) readily available in Alaskan thermokarst (thawing permafrost) lake mud. Psychrophilic methanogens, despite a temperature optimum of 25°C, still actively produce methane year-round at temperatures as low as 1°C, unlike conventional microbes.

The objectives of this project were to: Test the potential for cold-adapted microbes collected from an Alaskan thermokarst lake to improve biogas production rates at cold temperatures in existing anaerobic digester technology, produce a renewable and alternative fuel, reduce the release of harmful greenhouse gases, and implement dwelling-size applications to evaluate their acceptance and sustainability for wide spread application in Alaska. This project was a collaboration among the Cordova Electric Cooperative, the University of Alaska Fairbanks, and the Cordova High School science program.

In Phase I of the two-year study, we used an experimental approach to compare biogas production rates from psychrophilic (lake mud) vs. mesophilic (manure) microbial consortia in six small, 1000-L household scale digesters under two relatively cold temperature regimes (15ºC and 25ºC). Phase II research focused on the utilization (the capture, compression, analysis and usage) of biogas produced during the project and assessment of this technology for application in Alaska.

We found that digesters containing psychrophiles were more robust to temperature and pH fluctuations. Among our experimental digesters, tanks containing psychrophile-rich lake mud produced more biogas (275 ± 82 L gas d^{-1}, mean ± standard deviation) than tanks inoculated with only mesophile-rich manure (173 ± 82 L gas d^{-1}); however, digester temperature appeared to be the overarching control over biogas production among all tanks. Extrapolating the linear relationship between biogas production and mean digester temperature observed among our study tanks [Production (L gas d^{-1}) = 34.35*Temperature (ºC)- 432] to the temperatures typically used for biogas production in warmer climates (35-40ºC), it is possible that our digesters would have produced 770-940 L gas d^{-1}, a rate similar to that reported for warm climate digesters. Without knowing the temperature response from the microbial communities in our specific digesters, it is not possible to extrapolate these results with a high level of certainty; however, we can conclude that psychrophile-rich lake mud is a viable source of microbial inoculum for producing biogas at cold temperatures, albeit at only 28-56% of rates typical of warmer temperature regimes. Other benefits of the psychrophile-rich lake mud digesters included reduction of foul odor and a source of nutrient-rich, liquid organic fertilizer for growing plants.

Combining the observed biogas production rates with the long-term mean methane concentration of biogas collected from the digesters (~67% CH_4 by volume), biogas had an equivalent BTU rating of 3,950-6,270 BTU per digester per day (mean) and 12,750 BTU per digester per day (maximum).

In Phase II of the project, we designed and implemented a new gas collection system suitable for small-scale applications in Alaska. The system, based on a telescoping holding tank principle, is simple and easy to assemble in areas where elaborate mechanized storage and gas delivery systems are not available. The gas was collected from the primary digesters using the telescoping storage system and delivered for use in a variety of applications to demonstrate biogas utility as a source of combustion fuel. The most notable demonstration projects included the use of biogas as a cooking fuel with a cast iron single-burner stove, powering of a 4-cycle lawn mower engine, production of electricity using a converted gas-powered generator and use of digester effluent as liquid fertilizer in a student greenhouse project.

A Benefit-Cost Analysis and Sensitivity Analysis to assess the economic feasibility of the project showed that small scale biogas digesters are not cost-effective at the current prices of displaced fuels and electricity. Replication of the small, household-scale biogas digester technology is unlikely in Alaska due to the heat and energy requirements of maintaining digesters above freezing in winter, the time required for building and maintenance, and the relatively low energy yield. However, large-scale digester projects are becoming more widespread in the United States, Europe and elsewhere globally. Large-scale biogas operations may have potential in Alaska too in association with converting waste from fisheries into usable biogas and in landfill operations.

The benefits of biogas technology are global. The collection and utilization of methane, one of the strongest greenhouse gases, prevents its release into the atmosphere. Waste streams often present a liability to communities by filling landfills and posing environmental hazards. The overall impacts of biogas technology include protection of the environment and the potential for reduced energy costs if implemented at larger scales.

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Keywords: Biogas, anaerobic digester, reactor, psychrophiles, mesophiles, methane, methanogens, Alaska, cold-climate, thermokarst lakes.

1. Introduction

1a) Background

Anaerobic digester technology has been in use for hundreds of years for the making of high energy, methane-rich gas, known as biogas. Modern implementation of the technology is wide-spread throughout urban and rural communities in India and China, with emerging efforts in Africa and Europe gaining popularity in recent decades. The technology is based on the biological production of methane by bacterial microbes, particularly methanogens, which naturally break down organic feedstock to produce methane in anaerobic conditions (without oxygen). This process can be observed in nature in bubbling methane seeps from lakes, peat bogs, and other organic-rich oxygen deficient environments (Walter et al., 2006).

The basic concept behind a biogas digester is to create an ideal environment for a methanogenic microbial community, and then harvest the methane which it produces over time. As the microbe's needs are minimal, a relatively simple technology develops: provided with an organic, water-logged, food substrate, the anaerobic microbes produce methane which bubbles out of the substrate into a collection vessel. This is opposed to aerobic microbes which consume oxygen and produce carbon dioxide as a byproduct of respiration. By collecting the gases vented from a biogas digester, useful work can be performed by diverting and combusting the gas in variety of conventional gas-powered devices.

Temperature is a major restricting factor in biogas technology (House, 1978, Massé et al., 1997, Gerardi, 2003). Traditionally, ungulate manure containing mesophilic (warm-loving) microbes is used as a source of both methanogens and substrate. Each addition of manure to anaerobic digesters simultaneously supplies microbes and organic material, allowing conversion of organic matter to methane-rich biogas. However, the metabolism of mesophiles slows or shuts down at cold temperatures (usually below 20-25°C). This requires that digesters employing mesophilic microbes be stored indoors, heated, or retired in the cold season.

If solutions to this temperature-limitation were achieved, biogas technology could prove an excellent alternative energy source for rural Alaskan communities which face particularly high fuel costs and have a per capita energy consumption rate over three times the national average (EIA, 2011). It is already known that psychrophilic (cold tolerant) methanogens thrive in cold lake bottom mud across Alaska and Siberia, producing methane year round. These microbes have been shown to produce strong methane seeps in thermokarst (permafrost thaw) lakes even in the middle of winter, at temperatures close to freezing (Walter et al., 2006, 2007). With this in mind, this project set out to test the capacity of psychrophilic microbes collected from Alaskan thermokarst lake sediments to improve biogas production in existing small-scale digester technology under cold temperatures.

In Phase I of the two-year study, we used an experimental approach to compare biogas production rates from psychrophilic vs. mesophilic microbial consortia in small, household scale digesters under two relatively cold temperature regimes (15°C and 25°C). Phase II research focused on the utilization (the capture, compression, analysis and usage) of biogas produced during the project and assessment of this technology for application in Alaska.

1b) Project Goals and Hypotheses

The objectives of this project were to: improve the efficiency of existing methane biogas digesters operating at cold temperatures by utilizing cold-adapted microbes from thermokarst lake bottoms, produce a renewable and alternative fuel, reduce the release of harmful greenhouse gasses, and implement dwelling-size applications to evaluate their acceptance and sustainability for wide spread application in Alaska.

In experimental Phase I, we tested the following hypotheses:

- H1: Biogas production will be greater at tepid (25 °C) temperature than at cold (15 °C) temperature.
- H2: At any given cold or tepid temperature, tanks inoculated with cold-tolerant microorganisms (psycrophiles) from thermokarst lakes will produce more biogas than tanks inoculated with warm-loving microorganisms (mesophiles) in manure.
- H3: Despite psycrophiles having an advantage over mesophiles at cold temperatures, biogas production at cold temperatures (15-25 °C) will not be as great as at warm temperatures (35-50°C).

Phase II Objectives:

- O1: Demonstrate the capture, storage and utilization of produced biogas to power household-scale appliances
- O2: Evaluate the technology with respect to the potential for its practical application in Alaska.

1c) Project Team Personnel

The project was administered through the Cordova Electric Cooperative, conducted largely on site at the Cordova High School with participation from students and their science teacher, and conducted by researchers at the University of Alaska, Fairbanks. Specific project participants included:

Cordova Electric Cooperative http://cordovaelectric.com/

Clay Koplin, CEO – Grant Administrator. Koplin administered the financial aspects of the grant and served as a technical advisor to the project.

University of Alaska, Fairbanks http://www.alaska.edu/uaf/cem/ine/walter/

Katey Walter Anthony – Research Director. Walter Anthony spearheaded the scientific goals and directions of the project. She provided scientific expertise and project management, and contributed to data analysis, interpretation and report writing. Anthony led preparation of the Final Report.

Casey Pape – Primary Research Technician. Pape worked both extensively on-site in Cordova and from Fairbanks maintaining the digester experiment, including data collection, analysis, and troubleshooting. Pape contributed substantially to the preparation of the Final Report and led preparation of most other reports.

Laurel McFadden –Research Technician. McFadden, served the project as Research Technician from the start of the project until August 2010 and led preparation of the Biogas Handbook for Alaskans.

Dane McFadden – Project Intern. McFadden, a Stanford University undergraduate student, helped maintain digester performance during August 2010.

Peter Anthony – Research Technician. Anthony helped set up the project in Cordova, provided technical expertise to the maintenance and application of digesters, and conducted gas chromatography analyses.

Cordova High School http://blogs.cordovasd.org/chs/

Adam Low – Science Teacher. Low was integral in realizing student involvement via classroom curriculum and extracurricular projects.

Cordova High School Students – Volunteers. The students of Cordova High School were highly involved with construction, feeding, maintenance, demonstration of the use of biogas in science fair projects for Phase II, and public presentations for the project. They include the seventeen Chemistry class students and Science Club students (Craig Bailer, Ben Americus, Adam Zamudio, Sophia Myers, James Allen, Eli Beedle, Josh Hamberger, Keegan Crowley, Kris Ranney, and Carl Ranney).

SOLAR Cities http://solarcities.blogspot.com/

Thomas "TH" Culhane – Biogas Expert. Culhane provided extensive technical knowledge and participated in building digesters in January 2010. Through collaboration with a National Geographic Society outreach project, Culhane used psychrophilic effluent from the Cordova digesters to initiate new biogas digesters in Europe, Asia and Africa.

Sybille Culhane – Co-founder of SOLAR Cities. S. Culhane assisted in initial construction efforts and managing financial aspects of SOLAR Cities involvement.

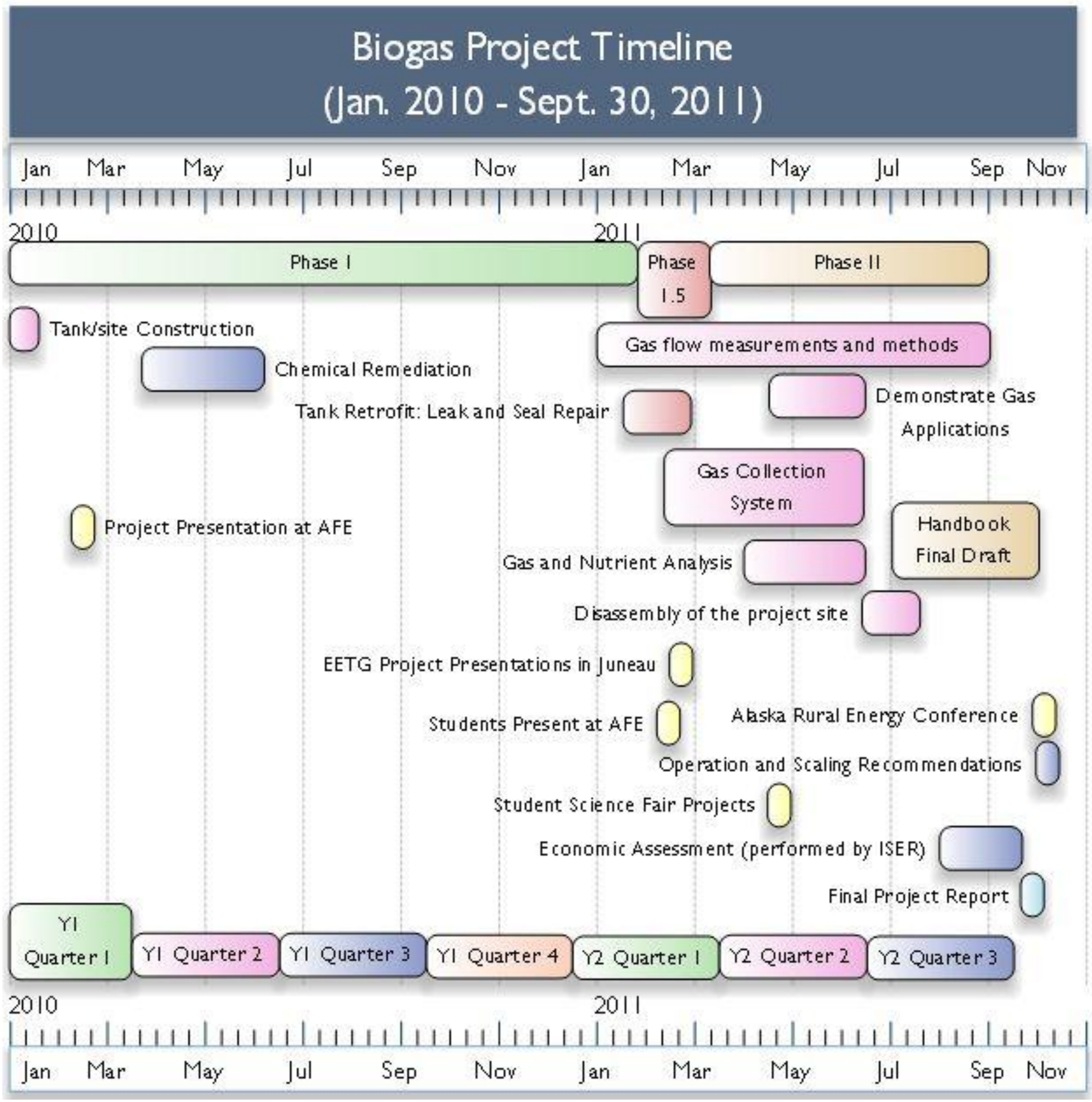
Others http://www.cordovaenergycenter.org/

Brandon Shaw – Website Developer. Shaw designed the CordovaEnergyCenter.org website and assisted in digester set-up in January 2010.

Jeffrey Werner – State FFA Director. Werner is interested in using the effluent from anaerobic digesters as a liquid fertilizer for agricultural crops.

Bernie Carl – Owner of Chena Hot Springs. http://www.chenahotsprings.com/. Carl has expressed interest in deploying a large scale biogas digester at Chena Hot Springs to meet fuel needs and enhance greenhouse agriculture.

1d) Project Timeline



2. Methods

Phase I

2a. Experimental design. Figure 1 shows the experimental design of the Cordova anaerobic digester experiment of Phase I. Six 1000-L Sorbitol HDPE containers (tanks), obtained from local Cordova fish processing facilities, were converted into single batch-style anaerobic digestion reactors and inoculated with methanogenic microbial cultures obtained from thermokarst lake sediments in Fairbanks (psychrophiles) and manure from Northern Lights dairy farm in Delta Junction (mesophiles). The reactors were placed inside of a 40-foot Conex, which we lined with R-10 Owens Corning foam board insulation. We built a wall with a door in the middle of the Conex to create two separate rooms. Three tanks were placed in each of the two rooms that were maintained at approximately 15°C (cold) and 25°C (tepid). We do not consider the 25°C room to be 'warm' since numerous other studies have shown that warm-loving mesophiles prefer temperatures closer to 37°C. Temperature was controlled with 1500-W radiator heaters.

Within the separate rooms, each of three tanks was inoculated and labeled with one of the following microbial treatments: Lake mud only (psychrophiles; 48 L mud per tank); Manure only (mesophiles; 60 L manure per tank); and Mixture of lake mud and manure (48 L mud + 60 L manure). Crushed rock (~8 L per tank) was spread over the bottom of tanks to provide surface area for microbial growth. Tanks were filled 7/8 of the way full with warm tap water.

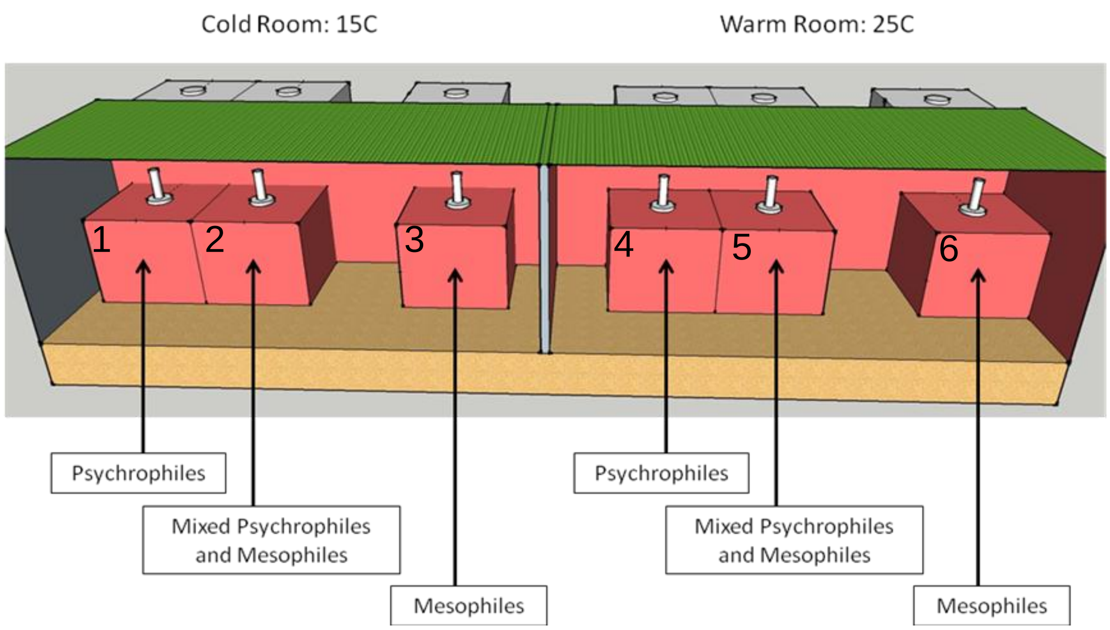


Figure 1. Phase 1 experimental design to compare biogas production efficiency of different combinations of psychrophilic and mesophilic methanogen communities under 15°C and 25°C temperature treatments.

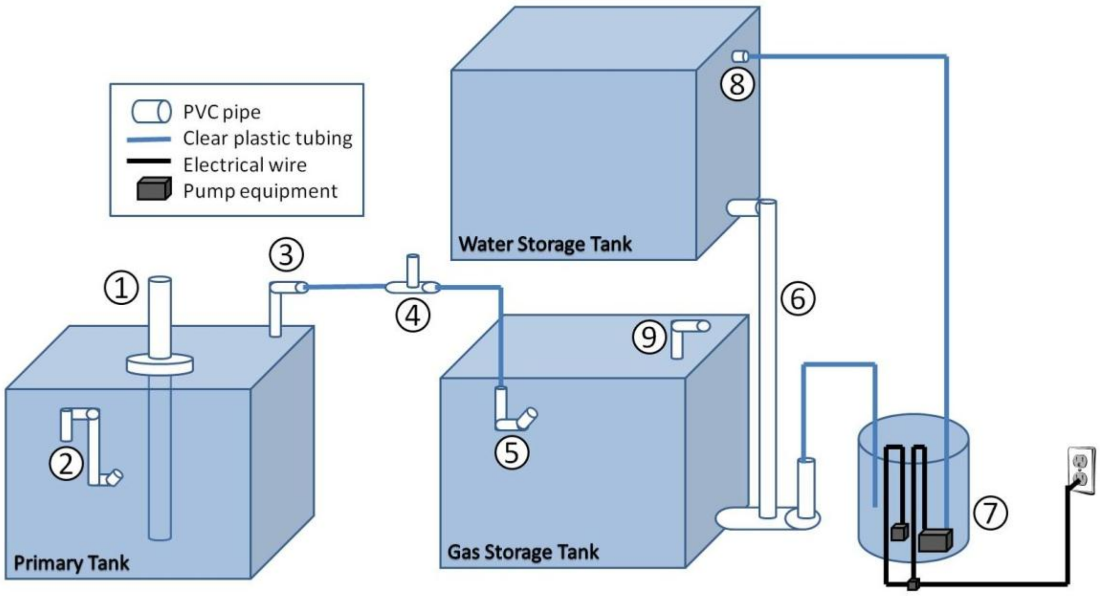


Figure 2. Schematic showing the 3-tank digester and water pressure system. 1) Feeding tube 2) Effluent pipe 3) Primary gas outlet 4) Flame tester 5) Gas inlet 6) Water transport 7) Pump bucket 8) Water inlet 9) Final gas outlet. After experiencing considerable drawbacks of the water storage tanks and gas pressurization system, we removed components 5-9 and either exhausted biogas outside or collected and pressurized biogas in a secondary, telescoping holding tank that required no external power source.

Hobo temperature data loggers (HOBO water temp pro v2 U22-001) were secured to the feeding inlet tube in each tank. Tanks 1, 3, 4 and 6 had multiple loggers installed at the top, middle and bottom of the tank in order to observe potential temperature stratification. Both rooms within the Conex were monitored by Onset pendant loggers (HOBO UA-002-64). Cordova local area temperature data was obtained from online sources (www.wunderground.com).

On February 19, 2010, the reaction vessels were sealed to facilitate microbial O_2 consumption in the tanks for the establishment of anaerobic conditions. Initial physical and chemical data on starting conditions were recorded.

2b. Tank chemistry measurements.

We measured pH, dissolved oxygen (DO) and oxidation reduction potential (ORP) initially three times per week, and later weekly, in 100-mL samples collected from each of the six digesters. pH measurement were initially quantified by visual assessment using Macherey-Nagel litmus paper (used until April 16, 2010) and with a more precise electrode (Oakton PC510) from April 17, 2010 through June 6, 2011. ORP measurements were performed with an Xplorer GLX Pasco PS-2002 Multi-Datalogger from January 21st to April 9, 2010, before more accurate instrumentation was available (Oakton PC510 ORP meter). Dissolved oxygen measurements were recorded with an Xplorer GLX Pasco PS-2002 Multi-Datalogger until March 24, 2010, and later with a Hanna HI9142 DO meter.

2c. Feeding digesters

Once it was established through chemistry measurements that the tanks were mostly anaerobic and through positive flame tests that biogas production had begun (within 2 days to 2 weeks, depending on the tank), we began feeding tanks to provide substrate to fuel methanogenesis. In accordance with conventional warm-temperature, small-scale biogas system protocols (Samuchit Enviro-Tech Pvt. Ltd.), students from Cordova High School's chemistry class fed each tank a 2-kg organic slurry consisting of 1-kg wet food weight plus 1-kg water. Food scraps from the school lunch hall were collected daily and processed in large batches by way of an industrial sink disposal (Appendix 1). The processed food scraps were then divided into measured 1-kg portions, labeled and frozen in a large storage freezer kept in the school's science classroom. Each day, individual portions were removed from the freezer, thawed, and fed to digesters through a 2" PVC (schedule 40) pipe that extended 2 feet above and 3 feet down into the reactor vessel, into the water liquor. At the time of feeding, reactor gas valves were closed off and equivalent volume of effluent was removed via a 1 inch ball-valve located mid-level in the side of each tank. After each feeding treatment was performed, the students re-opened the reactor gas valves and capped the feed inlet tube. Effluent was disposed of through the local storm water sewer system, located near the project site.

2d. Gas flow measurements

Gas flow was measured in real-time from February 18 – December 11, 2010 using mass flow meters installed in-line with the gas outlet valve on each reactor vessel (Sierra Top-Track 820 Series). For better quality measurements, later gas flow data were obtained using the same flow meters, but on different, labor-intensive sampling intervals. As of December 2010, all monitoring of biogas production was performed by closing off tank gas outlet valves for 6-8 hours to allow the reactors to build positive pressure. As the tanks began to distend, pressure was relieved by partially opening the valve and allowing biogas to flow past the mass flow meters at a higher rate, which was in the range of the flow meter calibration.

2e. Gas composition analysis

We sampled biogas from the outflow pipes of each digester over the course of the two-year study. Samples were collected into 60-ml glass serum vials, sealed with butyl rubber stoppers, and stored under refrigeration in the dark until analysis in the laboratory following the method described in detail by Walter et al. (2008). We measured the concentration of methane (CH_4), carbon dioxide (CO_2), oxygen (O_2) and nitrogen (N_2) in samples using a Shimadzu 2014 gas chromatograph equipped with an FID and TCD at the Water and Environmental Research Center (WERC) at University of Alaska, Fairbanks.

2f. Effluent nutrient analysis

Samples of reactor effluent were periodically collected from each digester over the course of the experiment. Samples were stored in 20-mL scintillation vials, sealed with paraffin tape, and frozen on-site until being sent to the University of Alaska, Fairbanks WERC lab for analysis. Nutrient fractions were analyzed on a high pressure liquid chromatograph (Dionex LC 20) equipped with auto feed sampler on April 18, 2010. Samples were run [unfiltered] with a five to one dilution ratio (1:5).

2g. Odor. Qualitative observations of odor from digester effluent samples were recorded.

Phase II

2h. Biogas collection and storage

Initially, a gas storage system was constructed outside the project Conex and used to store biogas via a water-pressure and pump system. The system was built by collaborator T.H. Culhane to demonstrate to the project how biogas is stored and utilized in his projects outside Alaska. In September 2010 this system, which is not appropriate for Alaskan environments, was disassembled, allowing biogas to vent from digesters to the outside atmosphere. In June 2011, a telescoping 500-gallon (approx. 2000-L) HDPE tank was installed on-site to collect and distribute biogas produced inside the project Conex container (modified from a 500 gal and 1000 gal tank, Greer Tank and Welding, Inc., Fairbanks, AK). The collection vessel consolidated and stored gas produced from active tanks 1, 4, 5 and 6 using ½" reinforced vinyl and ¼"air tubing. Standardized ¼" gas ball-valve and female flaring were used to make further connections down line of the storage vessel.

The larger 1000 gal containment vessel was filled with approximately 500 gal of water to serve as an air seal for the top gas-holding tank. Pressurization of the gas was performed by placement of a water-filled 1000-L HDPE tank above the floating tank (Fig. 3).

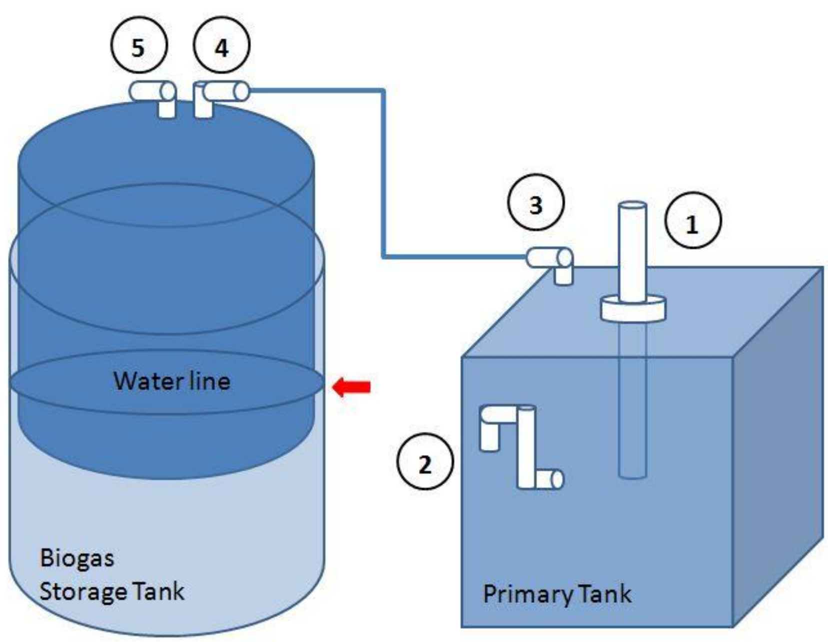


Figure 3. Schematic of a successful telescoping gas collection and re-distribution system. 1) Feeding tube 2) Effluent pipe 3) Primary gas outlet 4) Storage collector inlet 5) Gas outlet valve. The biogas storage container was filled approximately half way full in order to create an air seal for the collector vessel above. The top floating collection vessel was open at the bottom. Additional weight was placed on top of the floating tank to increase biogas line pressure.

2i. End use testing

Biogas combustion demonstrations were performed using a converted single-burner cast iron stove with 3/8" natural gas conversion kit (SGB-01 NGKIT). Power generation demonstrations were performed using an 1850-W generator with 4-cycle Subaru engine (Husky) with a tri-fuel carburetor conversion kit installed. All fittings were adapted with ¼" male compression to female swivel flares for ease of operation.

Additional student science projects and demonstrations were performed with biogas stored in car tire inner tubes. Air hose lines were connected to ¼" Schrader valves which were used to fill the tubes. The tubes were then transported to a proper testing site in order to distribute the contained biogas.

For further details on Methods in Phase I and II, refer to the project's Year 1 and Year 2 quarterly reports.

3. Results

3a. Temperature control in the Conex

Temperature fluctuations inside the project Conex closely mimicked changes in ambient outside temperature at the Cordova study site (Fig. 4). The average temperature ± standard deviation recorded in Cordova for the study period (January 15, 2010 – June 15, 2011) was 3.6°C. Though experimental room temperatures drifted from design conditions of 15°C and 25°C throughout the course of the project, the average temperatures remained elevated above ambient air temperature and were within close proximity of intial targets. Average ± standard deviation of the recorded 'cold' and 'tepid' room temperatures in the Conex were 15.4 ± 7.1°C and 25.6 ± 5.1 °C respectively.

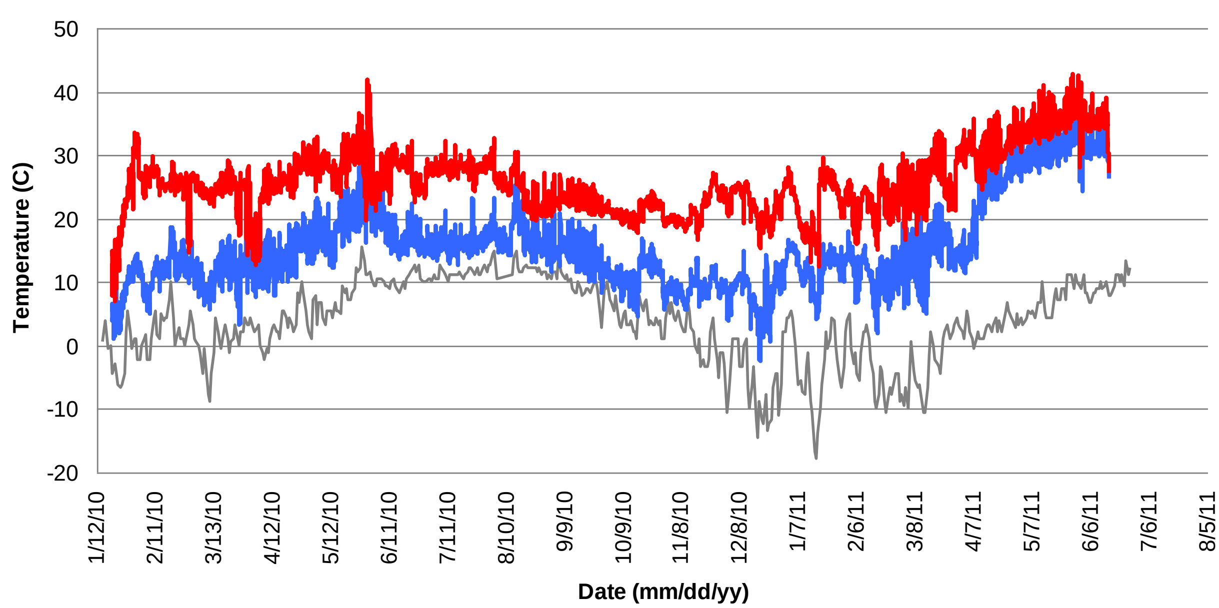


Figure 4. Ambient Cordova mean daily air temperature (grey) and mean hourly room temperature in the Connex 'cold' (blue) and 'tepid' (red) rooms during the study period, January 15, 2010 – June 15, 2011.

The average temperature of digester slurry, recorded from temperature loggers located at the bottom of each tank, varied by as much as 3.3 °C among tanks within each of the two rooms (Fig. 5). The average temperature ± standard deviation in each tank was: tank 1 (15.9° ± 6.7 C), tank 2 (16.1 ± 7.1 °C), tank 3 (14.8 ± 6.0 °C), tank 4 (22.5 ± 4.3 °C), tank 5 (22.8 ± 4.3 °C), and tank 6 (19.5 ± 4.4 °C). When available, data from loggers placed in the tops of tanks showed higher temperatures than loggers placed at the bottom of tanks (Fig. 6).

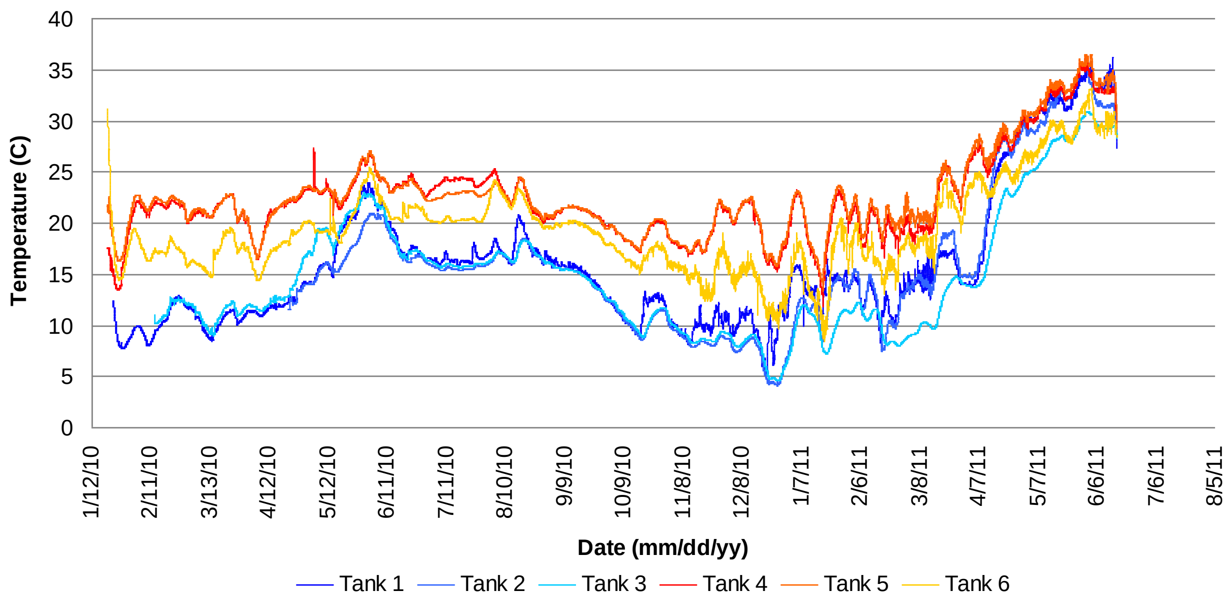


Figure 5. Mean hourly temperature of the data loggers in the bottom of the digesters. Tanks 1-3 were located in the cold room, while tanks 4-6 were located in the tepid room. Digester temperatures tended to track room temperatures, which followed the trend of outdoor air temperatures (Fig. 4).

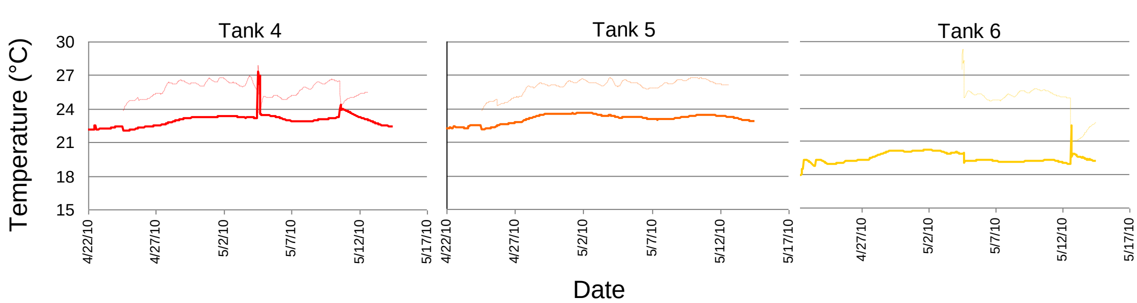


Figure 6. Temperature at the top (dashed lines) and bottom (solid lines) of three digesters. The temperature differences within individual tanks indicate thermal stratification in digesters.

3b. Digester chemistry

Measurements of pH, oxidation-reduction potential (ORP) and dissolved oxygen (DO) were conducted to monitor conditions inside digesters over the course of the experiment, and to alert researchers to potential conditions which could inhibit methanogenesis, such as low pH or high DO or ORP.

We observed that the pH of digester slurries drifted significantly from neutral pH towards acidic pH during the initial part of Phase I. On March 22, 2010, digester feeding regimens were halted and chemical remediation treatments commenced using calcium carbonate ($CaCO_3$), calcium oxide (lime, CaO) and sodium hydroxide (NaOH) in order to restore digester pH to more neutral conditions. On June 6, 2010, chemical remediation treatments were stopped and the feeding schedule recommenced. By September, 2010, all tanks had recovered to a near neutral pH, except tank 3, which remained acidic. The final pH values, recorded June 11, 2011, were: tank 1 (7.71), tank 2 (7.49), tank 3 (4.82), tank 4 (7.52), tank 5 (7.49), and tank 6 (7.64) (Fig. 10).

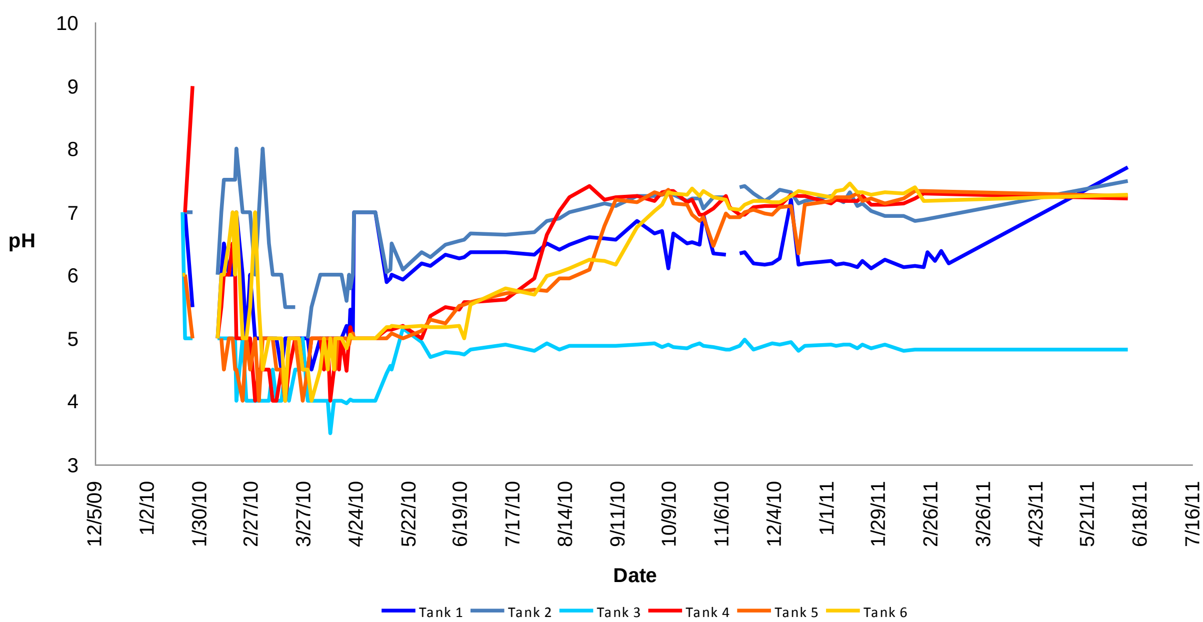


Figure 7. pH of digester slurries in six anaerobic digesters from January 2010 until June 15, 2011.

The oxidation-reduction potential (ORP) of reactor effluent, recorded throughout the experiment, was appropriately low at the onset of the study. ORP increased after feeding commenced, in parallel to the decrease in pH. After pH stabilization, ORP decreased in all of the digesters except Tank 3 (Fig. 8).

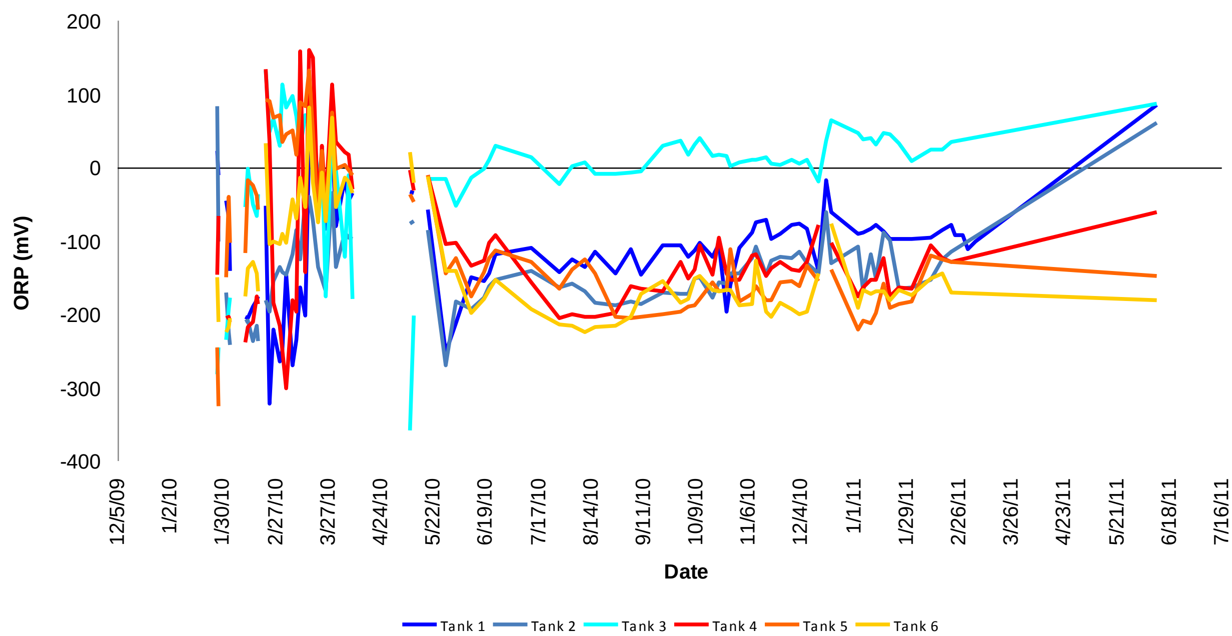


Figure 8. Oxidation reduction potential (ORP) in anaerobic digester slurries.

Measured dissolved oxygen (DO) levels were low, but rarely zero, during the course of the project. The Hanna instrument used to measure DO was reported to be improperly calibrated on several occasions during the fall of 2010, resulting in slightly elevated levels of DO being recorded (data not shown). After servicing in December 2010, DO measurements returned to values observed earlier in the project (Fig. 9).

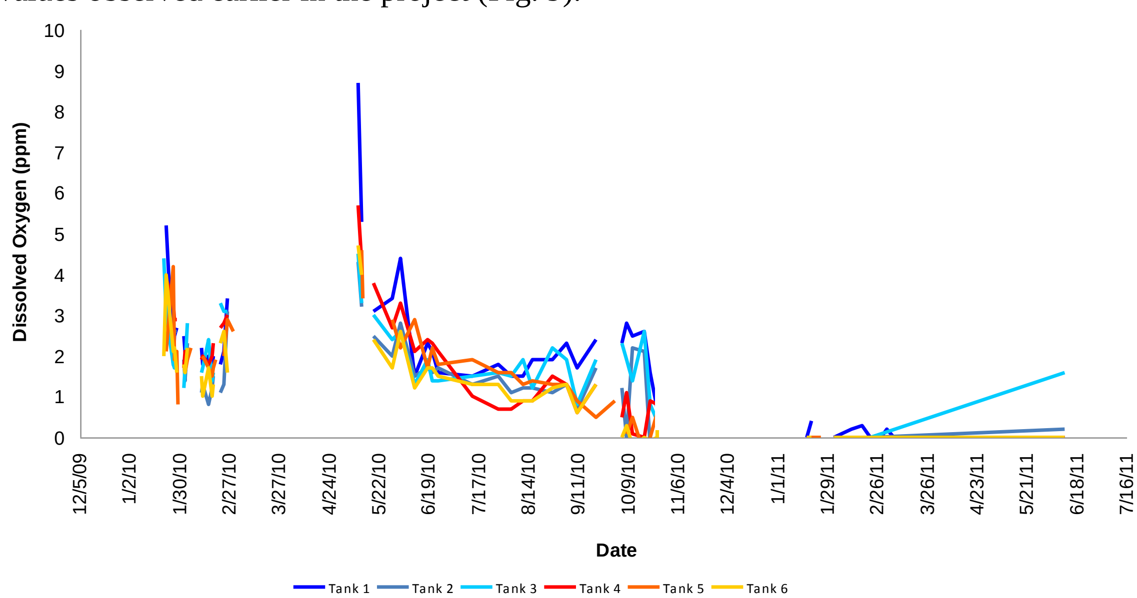


Figure 9. Dissolved oxygen concentration measured in anaerobic digester slurries.

3c. Gas production: Psychrophiles vs. mesophiles at two temperatures

Biogas production was observed throughout the majority of this project. Within two days to two weeks after initial set up, all tanks were producing flammable biogas. The methane content of the gas decreased when tanks acidified in winter 2010 due to over-feeding; however, flammable biogas production was again demonstrated in all tanks except Tanks 2 and 3 by December 2010 (Table 1). Throughout the duration of the project we qualitatively observed that anaerobic digesters in the tepid room produced more biogas than digesters in the cold room.

Table 1. Results of flammability tests

Tank	First positive flame	Last confirmed flame
1	1/31/10	6/6/11
2	NA	NA
3	1/22/10	2/1/10
4	2/1/10	6/6/11
5	1/21/10	6/6/11
6	1/26/10	6/6/11

After improving the method for quantitative measurement of gas flow rates, we found that indeed, biogas production was on average 6 times higher in the psychrophile-only digester in the 25 ºC room (Tank 4; 275 ± 90 L gas d^{-1} expressed as average ± standard deviation) compared to the psychrophile-only digester in the 15 ºC room (Tank 1; 46 ± 23 L gas d^{-1}) (Fig.10).

The psychrophile-only Tank 4 (275 ± 90 L gas d^{-1}) had the highest average biogas production rate among all digesters, and produced roughly 60% more biogas per day than the mesophile-only Tank 6 (173 ± 82 L gas d^{-1}) in the 25 ºC room. Tank 5 in the 25 ºC room, containing a mixture of psychrophile-rich lake bottom mud and mesophile-rich manure, produced biogas at a similar average rate to Tank 4 (265 ± 80 L gas d^{-1}), and exhibited the highest maximum daily production rate among all digesters (559 L gas d^{-1}) during the period of measurements.

It should be noted that these biogas production rates were approximate estimates on several dates owing to observed spills from the tanks during measurement on three days each for Tanks 4 and 5, and on two days for Tank 6 (Table 2). Due to a lack of sufficient pressure (e.g. low biogas production) in Tanks 2 and 3 we were unable to obtain flow rate measurements in 2011.

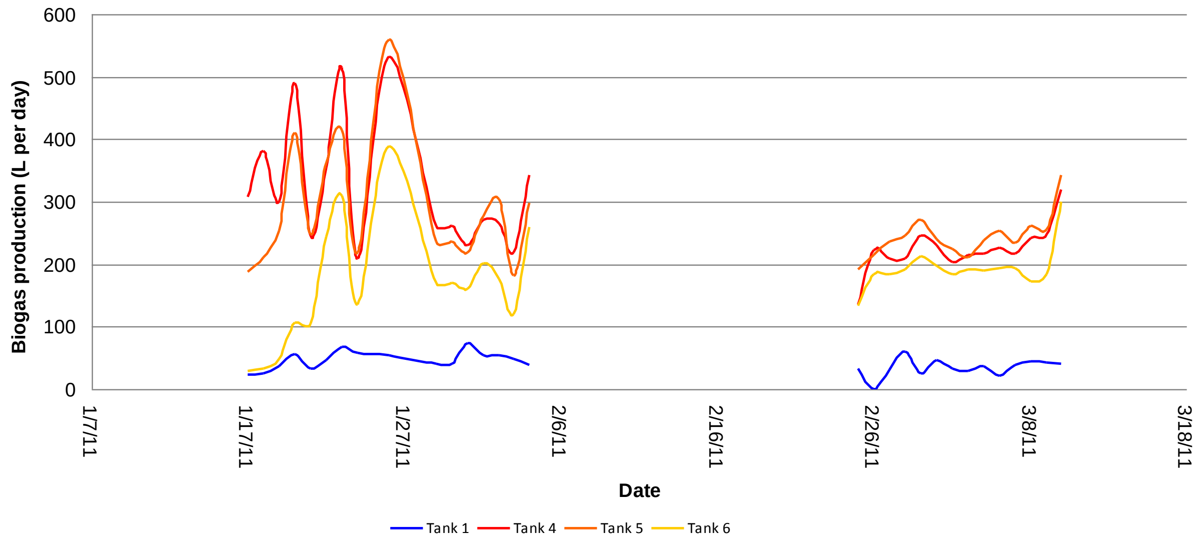


Figure 10. Biogas production, normalized to 1000-L of slurry per digester, observed in Tanks 1, 4, 5 and 6 during winter 2011. Fluctuations in production are an artifact of the sampling method, where tanks were sealed for 6-8 hours to build pressure in between gas flow readings.

Table 2. Daily biogas production values for winter 2011, normalized to 1000-L of slurry volume. The values represent average gas production within a 24hr period for each tank. On several occasions, built up gas pressure contained in the headspace of the reactors caused tanks to expel some of their liquid contents from the tanks (indicated by *). Dates of occurrences of tanks spills were both documented and undocumented as students may not have reported a spill during several instances when researcher and teacher support was not available.

Gas Production Summary Data (L gas d^{-1} normalized to 1000-L of slurry)

	15°C Room			25°C Room		
Date	**Tank 1**	**Tank 2**	**Tank 3**	**Tank 4**	**Tank 5**	**Tank 6**
12/11/2010	33	0	0	188	195	0.5
12/12/2010						
1/17/2011	23	0	0	308	187	28
1/18/2011	25	0	0	382	210	32
1/19/2011	37	0	0	300	254	49
1/20/2011	56	0	0	491	410	107
1/21/2011	32	0	0	246	247	104
1/22/2011	46	0	0	353	361	244
1/23/2011	68	0	0	514	413	310
1/24/2011	58	0	0	209	218	135
1/26/2011	53	0	0	532	559	390
1/29/2011	41	0	0	*260	236	170
1/30/2011	41	0	0	260	236	170
1/31/2011	73	0	0	230	*218	160
2/1/2011	55	0	0	270	277	201
2/2/2011	54	0	0	266	304	176
2/3/2011	49	0	0	*219	181	*120
2/4/2011	39	0	0	343	298	259
2/5/2011						
2/25/2011	32	0	0	135	191	133
2/26/2011	1	0	0	222	*215	184
2/27/2011	32	0	0	209	235	183
2/28/2011	59	0	0	209	246	191
3/1/2011	25	0	0	246	271	212
3/2/2011	47	0	0	231	241	198
3/3/2011	32	0	0	203	225	185
3/4/2011	28	0	0	*215	*211	192
3/5/2011	37	0	0	217	238	189
3/6/2011	21	0	0	226	254	194
3/7/2011	38	0	0	217	235	194
3/8/2011	45	0	0	241	262	*172
3/9/2011	43	0	0	247	256	185
3/10/2011	41	0	0	319	343	300
3/11/2011						
6/1/2011	47					
6/11/2011	105					
6/12/2011	116					
6/13/2011	86					
Average	**46**	**0**	**0**	**275**	**265**	**173**
Standard Dev.	**23**	**0**	**0**	**94**	**80**	**82**
Daily Max.	**116**	**0**	**0**	**532**	**559**	**390**

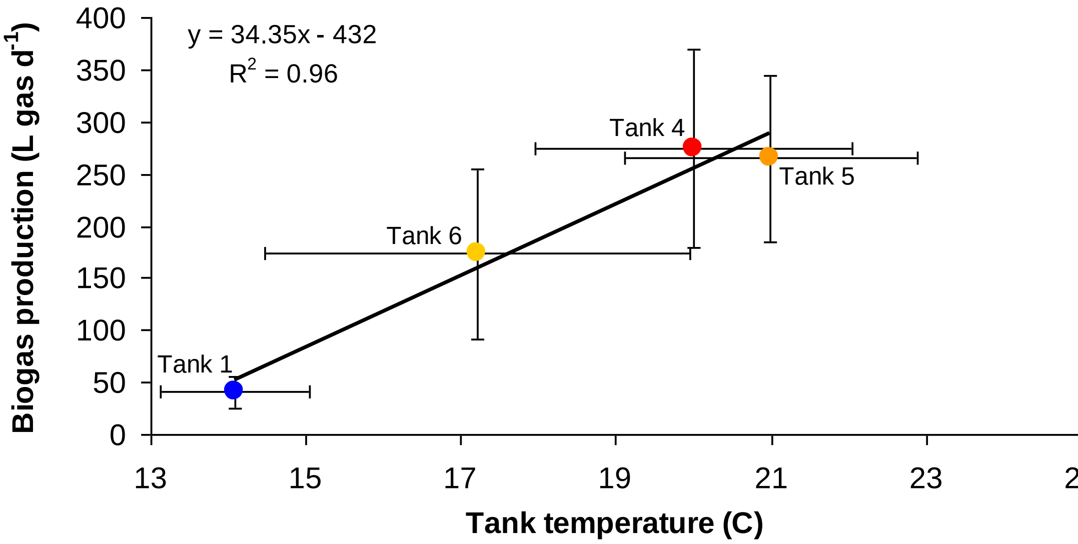


Figure 11. The linear relationship between average daily biogas production and the average temperature of digesters on days of gas production measurements.

3d. Biogas composition

Gas samples collected over the course of the project map the internal environment of each reactor during the experiment. In general, all tank headspace gases exhibited a large increase in methane (CH_4) concentration from the start to end of the study (Fig. 12). Peak methane concentrations were recorded at one time during the experiment as high as 82% by volume. The high concentration was likely due to a pause in feeding over the holidays leading to increased methanogenic/acetogenic activity ratios (Massé, et al., 1997). However, subsequent samples collected during the second year of the project had an average methane concentration of 65% by volume, similar to most anaerobic digester operations (40-60% CH_4) (House, 1978).

Though the target, high-energy molecule in this experiment was methane, other gases also helped illustrate microbial activity as well as overall system health (Figs. 13-15). Atmospheric gases, such as oxygen and nitrogen, were found early in the study in significant quantities (> 5% by volume) among certain tanks, but decreased in samples collected later in phase 1 and 2 of the project (Figs. 6 and 7) after discovered leaks were repaired. Several samples with elevated oxygen and nitrogen concentrations were due to errors in sampling (atmospheric contamination). Finally, a consolidated sample was collected from gas stored in the large biogas collector installed on June 1, 2011. The sample was known to contain trace atmospheric gases as the headspace of the containment vessel was not completely evacuated prior to collecting biogas.

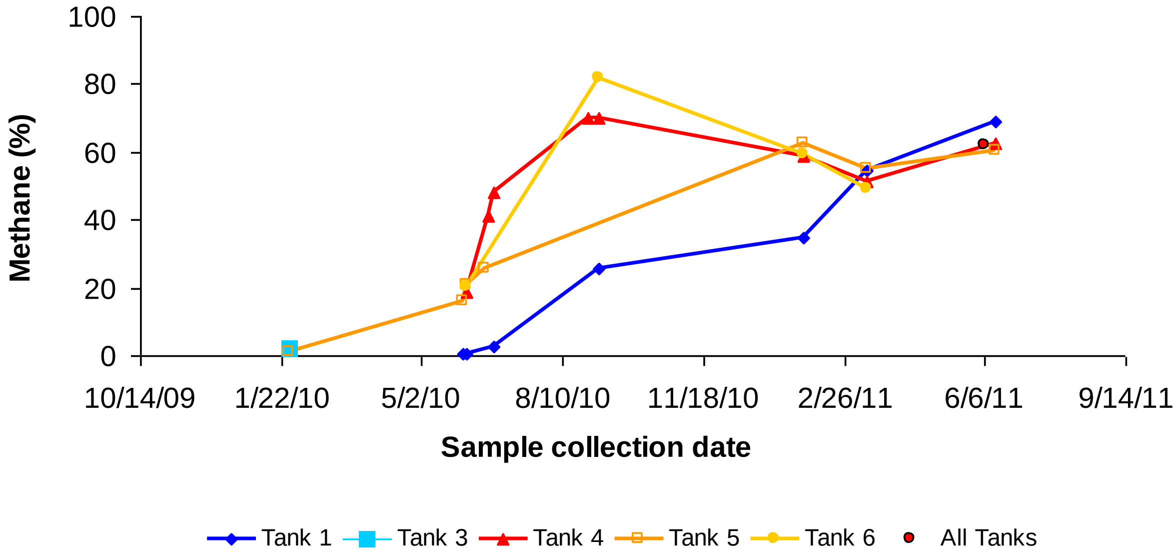


Figure 12. Methane (CH_4) concentration in biogas samples determined on a Shimadzu 2014 gas chromatograph equipped with FID and TCD. The concentration of gases is presented as percent by volume. It should be noted that 70% CH_4 in Tank 4 shown for Aug. 28 and Sep. 5, 2010 was calculated as a correction to lower concentrations measured in samples due to a leak in the sampling system. Both the samples from August/September Tank 4 had the same methane/carbon dioxide ratio - =4.4 Based on a review of the other biogas samples, this should put the methane level of the biogas at ~65-70%, after correcting for presumed dilution from air contamination. The fact that the two samples had the same ratio of these gases, despite a two-fold difference in the methane level, is a good indication that the low reading is due to dilution by atmospheric air in the sample collection stage.

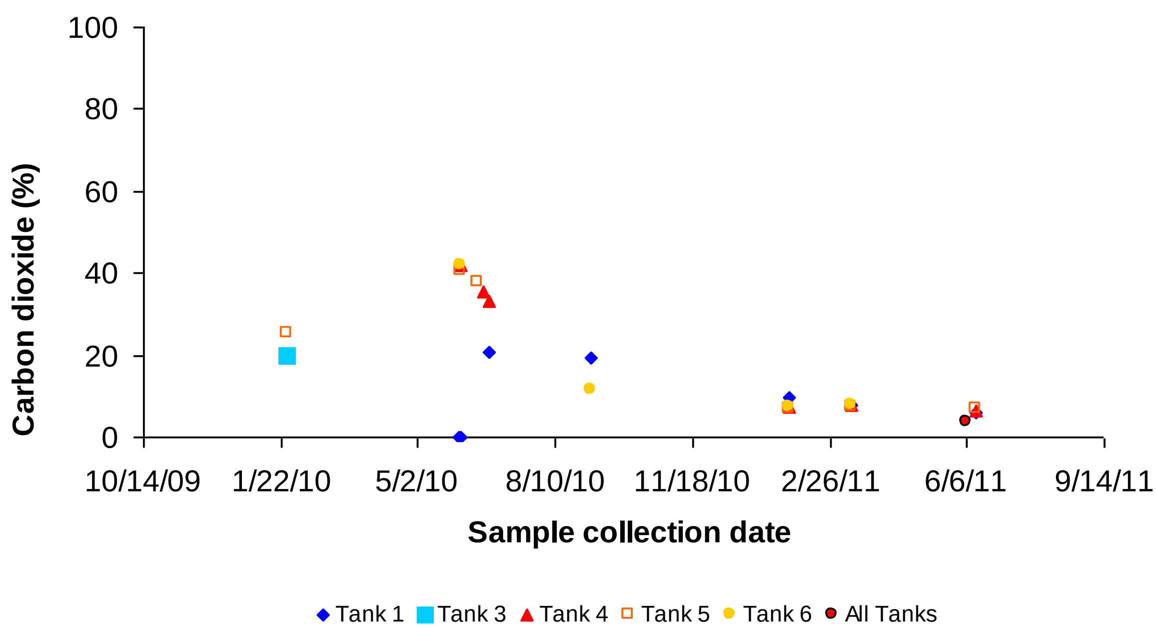


Figure 13. Concentration of carbon dioxide (CO_2) in digesters, presented as percent by volume.

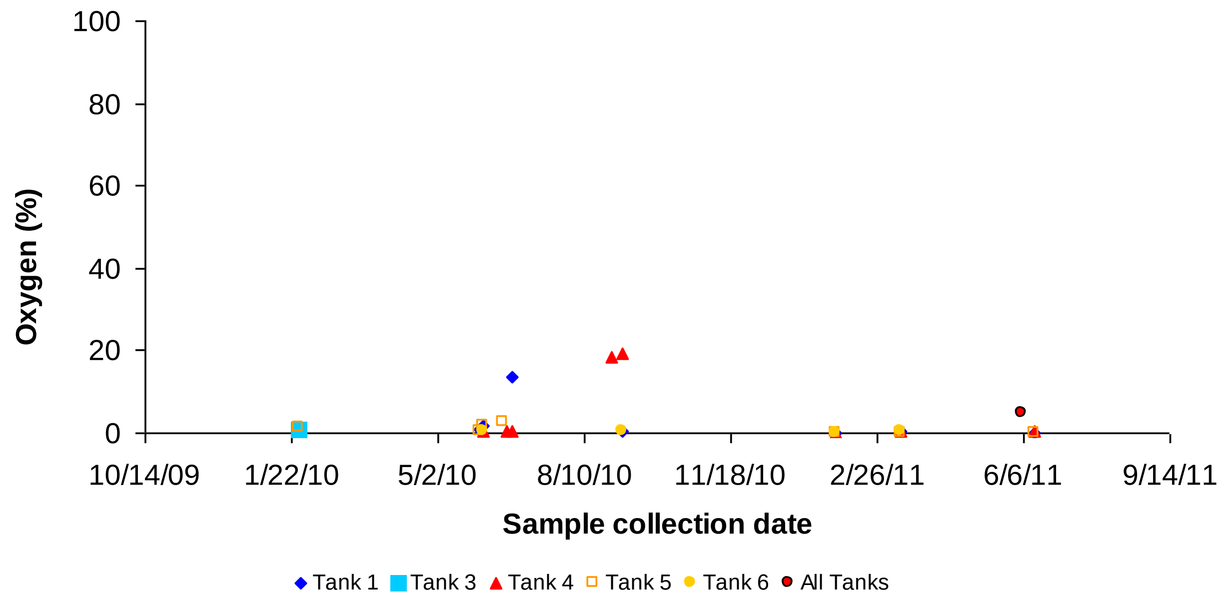


Figure 14. Concentration of oxygen (O_2) presented as percent by volume. Air contamination was known to be present in the samples with $O_2\% > 2\%$, and was an artifact of sampling rather than an accurate representation of digester headspace O_2 concentration.

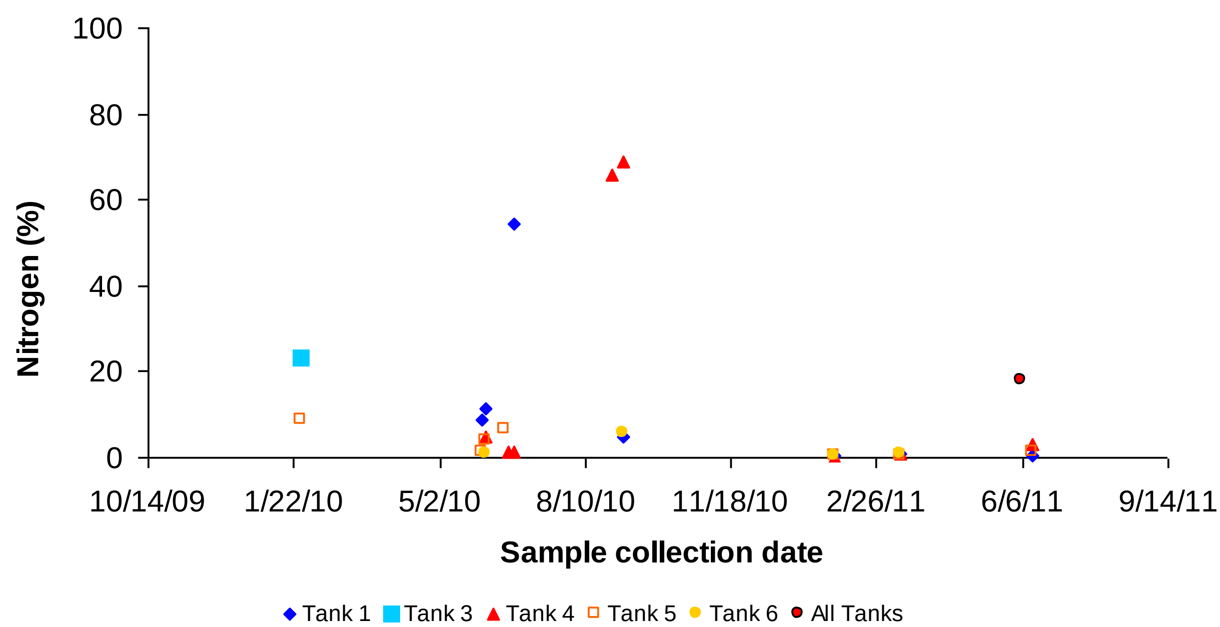


Figure 15. Concentration of nitrogen in digesters presented as percent by volume. Air contamination was known to be present in the samples with $N_2\% > 25\%$, and was an artifact of sampling rather than an accurate representation of digester headspace N_2 concentration.

3e. BTU content of biogas

Using Equation 1 together with results of methane concentration in biogas samples we determined the BTU content of biogas. The highest observed production rate of any given 1000-L tank within a twenty-four hour period was 559-L d^{-1}(Table 2). Combining the observed production rates with the average methane concentration of biogas collected from the site (~67% CH_4 by volume), gas collected at the end the project, had an equivalent BTU rating of approximately 1,275 BTU day^{-1} per digester. Applying the average methane concentration to the average production rates observed in the tepid room digesters, the average BTU production was 3,950-6,270 BTU d^{-1} per digester. It is important to note, that this BTU rating is helpful in calculating possible efficiencies of combustion across a range of gas powered devices, but should not be viewed as a static number as the methane content of produced biogas changed over time (Fig. 12) and should therefore be viewed only as a helpful approximation of gas heat content.

Equation 1. Rating BTU content of biogas

$$\frac{Production\ Rate \times Gas\ Composition\ \% \times Density\ of\ CH_4\ @\ 1bar}{100} = g\ CH_4$$

$$g\ CH_4 \times \frac{1\ mol}{16.042g} CH_4 = moles\ of\ CH_4\ per\ daily\ output$$

$$n\ Mols\ CH_4 \times \frac{891kJ}{mol} CH_4 = n\ kJ\ per\ day^*$$

$$1\ kJ \cong 0.95\ BTUs\ \therefore\ equivalent\ measure\ of\ gas\ energy\ content$$

* MSDS for Methane (source: encyclopedia.airliquide.com)

3f. Nutrient content of digester effluent

In addition to methane-energy, biogas digesters have the added benefit of producing nutrient-rich organic fertilizer that can be used in agricultural and horticultural efforts. Effluent samples collected over the course of the experiment yielded mixed results with regard to the amount of available nutrients produced from each tank. Analyses were conducted to test the relative concentrations of chloride, fluoride, nitrate, nitrite, phosphate and sulfates using High Pressure Liquid Chromatography. Other tests to measure concentrations of ammonia and ammonium were not available. Samples were run after proper calibration tests were performed to ensure accurate measurement and to track instrument performance during the analysis (Fig. 8).

Concentrations of only chloride and phosphate measured above the detection limit of the instrument used during the analysis. Chloride is commonly used for potable water treatment and showed a strong absorption signal in all samples. This is explainable through the projects use of tap water during the course of the experiment. Phosphate concentrations were observed in most samples in low to moderate concentration(s) – between 5-55 ppm (Table 3).

Table 3. Phosphate concentration in liquid organic fertilizer sampled on n different dates. All samples were run on a Dionex LC 20 chromatograph with Chromeleon data processing software package.

		Phosphate (ppm)			
Tank	*n*	mean	stdev	min	max
1	1	9.0			
2	4	9.0	6.7	5.0	19.0
3	4	17.3	7.4	12.0	28.0
4	1	42.0			
5	1	30.0			
6	5	36.8	10.6	28.0	55.0

3g. Odor

Qualitative measures of relative odor among tanks were noted during the research phase of the project. We found that digesters containing lake mud-only had a more agreeable odor than digesters containing manure. Tanks inoculated with psychrophilic methanogens from the thermokarst lake were said to exhibit a smell much like that of a pond or bog. The odor was found to be an earthier and less unsettling smell than that of mesophilic tanks, which smelled of animal manure, the traditional "barn-like" odor commonly used to describe anaerobic digestion facilities, commercial and small-scale. Upon wafting, even the lake-mud-only tanks exhibited a strong ammonia-like smell. Analytical instrumentation was not available for quantification of ammonia, though ammonia is commonly observed in other biogas digesters (Brock, et al. 1970; House, 1978; Gerardi, 2003).

Phase II Results

3h. Biogas storage

Phase II efforts to collect, store, distribute and demonstrate end-use applications of the biogas technology were largely successful. We designed and implemented a new gas collection system suitable for small-scale applications in Alaska. The system, based on a telescoping holding tank principal (Fig. 3), is simple and easy to assemble in areas where elaborate mechanized storage and gas delivery systems are not available. Gas pressurization was accomplished by placing additional water weight above the 500 gallon (~2000L) holding vessel, though brick or other weight equivalent could be used in areas were water resources are scarce. During the phase 2 experimental stages, the gas was collected from the primary digesters in the Conex using the telescoping storage system, and delivered for use in a variety of applications to demonstrated biogas utility as a source of combustion fuel. The most notable demonstration projects included the use of biogas as a cooking fuel with a cast iron single-burner stove, powering of a 4-cycle lawn mower engine, production of electricity using a converted gas-powered generator and use of digester effluent as liquid fertilizer in a student project greenhouse.

3i. End use testing

Demonstrating small-scale applications of biogas technology was the primary goal of Phase 2. Through a variety of projects utilizing combustion, conversion, and transduction capabilities of biogas energy as well as provided educational opportunities for students interested in alternative energies. Phase 2 demonstrations took the form of the continuous powering of a combustion engine and electrical generator, use of biogas as a stove fuel, and application of organic liquid fertilizer obtained from digester effluent. These demonstration projects enhanced the curriculum of Cordova High School students who worked with and presented their findings on the project in multiple appearances at conferences around the state. Photographs of the demonstration projects are provided in Appendix 2. The following section addresses each of the phase 2 project results:

Generator. An 1850 Watt electrical generator (Husky) was operated solely on biogas collected from individual project reactors in June 2011. By augmenting the engine carburetor and installing a tri-fuel gas conversion kit, this gasoline powered generator was adapted to run on a variety of gaseous fuels, including biogas. Initial efforts to start the generator were unsuccessful due to limited gas availability and generator requirements for ignition. After raising the pressure of biogas delivery to approximately 0.5-psi and injecting small amounts of ether starting fluid, the generator fired on the first draw of the pull-start cord. At pressures below 0.5-psi the engine was able to maintain idle, but could not achieve sufficient revolutions per minute (RPM) in order to sustain 120V 60Hz AC power. Generator performance was monitored with a 3500K 23W CFL light bulb which maintained continuous luminous quality during generator operation.

We achieved increased gas pressure by adding a second tank on top of the telescoping collection vessel used to store gas and filling it with approx. 175 Gal of water (D_{H2O} @ 15°C = 1000kg/m^3 or 8.34 lb/US gallon). The resulting water weight (approx. 1500 lbs) was enough to increase the pressure in the gas line to about 0.5-psi, sufficient to operate the generator. To this end, the 1850 Watt generator was rated at a consumption rate of approx. 300 gal/hr or ~1,100 L/hr.

Cooking fuel. The primary application for small-scale anaerobic digester technology around the world is in production of biogas for use as a cooking fuel. With minimal amounts of positive pressure, biogas from the Conex digesters sustained a continuous, clean-burning flame once ignited by local spark and/or flame. By adapting a cast iron single-burner stove with natural gas conversion kit, the project was able to boil water and fully cook a variety of foodstuffs using gas collected from project reactors. Using biogas to fuel the stove, 4 liters of water were boiled (T_i = 15°C, placed in a covered pot) within 20 min of exposure to flame. The stove sustained a continuous flame throughout the demonstration despite being in an open, outdoor environment. The stove was used to cook a meal consisting of hot dogs and carrots, consuming roughly 300 L of biogas per hour (~80 Gal/hr).

Liquid fertilizer. In addition to nutrient analysis confirming reactor effluent benefits as a liquid fertilizer treatment for nutrient poor soils (Table 3), Cordova High School students tested samples of reactor slurry in a controlled greenhouse experiment to provide further evidence on nutrient qualities of digester effluent. To duplicate sets of plants, students supplied either the liquid fertilizer from the tank 4 digester, or water as a control. Tank 4 effluent exhibited considerable nutrient values when applied to several different plant species within greenhouse trials. Nutrient analysis of all tanks later confirmed elevated levels of phosphate as high as 55ppm (Table 3), indicating potential use as a fertilizer treatment to soils lacking in sufficient nutrient content (Swift, 2009). Students contend that there was a noticeable difference in height, leaf fullness and health of several plant species treated with effluent over those which only received water additions. Project Administrator, Clay Koplin, visited the site and confirmed the positive response of plants subject to the digester liquid fertilizer. The largest differences in growth were observed among the flowering plants, *Lilium Pumilum* and Asiatic Pink Pixies, which responded very well to effluent treatments; however, others like *Lilium Regales* and Asiatic Orange Pixies hardy grew at all when given effluent treatment. Less of a difference in size was noted among the food crop plants, but it was observed that plants fertilized with effluent tasted better on many occasions during blind taste tests. One exception was the root and carrot plants, which were said to not be very appetizing when treated with effluent fertilizer, though no note was provided on whether this was due improper washing/preparation of the crop or if the undesirable taste came from flavors incorporated into the plant roots themselves. No quantitative biomass or root/shoot length measurements were taken.

Curriculum enhancement. Student-led projects were a major component of Phases 1 and 2. In Phase I, students from the high school chemistry class and science club were charged with daily food processing and feeding during phase 1 of the study. The students came together on several projects intending to streamline the process which resulted in a number of useful innovations including construction of an industrial sink with built-in insinkerator and improved feeding practices. During Phase 2, students and teacher Adam Low took the lead in design, setup and maintenance of a greenhouse experiment to test effluent nutrient characteristics (with assistance from Clay Koplin at CEC). Low and students purchased and converted an 1850W gas-powered generator and 4-cycle lawn mower engine to run on biogas using inflatable tire inner tubes to transport and deliver the biogas from project reactors. Several students went further into performing purification test of biogas by bubbling and collecting gas run through a saturated lime water column. Others still, conducted calorimetry tests in order to approximate the heat value and BTU properties of biogas produced compared to other known and available fuel-types. With these and other demonstrations, students used the biogas project as a platform for state science fair projects in both 2010 and 2011 conferences, held in Anchorage.

In addition, students presented on the project at a host of difference conference meetings and alternative energy forums. Further information on the educational benefits of the project at the Cordova High School is contained within section VI of this report.

3j. Public outreach and dissemination

This project, performed through collaboration among a local public utility, city high school and a research university was intended from the beginning to have a large emphasis on public outreach and information dissemination. The project received a substantial amount of publicity since ground broke in winter of 2009 and has enjoyed high praise and support from multiple areas of local and state government. Students, researchers and other team members have traveled to numerous conferences in the past two year to discuss the project and its goals as well as share information about biogas technology and the Emerging Energy Technology grant in general.

High school students and UAF researchers were given the opportunity to present on project ideas and preliminary results at meetings with the Alaska Power Association and Alaska state legislators in Juneau, and at a variety of conferences, including the Alaska Rural Energy Conference (April 27-29th, 2010) and the Alaska Forum on the Environment (February 7-11th, 2011). In February 2010, the chemistry students took a class trip to the Alaska Power Association, where students C. Bailer, D. Hess, C. Morrissett, J. Smyke, S. Lindow, and T. Kelley presented on the project. Most recently, the project research was featured during ACEP's lecture series for the month of June 2011. The talk, given by Casey Pape, was hosted at the Blue Loon in Fairbanks. Slides as well as video of the speech can be found online (www.uaf.edu/acep/publications/). A final presentation will be made at the Alaska Rural Energy Conference in Juneau (September 27-29, 2011).

Titles of our project presentations and other public dissemination documents are:

Walter Anthony, K., Culhane, TH., Koplin, C., McFadden, L., Low, A. "Improving Cold Region Biogas Digester Efficiency." McFadden, L. Alaska Forum on the Environment. Anchorage, Alaska. February 8-12, 2010.

Bailer, C., D. Hess, C. Morrissett, J. Smyke, S. Lindow, and T. Kelley, "Methane Digesters using Psychrophiles", Invited talk, Alaska Power Association, Juneau, Alaska. February 2010.

Walter Anthony, K., Culhane, TH., Koplin, C., McFadden, L., Low, A. "Improving Cold Region Biogas Digester Efficiency." Low, A., Hess, E., Allen, J., Americus, I., Americus, B., Zamudio, A. Alaska Rural Energy Conference. Fairbanks, Alaska. April 27-29, 2010.

Pape, C. and the Project Team, "Energy from Psychrophilic Bacteria: A Cold-Region Alternative for Biogas", ACEP Community Energy Lecture Series, Fairbanks, Alaska, June 21, 2011.

New Scientist article featuring this project: "Cold climates no bar to biogas production". November 4, 2010. <http://www.newscientist.com/article/mg20827854.000-cold-climates-no-bar-to-biogas-production.html>

The project was featured by Alaskan Dispatch Magazine in an article on rural Alaska entitled, "Biogas could bring new energy to rural Alaska". January 17, 2011. <http://www.alaskadispatch.com/article/biogas-could-bring-new-energy-rural-alaska?page=0,0>

Low, A. "Youth Participation: Improving Cold Region Biogas Digester Efficiency." Low, A., Bailer, C., Allen, J., Americus, B., Zamudio, A. Alaska Forum on the Environment. Anchorage, Alaska. February 8, 2011.

Walter Anthony, K., Culhane, TH., Koplin, C., Low, A., Pape, C. "Improving Cold Region Biogas Digester Efficiency." Low, A., Bailer, C., Allen, J., Americus, B., Zamudio, A. Denali Commission Public Forum on the Emerging Energy Technology Grant. Juneau, Alaska. February 14-15, 2011.

The project was highlighted in Senator Lesil McGuire's recent press release on the 'Deadline for Emerging Energy Technology Fund Grant Applications Approaching'. Released March 3, 2011. http://www.aksenate.org/mcguire/030311EmergingEnergyFund.pdf

Pape, C. and Walter Anthony, K. (2011) "Biogas Technology in Alaska". ACEP Flyer Publication. Cooperative Extension Services, Fairbanks, Alaska.

Americus, B., Allen, J., Zamudio, A., Pape, C. "Cold Climate Anaerobic Digestion: Psychrophiles in Biogas Digesters" Alaska Rural Energy Conference. Juneau, Alaska. September 27-29, 2011.

Website for the project: www.cordovaenergycenter.org/

4. Discussion

4a. Phase 1 hypothesis testing

Phase I results supported the Hypothesis 1 that biogas production will be greater at tepid (25 °C) temperature than at cold (15 °C) temperature. Gas production rates were on average six times higher in the psychrophile-only tank 4 maintained in the tepid room than the psychrophile-only tank 1 maintained in the cold room. Similarly, no significant biogas production was observed among cold room tanks containing manure, while considerable biogas was produced in tanks 5 and 6 containing manure in the warm room. At no time during the entire study period did biogas production from cold room tanks exceed daily production rates of adjacent tanks in the tepid room (Fig. 10). The considerable divergence in daily gas production rates observed in tanks between the cold and tepid rooms suggests a strong temperature control on anaerobic digestion and methanogenic activity, such as has been found in other studies (Brock, et al. 1970; Metcaff and Eddy, 1991; Gerardi, 2003). When we plotted average biogas production as a function of average tank temperature, we also found strong temperature dependence among all tanks (Fig. 11).

With the exception of different starting inoculate microbial regimes (psychrophile-rich lake bottom mud vs. mesophile-rich manure), all tanks received identical quality of feedstock treatments and were treated in a similar manner. At times the quantity of feeding was adjusted in some tanks to avoid overfeeding, which can lead to souring, or acidification, of the slurry. Remarkable similarity in digester chemistry among all tanks, except tank 3 (Figs. 7-9), indicates that experimental conditions remained relatively consistent among tanks, and that differences among tanks were likely due to microbial community and temperature.

High variability in biogas production is explained in part by temperature; however other factors likely influenced the health and viability of methanogen populations in tanks. During the early stages of the biogas production test period, we began to observe acidification in most tanks

(Fig. 7). We expect that acidification was the result of overfeeding. When the metabolic rate of the methanogen community was insufficient to consume the large quantity of volatile fatty acids (VFAs) and acetate intermediates created by acetogenic microbes within each of the reactors (Gerardi, 2003), acid intermediates accumulate and effectively lower the pH to levels that can further inhibit methanogens, leading to a negative feedback in methane production. When the population and metabolism of methanogens is sufficient, simultaneous conversion of organic feedstock to VFA and acetic acid intermediates to methane and carbon dioxide occurs, and acidification concerns are averted. Excessive feeding prior to adequate establishment of methanogenic populations likely exacerbated the ratio of acetogenic/methanogenic activity and tank acidification to a greater extent in the cold room tanks than in the tepid room tanks, potentially knocking down methanogens more in the cold room than in the tepid room.

Chemical remediation steps were taken to avoid a collapse of each tank's microbial system and were largely successful within the first year of study. Additions of basic chemicals (i.e. Lime, calcium carbonate, and sodium hydroxide) were used to help restore system pH to optimal norms (6.8 – 7.2). These efforts regained digester activity among all tanks by early June 2010, with the exception of tank 3 which continued to exhibit acidic conditions (pH 4.82) through the duration of the project. Biogas production successfully resumed in all tepid room tanks (25°C), but only within tank 1 in the cold (15°C) room. Biogas production apparently ceased in tanks 2 and 3 despite continued additions of feedstock. Low tank acidity for extended periods of time undoubtedly weakened microbial communities within tanks 2 and 3, combined with depressed temperatures which likely resulted in failure of each tank's microbial community. The decreased activity in tank 1 (psychrophiles only) and complete inactivity among tank 2 (psychrophiles and mesophiles) and 3 (mesophiles only) in the cold (15°C) room provides clear evidence in favor of initial predictions about mesophile activity at depressed temperatures. However, evidence from tank 2 suggests that perhaps acidic activity was the predominate cause of tank(s) 2 and 3 becoming inactive as tank 2 contained psychrophilic cultures that would have been expected to continue production even when mesophilic contributions ceased. Despite acidification under depressed temperatures, no other cause can thoroughly explain why tanks 2 and 3 exhibited crash during the experiment as all tanks in the warmer 25°C room recovered fully from acidification after sufficient chemical remediation.

Through one set of trials, we found that increasing the feeding rate did not result in greater biogas production. However, increasing temperature in the cold room at the end of the study, from 15°C to 35°C increased production in tank 1. It is likely that Since the digester had not been fed in several months, we cannot be certain that there was enough remaining organic substrate in the digester to demonstrate its optimal gas production rate. However, these results did suggest that increasing temperature had a positive effect on gas production.

Temperature conditions varied substantially over the course of the experiment. Digester temperatures were lower during colder winter months and warmer in summer, though on average, the temperatures of the cold and tepid rooms were on target: 15.4°C and 25.6 °C respectively. A large effort was put forth during the initial experimental setup to properly insulate the project Conex and keep both rooms at constant temperature; however, electrical heating units and the initial electrical capacity of the site proved to be inadequate in order to maintain proper temperatures (15°C and 25°C respectively) during extended cold winter conditions. These seasonal temperature fluctuations are not unlike what would be expected in many Alaska residences.

Our results are inconclusive to support Hypothesis 2 that at any given cold or tepid temperature, tanks inoculated with cold-tolerant microorganisms (psycrophiles) from

thermokarst lakes will produce more biogas than tanks inoculated with warm-loving microorganisms (mesophiles) in manure. While the gas production data alone suggests that digesters containing lake mud had higher gas production rates than the digesters containing manure only in both temperature rooms, when average tank biogas production was plotted against average tank temperature, the data showed a linear relationship between gas production and temperature (Fig. 11). A likely reason for lower gas production rates in tank 6 (manure only, tepid room) was that the average temperature of that digester was lower than tanks 4 and 5. Tank 6 was located next to two exterior walls, and likely lost more heat than tanks 4 and 5. It is possible that a slight inhibitory effect of the mixed culture tank 5 (mud + manure) was observed as the biogas production rate in this tank was lower than what would be expected based on the trend line; however, there was too much variability in the data to draw a firm conclusion. It should also be noted that several recorded slurry spills were noted that obscured flow measurements during the study; however, the magnitude of these spills (<10 L per spill) was small relative to other sources of variability so they likely did not play a significant role.

Without genetic characterizing the microbial communities, we cannot say for certain what the fate of true psychrophiles and mesophiles was in our digesters. While we have no reason to think that cross contamination of the microbes from the lake mud and manure occurred in the digesters, we cannot rule out that this did not happen. It is very likely that the temperature and chemical fluctuations in the digesters benefited some types of microbes and inhibited others, and that the microbial consortium in the digesters at the end of the study was quite different than what it would have been initially in comparison to the original lake mud and manure microbial communities. Ideally, to confirm results of testing Hypothesis 2, microbial culturing and analysis of microbial DNA would have been conducted on the initial lake mud inoculum, manure inoculum, and each of the digester slurries at the end of the study period; however, microbial DNA work was outside the scope and budget of this project. Microbial analyses would be an exciting direction for future work in this field to go.

Phase I results did support Hypothesis 3 that, biogas production at cold temperatures (15-25 °C) will not be as efficient as at warm temperatures (35-50°C). The maximum daily biogas production rate we measured was 0.559 L gas per liter of slurry per day (L/L/day). Average values ranged from 0.046 (tank 1) in the 15°C room to 0.173 (tank 6), 0.265 (tank 5), and 0.275 (tank 4) L/L/day in 25°C room. These production rates were lower than those observed in other household scale digesters in warm climates and in warm, temperature-controlled projects in Alaska. Biogas production from Alaskan fish waste was demonstrated at 1.0 -1.1 L/L/day in traditional mesophilic batch digestion scenarios at warmer temperature regimes (35°C) (Hartman, et al., 2001). At the 1000-L scale digesters, we measured up to 559-L of biogas production per day under relatively cold temperatures. In comparison, typical 1000-L household scale digesters in India and other countries are known to produce 1000-L of biogas per day, but they are located in warm climates where temperatures (35-40 °C) are more optimal for mesophile metabolism (Karve, A. D., 2011). Extrapolating the linear relationship we observed between the average rate of biogas production and the average tank temperature in this study [Biogas production (L/day) = 34.35*Temperature (°C) – 432], then at 35-40 °C, biogas production rates in our digesters could have increased to 0.77-0.94 L/L/day (770-940 L d^{-1} per digester), similar to warm temperature biogas digester production rates. However, without knowing the temperature response from the microbial communities in our specific digesters, it is not possible to extrapolate these results with a high level of certainty.

4b. Lessons learned and recommendations for the technology

Through this project a great deal of information was gained regarding the benefits and limitations of biogas technology at the small-scale in Alaska. Data on the relative labor required to build and maintain small-scale digesters, as well as the affects of temperature, acidity, feeding and BTU rating/fuel offset characteristics of produced biogas from mesophilic and psychrophilic bacteria cultures were well documented.

Challenges of flow data measurement. Prior to this study, little information was available on gas production monitoring techniques for small-scale biogas technology. Approximate production rates were estimated at around 1,000-L gas per 1,000-L digester fed 2kg food per day, but this was not an analytical measurement. The inherent difficulty is due in large part to the very low volume and pressures generated at the small-scale. Commercially available instrumentation is difficult to calibrate when flow rates are on the order of fractions of mL/sec. During the project, several techniques were developed that answered this question and are a major accomplishment of this study. First we achieved a labor-intensive method of allowing gas to build pressure inside of the digesters for 6-8 hours so that when the outflow valve was opened, the gas flow rates were high enough to obtain reliable data within the calibration range of Sierra flow meters. Second, we developed a less expensive, less labor intensive method for measuring lower flow rates using a submerged tipping cup coupled to an event data logger. Based on the results of this study, two separate techniques now exist for testing and quantifying gas production for biogas digesters at the small scale.

Limitations of the technology at the small-scale. Based on the findings of this study, several recommendations for the future of biogas technology in Alaska can be offered at this time. It is clear, that of all variables which influence biogas production, temperature still remains the most formidable obstacle for digester projects at the small-scale. Though psychrophilic additions were demonstrated to improve digester conversion efficiency at low temperature, the BTU quantity of gas produced was not sufficient to meet the heating requirements of digesters at this scale. At elevated temperatures (>30^{o} C) in other climatic zones, household-scale biogas reactors are used in millions of homes to produce enough fuel to be used in practical daily applications, typically as a cooking fuel. In Alaska, however, replication of biogas technology is not economically viable because digesters require external heat sources. In situations where excess thermal or waste heat can be diverted in order to heat digesters, projects of smaller-scale (1000-2000L) may still be justifiable for the additional products they offer by way of secondary energy recovery (i.e. the formation of a clean-burning gaseous fuel), reducing waste stream and waste water treatment costs and production of liquid fertilizer for seasonal crop production.

This study aimed to test the feasibility of small-scale biogas digesters in Alaska that are typically intended for use by single-family, traditionally low-income rural peoples located within the equatorial region. For homes in places like India and China for example, daily per capita energy consumption is much lower than that of the typical Alaskan home of similar size and therefore additional scalability would be required in order to meet Alaskan individual heating and energy needs. Likely infrastructure and capital requirements to operate at this scale would not be cost competitive with current alternative fuel-types. For this reason, anaerobic digesters intended for the individual family-scale are not likely to catch on in great number within Alaskan communities.

Upscaling biogas in Alaska. The most likely future of biogas in Alaska lies in upscaling the technology. One great disadvantage of biogas technology within colder-climate regions is that it often only becomes cost competitive at the very large scales of operation. Large facilities that can process great quantities of waste (thousands of tons per year), are often required in order produce enough gas in order to justify the large capital investment in staff and mechanized equipment needed to maintain high process efficiency. Facilities like these require a continual supply of high energy animal and organic waste products (> 500 kg d^{-1}) in order to produce enough gas to maintain the process continuously. One obvious advantage of the technology is that waste can be consolidated from multiple sources and where sufficient resources exist, people within Alaskan communities may produce enough organic waste in order to justify investment in a processing facility. Here, psychrophiles may play a crucial role in future anaerobic digestion projects as, given the appropriate scale of operation, would require less energy input in order to sustain high levels of biogas output production (Massé, et al. 1996; 1997).

Within the continental United States, increasing numbers of biogas facilities are being implemented among dairy cow and pig farms. Typically, these operations have centrally located facilities where waste streams are concentrated and can be disposed of and processed easily with minimal mechanical investment in infrastructure. In Alaska, where agribusiness does not play a major role in the state-wide economy, small-farm facilities likely lack the necessary size in order to justify large projects; however, again, if several small farms can pool their individual waste resources, a commercial-scale processing facility may be justified. Alaska fisheries, however, is an industry that could benefit from generating biogas as a fuel source due to the large quantity of organic waste generated seasonally. For year-round biogas production, digester feedstock would require storage and feeding. Fortunately digesters are able to lie dormant for some seasons, and resume full operation over short times during other seasons. For Alaskans interested in biogas technology, a critical first step for projects at any level of operation will be waste stream and resource evaluation.

At present, the most basic method of anaerobic digestion gas recovery and the only current form of the technology being implemented in Alaska is that of covered landfill sour gas recovery. Projects of this kind are the most likely near-term application of the anaerobic digestion technology within far-north regions. Though this form of anaerobic digestion is considered to be the least efficient among the available technologies, covered-capped landfills benefit over other methods of anaerobic digestion in both scale of operation and minimal capital and maintenance required to operate them. Sour gas wells are currently installed at landfill sites in only two areas of Alaska, located in areas near Fairbanks and Anchorage. Projects in Anchorage as of now are the furthest along in the processing and utilization of landfill gas. Thirteen capped-wells are currently being tested at landfill sites located near Fairbanks, but no energy production efforts are yet underway. This summer, projects near Anchorage to install gas recovery, and power generation equipment broke ground and should come online within the year. Due to the relatively low population density of residents within the state of Alaska, anaerobic digestion projects of this kind are likely to remain the only project-type commercially viable as they combine secondary energy recovery on top of already required municipal waste processing sites and facilities.

Until resident populations increase to sufficient size where waste stream energy recovery processing equipment is justified, it is unlikely that biogas technology is likely to play a major role in Alaska’s energy portfolio within the near future.

5. Economic feasibility assessment of the project

UAF researchers worked together with the Institute of Social and Economic Research (ISER) to perform a Benefit-Cost Analysis and Sensitivity Analysis to assess the economic feasibility of the project, make recommendations regarding the future of the technology for Alaskans interested in installing a reactor of similar scale within an individual home, and determine the technology's level of marketability to Alaskan communities at large.

The following section of this report was compiled by Sohrab Pathan, research associate at ISER, and has not been edited by UAF researchers who wrote the Final Report.

Introduction

The psychrophile bio-digester in Cordova is a new technology that aims to produce low cost biogas for the rural Alaskans who live in extreme cold temperatures. The production of biogas varies significantly depending on ambient temperatures. The technology is in its research and development (R&D) phase which makes in-depth economic analysis challenging. This paper describes a preliminary economic analysis of this new technology. In order to provide a comprehensive study at this early stage in technology development, the analysis was prepared using a benefit-cost method and sensitivity analysis that show the impacts of variations in methane output, and diesel fuel, electricity and propane prices.

Assumptions

(1) The analysis is based on a conceptual bio-digester, not based on the actual bio-digester located at Cordova

(2) Project life of 10 years

(3) Real discount rate of 3%

(4) The biogas output at 30°C was not tested during the demonstration project's operation, it is an assumption based on literature review of the technology. Microbial metabolic rates were tested at 15°C and 25°C in Cordova. There is no extensive data to support that at 30°C this particular digester will produce 1,000 liter of methane in one day.

(5) The price projection of propane was done using propane prices as published by the University of Alaska Fairbanks, Cooperative Extension Service Food Survey[1]. All base prices are for year 2010. The base price was $4.2275 per gallon for propane and was set to increase over time at 4.64%, the average percentage increase from 2007 to 2010. The electricity base price was $0.2942 per kWh, and the projection was set to increase at 5.73%, the average percentage increase from 2003 to 2010[2]. The 'after Power Cost Equalization (PCE) adjustment' electricity base price was $0.1824 per kWh, and the projection was set to increase by 12.0%, the average percentage increase from 2003 to 2010. Two diesel fuel price projections, medium and high were used, based on projections previously published by ISER[3].

(6) Cost for food waste is assumed zero since those can be collected from the neighborhood with minimal effort.

(7) Labor cost is assumed to be $10/hr, adjusted for the opportunity costs of unemployed rural Alaskans (high estimate).

(8) O&M costs are projected to increase 2.53% per year, the average percent change of Anchorage CPI over last twenty years[4].

Benefit-Cost Analysis and Sensitivity Analysis
Methane production levels from a bio-digester differ significantly depending on ambiance temperatures. Methane production levels determine the amounts of fuel potentially displaced. Hence this analysis reviews benefit cost ratios based on three different ambient temperatures: 15°C, 25°C and 30°C, and fuel price projections for three types of fuel: diesel ($ per gallon) - medium projection, diesel ($ per gallon) - high projection, propane ($ per gallon), electricity ($ per kWh) - before PCE5 and electricity ($ per kWh) - after PCE.

Estimates of displaced fuel quantities were based on the methane production at three temperature levels. The following heat values were used6: Methane: 1 cubic feet = 1000 Btu, Diesel: 1 gallon = 138,690 Btu, Propane: 1 gallon = 92,500 Btu or 1 cubic feet = 2,500 Btu, and Electricity: 1kwh = 3,412 Btu. Table A shows *displaced fuel quantities* for diesel, propane, and electricity at different temperatures:

Table A. Estimated Fuel Displaced from a Psychrophiles Bio-Digester

	Displaced Fuel Quantity	
15°C	Diesel (gallon)	5
	Propane (gallon)	7
	Electricity (kWh)	188
25°C	Diesel (gallon)	32
	Propane (gallon)	49
	Electricity (kWh)	1,319
30°C	Diesel (gallon)	93
	Propane (gallon)	139
	Electricity (kWh)	3,767

Benefit-cost (B/C) analysis shows that B/C ratios for this developing technology are low (Table B). At 15°C, the benefit-cost ratio is 0.01 for displaced diesel with the medium-price projection, 0.03 for the displaced propane, and 0.04 for displaced electricity-after PCE. Higher ambient temperature assumptions yield higher bio-gas production, hence B/C ratios improve marginally. At 30°C, the B/C ratios increase, but are still below one; 0.25 for diesel at the medium price projection; 0.53 for propane and 0.96 for electricity-after PCE. As Table 2 shows, the only scenario that yields a B/C ratio higher than one is at 30°C for electricity-before PCE which results in 1.06. Table C shows the net present values for each scenario.

Table B. Benefit-Cost Ratios Estimated for a Psychrophiles Bio-Digester

	Benefit-Cost Analysis Scenario	B/C Ratio
15°C	Diesel - medium projection	0.01
	Diesel - high projection	0.02
	Propane	0.03
	Electricity - before PCE	0.05
	Electricity - after PCE	0.04
25°C	Diesel - medium projection	0.09
	Diesel - high projection	0.13
	Propane	0.18
	Electricity - before PCE	0.37
	Electricity - after PCE	0.34
30°C	Diesel - medium projection	0.25
	Diesel - high projection	0.38
	Propane	0.53
	Electricity - before PCE	**1.06**
	Electricity - after PCE	0.96

Table C. Net Present Values Estimated for a Psychrophiles Bio-Digester

	Displaced Fuel Cost	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	NPV of Benefit
15°C	Diesel - medium projection	15	17	17	18	18	18	19	19	20	20	21	$168
	Diesel - high projection	17	21	25	27	28	29	30	31	32	33	34	$254
	Propane	31	32	34	35	37	39	40	42	44	46	48	$356
	Electricity - before PCE	59	62	66	69	73	77	82	87	92	97	102	$716
	Electricity - after PCE	34	38	43	48	54	61	68	76	85	96	107	$579
25°C	Diesel - medium projection	106	116	120	123	126	129	132	135	139	142	146	$1,178
	Diesel - high projection	117	147	173	188	196	203	211	218	225	231	236	$1,775
	Propane	215	225	236	247	258	270	282	296	309	324	339	$2,490
	Electricity - before PCE	410	434	459	485	513	542	573	606	641	677	716	$5,010
	Electricity - after PCE	269	302	338	379	425	476	533	597	669	750	840	$4,539
30°C	Diesel - medium projection	302	332	343	350	359	367	376	386	397	407	416	$3,367
	Diesel - high projection	335	421	495	536	560	581	602	624	642	659	675	$5,073
	Propane	615	643	673	704	737	771	807	844	884	925	967	$7,113
	Electricity - before PCE	1,172	1,239	1,310	1,385	1,465	1,549	1,637	1,731	1,830	1,935	2,046	$14,315
	Electricity - after PCE	770	863	966	1,083	1,213	1,359	1,523	1,706	1,912	2,142	2,400	$12,969

Conclusion

Operating a bio-digester in an arctic environment remains challenging. In order for a psychrophiles bio-digester to be cost effective, a number of factors are necessary such as higher ambient temperatures (30°C), higher prices of displaced fuels and/or electricity, and lower cost of construction or labor. Therefore, according to this preliminary economic analysis, the psychrophiles bio-digester is not yet a cost effective system to produce energy and/or to reduce energy costs of rural Alaskans. However, changes of the factors previously described could improve the cost effectiveness of this technology.

1 University of Alaska Fairbanks, Cooperative Extension Service - Food Survey. Survey data is available at http://www.uaf.edu/ces/hhfd/fcs/

2 The average price increase for propane was calculated using prices for 2007 to 2010 due to limitations in available data.

3 Fay, G. and Villalobos Meléndez, A. and Pathan, S. 2011. Alaska Fuel Price Projections 2011-2035, Technical Report, Institute of Social and Economic Research, University of Alaska Anchorage, prepared for the Alaska Energy Authority, 13 pages.

4 Consumer Price Index for Anchorage Municipality & State of Alaska Department of Labor and Workforce Development. Data is available at http://www.labor.state.ak.us/research/cpi/cpi.htm

5 The Power Cost Equalization program is State assistance program that lowers electricity rates for eligible rural customers.

6 Conversion factors as published by the U.S. Energy Information Administration at www.eia.gov

6. Learning opportunities for curriculum enrichment

This section of this report was compiled by Adam Low, Cordova High School science teacher, and has not been edited by UAF researchers who wrote the Final Report.

The biogas digester project has had a deep and tangible effect on the students at Cordova high school. Increased energy awareness for the general student population was one of the broadest effects of the project. Members of the Science club learned countless valuable skills from data collection to construction. The group that had the most tangible effect was the one in the initial chemistry class of 2009-10. These 13 students had the opportunity to be a part of the application process for the grant. They researched biogas technology, they made movies depicting the effects of biogas on their community, and a few of the students participated in the grant application presentation to the Denali commission.

The education benefits that occurred during the course of this project are difficult to tease out of the plethora of experiences that happened. This project has evolved in six phases that I correlate to the educational moments that occurred. The following is a description of the phases.

Stage 1: Application for the grant

As the teacher, I had presented the Denali Commission EET Grant to the students as something that had come across my desk and that there were some folks who were willing to work with us on this. I took great care not to “tell” the class that this was what we were doing, but to mention the opportunity and leave it dangling for them. They asked me more about the project, and researched the grant proposal. They came back with more questions about what class would be like, and I worked out a scenario whereby chemistry class would put down the textbooks and focus our energies on learning the specific chemistry and technical skills necessary for the project. I assured them that a fair grading system would be worked out. Several members of the class asked the group if this was something they wanted to do, and the resounding response was YES! I cautioned them that this was more of a commitment than they alone would be able to make and that they would need to volunteer for the summer and next year, or else that they would need to get another group involved. Three students in chemistry class were also members of the CHS science club. These students brought the idea up at the next science club meeting and asked if they would be willing to help with the labor. Two students in particular, Dani Hess, and Craig Bailer orchestrated the plan for the division of labor that would occur if the grant was approved. This chemistry class had the exciting job of taking an idea, using Alaskan cold loving bacteria in traditional biogas digesters, and painting a picture of it in their first video assignment. Of the four videos turned in, the students chose one video to be a part of the grant application to the Denali Commission. Three students, Shannon Lindow, Jessica Smyke, and Craig Bailer, presented the grant proposal alongside Katey Walter Anthony, and Laurel McFadden in September of 2009.

Stage 2: Preparation

When the word came back that we had been awarded the grant, there was euphoria amongst these students. Somehow they had affected something big. And real science was going to happen. There was a buzz in the entire school and science club members, and chemistry class students gave each other high fives in the hall.

In the chemistry class we began to accelerate the pace of our studies in an effort to be ready for the upcoming project. We learned that the building where we proposed to do the project, The Cordova Energy Center, was not going to have a heat source by the time that the project was scheduled to start. The students spoke with the Superintendent and he identified a 40 foot container that had been used for storage as a possible location for our project. The students took to cleaning out the container with enthusiasm.

The arrival of Laurel McFadden and Katey Walter Anthony during the third week in November marked an exciting first step for the students. Laurel McFadden arrived with buckets filled with lake mud collected from Goldstream Lake and the tools to set up some experiments. She gave an informative and thorough presentation to students in both the chemistry class and in the Science Club. Over the long weekend and during the following two weeks students set up a variety of small scale experiments to attempt to measure biogas production. The students gained a great deal of insight into the methodology involved in collecting biogas and in recording appropriate data. Most importantly they had met the research scientists and had enjoyed the experience of working with them.

Stage 3: Construction

Building the biogas digesters commenced when TH Culhane, Katey Walter Anthony, and Laurel McFadden arrived in Cordova in January of 2010. TH met the students and quickly assessed the situation with our 40 foot container, our tanks and other available resources. Students worked during class time, and science club students worked after school and on the weekends to help accomplish the physical setup. This was a very exciting time in the student's education. TH himself had been a science teacher in the past, and was very good at inspiring the students. He painted a picture of a future where the technologies developed in our project would help keep mountain gorillas and snow leopards from extinction, and help liberate poor people from propane all over the world. TH spoke about the project and its potential impacts to many science classes, the school board, and to the community at an evening lecture series put on by the local Prince William Sound Science Center.

During the construction phase, students helped in a wide variety of tasks from digital documentation, to running errands, to construction tasks like gluing and cutting. There was a push to get the digesters setup and the kids loved being a part of it.

Stage 4: Food Processing and feeding

The feeding of the digesters was one of the areas of greatest student learning and involvement. Laurel McFadden and Katey Walter Anthony outlined a very strict set of guidelines for feeding the digesters that insured a consistency across the dataset. With these guidelines in mind the students from Chemistry class and Science Club set out to develop a set of protocols for taking the garbage bags full of food scraps and turning them into a food slurry. This slurry would be equally divided into six portions and fed to the digesters according to a schedule.

This is the point where all students in the school knew the goals of the biogas digester study. Signs about the project went up in the halls, the morning announcements included a message about recycling your food scraps, and large trash can with the words FOOD SCRAPS ONLY painted on the side was placed in the cafeteria.

The initial method of processing food scraps was exceedingly slow, and quickly the students looked for ways to streamline the process while at the same time maintaining the level of quality. This work fell to the students in chemistry class, as they had more time and the ability to work in groups of two or three on the task. A variety of methods for separating the mixtures were brainstormed, built and tested. The scientific team gave the students a high degree of freedom in the methodology for processing the food and this resulted in excellent training in engineering design and in communication skills.

One aspect of the food processing and feeding process that the students addressed early on was the need for food storage. The students quickly learned that feeding the digesters was a task that demanded considerable foresight, lest there not be enough food for the digesters. In the early phases of food processing the quantity of food was being processed just before adding it to the digesters. While this method was simple, there was not very much room for mistakes and equipment malfunctions. Soon they began to process for the next day. Ultimately this method of working ahead led to the processing of food in large batches and freezing the food for later thawing and feeding to the digesters.

Stage 5: Data Collection and troubleshooting

The students in the chemistry class and in science club learned a great deal about data collection during this project. The importance of the continuity and quality of the data set necessitated the direct supervision of the measurements by an adult working on the project. Taking samples and correctly labeling them, measuring pH, dissolved oxygen levels, temperature and other variables were part of the responsibilities of the chemistry class. Taking sub samples of the food slurry was part of the responsibilities of the science club. Later on in the project the data collection was primarily done by student Craig Bailer under the supervision of Casey Pape and Adam Low as part of his independent study class.

Troubleshooting proved to be a difficult task for the students to manage. While general enthusiasm about the project remained relatively high, the fears surrounding "messing up" were proportionally much greater. The students wanted a job that was systematic and straightforward to fulfill. When things didn't work out as planned, they didn't want to try to figure it out and fix it; they would leave it, and talk to me or the UAF research assistant about it the next day.

Stage 6: Science Fair and Presentations

In both 2010 and 2011 Science Club students brought biogas related projects to the state science fair. The opportunity to present the results of a part of the biogas project was exciting and rewarding for the students. Several of the students won awards at the state level for their work on the project.

Highlights of the project were in the public presentations that the students gave in a variety of different venues. From local presentations to the community, to keynote presentations at statewide conferences the students developed their skills in speaking and in fielding questions from the audience. For many of the students this was a pivotal moment in the project where they felt a sense of ownership and pride in the work that they had done. It can also be said that the adrenaline rush that comes with giving a presentation to a group of adults was sufficient to cause the students to really do their homework on the project and to practice their presentation.

In April of 2011, students in the Science Club gave a presentation to a group of 25 students from around Alaska attending the AASG (Alaska Association of Student Governments) conference at Cordova High School. The participants were eagerly taking notes and asking questions about both the biogas digesters and about the process of working on a project of this magnitude in collaboration with local organizations and University researchers. The students toured the methane digesters, and then visited the workshop where students had been working on the phase two projects. The students were shocked to see the amount of projects that the science club was involved in. In addition to the greenhouse used for testing effluent from the biogas digesters, and the electric generator that was converted to run off of methane, they saw a wind turbine that was being built from scratch, and a converted pressure cooker contraption that was being used to convert plastic bags into oil. The science club students encouraged the students to find real problems that needed to be addressed, and then to seek out organizations and adults in their community who were interested in working on the same thing.

Conclusion:

Students at Cordova High School and other school districts have benefited immensely from the biogas digester project. The most valuable overarching lesson that the students have taken is an attitude that they can tackle any problem with a systematic approach and the willingness to find resources.

7. Final Project Expenditures

This section of this report was prepared by Clay Koplin, CEO of the Cordova Electric Cooperative.

Overview

Per Final report guidelines, Final Project expenditures are to be itemized by the following categories: planning and design; materials and equipment; freight; labor; project administration/overhead and other expenses. These categories are not conducive to a research project, and do not reflect the budget categories presented with the final grant application. For continuity and clarity, the final budget presentation reflects the originally provided budget format, so that the original can be referenced for measuring performance and compliance with the grant objectives and constraints.

Executive Summary

As evidenced in the Final Budget Report, the financial execution of the grant exceeded performance requirements. Both the UAF and the CEC and Cordova Schools portions of the grants were under budget for grant expenses, and exceeded the match requirements proposed with the application. Variances from the budget line items expenses are discussed in more detail below. The grant application recognized that one of the greatest risks to the successful execution of the project was the performance of the Cordova High School Students in processing feedstock, disposing of waste, and collecting feedstock for maintenance of the digesters. The student travel stipend to disseminate the successful results of the project was intended to perform as a contingency to account for any deficiencies in digester maintenance. During semester breaks, the available student resources were not adequate to maintain the digesters. Amendment #2 was approved to allow a budget modification moving $14,000 of student travel stipend to digester maintenance by Adam Low, who was thoroughly familiar with the needs of the digesters, and was able to secure permission to drop a class teaching commitment to supplement student labor. This amendment is reflected in the final grant report as a $14,000 reduction of the student travel stipend line item from $40,000 to $26,000. An additional line item, Teacher Support, for $14,000, was created to track and account for time spent on this task.

Budget Performance

The UAF digester construction, data collection, and evaluation of results tasks were performed under budget. The technical assistance of T.H. Culhane during construction was on budget for airfare, and approximately $1,000 under budget for travel expenses. Unfortunately, many of the receipts for lodging and food expenses by T.H. Culhane were either not provided by vendors or were not kept by T.H. Culhane which resulted in approximately $1,300 in expenses that were not approved for the grant, though credit card receipts supported the expenses. This was largely responsible for travel expenses only being 30% of estimate. Cordova Schools, UAF, and Cordova Electric Cooperative each provided T.H. the budgeted honorarium, which helped defray his travel expenses. A data collection supervisor is reflected in the budget. This was the originally proposed solution to cover school breaks and gaps in student maintenance of digesters. It worked for the first student holiday, but the data collector left the community and the teacher assistance was the final solution. A minor $120 expense was incurred for hours of data applied to data collection by the Prince William Sound Science Center. The development of a website was, in the opinion of the project team, an essential element of the students disseminating the progress and results of their work to students worldwide through their website. A website was developed and charged to the student travel stipend. This expense was questioned by the UAF grant administration office, and at their request, CEC agreed to offer an additional $2,500 cash match for development of the website. This is reflected in the Final budget report as well. The Cordova Schools match hours were widely spread and mingled for several tasks including feedstock processing, waste disposal, and feedstock collection, so these were combined into one line item match. Similarly, Clay Koplin of Cordova Electric performed both the administrative and the majority of the accounting tasks for the grant, so these two tasks were combined into one line item for CEC match. The plumbing and feedstock supplies line item was approximately 50% over budget. One of the first obstacles to the grant was temperature control, and more than half of the final cost for this line item was for foam board insulation and lumber to properly insulate the shipping container used for the digester housing. Otherwise, materials expense would have been under budget for this item. The plumbing supplies were adequately procured with available grant funds, and the CEC plumbing supplies originally envisioned as match supplies were too large to be suitable for the project, resulting in a small match contribution for materials. The labor match of both CEC and Cordova Schools were more than adequate to meet and exceed the grant requirement. It should be noted that both CEC and Cordova Schools labor match are understated on the final grant report, and may conflict with the slightly higher match amounts indicated in the quarterly certifications because the hours spent on travel and preparation for the several presentation were not included in the final accounting of matching labor hours. Several of the phase 2, project demonstration, expense items were not purchased because the school provided them. These items were not presented as match, but helped defray project expenses. Paul Cloyd, the owner of Northern Lights Electric, donated significant labor hours and materials to extending code-compliant electrical distribution to the container van housing the project. A portion of the materials were purchased by the grant and by Cordova Electric. The estimated value of these donations of labor and materials exceed $5,000. They were not itemized on the final report, and represent additional match and support for the project.

In addition to the Final Budget Report, a Summary of CEC and Cordova Schools match activity was summarized by task and quarter, and submitted as a more detailed presentation of the grant match accounting summarized in the Final Budget Report Spreadsheet.

Finally, the 2011 Q3 expenses do not reflect the expenses for the Rural Energy Conference. In keeping with the match labor expended for presentation travel, these hours will not be included in the final match, and no additional match hours of labor are anticipated for Cordova Schools or Cordova Electric Cooperative. However, transportation, lodging, and expenses will be submitted for reimbursement, and are estimated under the Pay Request #4 column. The airfares, hotel rooms, and rental car have been reserved and their costs were included in this line item, while food and expenses were estimated at $50 per person per day for the four day conference. UAF final expenses for this quarter will include final report preparation and submittal, and attendance at the Rural Energy Conference to disseminate results.

Final Budget Report

CEC Grant Budget - Improving Cold Weather Efficiency of Methane Digestors

Category	Item	Quantity	Cost	Labor Salary $	Labor Fringe $	Labor Fringe %	Extended Labor Rate	Grant Project	Pay Req #1	Pay Req #2 RESUBMIT	Pay Req #3	Pay Req #4	Match from final	Grant Total	Notes
UAF	UAF Billable Portion								$68,164.96	$18,426.96	$61,749.32	Voucher #14		$148,341.24	
Materials ID#														$0.00	
1)	1) HDPE Containers	12.00	$400.00										$4,800.00	$0.00	
2)	2) Plumbing pipe match	100.00	$2.50						$0.00				$281.87	$0.00	
3)	3) Plumbing & Feedstock Supplies	1.00	$5,480.00					$5,670.00	$6,096.38	$714.06	$306.76		$0.00	$7,117.20	
4)	4) Plumb & Feed Supply Match	1.00	$5,000.00										$63.23	$0.00	
5)	5) Floor Space Match (no value)												$0.00	$0.00	
6)	6) Gas cook stove		$600.00					$600.00					$0.00	$0.00	
7)	7) Gas cook stove plumbing/fittings		$100.00					$100.00			$1,013.88		$0.00	$1,013.88	
8)	8) Gas Heater	1.00	$1,000.00					$1,000.00					$0.00	$0.00	
9)	9) Gas Heater Plumbing/fittings	1.00	$100.00					$100.00			$333.32		$0.00	$333.32	
10)	10) Heavy-duty Insinkerator	1	$350					$460	$460.18				$0.00	$460.18	
11)	11) Tri-fuel conversion kit	1	$200					$200			$187.00		$0.00	$187.00	
12)	12) 900W Generator	1	$400					$400			$449.00		$0.00	$449.00	
Contract Labor	13) Gas Heater install (external)	1.00	$500.00					$500.00					$0.00	$0.00	
& Expense	14) T.H. Culhane Airfare	2.00	$2,100.00					$3,900.00	$3,836.48				$0.00	$3,836.48	
	15) T.H. Culhane Travel	14.00	$139.00					$1,946.00	$850.00				$0.00	$850.00	
Labor/Individual													$0.00	$0.00	
Students	16) Feedstock Processing	1456.00		$15.00									$66,276.70	$0.00	All CHS Match
Students	16) Waste Disposal	416.00		$15.00									$0.00	$0.00	Combined
Students	16) Feedstock Collection	728.00		$15.00									$0.00	$0.00	
Students	17) Travel Stipend	31.50	$1,000.00					$26,000.00	$9,536.41		$4,346.65	$4,167.17	$0.00	$18,050.23	
Website	19) Develop Website	1.00	$2,500.00					$0.00	$1,250.00		-$1,250.00		$2,500.00	$0.00	
Data Collection	20) Data Collection Supervisor	400.00	$15.00					$0.00	$120.00				$0.00	$120.00	
Adam Low	18) Teacher Support (amend #2)							$14,000.00			$12,806.03		$0.00	$12,806.03	
Clay Koplin	21) Admin Labor Match	160.00		$55.29	$23.45	42.41%	$78.74						$24,649.96	$0.00	All CEC match
Adam Low	Schools labor match (Low)	160.00		$49.02	$20.47	41.76%	$69.49						$0.00	$0.00	Combined
Val Covel	22) CEC accounting/admin match	108.00		48.26	20.47	42.42%	$68.73						$0.00	$0.00	
	23) Cordova Schools Cash Match	1.00	$1,000.00										$1,000.00	$0.00	
	24) CEC Cash Match	1.00	$1,000.00										$1,000.00	$0.00	
	TOTALS							$54,876.00	$90,314.41	$19,141.02	$79,941.96	$4,167.17	$100,571.76	$45,223.32	UAF Not Inc.

Partner	Cost	Match
CEC & Cordova Schools	**$54,876.00**	**$79,789.67**
UAF	**$196,034.00**	**$16,312.00**
Grant Total	**$250,910.00**	**$96,101.67**

Work Order Activity Detail
Work Order 09-47 Match Detail — Close Group ID
09-47 Denali Methane Grant Match - CEC Portion
Address

CEC & Cordova Schools

Match Item	Q4 2009	Q1 2010	Q2 2010	Q3 2010	Q4 2010	Q1 2011	Q2 2011	Q3 2011	Q4 2011	Totals	Category
12 Ea. 250 Gallon HDPE Containers $400/ea		$4,800.00								$4,800.00	1
CEC Labor Koplin	$747.36	$3,577.86	$5,060.08	$3,741.73	$2,232.75	$4,602.37	$1,001.01	$3,551.80		$24,514.96	21
Plumbing Supplies Match	$10.16									$10.16	2
TH Culhane Honorarium - CEC		$1,000.00								$1,000.00	24
Plumbline Pipe		$43.25								$43.25	2
CEC Materials Match - Pipe, etc.		$228.46								$228.46	2
Lowe's Parts				$63.23						$63.23	4
Website Development CHS - CEC Cash Match		$1,250.00		$1,250.00						$2,500.00	19
Cordova High Schools Match Students		$3,060.00	$2,040.00		$6,240.00	$5,400.00	$4,230.00			$20,970.00	16
Cordova High Schools Match Adam Low		$16,677.60	$11,118.40		$2,347.50	$6,671.04	$5,837.16			$42,651.70	16
TH Culhane Honorarium - Cordova Schools		$1,000.00								$1,000.00	23
Sheridan Joyce CEC Laborer - Teardown							$135.00			$135.00	21
Brandon Shaw Match - Cordova Schools 177 hrs		$2,655.00								$2,655.00	16
										$0.00	
Total	$757.52	$34,292.17	$18,218.48	$5,054.96	$10,820.25	$16,673.41	$11,203.17	$3,551.80	$0.00	$100,571.76	

Match Category Summaries	Totals
1 HDPE Containers	$4,800.00
2 Plumbing Supplies Match	$281.87
4 Supplies Match	$63.23
16 Cordova Schools Match (all)	$66,276.70
19 Additional CEC Cash match for Website	$2,500.00
21 CEC Match Labor (all)	$24,649.96
23 Cordova Schools Cash Match	$1,000.00
24 CEC Cash Match	$1,000.00
Total	$100,571.76

References

House, David. (1978) *The Complete Biogas Handbook*. (Alternative House Information, United States), 52.

Massé, D.I., Droste, R.L., Kennedy, K.J., Patni, N.K., and Munroe, J.A.(1997) *Potential for the psychrophilic anaerobic treatment of swine manure using a sequencing batch reactor*. Canadian Agricultural Engineering. Vol. 39, No. 1. pp. 25-33.

Swift, C.E. (2009) *Colorado State University area extension agent, horticulture, Tri River Area, Grand Junction*; and J. Self, CSU extension specialist – soil testing, soil, water, and plant pesting lab manager, Colorado State University, Fort Collins. Revised 2/09. <http://www.ext.colostate.edu/pubs/garden/07611.html>

Gerardi, Michael. *The Microbiology of Anaerobic Digesters* (New Jersey: John Wiley & Sons, Inc., 2003), 23 - 45.

Karve, Anand D. (2011). Appropriate Rural Technology Institute. *Email Correspondence*. January 22, 2011. <www.ARTI-IND.org>

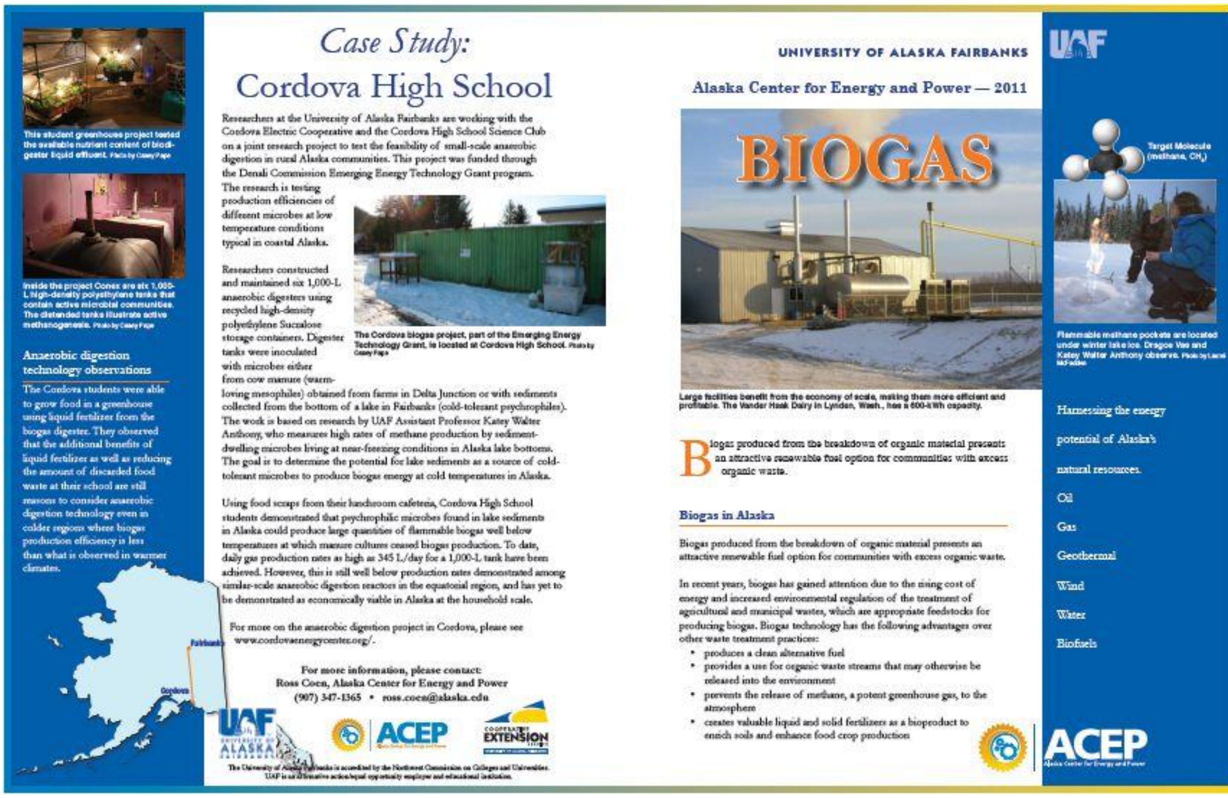
Walter, K. M., Zimov, S. A., Chanton, J. P., Verbyla, D., and F. S. Chapin III. 2006 Methane Bubbling from Siberian Thaw Lakes as a Positive Feedback to Climate Warming, Nature 443, 71-75.

Walter, K. M., M. Edwards, G. Grosse, S. A. Zimov, F. Stuart Chapin III, 2007. Thermokarst lakes as a source of atmospheric CH4 during the last deglaciation. Science 318: 633-636.

Walter, K. M., J. P. Chanton, F. S. Chapin, III, E. A. G. Schuur, S. A. Zimov, 2008. Methane production and bubble emissions from arctic lakes: Isotopic implications for source pathways and ages, J. Geophys. Res., 113, G00A08,doi:10.1029/2007JG000569.

U.S. Energy Information Administration. 2011. U.S. States: Alaska. *U.S. Dept. of Energy*. Updated March 24, 2011. http://www.eia.doe.gov/state/state-energy-profiles-analysis.cfm?sid=AK

Appendix 1 : ACEP & CES Biogas Flyer



This student greenhouse project tested the available nutrient content of biodigester liquid effluent.

Inside the project Conex are six 1,000-L high-density polyethylene tanks that contain active microbial communities. The distended tanks illustrate active methanogenesis.

Anaerobic digestion technology observations

The Cordova students were able to grow food in a greenhouse using liquid fertilizer from the biogas digester. They observed that the additional benefits of liquid fertilizer as well as reducing the amount of discarded food waste at their school are still reasons to consider anaerobic digestion technology even in colder regions where biogas production efficiency is less than what is observed in warmer climates.

Fairbanks

Cordova

Case Study: Cordova High School

Researchers at the University of Alaska Fairbanks are working with the Cordova Electric Cooperative and the Cordova High School Science Club on a joint research project to test the feasibility of small-scale anaerobic digestion in rural Alaska communities. This project was funded through the Denali Commission Emerging Energy Technology Grant program. The research is testing production efficiencies of different microbes at low temperature conditions typical in coastal Alaska.

Researchers constructed and maintained six 1,000-L anaerobic digesters using recycled high-density polyethylene Sucralose storage containers. Digester tanks were inoculated with microbes either from cow manure (warm-loving mesophiles) obtained from farms in Delta Junction or with sediments collected from the bottom of a lake in Fairbanks (cold-tolerant psychrophiles). The work is based on research by UAF Assistant Professor Katey Walter Anthony, who measures high rates of methane production by sediment-dwelling microbes living at near-freezing conditions in Alaska lake bottoms. The goal is to determine the potential for lake sediments as a source of cold-tolerant microbes to produce biogas energy at cold temperatures in Alaska.

The Cordova biogas project, part of the Emerging Energy Technology Grant, is located at Cordova High School.

Using food scraps from their lunchroom cafeteria, Cordova High School students demonstrated that psychrophilic microbes found in lake sediments in Alaska could produce large quantities of flammable biogas well below temperatures at which manure cultures ceased biogas production. To date, daily gas production rates as high as 345 L/day for a 1,000-L tank have been achieved. However, this is still well below production rates demonstrated among similar-scale anaerobic digestion reactors in the equatorial region, and has yet to be demonstrated as economically viable in Alaska at the household scale.

For more on the anaerobic digestion project in Cordova, please see www.cordovaenergycenter.org/.

For more information, please contact:
Ross Coen, Alaska Center for Energy and Power
(907) 347-1365 • ross.coen@alaska.edu

ACEP

Cooperative Extension

The University of Alaska Fairbanks is accredited by the Northwest Commission on Colleges and Universities. UAF is an affirmative action/equal opportunity employer and educational institution.

UNIVERSITY OF ALASKA FAIRBANKS

Alaska Center for Energy and Power — 2011

BIOGAS

Large facilities benefit from the economy of scale, making them more efficient and profitable. The Vander Haak Dairy in Lynden, Wash., has a 600-kWh capacity.

Biogas produced from the breakdown of organic material presents an attractive renewable fuel option for communities with excess organic waste.

Biogas in Alaska

Biogas produced from the breakdown of organic material presents an attractive renewable fuel option for communities with excess organic waste.

In recent years, biogas has gained attention due to the rising cost of energy and increased environmental regulation of the treatment of agricultural and municipal wastes, which are appropriate feedstocks for producing biogas. Biogas technology has the following advantages over other waste treatment practices:

- produces a clean alternative fuel
- provides a use for organic waste streams that may otherwise be released into the environment
- prevents the release of methane, a potent greenhouse gas, to the atmosphere
- creates valuable liquid and solid fertilizers as a bioproduct to enrich soils and enhance food crop production

UAF

Target Molecule (methane, CH_4)

Flammable methane pockets are located under winter lake ice. Dragos Vas and Katey Walter Anthony observe.

Harnessing the energy potential of Alaska's natural resources.

Oil

Gas

Geothermal

Wind

Water

Biofuels

ACEP
Alaska Center for Energy and Power

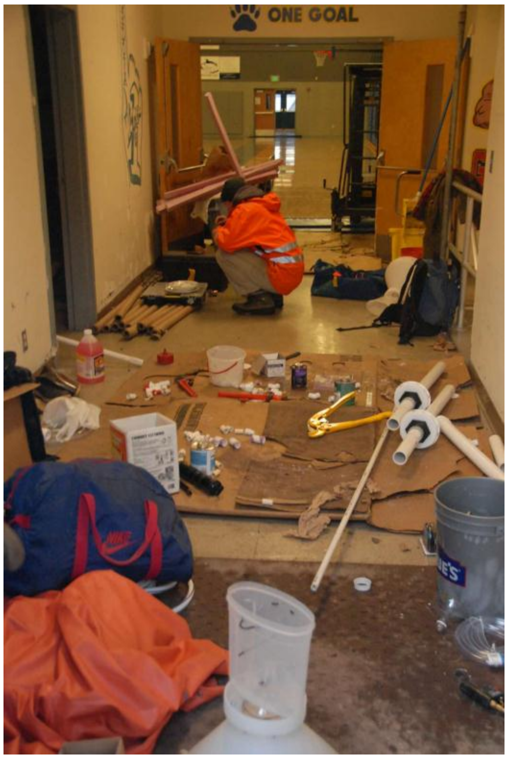
Appendix 2: Photo summary of the project

Laurel McFadden coring for psychrophile-containing lake sediments near Fairbanks, Nov. 2009.

Brandon Shaw collecting mesophile-containing cow manure at the Northern Lights Dairy in Delta Junction, Jan. 2010.

The Conex in first stages of construction behind CHS, with water pressure tanks outside.

TH Culhane prepares fitting pipes for the 1000-L primary digester tanks.



Peter Anthony prepares construction materials.

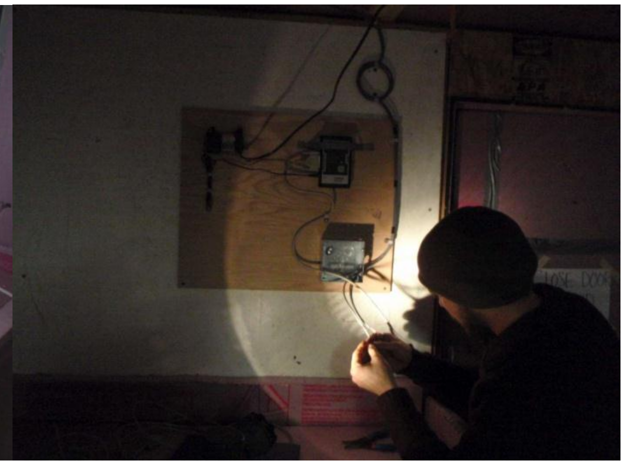
Culhane organizes pipe fittings.

McFadden and Culhane make internal fittings on a water pressure tank.

Insulation panels going up inside the Connex, while McFadden and Culhane place the primary slurry tanks.

First biogas flame is observed on January 21, 2010.

Materials for installing Sierra gas flow meters.



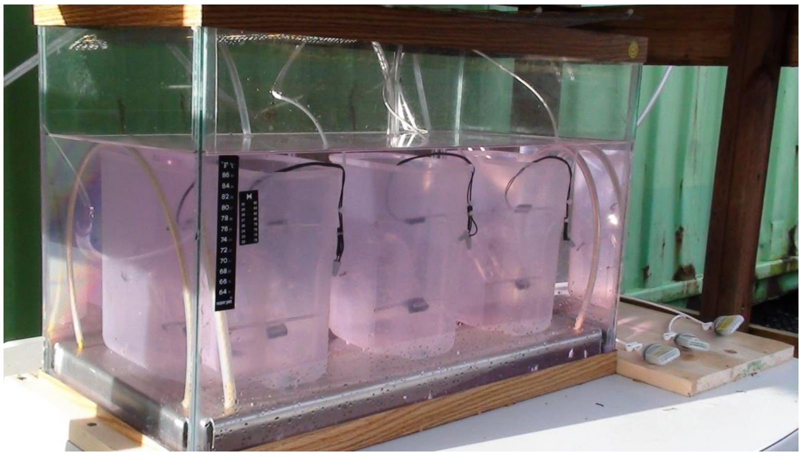
Shaw wires flow meters to a data logger and computer.

Complete digester set-up, with feeding pitcher, effluent test beaker, and running flow meter.

CHS student monitors chemistry by measuring pH with litmus paper. As of April 14, pH measurements are made with an Oakton PC510 meter.

Low and CHS students visit the Fairbanks Permafrost Tunnel with Kenji Yoshikawa after presenting at the AREC.

Mr. Low's 2010 Science Club students after one of their weekly meetings. (In this picture: Craig Bailer, Ben Americus, Adam Zamudio, Sophia Myers, James Allen, Eli Beedle, Josh Hamberger, Keegan Crowley, Kris Ranney, and Carl Ranney)



Automated bubble traps were installed on 10/15/2010 in an effort to monitor total gas flux from digesters 1, 4, 5, and 6 into the Sierra Top-Trak Mass Flow meters

Student Craig Bailer working with CHS teacher Adam Low to try and obtain gas samples from the aquarium in mid-November. Despite being almost completely frozen, a very distinct bulge was observed to contain flammable gas.

Aquarium pictured here with a car battery jacket in an effort to thaw out the tank. The jacket worked very well and was used periodically to prevent freeze up.

Student Craig Bailer is pictured preparing a week's worth of food for the digesters. The apron and eye protection are more a precaution than a necessity as the process can be messy.

The new greenhouse experiment is currently up and running inside of the Cordova Energy Center. Inside are the starts of several experiments which use effluent samples to test its possible use as a liquid fertilizer product

Newly installed gas outlet system. Work was completed retrofitting all tanks on February 25, 2011. The new system only uses standard pipe and gas fittings and the sealant used is Teflon tape. This system is easy to maintain and service in case of future leaks.

Following the installation of new gas outlets among all of the tanks in the 25°C room each tank began demonstrating the ability to hold pressure. Here each tank is pictured accumulating biogas prior to a venting.

CHS student and teacher Adam Low pictured with Alaska State Senator Albert Kookesh. Kookesh met with students following their presentation on Biogas to the Denali Commission, emphasizing the need for projects that include participation among Alaskan youth. The presentation was held in Juneau on February 14, 2011.

CHS students and teacher Adam Low pictured at the Alaska Forum on the Environment in Anchorage, AK. The conference was held between February 7-11, 2011 and the students participated in a variety of events show casing the project. The students presented posters on work with biogas as well as presented among other youth oriented projects.

Student Craig Bailer and others working with CHS teacher Adam Low demonstrating the heating potential of biogas. Students later recorded a video showing the ability to boil water with biogas collected from the experiment.

Student Brian seen here fills an inner tube in order to use it in the student's classroom for science experiments. The inner tube demonstrates the idea that a simple and elegant containments system provided by using bags or other collapsible structure ultimately has several advantages over other previously explored collections systems.

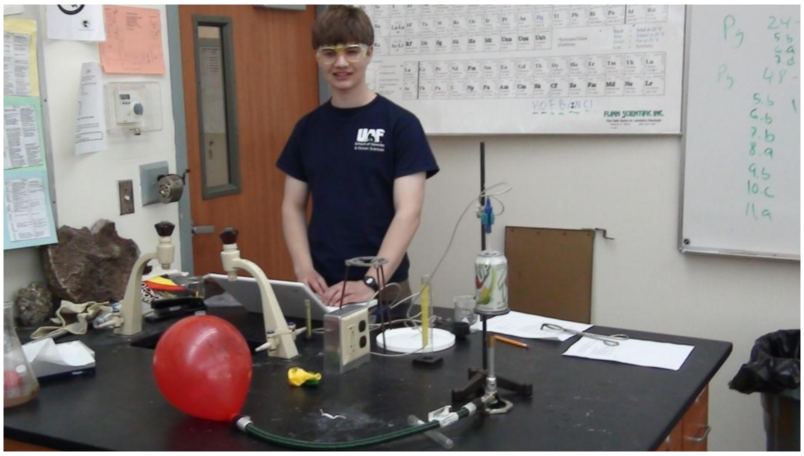
Updated photos of the student greenhouse experiment. The interest here is in order to test if the effluent from each tank has potential liquid fertilizer benefits in addition to producing biogas.

Several different crops are being tested for and more information will be available later.

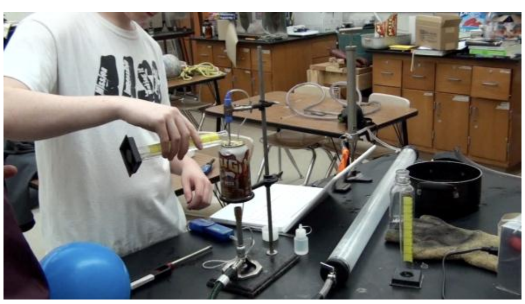
One gallon of boiling water is used to illustrate biogas usage as a cooking fuel. The modified stove pictured sustained a constant flame with a burn rate of about 300 L/hr.

Biogas being used to power a generator. Note the additional water weight used to increase the pressure of the gas supply for running an electrical generator. The water weight was not required for cook stove operation on biogas.

This 1850 Watt Husky generator ran completely on biogas for over an hour before exhausting the biogas storage tank and powering down. Starter fluid was used in order to start the device, but then was sustained entirely on gas collected from inside the Conex (behind). The estimated burn rate for this device is around 1,100 L/hr or 300 gal/hr @ 0.5psi.



Student Craig Bailer prepares his calorimetry experiment for testing the heat content of biogas vs. propane.



Student Keegan Crowley performs a calorimetry experiment to test the heat content of biogas prior to purifying the gas through lime water.

Keegan reports his findings at the state science fair, Anchorage, 2011.

Here, students Keegan Crowley and Ben Americas attempt to purify biogas along with teacher Adam Low.

CHS students Elaina Allen and Jessica Smyke touting their awards for their project on Anaerobic digestor effluent as liquid fertilizer.


Students used the liquid effluent from tank 4 to test an experimental greenhouse over the course of the school year. Here, student Sophie Myers uses a diluted solution of effluent to water and treat plants in the Cordova Energy Center.

Student Brian seen here along with Josh Hamberger burning biogas. Students were acutely aware of biogas properties and potential uses for Alaskans interested in the technology.

CHS Students Ben Americus and Adam Zamudio present on their work to run a generator off of biogas at the state science fair, Anchorage, AK April 15-17, 2011.

Students rig a common lawnmower to run off of biogas.

A 4-cycle 1850 Watt Husky generator was converted to run on biogas and other available gaseous fuel types. Here students celebrate as the generator successfully starts using propane.

The project profile when viewed from outside. At this point the project has a very minimal footprint. Previous gas pressure systems have been dismantled and the project team has taken a minimalistic approach. This is how the project appeared until final breakdown commenced on June 15, 2011.

Final project site as of July 18, 2011. Insulation and lighting arrays remain to be removed at the school districts discretion. Photo credit: Clay Koplin.

Evacuated tanks had to be cut with a sawz-al in order to be removed and their remaining contents disposed of properly. Photo credit: Clay Koplin.

Appendix 3:

Handbook of small scale biogas digesters for Alaskans

Prepared by Laurel McFadden and Casey Pape

<u>Contents</u>

- **Rural communities**
- **Portability**
- **Sizing – household versus community**
- **Alaskan organics**

Global application

- **High latitude**
- **Scandinavia**
- **Siberia**
- **Canada**
- **High altitude**

Construction

- **Total Materials**
- **Basic setup**
- **Assembling the parts**
- **Final construction**
- **Primary Slurry Tank**
- **Water pressure system**
- **Alternative systems**
- **Food preparation system**

Maintenance

- **Feeding**
- **Chemistry**
- **Flame tests**

Troubleshooting

- **Low pH**
- **Oxygen content**
- **Clogged pipes**

Introduction: Energy in Alaska

As fossil fuel resources are depleted across the globe, Alaskans are hard-hit in the search for energy. Northern households are especially dependent on gas for heating and transportation. As fuel prices rise, Alaskans, and rural Alaskans in particular, face some of the highest fuel prices in the country. These economic stresses threaten Alaskan livelihoods, while political pressures threaten the state's landscape and wildlife in a push for increased drilling and risky fuel transportation.

Renewable energy offers the opportunity for communities to harvest natural fuel from unlimited sources. Solar power, wind energy, and hydroelectric are becoming increasingly common as Alaskans seek independence from fossil fuels. Funding for research and development of efficient renewables is on the rise as economic and political pressures increase.

Biogas energy is a relatively simple technology that has been in use around the world for decades. With funding from the Denali Commission Emerging Technology Grant, a collaboration of scientists, engineers, and teachers has advanced digester technology for use in the north. These cold-adapted digesters, engineered for small-scale household use, allow individuals to uniquely contribute to offsetting their fuel costs and waste output.

This booklet was written as a resource for Alaskans and other northern communities interested in biogas technology. Included is the history and science behind digesters, a detailed construction manual and troubleshooting section, and a description of the challenges and benefits of biogas. With this information, we hope to encourage the further development of biogas digesters as a mainstay of Alaska's renewable energy resources.

What is Biogas?

Biogas is a flammable gas that is created by methanogenic bacteria under anaerobic (without oxygen) conditions. It consists primarily of methane with carbon dioxide and other trace gases. Usable biogas is indicated by a methane concentration of 60% or above, at which point the gas is flammable. Biogas is produced naturally in a variety of environments, including cow's guts and arctic lake sediments. Biogas digesters are designed to mimic the natural habitat and optimal conditions for methanogens, and are inoculated with microbial communities from natural sources. The biogas that is produced can be directly utilized by gas-burning technologies, with no subsequent processing.

How can it be used?

Biogas can be used much in the same way as natural gas. Any gas-burning technology can be modified to run on biogas. The most common use of biogas is for cooking, powering simple single- or double-burner stoves. It is an excellent fuel for cooking systems as it produces a clear blue flame with no soot.

Biogas can also be used to fuel heaters, gas lights, refrigerators, engines, and generators. However, some of those technologies (such as electrical generators and engines) require the biogas to be applied at pressure, and may require some modifications to the technology to run on biogas.

Overview of Benefits

The primary benefit of biogas is offsetting the financial cost of fossil fuels with a renewable, inexpensive biogas fuel. A household scale digester will not completely compensate for the fuel needs of a typical family, but it will reduce the amount of propane or other fuels needed to run common appliances, such as stoves and heaters. As the digesters are feed organic household waste, the systems help reduce the amount of organic trash dumped into landfills. The waste or effluent from the systems is a natural fertilizer, which can promote local greenhouse efforts. Finally, while empowering individuals at a community level to seek cheap renewable energy, digesters also help mitigate the greenhouse effect by burning methane instead of releasing it into the atmosphere.

Brief economic analysis

A household scale digester has a holding tank of approximately 1000L. At optimal conditions, a tank of that size can produce up to about 1000 L/day (www.samuchit.com/). A cubic meter (1000L) of biogas (at 60% methane) has an energy equivalent of about 6.0 kWh, which is equal to roughly 0.6 L of diesel (0.2gal). That amount of biogas is enough to fuel a cook stove to run for up to an hour, typically enough to cook one meal for a household.

Yearly, a small-scale digester can be optimally expected to have an output of 365,000L, or 2190 kWh, equivalent to 73 gal of diesel. At current prices in a rural Alaskan town, this is a fuel displacement of $291.

Within initial construction costs around $300, the digesters are expected to take one year to return their direct financial value, not counting the monetary equivalent of non-technical labor time spent maintaining the systems (roughly 145 hours/year).

The economic benefits of these digesters are not only in offsetting fuel costs, but also in long-term waste-management and environmental protection. Many of these benefits are not immediately quantifiable.

History

Uses around the world

There is speculation that biogas was first used over 3000 years ago to heat Assyrian bath water. The first digester was reportedly built in a leper colony in Bombay in 1859. Biogas was first concretely investigated as a fuel source in 1884, when Pasteur suggested using horse manure to power street lights, an idea that was actually used in 1895 in Exeter. The first anaerobic digester used for waste processing was built in 1908 in Germany, and by 1951 biogas from Germany's sewage treatment was used to power automobiles. (Residua)

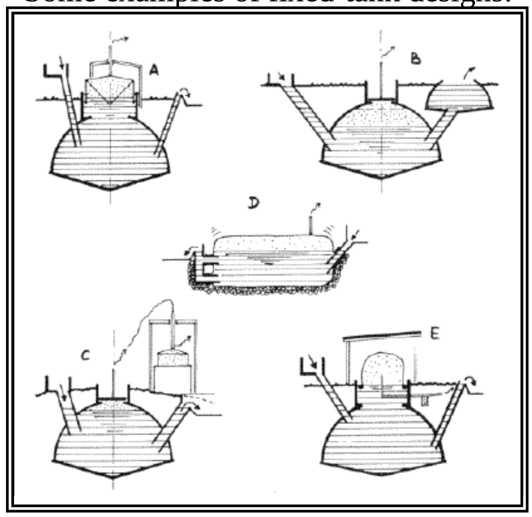
Although biogas research has largely been documented in Western Europe, the technology has been most widely dispersed in southern Asia. The warm climate of Southeast Asia supports the high-temperature demands of the traditional bacterial populations powering biogas digesters.   India began research into biogas as a fuel in 1938, and began implementing digesters in 1951 (Barnett, Pyle, &Subramanian). The Office of Rural Development in Korea began building digesters in 1969, although with Korea's cold winters the traditional systems were shut down during the cold months. In the Philippines, digesters were encouraged as waste disposal units rather than fuel sources. Thailand began building digesters in 1965, although the technology has not been popular due to the lack of manure. The Muslim culture in Indonesia has discouraged the handling of pig dung, making digesters largely culturally unusable. In China, digesters are very common, where most farms use underground systems directly connected to stables and latrines for continual processing.

As the technology developed, large-scale digesters became popular in Europe for community waste processing and power sources. Denmark, Finland, Sweden, and Norway use biogas to fuel public transportation vehicles, most recently with the construction of a biogas-fueled bullet train in Sweden. Sweden currently produces 1.3 TWh of energy in biogas a year – almost enough to power the entire city of Anchorage for a year. (http://www.mlandp.com/redesign/about_mlp.htm). Farms in the USA, particularly dairy and pig farms in the mid-west, commonly use large-volume processing plants to provide heat and energy in addition to manure waste management. These large-scale enterprises, however, require high venture capital, extensive upkeep, and advanced technical maintenance. Although appropriate for certain communities, we will focus on small-scale digesters most common to rural areas with fewer capital and technical resources.

Traditional construction

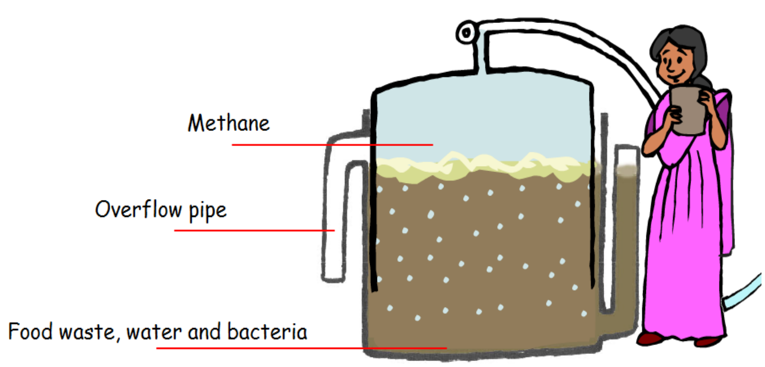
Household-scale digesters have a variety of construction schemes, depending on where they are located. The two primary designs are either fixed or mobile. Fixed tanks are structures meant for permanent placement, typically dug into the ground and usually joined with some other aspect of the house or farm, such as the latrines or stable.

Some examples of fixed-tank designs:



Germany: Information and Advisory Service on Appropriate Technology (ISAT) and Gesellschaft für Technische Zusammenarbeit (GTZ), *Biogas Digest: Volume 1, Biogas Basics,* 1999.

Mobile tanks are free-standing and are typically smaller, meant for gardens or apartment roofs. Our Alaskan digesters are modeled more closely to mobile systems. Traditionally, they consist of a large primary holding tank, with an inverted tank that telescopes with the production of gas. A tube to the bottom of the tank allows food to go to the bacterial population, while a tube towards the top of the tank allows excess effluent to be released. A hose out of the top of the inverted tank leads either directly to a gas burning technology (like a stove) or to a storage compartment for use later.



http://enviro-toons.com/page2.html

Traditional contents

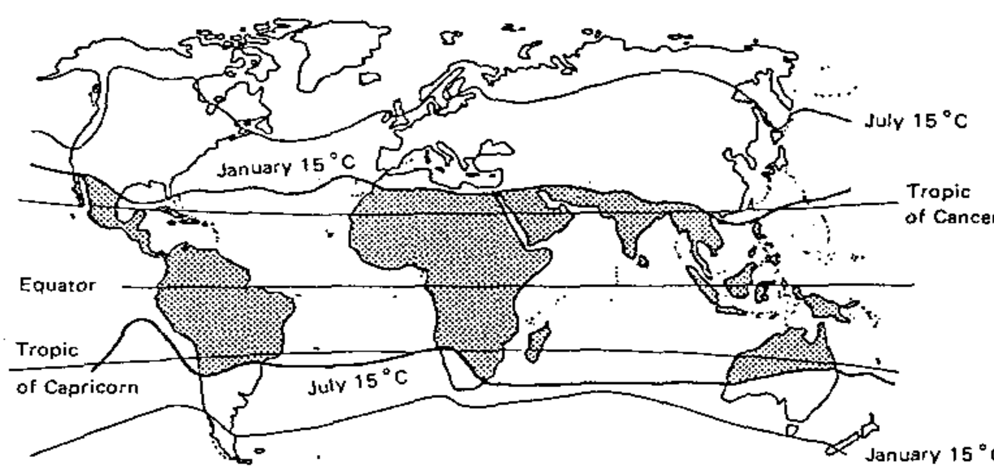
Biogas digesters traditionally contain two things: manure and water. People collect manure, typically either from cows or pigs (ideally from any ruminate, but most solid waste including human feces can be used). The manure and water is mixed in a 1:1 ratio in the primary tank, then closed off with the top tank and allowed to sit undisturbed while the contents turn anaerobic, a process that typically takes up to 40 days. The microbial community in the manure has a variety of bacteria, including methanogens that will begin to produce methane once they are in a healthy anaerobic environment. In these digesters, the slurry would be replenished with new manure periodically (depending on the rate of biogas production). The old manure settles into a sludge that also has to be cleaned out of the tank.

Problems

There are three primary problems with the traditional systems. First, manure is a nutrient-poor resource. The organic material in the manure has already been processed and striped inside the cow; the remainder that comes out in manure is either depleted or consists of materials that are too hard to digest. This leads to a slow digestion rate, slow biogas output, and the production of an indigestible sludge that must be cleaned out of the system. It also requires a larger tank system to contain enough manure to produce an economically useable amount of biogas

Second, the methanogens that live inside of cows and other animal's digestive tracks are accustomed to living in warm environments. These bacteria are mesophiles, or microbes that are specifically adapted to warm temperatures. Mesophiles, which are used in most traditional manure-based digesters, have an optimal temperature range of 20-40°C, and completely shut down at 15°C. Some systems have experimented with thermophiles, or hot-loving microbes, which prefer temperatures of 50-60°C. Simple digester systems, especially tanks above-ground, require climates where temperatures rarely go below 15°C, making the systems unusable in higher latitudes and altitudes.

Traditional mesophilic biogas digesters are restricted above and below the Tropics, and are almost unusable above the northern July 15°C isotherm:



Finally, traditional digesters are set up for immediate use in simple appliances, such as cook stoves. All application to more advanced technologies, such as engines or generators, requires that the gas be stored and then used at pressure. Most fixed systems are not designed for pressurizing gas, while mobile telescoping systems provide only limited pressure and are not adapted for engines.

Alaskan-adapted biogas digesters address all of these problems. In 2003, the Appropriate Rural Technology Institute in India developed a system of digester that was based on initial slurry of manure and water, but once the system turned anaerobic and produced biogas, it was fed nutrient-rich slurry of water and kitchen scraps. That organic "waste", which has not gone through a digestive process, is prime food substrate for methanogens. High-quality food allows the digesters to produce biogas faster and at a higher ratio of food-in to gas-out. The waste material, instead of being a hard-to-handle sludge, comes out through the effluent pipe as a watery fertilizer. This method of feeding and upkeep has been estimated as being 800 times more efficient than the traditional system, and allows household-sized digesters to be economically viable with smaller, 1000L sized tanks.

The temperature restriction of the mesophiles is one of the biggest problems in bringing digester technology north. Although the systems can be heated, the energy output in heating the tanks can negate the economic benefit of producing biogas. Our Alaskan-adapted digesters take the innovative approach of using cold-adapted, or psychrophilic, methanogens as the primary biogas-producing community. Instead of beginning with a slurry of manure, Alaskan digesters use lake mud from Arctic lakes that naturally produce methane.

It has been found that the bacteria producing methane in these lakes are adapted to function at temperatures as low as 0°C (Zimov et al. *Science* 1997; Walter et al. *Nature* 2006). While these bacteria have an optimal methane production at 25°C, tanks running on psychrophiles will continue to produce methane throughout the year.

Science

Microbial consortium

The production of methane is a result of a community process in a bacterial population. Manure and lake mud have a variety of bacterial populations, including (initially), aerobes that require oxygen to survive. When the manure or mud is initially put into the digester tank, the tanks must be sealed off to allow any aerobes or facultative anaerobes (bacteria that use oxygen if it is available, but don't require it) to use up any oxygen in the system. Once the system is free of oxygen, a combination of different anaerobes works symbiotically to break down large compounds.

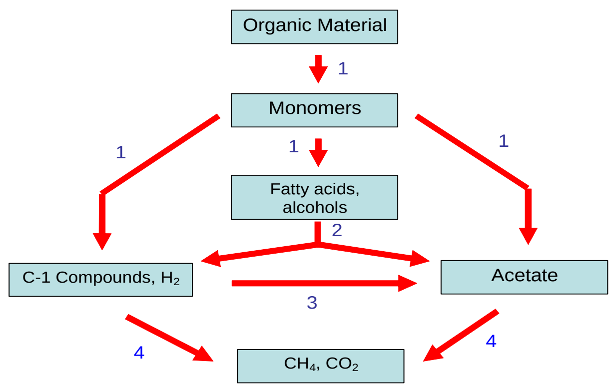
Through a process known as fermentation, complex sugars like glucose and fructose are broken down by fermentative, anaerobic bacteria into a variety of smaller compounds, including acetate and hydrogen. Acetate is important for methanogens as one of the primary substrates for producing methane. These bacteria depend on each other to maintain a healthy environment.

Methanogens use both the acetate and the hydrogen produced in fermentation. If the hydrogen concentration in a system gets too high, fermentative bacteria can no longer produce acetate – causing the community to fail.

Methanogenesis

In an anaerobic environment, methanogens can break down acetate, formate, methanol, or methylamine to produce methane. Methane can also be produced by the bacteria combining carbon dioxide and hydrogen (which are also produced in the fermentative stage).

The full processing of compounds into methane is a three-stage production: hydrolysis, acid-formation, and menathogenesis. Hydrolysis is the splitting of large complex polysaccharides by anaerobes into smaller compounds like glucose. Acid formation is completed via fermentation, also by anaerobes, to produce acetate, formate, carbon dioxide, hydrogen, and other substrates. Finally, methanogens use consume these compounds and produce methane and carbon dioxide as waste products.

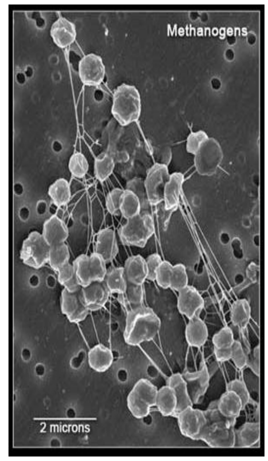


Any complex compound that is not broken down, or any substrate produced during fermentation that is not used by methanogens, becomes waste. As many of those compounds are organic and nitrogen-rich, the waste material that comes out of the systems is a rich fertilizer.

Methane is the end product of a deconstruction line: anaerobic digestion is a process of breaking down complex molecules. Because of this process, anaerobic digestion is not merely a way to produce methane as a fuel source, but is also an excellent way to break down organic waste into less dangerous and more useable materials. Waste processing has been one of the most popular applications of anaerobic bacteria technologies. In small-scale systems, biogas production for fuel coincides smoothly with household waste management, as most households will feed their systems approximately as much organic waste as they produce, and utilize approximately as much biogas is produced for cooking.

Optimal conditions

The bacteria involved with anaerobic digestion require relatively strict conditions to survive and thrive. Methanogens have set environmental parameters in which they can successfully produce methane, and particularly in which they can produce the optimal (most economical) amount of methane.



NASA and STScI

The most important condition is that the environment be anaerobic, without oxygen. The methanogens cannot function, and will eventually die, in the presence of oxygen. There are two measurements of chemical functions that serve as indicators for the presence or absence of oxygen in a system: oxidation-reduction potential and dissolved oxygen. The oxidation-reduction potential, or ORP, is the ability of a compound to add or remove oxygen in a particular solution. The lower the ORP, the less oxygen is available. Although solutions begin to turn anoxic at an ORP of +50mV, methanogens cannot fully function until ORP readings are as low as -300 mV. Fermentation, a symbiotic precursor of methanogenesis, can occur at ORP levels of <-100mV (Gerardi, 2003).

Dissolved oxygen is a direct measurement of how much oxygen is dissolved in a solution. Again, the lower the reading, the less oxygen is present. Atmospheric air has a reading of about 10.0 mg/L; an optimal methanogenic slurry should read as close to 0 mg/L as possible.

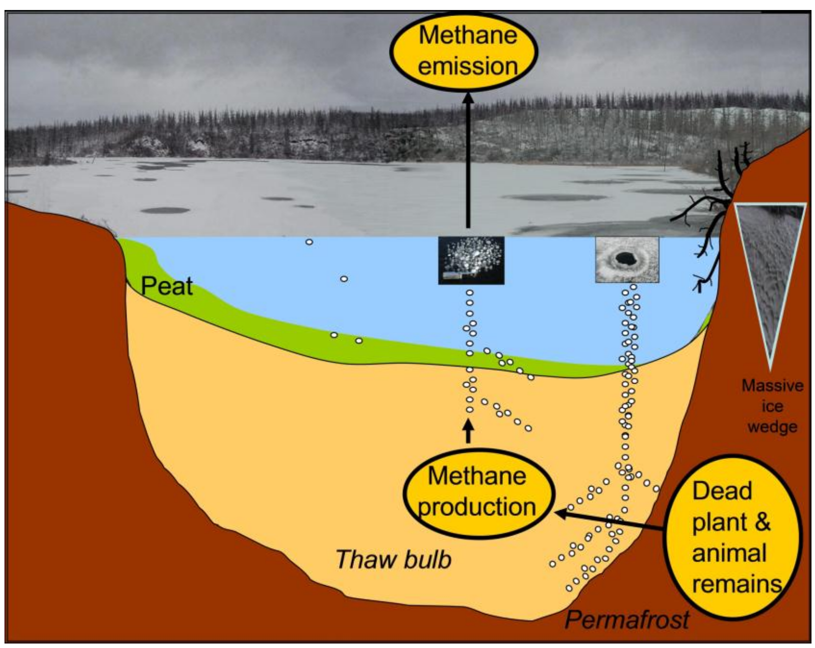
pH is a good indicator of the health of a methanogenic system. Although acid-forming bacteria will function above a pH of 5, and methanogens will function above 6.2, optimal pH for the system is between 6.8 and 7.5. The pH influences the enzymatic activity of the bacteria, or how well they are able to process compounds. A low pH usually indicates that the system has a problem. If the methanogens are unable to produce methane, there can be a build-up of organic acids that can drop the pH. This can be a result of environmental conditions (such as too much oxygen), or due to the presence of chemicals that inhibit methanogenesis. Although it is more unusual, a too-basic pH (anything above a pH of 8) is also toxic to the system. While the bacteria can survive a high or low pH temporarily, they will eventually die under these conditions.

Methanogens are also divided into groups according to their optimal temperature regimes. Within those groups, the bacteria are sensitive to their preferred range, and will not function above or below certain temperatures. Psychrophiles, or cold-loving bacteria, will function from 0-35°C with optimal production at 25°C. Mesophiles (warm-loving) prefer 15-50°C with optimal performance at 42°C. Thermophiles (hot-loving) live at 45-80°C, with an optimal production for methanogens at 60°C (Pfeffer, "Temperature Effects on Anaerobic Fermentation of Domestic Refuse, 1974). Digesters are traditionally run off of mesophilies, which shut down at 15°C. Within each temperature group, the bacteria are also sensitive to changes in temperature. Most bacteria cannot tolerate more than a 2°C change in temperature per hour. This makes the systems susceptible to shock if any substrate entering the digesters has a significantly different temperature than the internal slurry.

Mimicking Natural Environments

All of the above conditions are met in the methanogens' natural environments – the trick with digesters, therefore, is to mimic where the bacteria come from. The mesophiles in traditional systems come from cows' or ruminant's guts. Animal intestines are warm (typically about 38°C), completely anaerobic, and have evolved to favor bacterial chemical needs: cows cannot survive without methanogenic support in their guts; the bacteria help break down food and provide the animal with nutrition. The bacteria in return are provided with a constant food source via the cow's consumption of vegetation.

Similarly, methanogens are supported in lake sediments, although in different temperature regimes. Thermokarst lakes, which are formed in the Arctic by the melting of ice wedges in the permafrost, are known to cultivate cold-adapted psychrophiles. The lake sediments have a sustained temperature of 0-4°C, being kept above freezing by the liquid water. The sediments and water create and anaerobic environment below the sediment-water interface. Carbon and nutrient resources are available to the microbes via organics settling through the sediment, and in thermokarst lakes, by the continual exposure of ancient carbon remains thawed out of the permafrost.



Cold-adapted theory

Alaskan Restrictions

Temperatures in Alaska are too cold to support traditional digester systems. The primary problem is the temperature restrictions of mesophiles, although a variety of other factors have traditionally discouraged the construction of small-scale digesters in cold areas. Ruminant farming is less common in the north, meaning there are fewer resources for an initial bacterial substrate. Freezing temperatures not only affect the bacteria, but also can be detrimental to the equipment involved with biogas technology, presenting an engineering challenge in preventing the freeze-up of pipes and tanks.

In more temperate climates, occasional temperature drops are dealt with via short-term shut off, manual heating attempts, or insulation. In Alaska, however, although summer temperatures may occasionally support mesophilic activity, the extended cold spells make traditional systems uneconomical if they are shut off during cold periods. Manual heating attempts, such as via heat coils or solar paneling, can be helpful but due to high fuel costs, including gas and electric; low sunlight during the winter months; and the amount of heating needed makes constant manual heating especially uneconomical. This is particularly true for small-scale digesters with limited output. Traditional insulation attempts include building digesters underground, which in Alaska can be a counter-productive force if dealing with a mesophilic population: although it may keep the system above freezing, it can also act as an ice box and prevent the system from reaching warmer air temperature.

Bacterial solutions

Most of the problems with traditional digesters in cold areas stem from the restrictions of the mesophilic bacteria. A fundamental, although revolutionary, solution is to inoculate the systems with cold-adapted psychrophiles. While methane has been extensively observed in cow flatulence, it is only relatively recently that methane seeps in Arctic lakes have been differentiated between geologic and biologic sources. In 2005 psychrophiles in Alaskan thermokarst lakes were identified as producing methane down to 1°C and being four times as efficient as similar psychrophiles found in European lakes.

K. Walter and L. McFadden lighting methane seeps on a lake outside Fairbanks, AK.

While mesophiles can be simply collected in manure, it is somewhat more difficult to collect lake psychrophiles. Collecting mud from the bottom of a lake, particularly from a certain depth below the top of the sediments, takes special equipment and time.

L. McFadden coring for psychrophilic lake mud.

Once the psychrophiles are cultured into a thriving community in a digester, however, a subsample of that slurry can be inoculated into subsequent tanks. The same method can be used for mesophilic tanks. Although the first cold-adapted systems require extensive efforts to core mud from psychrophile-rich areas, it is easy to propagate the bacteria into other systems after the initial development.

Once the psychrophiles are established in a digester, they require the same relative care as the traditional systems. An anaerobic environment with a healthy pH must be maintained, while temperatures are kept at an appropriate level. Although psychrophiles will continue to produce methane down to 0°C, they have an exponentially higher output to about 25°C at their peak. This gives psychrophilic systems a two-fold benefit: they will produce more methane in warmer temperatures, and they will work year-round, in cold or warm Alaskan weather.

Heating

Although psychrophiles have lower temperature tolerances than mesophiles, they still must be kept above freezing, and above about 10°C to allow optimal gas output. Depending on the local climate, there are a variety of solutions for heating the digesters. Burying the tanks is not recommended in northern climates, as the ground has a high heat capacity and will remain cold year-round. Although the systems may be kept from freezing, they will also have trouble getting warm.

Ideally, an Alaskan digester would be kept in a semi-heated area such as a garden shed, greenhouse, or garage. Due to the occasional smell and mess of feeding, most people would not want the digesters directly in the house. Arctic entries, or snow rooms, are also ideal places: these semi-indoor locations gain heat from the house, allow smells and any messes to be redirected outside, and heat easily in response to warm weather.

Manual heating efforts may be necessary, but are best kept to a minimum to maximize the economic benefit of the digesters. If more energy is put into heating the system than can be gained from the biogas produced, the digester will have little economic benefit beyond organic waste management. Heating efforts can include space heaters or wall units that heat a room as a whole, such as a garage. Greenhouses can help conduct heat during warm or sunny weather, but may also require space heating during the cold months. Although solar heaters have been effective in Germany, the lack of sun during the coldest Alaskan months may not be effective for heating northern digesters. It is also possible to re-direct the biogas produced into powering heat coils that can be wrapped around or through the digesters, hopefully self-mitigating the energy of heating depending on the amount of biogas produced.

Insulation is key for Alaskan digesters. Whatever the method of heating, simple foam insulation around the units can help keep the systems warm. It is equally important to insulate the room or building where the digester is kept, so that space-heaters are as effective as possible.

Construction types

Small-scale, household sized digesters are typically around 1000L for the primary slurry tank. They can be expected to have a max production of 1000L/day of gas (for approximately every 1kg of food slurry). The Alaskan-style digester engineering adopts three methods of coping with cold. The first, as mentioned above, is extensive insulation. The primary slurry tank is kept indoors, ideally in a heated area of above 10°C for optimal production, and insulated on all sides by inch-thick (or more) foam insulation. In addition to helping to keep the tank warm, the insulation protects the microbial slurry from dramatic changes in temperature. Even though the bacteria may produce more methane at warmer temperatures, they will also be damaged if the temperature changes quickly. As Alaskan temperatures have been known to range more than 30°C in under 24 hours, insulation can buffer those changes on the tanks.

Benefits

Power

The household sized digester is an excellent way for individuals to create their own renewable energy. After a relatively low initial expense for construction, maintenance of the system requires a primary input of time. In cold climates, there may be some heating expense, although this may be mitigated if the unit is put in an area that is already heated (thus not requiring any new additional expense to the household).

The biogas that is produced can be used in any gas-burning technology. Some common appliances can also be modified to run off of biogas. On a small scale, the most efficient use of the gas is probably for cooking, in gas-burning stoves. Although any amount of gas can be used in the other applicable technologies, a fixed amount of gas volume will run longer in simple appliances, such as a stove, than in complex machinery, such as an electrical generator (which also requires that the gas be applied at pressure). As the expected amount of gas produced daily is typically enough to offset the cooking needs of a small household, the system can be estimated to eliminate the previous cost of fuel spent on cooking.

If the system has an external storage unit, to allow many days worth of gas to build up and be released at pressure, other technologies that either require pressure or more gas can be viable. The previously mentioned electric generator, for example, could use many days worth of gas to run for some hours, providing electricity to a household for a day – offsetting one day's worth of diesel costs that would have otherwise been spent creating electricity. Heating units that run off gas may not need pressure, but are more efficient if allowed to run for an extended period: a week's worth of biogas production could run an infrared heater for a day, offsetting one day's worth of heating fuel a week for a household.

Other gas-burning appliances, such as hot water heaters and lights, can be powered by biogas to reduce electrical costs. Some of those technologies, however, such as street lights, are better powered by biogas if there is a large-scale community digester.

Migrating fuel-type needs

In addition to the financial benefit of offsetting fuel expenditures with self-produced renewable biogas, the use of digesters reduces the demand for fossil fuels as a whole. For Alaskans in particular, this has a number of benefits. Reduced fuel demand lessens the current oil crisis as companies have less pressure to draw out dwindling reserves. By enabling less gas to go farther, oil companies are also under less political and financial pressure to find and drill oil reserves. This helps protect Alaskan wildlife and landscapes from attempts to industrialize natural areas. With less fossil fuel demand, risky transportation efforts through Alaskan waters and overland will be reduced, lessening the possibility of disasters like the Exxon-Valdez oil spill by reducing the number of freighters in the water. By reducing the risk of oil spills, digesters help promote the security and health of the fishing industry. By reducing the need for exploratory drilling and industrial mining, digesters help protect wildlife populations such as caribou, supporting traditional sustenance hunting.

Provides fertilizer

Anaerobic digestion breaks down complex organic compounds. The smaller compounds that are produced can be used as a food substrate for plants. As the bacteria in the digester slurry only process certain molecules and nutrients, their waste product is rich with material that plants need to grow. In areas with poor or overused soil, this fertilizer can re-vitalize the ground with necessary organic compounds. The digester waste is also high in nitrogen, a chemical with a relatively low natural abundance that restricts plant growth.

In Alaska, this fertilizer is exceptionally useful considering limited agricultural options. If the digester is kept in a greenhouse, plants can benefit not only from the fertilizer waste, but also from the carbon dioxide created.

Reduces organic trash waste

Digesters reduce organic trash in two ways, according to amount and type. Kitchen waste that would previously have gone into the trash can be fed to the digester to be turned into biogas. This keeps household organic waste out of landfills and dumps. Although organic waste can be degraded in dumps, it can also create a heated composting effect. This is particularly a problem in the Arctic, where a warm trash pile can melt the permafrost and create ponds or "dump lagoons". These ponds act as pseudo-thermokarst lakes, continually melting the ground around them and using the local organic trash to fuel methanogenesis – exactly like in a digester, except that the products are released to the atmosphere. As there is very little maintenance or regulation of many Alaskan dump sites, the lagoons can also become a focal point for diseases, contaminants, and toxins as chemicals and bacteria filter towards the sink holes. By keeping organic waste in dump sites to a minimum, digesters can reduce dangerous environmental and health conditions.

A dump lagoon created by melting permafrost.

Through the anaerobic digestion, organic waste is also “cleaned up”. Solids are reduced to a liquid slurry. Many dangerous toxins, and many pathogens, are broken down and effectively eaten by the bacteria in the digester. The waste product that emerges is not only safe, but also a powerful fertilizer. Many countries in Europe currently use anaerobic digestion primarily as a method of waste management, reducing organic waste in volume and in toxicity.

Reduces greenhouse emissions

Biogas digesters reduce greenhouse gas emissions into the atmosphere in two ways. Methane is a greenhouse gas with 32 times the effect of carbon dioxide. By burning the biogas produced, instead of releasing methane into the air, the biogas is converted into heat and carbon dioxide. Although carbon dioxide is also a greenhouse gas, the net output of CO_2 into the atmosphere is zero, as the amount of carbon dioxide out is equal to or less than the CO_2 that was originally used to create the plant and animal matter that feeds the digesters. Burning methane is significantly better for atmospheric methane levels than burning fossil fuels, which produce a net gain (an increase in the greenhouse effect) of carbon dioxide.

Secondly, as the digesters eat household organic waste, kitchen scraps go towards feeding the microbes and creating useable biogas instead of being dumped into landfills. When organic waste settles into dumps, particularly in the Arctic, the weight and heat of the material (a composting effect) can create dump lagoons. The organic material then naturally feeds a microbial community that produces biogas and methane exactly as it would in a digester, except that the gas is released directly into the atmosphere. That kitchen waste, then, is entering the air with 32 times the greenhouse effect that it would have if it had been processed in a digester.

Puts Alaska at head of cold-adapted biogas technology

While other northern countries have successfully employed biogas technologies, nearly all have been developed on a large scale. Large scale operations have a high capital cost and require constant technical support and maintenance, but also have a high heat and energy output. Although they face the same challenges in terms of maintaining high temperatures to support the mesophiles, large operations can afford to cope with the problem via manual heating. Small-scale digesters are almost unheard-of in the north, particularly in areas with limited financial resources.

This type of Alaskan-adapted digester will allow Alaskans to lead the field in cold-adapted digesters, with a unique method of solving temperature regime problems via locally-evolved bacterial resources.

Alaskan application

Rural communities

In many of Alaska's smaller and more remote communities, resources are limited. Alternatives to conventional fossil fuels can be hard to come by due to lack of financial and technical assistance. Although other forms of renewable energy, such as wind or hydro power, may be viable options in these locations, towns are restricted by location (too far or too hard to easily deliver construction equipment), size (too small of a population to be considered worth a large investment by governments), and economics (too little money to self-finance significant infrastructure).

Small-scale biogas digesters are ideal for remote Alaskan towns. The construction, detailed in this manual, is relatively inexpensive. Upkeep and maintenance take little to no money, although they do take some dedication of time. Unlike more expensive energy alternatives, small-scale biogas digesters are technically very simple: you do not need to be trained as an engineer or biologist to build or run one. Labor, therefore, is contained within the community, with no expense for specially trained technicians.

As remote towns also frequently face a lack of resources, digesters can also largely be built with recycled materials. This cuts down on the initial price of the unit, and encourages clean up and recycling of materials that would have otherwise gone into a landfill.

Portability

These small-scale, above-ground digesters are relatively portable. They can be moved with a truck or a sled. This gives the units three benefits: they can be easily moved to new locations, they can be built in one place and then moved to their permanent location, and they can conceivably be permanently portable. Unlike large-scale operations, these Alaskan digesters can evolve with community growth, easily moved around expanding infrastructure. In Alaska, nomadic communities could use a digester on portable transportation. This could include native communities with a digester on a sled, or anyone with a flatbed or trailer. As long as the digester is kept above freezing, it will produce biogas.

Sizing – household versus community

For a community with the necessary financial and construction capacities, a large-scale digester could be viable. However, large industrial units typically require extensive engineering expertise and constant maintenance. They are usually government or company utility efforts, characterized by a distance from individuals. Although those units can be highly successful and well-integrated into community use, such as has been seen in Sweden, they have a longer turn-around in financial investment, and take long-term infrastructure planning for biogas dispersal.

Small-scale systems are tightly knit with individual and family efforts. They allow people to be directly involved with creating their own energy, reducing their waste disposal, encouraging the growth of their own food, and having a personal connection to mitigating the greenhouse effect. A low initial capital allows the system to have little risk, encouraging people to try the technology. It is a community-friendly system, easily spread around a town once a few individuals understand the basics of the system. Small-scale digesters encourage local education and a greater understanding of local waste management and energy production.

Alaskan organics

Alaska has some unique resources to power Alaska-specific digesters. The microbial slurry in the digester benefits from Alaskan bacteria. If a household has an area warm enough to support a mesophilic community, they can use manure to startup their digester. However, Alaska has very few farms of cattle or pigs. Many communities, however, are near populations of moose or caribou, which are also ruminants that produce methane. While moose or caribou scat can be used, it can be challenging to collect enough to power the digester, and care must be taken that the manure has not been frozen or completely dried out. If manure has been frozen, it kills off any bacteria. If it has dried out, it is no longer anaerobic, nor can the methanogens survive without water.

An even better Alaskan microbial resource is thermokarst lake mud. The psychrophiles used to power cold-adapted systems ideally come specifically from Alaskan lakes. Although there are psychrophiles found in other high-northern lakes in Europe, Alaskan psychrophiles have been found to produce methane at lower temperatures, down to 0°C. No other digester system in the world has employed these specific bacteria before. Alaskan psychrophiles could be the key to expanding small-scale digester technology to rural communities across the north.

Alaskan waste resources also provide a unique benefit to optimal biogas production. All methanogens require specific nutrient needs, and specifically a high carbon to nitrogen ratio. While carbon is relatively easy to come by, nitrogen is a limited resource. Many agricultural areas across the world spread nitrogen as a fertilizer. Along the coast, many Alaskan communities are supported by fisheries business. Fish, and fisheries waste, are high in nitrogen content, and make an excellent feeding substrate for biogas digesters. While any organic kitchen waste will make a rich feeding source, fish waste in particular, when balanced with other carbon wastes, can optimize gas production. Large-scale processing of fisheries waste could also encourage and financially support a large-scale digester in some communities.

Global application

High latitude

Cold-adapted digesters can be used anywhere that the temperature frequently dips below 15°C. Globally, the July 15°C isotherm marks the line where traditional digesters are not economically viable. Above that line, average temperatures in July – the warmest month - are 15°C. Between the Tropic of Cancer and the July 15°C isotherm, traditional digesters have limited usefulness, but can be reasonably economical with some manual heating and other adjustments. Alaskan digesters can be used across the north, having been inoculated with bacteria generated from Alaskan lake mud.

Scandinavia

Many European countries have experimented extensively with biogas technologies, although almost exclusively on a large scale. The Scandinavian countries have taken a very forward stance in implementing wide-spread effort to employ biogas. Sweden recently introduced a biogas-powered train, while Denmark powers public transportation buses with biogas. Volkswagon and Volvo have introduced biogas-powered cars to the automobile market, although those are still rare due to the limited locations of biogas vehicle fueling stations.

However, all of these advances have been on a large scale. Scandinavian countries have developed both community digesters, and supported integration of large agricultural digesters into a community network. There are many small farms, and urban households, that would benefit from a small-scale digester that could be used for organic waste disposal and individual power. Although the Scandinavian countries have highly organized and researched energy resources, they face extraordinarily high fossil fuel prices. This has led to the rise of public transportation as a government-organized resource. For household fuel needs, Scandinavian families may be interested in offsetting fuel prices, but also in waste-mitigation and other climate benefits.

Siberia

Siberia, in north-east Russia, suffers from lack of infrastructure. The size of Russia, and the limited dispersal of resources, has led to the deterioration of the more remote areas of the country. Following the fall of the Soviet Union, this also had an interesting counter-effect of encouraging the re-emergence of traditional native nomadic reindeer herding. Siberian residents now consist of urban city or town dwellers, working with limited infrastructure, and rural communities including nomadic agriculturalists, fishermen, and hunters.

Small scale digesters are ideal in this situation. They benefit both urban and rural communities in Siberia. Digesters can be built largely out of recycled materials, requiring little financial capital. They can be powered by materials (manure, psychrophilic mud, and organic waste) that only require collection and time, rather than purchase. The digesters take up little space, so they can be placed on balconies or roofs of houses or apartment buildings. Rural communities can include them in sheds or lean-tos against the main house, or they can be modified to work with portable yurts in nomadic communities. Nomadic reindeer herding communities require fuel for cooking stoves but otherwise often have few other fuel needs; a portable digester running off reindeer manure could offset that cost.

Canada

The Canadian high-north is similar to Alaska. Rural communities would benefit more from small-scale systems considering limited resources. Fishing waste could be used in some areas to power the digesters. It would be easy to transport Alaskan psychrophiles to Canadian communities for digester inoculation (it is not currently known what the comparison is between Alaskan and Canadian thermokarst bacterial communities, although they could be similar).

High altitude

Cold-adapted digesters would be equally useful in high-altitude areas in warmer climates. Although the focus of the Alaskan digester is to offset fossil fuel expenses, the digesters can also offset the need to cut wood for fuel. In areas of Africa, extensive deforestation has led to the endangerment of the highland gorilla. The adoption of digester technology in those areas can help slow wood cutting, backing away from the destruction of the gorilla habitat. Biogas is also a very clean-burning fuel. It has already been shown in many parts of Asia to be much better for human health, particularly for those cooking (typically women in many traditional cultures). With digesters, there is a significant decrease in the risk for smoke-inflicted diseases such as bronchitis.

Extremely high-altitude areas, such as communities in the Himalayas, have very few fuel resources. Gas transportation costs are high, while timber fuel resources are relatively sparse. Cold-adapted digester technology would be useful in these areas, and perhaps easily integrated considering the existing popularity of the technology in Nepal and India.

Construction

The cold-adapted, small-scale biogas digester consists of a air-tight tank, roughly 1000L . The approximate volume is not important, although 1000L is about the minimum size for usefulness for a typical household. The recommended tank is a 1000L HDPE tank, which is made of plastic built to resist corrosion and is food grade quality (ie, will not leach chemicals into the slurry). Ideally, the tank will have a metal cage, which is common in the HDPE models, found around the world. In the construction example photographed here, the tanks do not have metal cages. Although these can work well, they lack structure and can distort with the weight of the slurry and the water.

Ideal tank:

carchem.co.uk

The first tank is the primary tank. This tank holds the microbial community in the manure or mud slurry. There is a feeding tube coming out of the top, an effluent tube coming out of the middle of one side, and a gas outlet off of one top corner. A secondary gas storage tank is required in order to store and pressurize gas for continuous delivery to some biogas-powered technology further down line.

List of Materials

· 1000L HDPE tanks in metal cages
· 3m: ½" clear plastic tubing
· Plumbers tape
· Plumbers grease
· PVC glue
· PTFE Tape (Teflon)
· 2m: 2" PVC pipe
· 1m: 1" PVC pipe
· 1: 2" PVC pipe cap
· 1: 2" bulk-head fittings with rubber o-rings
· 1: 1" bulk-head fittings with rubber o-rings
· 1: ½" bulk-head fittings with rubber o-rings
· 2: 2" male threaded nipples
· 1: 1" female threaded nipple
· 1: 1" plastic union
· 1: ½" plastic union
· 1: 1" PVC (schedule 40) ball valve
·1: ½" PVC (schedule 40) ball valve
· 1: 1" male threaded to 1" hose barb (king nipple)
· 1: ½" male threaded to ½" hose barb (king nipple)
· 2: ½" hose clamps
· 1: ½" T connector – for staging multiple tanks (optional)

Basic setup

Each tank has a base of 1m^2. The primary tank should be located somewhere as warm as possible, but the gas storage tanks can be placed anywhere above freezing if water is used to seal or passively pressurized the gas.

Total floor space needed: 1-2m^2, total height clearance needed: 1-2m.

Assembling the parts

Each piece of the piping involved should be put together and the glue allowed to dry before attaching to the tanks. It is very important to ensure that all parts attached to the tanks are air-tight – use plenty of glue and grease as necessary. Each component is detailed in the following section.

1) **Feeding tube**

Materials:
· 1m: 2” PVC pipe
· 1: 2” PVC pipe cap
· 1: 2” tank adaptor with rubber o-rings
· 2: 2” female socket to male threaded nipple
·1: HDPE 1000L lid

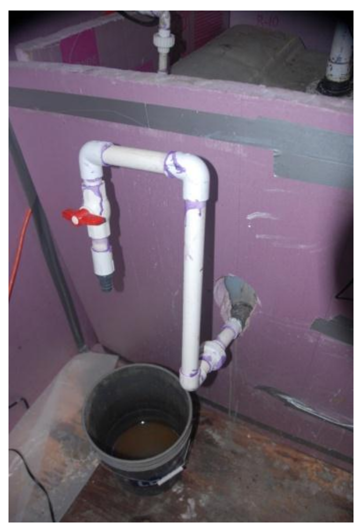
The feeding tube is built into the middle of the top of the tank, extending down into the center of the primary slurry tank. The blended food slurry is delivered to the methanogens via this tube, insuring that the microbial slurry has minimal contact with atmospheric air.

The bottom of the feeding tube should end above the mass of the slurry sludge in order to allow food to exit the tube. Generally, this should come to about 70cm, although that will depend on your microbial source and the size of your tanks.

Cut the 2” PVC pipe into two sections, one approximately 70cm and the other approximately 30cm. Remove the cap from one HDPE tank (this will be your primary slurry tank). Drill a 2” hole through the center of the HDPE cap. Fit the 2” tank adaptor through the HDPE cap, ensuring a tight seal with rubber O-rings and PVC glue if necessary. Screw in one 2” male threaded nipple to female socket into each end of the tank adaptor. Fit the long piece of 2” PVC pipe into the bottom 2” female socket and glue tightly (this will be the section that extended into the interior of the tank). Fit the short piece of 2” PVC pipe into the top socket, and glue tightly (this will be the pipe protruding from the top of the tank). Fit the 2” PVC cap to the top, short, external section of pipe, but do NOT glue – this cap will be removable for feedings.

When the glue on each section has dried, apply a liberal amount of plumbers grease to the jointing on the bottom of the HDPE lid. This will help insure that the feeding tube is air-tight.

2) Effluent pipe



Materials:
· 1: 1” tank adapter with rubber o-rings
· 1: 1” male threaded to female socket nipple
· 1: 1” union
· 3: 1” elbows
· 1: 1” valve
· 1: 1” male threaded to 1” hose barb
· 5 gallon effluent bucket
· 1m: 1” PVC pipe

The effluent pipe should extrude from the middle of one side of the primary tank. The exact placement is not important; however the hole should be well-below the level of the slurry in the tank. The U-turn in the piping should come <u>above</u> the level of the tank. This insures that effluent cannot come out of the pipe unless the system is under pressure.

Drill a 1” hole approximately in the middle of one side of the primary slurry tank. Fit a 1” tank adapter through the hole, taking care to place the rubber o-rings to make the joint air-tight (this will require you to put your arm through the top lid-hole of the HDPE tank to reach the interior. Screw a 1” male threaded to female socket nipple into the external side of the tank adapter. Cut a small (roughly 2” long) piece of 1” PVC pipe and glue it into the female socket end of the nipple. Glue the opposite end of the short 1” PVC section into one side of the 1” union.

Build the rest of the pipe separately. Glue another 2” section of 1” PVC pipe into a 1” elbow, bending upward. Glue a longer section of 1” PVC pipe into the other end of the elbow – this section should be long enough to extend slightly above the height of the tank from the effluent hole (roughly 40cm). Glue a second elbow to the end, bending right or left. Construct a U-turn in the pipe with another short section of 1” PVC pipe and a third elbow, bending down. This elbow should be joined to a final section of 1” PVC and into a 1” valve. The end tip of the effluent pipe can be built to end with a hose barb, although that is not necessary.

When the glue is dry, return to the primary slurry tank and glue the bottom segment of 1” PVC pipe into the union, and tighten.

3) Primary tank gas outlet

Materials:
· 1: ½” bulk-head fitting with rubber o-rings
· 1: ½” male hose barb king nipple
· 1: ½” union
· 1: ½” valve
· 1: 1/2" hose clamp
· PTFE Tape

4.) Biogas Storage and delivery system

Materials:
· 1: 1000Gal HDPE water tank with 1.5” ball-valve (from Greer tank and welding, Inc.)
· 1: 500Gal HDPE water tank (from Greer tank and welding, Inc.)
· 1: ½” male hose barb king nipple
· 2: ¼“ air house (25 foot)
· 2: ½” PVC ball-valve (schedule 40)
· 4: 1/2" hose clamp
· PTFE Tape
· 1: 8’ aluminum bar for level measure

Final construction

Once all of the components are in place, you are ready to fill and seal the tanks. The gas collection tank should be filled with water, with as little headspace as possible.

The primary slurry tank should ideally be initiated with a subsample of slurry from a working biogas digester running on psychrophiles. Approximately a liter of concentrated healthy microbial community can be enough to jump-start another system. Inoculate the primary tank with the subsample in lukewarm (approximately 15°C) water. Adding a small amount of sugar (roughly 2 cups for a 1000L tank) can help give the psychrophiles a food source while the population grows.

It is also possible to start a psychrophilic digester by using lake mud from areas in which methane seeps have been observed. However, as lake methane seeps can have different origins, it is not guaranteed that all lake mud will contain methanogens. If you do have access to methanogenic lake mud, approximately 5-10% total volume of mud can be enough to initiate a biogas-producing microbial community.

Alternative systems

Traditional biogas digesters use a simple telescoping system of inverted barrels to capture gas in one primary tank. One barrel is set up like a large bucket, which is filled with the bacterial slurry of mud (or manure) and water. The second barrel, which must be slightly smaller than the first, is inverted (turned upside-down, with the top opening facing down) and telescoped down into the first barrel. A feeding tube can be built leading from the base of the first barrel to at least as high as the level of the slurry. The effluent tube is placed at a point that maintains the height of the slurry. As gas is produced, the internal barrel slowly rises up, full of gas. A pipe leading out of the top of the internal barrel can direct gas to the methane-burning technology being used. However, without additional force, the gas will not be at pressure and is best used for low-pressure cooking stoves, rather than attempting to power an electric generator. Some pressure can be achieved by using rocks to force the barrel down and gas out.

Food preparation system

Once flammable biogas begins to be produced, a 1000L digester system should be fed about 1kg of food every day. The food can be made of almost any organic kitchen waste. The bacteria have trouble digesting woody or fibrous material; otherwise if well-blended almost any organic waste will work. As the bacteria thrive under optimal carbon-nitrogen nutrient ratios, certain materials such as fish (which are high in nitrogen) can be particularly good food sources. This adds another benefit in coastal communities in particular, where fisheries and canneries waste can be used as a premium food source for biogas production. Other organic materials, such as some non-woody plant material (like grass clippings), biodegradable utensils, and liquid food waste (like milk) can also be used in the food slurry.

Food should be well-blended with about a liter of water to produce almost-smooth food-soup slurry. The more blended the mixture, the easier it will be for the bacteria to break down the smaller food compounds, although some chunks are ok.

For a single-digester household, a blender or Insinkerator can be used to prepare the food. If using a blender, be sure to remove bones; some Insinkerator models can handle bones and other strong materials. Roughly 1kg of food and 1L of water should be poured into the blender or Insinkerator, and then collected in a pitcher. The food is poured into the central feeding tube on the primary tank. After the food slurry is poured into the tank, an equal volume of effluent should be removed through the effluent tube. If 2L of food material is poured in, 2L of effluent should be poured out. Be careful, though, if the system is under gas pressure – the effluent tube may try to force out more effluent than necessary. Keep a hand on the valve to avoid losing too much effluent.

You can also mix your food slurry with effluent instead of water. This helps keep bacterial loss to a minimum. Every time effluent is removed, some amount of the methanogenic bacterial population is removed. By taking that effluent and mixing 1L with your 1kg of organic waste instead of using water, the bacterial population is more likely to be sustained. If you feed a rough amount of 2L of food slurry every day, using 1L of effluent instead of water in your food preparation will reduce your daily loss of bacterial slurry by 1L.

Maintenance

There are a few simple guidelines you can follow to help maintain the health of your biogas digester. Although it is a relatively simple technology, digesters contain bacteria that respond best to specific environments and chemical parameters.

Feeding

Although the methanogens can eat almost any organic waste, they prefer materials with a high carbon:nitrogen ratio, and with compounds that are easily digestible. To get the maximum amount of biogas out of your digester, you can feed materials that are nutrient-rich, high in nitrogen, and made of relatively simple compounds. Nutrient-rich foods are materials that are not "waste" – food that has not been broken down or digested. Although you might think of the old leftovers in your fridge as "waste", they are technically undigested (unlike the organic material in, say, manure, which has already been stripped via a cow's digestive system). Sugary, fatty foods contain high amounts of carbohydrates and polysaccharides (sugars) that when broken down provide the compounds needed for methanogens to produce biogas. Foods with high nitrogen content include fish and meat scraps. These will encourage increased biogas production as they balance the bacteria's chemical environment. Feeding simple compounds means avoiding fibrous materials, such as woody plant scraps, vegetables with excessive cellulose (like celery), and other difficult to digester materials such as corn kernels.

Feeding should not begin until your digester has begun to produce flammable gas. This may take up to a month or more after sealing your primary tank. Your first feedings should be small – start with maybe 250g (a quarter of the normal amount) of food. When your digester is starting up, it is still building a strong bacterial community, and will not be able to handle as much food as a fully-running system. The food can fuel other acid-forming bacteria, which will over-produce acid faster than the methanogens can process it. This can turn the entire primary tank acidic. As methanogens require a chemical environment with a pH between 6.8-7.5, biogas production can fail if the tank becomes too acidic. You should also begin feeding every two to three days, increasing the amount and frequency to 1kg food every day, if the tank is showing consistent flammable gas production and pH measurements are within the safety zone.

The effluent release is important to allow waste materials to exit the primary tank. Although some bacteria will be flushed out in the effluent, the unused compounds from the food slurry should be removed from the system. By taking an equal amount of effluent out as the volume of food that goes in, the tank can slowly get rid of the digested waste materials.

Chemistry

There are a number of chemical tests that can be used to test the health of the microbial community in your digester. The primary tests look at oxygen content and pH. Measuring oxygen content via DO (dissolved oxygen) and ORP (oxidation-reduction potential) can be complicated and requires some advanced equipment. If you do have access to those kinds of instruments, DO measurements should be as close to 0 mg/L as possible (indicating an oxygen-free solution) and ORP should optimally be below -300 for methane production.

pH, however, can be measured relatively easily with litmus paper, which can be found in most pharmacies. To measure pH, take a small sample of effluent, and dip the litmus paper in the solution for some seconds (follow the instructions on your particular litmus paper package). Although litmus paper will only give a general range, usually with an accuracy of +/- 1, it can tell you if your digester has gone highly acidic or basic.

Flame tests

The best way to see if your digester is healthy and functioning is to do a safe flame test. Even if you appear to be collecting gas, it may be primarily carbon dioxide and other gases rather than methane-based biogas. A positive flame test will show that the gas being produced is at least 15% methane (optimally, the biogas produced will have a higher methane content, 40% or higher, but the gas will be flammable and useable at 15%).

Using the flame test router built into the gas collection tank, open the gas output valve slightly to allow a light stream of gas to be released. Make sure the valve to the primary tank is closed, and that there is a flame-check (such as a wad of steel wool) in the pipe to prevent a back-flash into the collection tank. Attempt to light the gas flow, making sure the flow is directed away from everyone and anything flammable. If the digester is producing useable biogas, the gas will light into a blue flame similar to a blow-torch.

Troubleshooting

If your digester is failing to produce gas, or is not producing flammable gas, there are a number of things to check that might help you treat the problem and find a solution. Methanogens are sensitive to environmental, chemical, and nutrition changes. In extreme cases, if the methanogenic community has been totally decimated, the digester may need to be re-inoculated with new bacteria and fresh water to re-build the population. However, if you keep an eye on the system and frequently run a few simple tests, your digester will only need a few simple adjustments to run properly.

Low pH

Methanogens cannot produce biogas outside a pH range of approximately 6.8-7.5. With overfeeding, it is common for tanks to turn acidic. It can be helpful to check the pH of the digester almost daily when you begin feeding, and weekly after the digester is behaving consistently.

If your digester does become acidic, the pH can be neutralized by treating the tank with certain basic chemicals. Sodium bicarbonate, or baking soda, is an easily accessible chemical that can help bring up pH. Calcium carbonate, or lime, can also be used, although it can produced some precipitate (solid clumping) that can be difficult to remove from the tanks. Other chemicals, such as sodium hydroxide, may also be used to bring up pH, but can be hazardous and harder to acquire.

The key thing to remember when treating a pH problem is to add chemicals slowly, over the course of several days. It is much more difficult to bring down the pH of an overly-basic system than it is to bring up the pH of an acidic system – you do not want to add too much of any basic chemical. If you are able to catch and notice a problem with acidity early, you can stop feeding and treat the problem with chemicals before the tank turns overly acidic. In extreme cases, it can take a very large amount of chemicals (kilograms) to treat an entire 1000L tank.

Oxygen content

Although it is difficult to measure oxygen content without special instruments, it is important to realize that a high amount of oxygen can cause biogas failure. If your digester is failing the flame test, but your pH is within optimal range, you may have a problem with oxygen content. If the digester was recently sealed, it could be that the original oxygen in the system has not been consumed yet. Try waiting a week or more and try the flame test again. If the system has had ample time to initiate, you may have a leak somewhere in your system allowing atmospheric air to enter your primary tank.

Test for leaks by spraying soapy water on all joints and piping. Gently push on the tank and watch for bubbling around any seals or edges. If you find a leak, fix it with waterproof air-tight glue, and test again. The system must be air-tight to prevent oxygen contamination, and to prevent loss of biogas.

Clogged pipes

A digester may fail a flame test if there is a clog or bubble somewhere in the piping. In the primary tank, sometimes a layer of sludge can settle on the top of the slurry. This sludge is mostly made of undigested food and can be difficult to remove. If you find that your primary gas output pipe on your primary tank appears to be clogged, you may need to open the tank and clean out some of the sludge layer.

Appendix 4

Scaling and Feasibility Recommendations for Biogas Production in Alaska

Prepared by Casey Pape

<u>Content</u>

Summary

- Anaerobic digesters serve as an important renewable methane source that has shown rapid growth and profitability in the United States over the past decade
- For Alaskans, the need to develop alternative fuel and energy sources has gained considerable interest in recent years as the cost of heating oil and fuel has steadily increased with demand remaining high throughout all regions of Alaska.
- Despite research efforts to utilize cold adapted "psychrophilic" bacteria, temperature remains the major limitation of the metabolic rate of microbial biogas production. Due to the need for excess heat and maintenance in order to stimulate efficient biogas production, small-scale projects are not likely to catch on in Alaska beyond the hobbyist level. The main problem is that the energy output gained from synthesis of biogas at the small (1000-L) household digestor scale does not meet resource and heating input.
- Anaerobic digestion technology is most appropriately suited in Alaska to industrial mid to large-scale facilities, where dedicated equipment and staff could profitably maintain the production of biogas using Alaskan feedstocks in the form of organic waste streams from fisheries, agriculture, food services, and municipal waste.
- At present, the only anaerobic digestion facilities being pursued in the state of Alaska are in covered municipal landfill sites in Anchorage and Fairbanks, where population densities are highest in the state.
- This report reviews the current trends in biogas technology in the United States and provides recommendations specific to future biogas production in Alaska.

Introduction

Methane is an important energy source extensively used throughout the world. Consisting of a single carbon atom covalently bonded to four hydrogen atoms (CH_4), methane stands – at 890.8 kJ/mol – as one of the most energy dense and efficient hydrocarbons known (Baukal, et al. 2001). Anaerobic digesters serve as an important renewable methane source that has shown rapid growth over the past decade (AgStar, 2009). Biogas, the product of anaerobic digestion, is a gas mixture of methane, carbon dioxide, and trace levels of other gases such as hydrogen, carbon monoxide, nitrogen, oxygen, hydrogen sulfide and water vapor. Biogas is the product of fermentation, and methanogenesis processes in which microbial consortia metabolize organic compounds in the absence of oxygen to produce organic acids, methane carbon dioxide, and other byproducts. Biogas can be purified to form pure natural gas [methane] or combusted directly and is applicable to many different energy and mechanical processes. Biogas methane can also be compressed to form liquefied natural gas (LNG), used directly to produce heat, power and electricity, or simply utilized as a fuel source for a multitude of applications. The use of biogas and biomethane has a well documented history and can be used in many different applications, however, efforts to develop and modernize the technology have only come about in recent decades as the cost of fossil fuel resources have increased, making biogas more cost competitive. Nearly all large-scale anaerobic digester projects have been implemented for the treatment of animal and municipal waste byproducts as a form of sanitation and secondary energy recovery offering net-zero waste, bioproducts and services.

It is the intention of this paper to highlight some of the science and biology of anaerobic digestion, explore recent developments in methane digester projects as well as analyze some of the complications and costs associated with digester projects in Alaska. For Alaskans, the need to develop alternative fuel and energy sources has gained considerable interest in recent years as the cost of heating oil and fuel has steadily increased with demand remaining high throughout all regions of Alaska. "Although Alaska has a low absolute energy demand compared to the U.S.

average, its per capita energy consumption is the highest in the country – more than three times the U.S. average." (EIA, 2011). In addition, rural communities share the bulk of this burden due to the remoteness of their location. In remote communities, the appeal of a non-point source fuel alternative offered by biogas produced from anaerobic digestion has obvious advantages, which inspired the current research effort to uncover its feasibility at the small-scale.

Despite research efforts to utilize cold adapted "psychrophilic" bacteria, temperature still greatly limits the metabolic rate of biogas production. Due to the need for excess heat and maintenance in order to stimulate efficient biogas production, small-scale projects are not likely to catch on in Alaska beyond the hobbyist level. The main problem is that the energy output gained from synthesis of biogas at the small (1000-L) household digestor scale does not meet resource input. Small-scale digesters, common in warmer rural regions of the world where they are often placed outdoors, are not deemed sustainable for most Alaskan climate regimes. However, given that biogas, produced through larger scale projects, is the main fuel source in both large and small communities in Scandinavia and Germany, larger scale projects have a high potential for success in Alaska too. The feasibility of large scale biogas production has yet to be assessed for Alaska. Many of the obstacles that impede individual-scale projects are usually overcome with bigger projects. Understanding the basic concepts of large-scale anaerobic digestion is important in order to understand what likely future biogas projects may look like in Alaska.

Technology Overview

The construction of anaerobic digestion systems for use in livestock and municipal waste stabilization has seen substantial growth over the last decade (Figure 1). As of April 2010, the EPA recognized over 151 anaerobic digester plant facilities within the United States. As of 2008, over 244 MkWh of power were produced annually. The current combined energy potential of these facilities now produces about 340MkWh of electricity annually, and "boiler projects, pipeline injection, and other energy projects generate an additional 52 MkWh equivalent per year" (EPA, 2010).

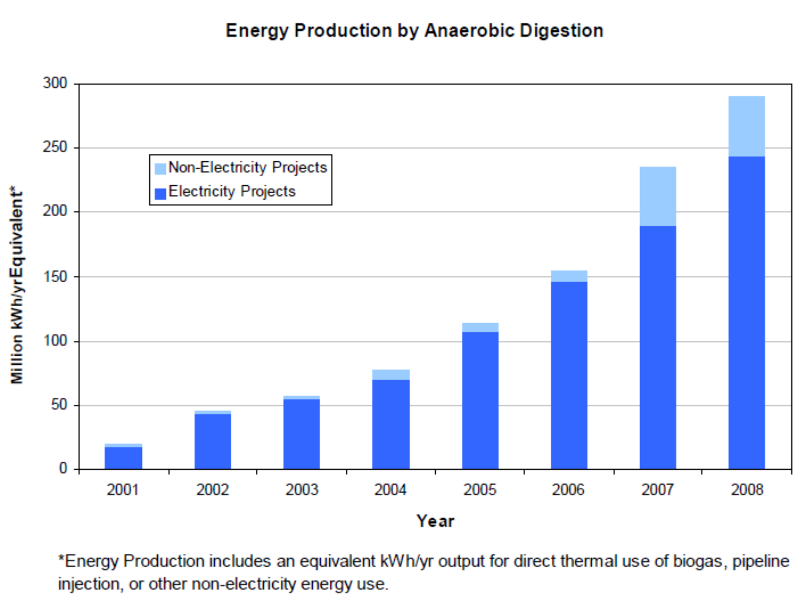


Figure 1. Trends in Energy Production from Anaerobic Digesters – 2001 through 2008.

www.epa.gov/agstar (EPA, 2009)

Currently, of the 680 registered farms in Alaska, none have anaerobic digester facilities to reduce waste. Though the average size of Alaskan farms is relatively high compared to the national average (1,285 acres AK vs. 418 acres US), Alaska is ranked 50^{th} in the nation for agricultural exports. More will be discussed later in the report (see *Alaskan Resource Evaluation*). All anaerobic digester designs have different advantages and efficiencies associated with maintenance and operation. These as well as environmental considerations will be examined in the next section of this report.

Anaerobic Digestion

Production of renewable methane from biogas is a complex and dynamic process. Anaerobic digestion is a multistep process that involves several different types of microorganisms in order to convert organic solids into methane gas in the absence of oxygen. In the first step, a consortium of bacteria and archaea (known as "acid formers") must decompose volatile organic solids into simpler organic fatty acids. These organic acids are then converted by methanogenic archaea to complete the decomposition process resulting in the production of methane gas (DOE, 2008). The process of digestion is dependent on the balance of the two different biological pathways which are very sensitive to changing environment and requires delicate control in order to maintain maximum yield and efficiency.

The rate of methane production is determined by the ability of the different types of bacteria to produce and consume their respective feedstock's (i.e. the product of one process is the reagent of the other). The most important variable that affects the rate of methane production is temperature, though other factors such as pH and carbon/nitrogen ratios also affect the rate of gas production (DOE, 2008). Though anaerobic bacteria can survive at temperatures below freezing and above 135° Fahrenheit (F) (57.2° Centigrade [C]) they tend to thrive within two distinct ranges that define two distinctive forms of anaerobic digestion (Balsam, et al. 2006). The bacteria thrive best at temperatures of about 98°F (36.7°C) (mesophilic) and 130°F (54.4°C) (thermophilic) (DOE, 2008). A third class of anaerobic bacteria (psychrophilic) operates at temperatures lower than both mesophilic and thermophilic regimes (25°C, 77°F optimum), but efficiency is greatly increased at warmer temperatures (Masse, et al. 1996). Currently, only one engineering company is known for constructing large-scale psychrophilic projects (Bio-Terre Systems, Inc.). In general, the high cost of startup and capital investments results in most projects deploying thermally regulated reactors under warm conditions in order to maintain the highest production efficiency.

The advantage of the thermophilic process in addition to being more productive is the bacteria's ability to destroy undesired plant seeds, spores, and pathogens; however, this form of digestion is the most sensitive to change and requires the most amount of input in order to maintain high yields and efficiency. The mesophilic or psychophilic optimally produce methane at temperature of between 90° and 110° F (32°C to 43°C) and require less maintenance to maximize gas production (Balsam, et al. 2006). It is important to understand that bacteria activity, and thus biogas production, is not a linear process and falls off significantly between about 103° and 125°F (39.4° and 51.7°C) and gradually from 95° to 32°F (35° to 0°C) (DOE, 2008) depending on the types of organisms utilized. Therefore temperature control is of major concern for maintaining high levels of gas production as temperature fluctuations as little as 5° F (2.5°C) can inhibit methane formers enough to cause failure within a system (Balsam, et al. 2006). This is the main challenge involved with making anaerobic digester projects economically viable. In general, tight monitoring equipment as well as continual maintenance of digester reactors favors large-scale projects where operators and facility managers can ensure better performance and conversion efficiency.

Types of Digesters

Anaerobic digesters are fairly simple closed systems that have some very basic and general components. Figure 2 is a diagram of generalized biodigester that uses liquefied waste sludge as feedstock for the methanogenic bacteria.

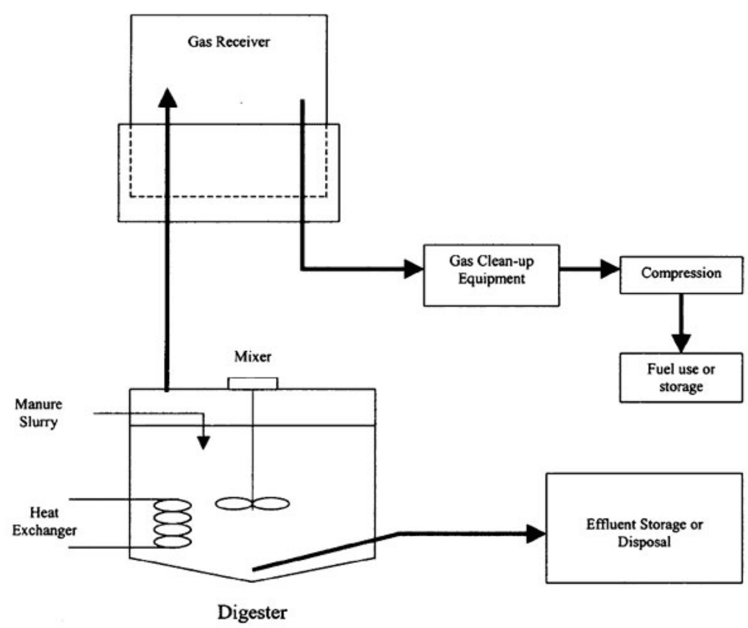


Figure 2. Basic Components of an Anaerobic-Digestion System
www.ext.colostate.edu/pubs/farmmgt/05002.html

There are several different types of anaerobic digesters.

Covered Lagoons – About 18 percent of all digesters employ this method. A pool of liquid manure is covered by a tarp or some form of floating cover. This type of digester requires the least amount of energy inputs and for this reason is used in generally southern climates where warmer air temperatures help to mediate the digestion process. The liquid pool contains about 2 percent solid waste and for this reason requires high "throughput" in order to provide bacteria with enough solids to feed.

Complete Mix or Batch Reactors – This is the most expensive form of digester, comprised of a silo-like tank that heats the manure mixture in order to maintain high gas production. This particular system is designed to handle organic solids up to 10 percent. Nearly 28% of all digesters in the United States use this method.

Plug Flow – By far the most common form of anaerobic digester (nearly 50% of digesters in the United States). This system constantly cycles new inputs of solids in order to move older material through the system. In it, a cylindrical tank containing 11 to 13 percent solids is typically maintained with radiant water pipes that stabilize the temperature. Systems like these are primarily used among livestock operations that remove manure mechanically rather than washing it out.

Fixed Film – This is the least common form of digestion (only about 1% of United States digesters). In a fixed film process, a liquid manure solution (about 2 percent) is retained in a holding tank for two to six days. To the solution, a mixture of polymers or biofilm is added which has been impregnated with bacteria that consume the solids. The bacteria can later be recovered as new manure is cycled through. (Balsam, et al. 2006)

In addition, small-scale batch and single-phase digesters are implemented all over the world. Currently, over 4,000 agricultural digesters exist in Germany alone, with an additional 8 million small-scale anaerobic digesters operating in China. For many small-scale projects, temperature control is the largest constraint on project performance. Usually, smaller projects are located in regions of the world where ambient air temperatures are warm enough to allow active methanogenesis to take place year-round. Factors that negatively impact the success of projects will be addressed in the next section of this report.

Considerations for Anaerobic Digesters

Digesters have many advantages for the treatment of waste and the reduction of emissions as well as odor control near livestock and animal farms; however, they also present a number of challenges that will be identified here and further addressed in the Life-Cycle-Analysis portion of the paper. One of the major issues surrounding methane production using digesters is the production of hydrogen sulfide gas (H_2S). This gas can exist in concentrations of between (0-3% by volume) and results in the biogas having a foul order (termed "sour gas"). The issue surrounding H_2S gas is that it is extremely toxic. In addition the gas is heavier than air and poses a potential threat to farmer and digester operators. If burned the gas leads to acid rain and is generally corrosive in pipes and engines (Scharlemann, et al. 2008). Though there is no current regulation on the burning of this sulfur-rich biogas, it is likely to change in the future as the technology becomes more prevalent. Currently, the gas must be treated further if desired to be purified into bio-methane, usually using onsite pressure swing absorption (PSA) equipment or other purification techniques. Many operating facilities do not produce enough gas products in order to justify the additional capital investments required to clean the gas and the gas is usually consumed onsite in order to avoid issues with gas storage.

The sensitivity of the bacteria to perturbations in temperature usually results in high inputs of capital and machinery in order to maintain steady temperatures. Based on regional climatic regimes, temperature regulation can diminish the returns of a project (i.e. if the temperature gradient between the ambient atmosphere and the digester microcosm is too great, it can limit the feasibility of a plant's success). Generally, digester plants are only commercially viable in the warmer regions of the world; however, many projects have been implemented in cold climate regions (see Case Studies).

Reactor vessels must run continuously in order to maintain bacteria cultures. This requires intense automated systems or stringent supervision. Failure to maintain conditions within the digestion reactor can result in degradation or total loss of methane generation. In case of such an event, the digester must be cleaned and the process must start over from scratch, an often costly and repugnant occurrence.

Finally, the high cost of startup and investment in infrastructure limits the feasibility of digesters to larger farms. This, however, is becoming less of an issue as time goes on. More interest in the technology is driving costs down and the technology benefits from one of the highest returns on investment indices of any renewable (Raysoni, 2002).

Alaskan Resource Evaluation

For Alaskans interested in renewable technologies, biogas has considerable appeal over other forms of energy production. Whereas light, wind or wave energy must be somewhat constant, limiting the placement and penetration of the individual technologies, biogas can be successful wherever appropriate feedstock can be found. The energy content stored in molecular bonds of tissues and volatile organics is ultimately the energy recovered from anaerobic digestion.

Feedstock, or an appropriate organic carbon source, is ultimately what justifies the cost and maintenance of a biogas plant. Though temperature is important to the efficiency of a facility, temperature requirements can be largely met with mechanical equipment, infrastructure and maintenance. Most digesters implemented domestically today are used in large-scale dairy operations or local municipal waste water treatment plants (WWTP). Here, anaerobic digestion is being used as a way to treat and reduce waste streams. In Alaska, considerable waste exists among communities and industry throughout the state. Fisheries, farm and stock waste, human and food waste are all appropriate substrates for anaerobic bacteria to process and generate biogas. This section of the report aims to evaluate those resources for their potential use in anaerobic digestion. But first, let’s explore some of the implications of the current research performed under the Denali Emerging Energy Technology project, “Improving Cold Region Biogas Digester Efficiency” in Cordova, Alaska.

In this Improving Cold Region Biogas Digester Efficiency project the collaborative research team from the University of Alaska, Fairbanks; Cordova Electric Cooperative; and the Cordova High School set out to test small-scale anaerobic digesters and evaluate their likelihood of success in Alaska. Based on the performance of individual digesters, psychrophilic bacteria where shown to perform as well if not better at lower temperatures than more traditional mesophilic tanks, but still failed to produce enough gas to be deemed an appropriate technology for individual Alaskan homes. Temperature and daily maintenance were found to be the most important variables in determining an operations’ success or failure. Due to the need for constant temperature regulation as well as daily maintenance, it is likely that anaerobic digestion is most appropriately suited in Alaska to industrial mid to large-scale facilities, where dedicated equipment and staff can maintain the production of biogas. In order to justify the initial capital costs and maintenance associated with larger-scale operations, appropriate feedstock and minimal size requirements have to be addressed.

In the United States, most development in anaerobic digester technology in recent years has been for use on rural mid to large-size dairy farms. Here, the benefits of anaerobic digestion are catching on at a time when stricter regulations on waste containment and disposal are causing farmers to reevaluate their waste streams. Typically, an operation facility of around 500 cows is considered to be necessary in order to justify the capital intensive start up costs (Vik, 2003). Basically, this amounts to anywhere from ten to forty (short) tons of material processed per day. Operations can be scaled up well beyond this, for example a Linkoping biogas plant in Sweden processes over 100,000 (metric) tons of animal waste per year (~ 275 tons/day average). Generally speaking, high volumes of material have to be processed in order for the technology to be viable. The EPA has issued some cost estimates for facility cost in terms of animal units (AUs), where each AU equals 1,000 pounds of live animal weight (Motschenbacher, 2009). Cost estimates are anywhere from $150-400 per AU. While this is just one index, it is important from the standpoint of Alaskan farming potential for anaerobic digestion technology.

Alaska agriculture is ranked 50th in the United States based on total export value. In 2010, only about $6.3 million in revenue was generated from animal products grown in Alaska, $40 million for all agricultural output (USDA, 2011). From the standpoint of an Alaskan farmer, the quantity of waste generated at an individual farm may not be enough to justify the investment required to install a biogas plant. There are currently 680 recognized farms within the state (average size 1,285 acres). In many cases, farmers who install biogas facilities consolidate waste from other farms in order to generate additional revenue, charging for processing of waste as well as selling of bedding and fertilizer material once the waste has been processed. This has immense appeal to farmers who wish to diversify their services as all points of anaerobic digestion are considered commercial products and services. However, since the bulk of the Alaskan economy is not focused on farming, currently there is little demand for waste disposal and treatment practices which might justify implementing a large-scale biogas facilities.

In Alaska, the bulk industry-scale organic waste is generated along the Alaskan coast by fisheries, and is of concern from an environmental and ecological perspective. The Alaska fishing industry produces about one million metric tons of fish byproduct and waste annually (USDA, 2011). This byproduct could easily be used and consumed within a biogas facility, yielding high quality organic fertilizer in addition to biogas production. Biogas production from Alaskan fish waste has been demonstrated at 1.0 -1.1 L/L/day in traditional batch digestion scenarios, indicating its high energy content and potential use as a fuel source (Hartman et al., 2001). A potential setback is that fish waste is often seasonal and feedstock availability may result in a biogas facility being underutilized or overtaxed at different times of the year. In addition, the fisheries market has begun to see the value in commercial products such as fish oil and fish mill as well as fertilizers. Efforts to further process fish waste have intensified in recent years. Operations are likely to invest in equipment designed at extracting fish oils and processing fish waste in order to sell these products on a global market. An economic feasibility study would be required to determine if biogas production from fish waste was competitively viable with these other potential waste stream applications. Smaller native or subsistence fisherman may also have an opportunity in biogas production from fish waste within medium to large scale processing facilities. Finally, local municipalities in Alaska may be interested in this technology as anaerobic digestion is already a common technology of many waste water treatment plants. Many WWTPs in the United States and globally have anaerobic digestion facilities installed to harvest biogas produced from the facility. Facilities throughout Alaska have not been evaluated fully at this time and conclusions about feasibility are omitted in this report.

Life-Cycle-Analysis

Anaerobic digester technology is growing at an exponential rate as importance for renewable fuel sources is being aided by increased regulation on farm waste disposal management practices. For capital intensive projects, growth of biogas technology would only occur if there is a significant benefit that exceeds the cost associated with their production and operation. Tax incentives and state emissions standards play a key role in evaluating the feasibility of large-scale projects. Feed-in tariffs and renewable energy portfolios standards are often incentives which help biogas projects get started in local communities (Motschenbacher, 2009). Indeed, the Alaskan Energy Authority established renewable energy goals in 2009 that called for 50% renewable energy by 2025. Currently, about 24% of Alaska’s electricity demand is being met by renewable hydroelectric power, leaving much room for other technologies to penetrate the market (Alaska Energy Pathway, 2010). Globally, biogas projects are starting up at an accelerating rate as more governments are beginning to see the need for better recycling techniques and processing of organic waste.

Biogas has many advantages when compared with other traditional fuel sources. Scharlemann, et al. (2008) compared different biofuels as to their overall energy balance and found biogas methane to be one of the most efficient alternative fuels presently available. Figure 3 compares different types of renewable energies based on their overall environmental impact. This analysis illustrates "utilized" biogas methane as being superior to a variety of other feedstock and fuel types. Raysoni, (2002) states that anaerobic digestion is one of the safest (least amount of risk) and best forms of treatment of wastewater and animal waste products with energy recovery being a key advantage over other forms of treatment.

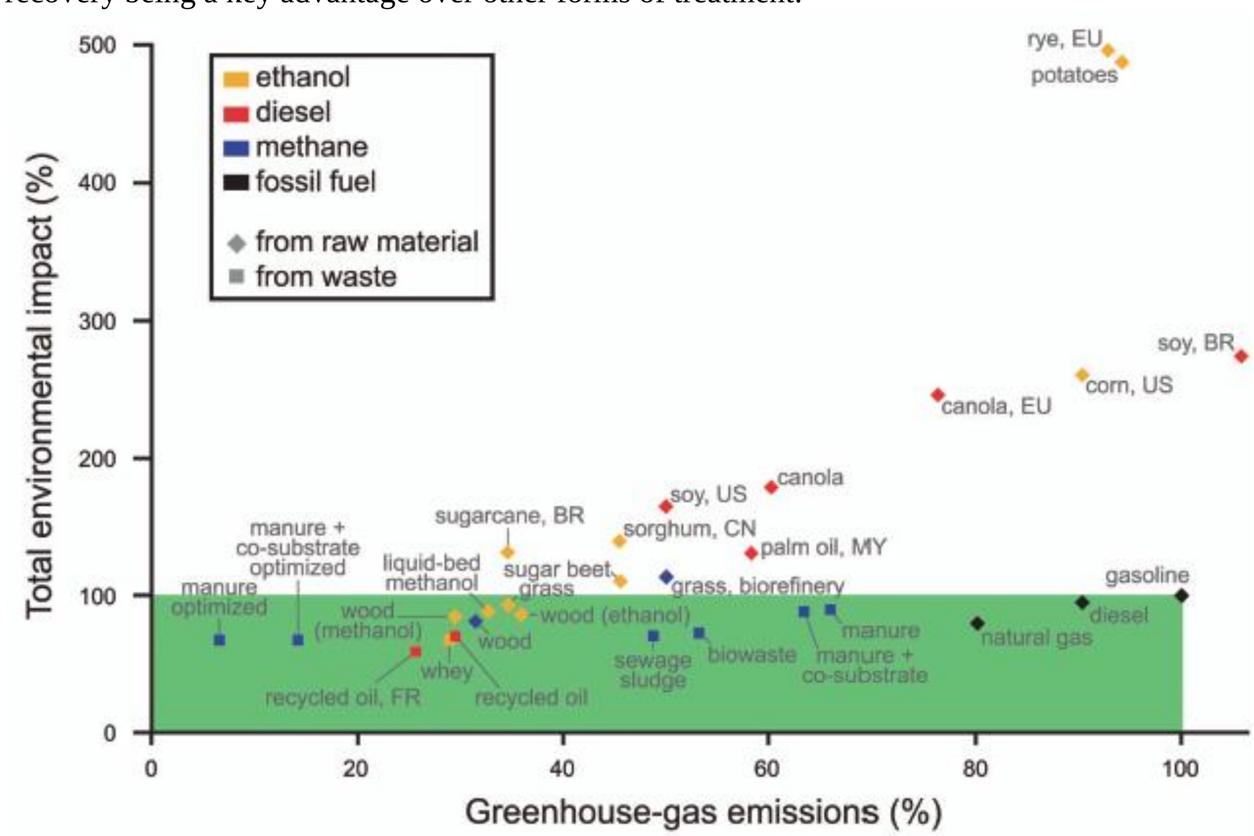


Figure 3**.** Comparative environmental impacts of different renewable fuel sources as compared to petroleum fuels. All points outside of the green area are considered found to have too heavy of energy inputs to be competitive with gasoline. (Zah, *et al*. 2007)

Much of the inherent waste associated with livestock and cattle lots is actually improved upon with treatment of an anaerobic digester. Though not directly applicable to all digester projects, Figure 4 highlights most [*not*] all processes and endpoints associated with digester projects to which we can pick apart and address individual waste streams:

Odor Control – Effluent odor is drastically reduced using anaerobic digesters as compared to aerobic effluent treatment or non-treatment. Comparative cost of disposal is also drastically reduced.

Ammonia Control – Ammonia emissions from anaerobic digester operations, especially lagoons are of increasing concern. Currently, there is no requirement for gas handling among digester projects; however, due to the nature of the digestion process and its storage systems, ammonia problems could easily be addressed. The smaller bifurcated holding systems could easily adapt a cover that would better contain ammonia emission or they could be extracted from waste water with additional equipment. This is much harder to achieve with traditional simplified waste pond systems and often waste and nutrient loading on the local watershed are common.

Greenhouse Gas Emissions – Conventional or “classic” liquid and slurry manure management practices typically emit large quantities of methane and other greenhouse gases to the atmosphere. Biogas acts as a form of secondary recovery that prevents these gases from escaping to the atmosphere and therefore reduces greenhouse gas emissions. At the same time the energy used offsets other inputs of fossil fuel and further reduces CO_2 emissions.

Improved Water Quality - “Anaerobic digestion provides several water quality benefits. When an anaerobic digester system, especially a covered lagoon, is properly managed, phosphorous and metals, such as copper and zinc, will settle out in the process cells, thus reducing phosphorous and metals loadings to surface waters when manure is land-applied. Digester systems, especially heated digesters, isolate and destroy disease causing organisms that might otherwise enter surface waters and pose a risk to human and animal health. Anaerobic digestion also helps protect ground water. Synthetic liners provide a high level of groundwater protection for manure management systems. These protective liners are a more affordable option with anaerobic digester systems than with conventional lagoons, because the multiple-cell design of anaerobic digesters requires less volume and, therefore, less lining material is needed. The concrete or steel tanks used in plug flow and complete mix digesters also effectively prevent untreated manure from reaching ground water” (EPA, 2002). Instances of fecal coliform entering the local watershed was greatly reduced due to the pretreatment of waste at the local project facility (EPA, 2009).

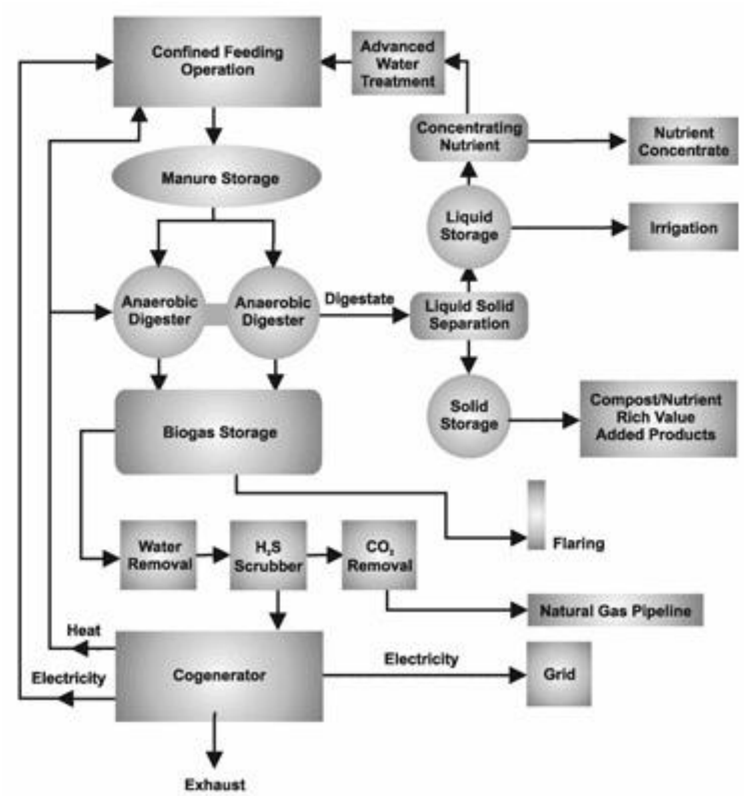


Figure 4. Process pathway for the synthesis of methane from fecal waste. (Nelson and Lamb, 2002)

Case Studies

Perhaps most importantly, anaerobic digesters have been shown to be profitable. Table 1 illustrates the projected and actualized pay-back periods for a case study dairy farm, part of the Minnesota Project (Nelson and Lamb, 2002). In this project case study, return upon initial investment was achieved 11 years after project startup, indicating the tremendous potential that these projects have and the economic and energy implications they can have for farmers, once debt consolidation on initial investment is achieved. Typical [agricultural] digester projects which are utilized for energy production will have a payback period of around 3 to 7 years, whereas a similar WWTP digester which simultaneously processes food waste will have a payback period of around 6 months to 3 years (Motschenbacher, 2009, Nelson and Lamb, 2002, Vik, 2003). Large-scale biogas projects are still regarded as capital intensive as the mechanical resources and labor maintenance inputs remain high in variable climates. Often, these projects are considered unreliable in terms of return on investment, limiting their acceptance and implementation in the past.

Table 1. Net annual returns for digester investments. Final Report: Haubenschild Farms, Minnesota Project. (Nelson and Lamb, 2002)

Scenario	Value of offset electricity (cents/kWh)	Value of excess electricity sales (cents/kWh)	Net annual revenue	Simple payback (years)
A. 1998 Projection	7.0	2.0	$31,489	11
B. 1998 Projection w/ high electricity price	7.3	7.3	$53,538	7
C. Actual, 2001	7.3	7.3	$72,616	5
D. Actual 2001 w/ mid electricity price	7.3	3.5	$50,596	7

Additional Case Studies Resources:

United States
http://www.mnproject.org/pdf/Digester%20resources.pdf
http://www.waste2profits.com/Articles/MN%20AURI%20Farm%20Assessment%201999%2011%2003.pdf
Sweden
http://www.kristianstad.se/upload/Sprak/dokument/2%20Biogas%20Kristianstad%20brochure%202009.pdf
http://www.cardiff.ac.uk/archi/programmes/cost8/case/watersewerage/sweden-brom.pdf\
http://www.youtube.com/watch?v=JIVBT8pp9Kk
http://www.youtube.com/watch?v=0B_9IKfrLJk&feature=related
http://www.nytimes.com/2010/12/11/science/earth/11fossil.html?_r=1&pagewanted=1&ref=general&src=me

Conclusions

In summary, the relative success of anaerobic digesters has led to their increased implementation over the past decade. Though large amounts of capital investment are initially required, returns are typically seen within the first ten years of operation. Technology investments are low for this process and result in its feasibility being extended to moderate to small sized farms and individual households. The use of anaerobic digesters appears to be a way of addressing some of the major waste issues that confront the livestock economies both of this country and the world. In this context, the use of methanogenic bacteria stands as an example of how the use and cultivation of a natural system yields an economic value and service that is of great use and increasingly high demand.

The treatment of waste water effluent with anaerobic bacteria has been demonstrated to greatly reduce the presence of harmful bacteria and pests. The remaining sludge left over from the treatment process is of substantial nutrient value and has a great economic value as fertilizer or bedding material. The impacts of this have resulted in large growth in the number of farms and municipalities that use digesters to offset their operation costs. Biogas then stands as a means of secondary energy recovery or improved efficiency for agribusiness-type processes.

Though the implementation of digesters may not be feasible for small farms individually, the presence of a digester on a farm stands independent from the farm itself, in other words, a single farm can consolidate waste from multiple sites and remain an alternative source of revenue to the owner at the same time, the gas can be converted into electricity or burned as fuel which can be sold and distributed back to other farms or communities further benefiting rural communities.

That said anaerobic digesters are not without setbacks. The waste streams associated with effluent still poses an environmental hazard due to the high nutrient content of the waste water; however, digester plant projects have now provided a way of separating, compartmentalizing and selectively reducing waste. Importantly, anaerobic digesters reduce the amount of greenhouse gases released to the atmosphere needlessly (methane in particular). For this reason, anaerobic digesters are and will be important part of our environmental, agricultural and economic future. There are plenty of farms that still could use this form of energy recovery to reduce cost and emissions impacts as well as generate additional sources of revenue.

For Alaska, a major consideration that will determine the feasibility of an anaerobic digester is appropriate feedstock. If the raw materials are available, biogas production could make sense in Alaska at many different scales. Temperature concerns can be overcome through proper insulation and heat exchanger technology, but the benefits or energy produced from the facility must justify the energy inputs to maintain bacteria cultures and operated equipment. At the large-scale (i.e. facilities that process tons of waste per day) the energy obtained from biogas production can in part be used at the site in order to maintain constant temperatures, making them a sustainable practice. For small-scale operations like that of the Improving Cold Region Biogas Digester Efficiency project, energy gained from digestion was not sufficient to meet the heating and cooling demands of the project. However, small to mid-sized operations may be justifiable in communities where recycling and human health concerns are important and in areas where waste heat is available. Nearly every Alaskan community has excess thermal from boiler heat or exhaust gas that can be used to warm an anaerobic digester. The biogas produced could then be used for any number of applications, but the main reason justifying projects like these would be for recycling purposes and producing fertilizer rather than energy recovery and power generation. At the small and mid-scale, anaerobic digesters set in Alaska would require considerable maintenance that may limit their appeal. Large-scale facilities avoid this because dedicated staff and machinery limit human exposure. In conclusion, Alaskans interested in biogas technology need to evaluate their communities for appropriate feedstock and waste streams, available thermal resources and public enthusiasm for developing alternative fuel sources before determining whether or not a biogas facility is appropriate in their community.

References

AgStar: Anaerobic Digesters Continue Growth in U.S. Livestock Market. *EPA.* February 2009. <www.epa.gov/agstar>

Alaska Energy Authority. 2010. Alaska Energy Pathway: A guide for Alaskan Communities to Utilize Local Energy Resources. *Alaska Energy Authority.* July 2010. <www.akenergyauthority.org>

Balsam, J. and Ryan, D. 2006. Anaerobic Digestions of Animal Wastes: Factors to Consider. *National Sustainable Agriculture Information Service.* <www.ncat.org/agri.html>

Baukal, C. E., Schwartz, R. E., Baukal, C. E., Schwartz, R. E., Baukal, C. E., Schwartz, E. 2001 Heat of Combustion: Handbook of Chemistry & Physics. *Chemical Rubber Co. Press LLC*. pp. 715–724

Hartman, K., Ruihong, Z., Antunes, M., Chornet, E., Turnbull, J., Shoemaker, S. 2001. Anaerobic Digestion of Fish and Wood Wastes for Biogas Production. *American Society of Agricultural and Biological Engineering.* Paper number 016014, 2001 ASABE Annual Meeting. @ 2001

Masse, D.I., Patni, N.K., Droste, R.L., Kennedy, K.J., 1996. Operation Strategies for Psychrophilic Anaerobic Digestion of Swine Manure Slurry in Sequencing Batch Reactors. *Canadian Journal of Civil Engineering.* **23**: 1285-1294

Motschenbacher, Anna. 2009. Climate Tech Book: Anaerobic Digesters. *PEW Center on Global Climate Change.* October 2009. pp. 1-8

Nelson, C. and Lamb, J. 2002. Final Report: Haubenschild Farms Anaerobic Digester. *The Minnesota Project*. 32.

Raysoni, Amit, 2002. Life Cycle Assessment for Anaerobic Digestion of Waste Products. *International Conference on EcoBalance.* Int J LCA 7 **(3)** 2002. pp. 187

Scharlemann, Jorn P. W. and Laurance W. F. 2008 ENVIRONMENTAL SCIENCE: How Green Are Biofuels? *Science.* **319** (5859), 43. [DOI: 10.1126/science.1153103]

Uchiyama, Y. 2007. Life Cycle Assessment of Renewable Energy Generation Technologies. *IEEJ Trans*. **1:**44-48

U.S. Department of Agriculture, 2011. Data Sets, State Fact Sheets: Alaska. Updated March 30, 2011. <http://www.ers.usda.gov/statefacts/ak.htm>

U.S. Department of Energy. 2008. Energy Savers: How Anaerobic Digestion (Methane Recovery) Works. <www.energysavers.gov/your_workplace/farms_ranches/index.cfm/mytopic=30003>

U.S. Department of Energy. 2010. Anearobic Energy Savers Web <www.energysavers.gov/your_workplace/farms_ranches/index.cfm/mytopic=30003>

U.S. Energy Information Administration. 2011. U.S. States: Alaska. *U.S. Dept. of Energy.* Updated March 24, 2011. <http://www.eia.doe.gov/state/state-energy-profiles-analysis.cfm?sid=AK>

U.S. Environmental Protection Agency Methane Web Page <*www.epa.gov/methane/*>

U.S. Environmental Protection Agency, 2002. Managing Manure with Biogass Recovery Systems: Improved Performance at Competitive Costs. *Office of Air and Radiation.* EPA-430-F-02-004 <www.epa.gov>

U.S. Environmental Protection Agency 2010. The AgSTAR Program: A guide to Anaerobic Digesters. <www.epa.gov/agstar/operational.html>

Vik, Thomas E. 2003. Anaerobic Digester Methane to Energy: A Statewide Assessment (Wisconsin). *Focus on Energy*. January 23, 2003. McM. No. W0937-920459

Zah, R. *et al*. 2007. Ökobilanz von Energieprodukten: Ökologische Bewertung von Biotreibstoffen. *Empa*, St. Gallen, Switzerland