

**Denali Emerging Energy Technology Grant:
“Improving Cold Region Biogas Digester Efficiency”
Quarterly Report, Q2 - June 15, 2010**

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i. Updated schedule and milestone information as identified in the Scope of Work.

The project is currently in Phase 1, as defined in the original two-year Scope of Work. In November 2009 we assembled materials and conducted a small pilot study. Phase 1 construction commenced on January 14, 2010 with the meeting of the team in Cordova. We completed the main site construction and digester setup, barring continual updates and improvements, on January 21, 2010. We have been collecting data on temperature, chemistry, and gas production since January 18, 2010. Flow meter data, quantifying gas output from each digester, has been collected since February 18th, 2010.

The project continues to closely follow the original outlined plan:

- **Construct Digesters for Phase 1 by December 15, 2009** – DONE, January 21 2010
- **Begin Data Collection by February 1, 2010** – DONE, January 18 forward
- **Perform mid-term Analysis of Data by July 30, 2010** – continual/forthcoming
- **Perform Analysis of final Data (Phase 1) by December 1, 2010** – forthcoming, updated according to “Data Collection Plan” submitted March 4, 2010
- **Phase 2 -Install Digester in Practical application by Sept 30, 2010** - upcoming
- **Evaluate performance/Sustainability by July 30, 2011** - upcoming
- **Submit Final report and project close-out documents by September 30, 2011** – upcoming, updated according to submitted Data Collection Plan

i.a) Personnel:

Cordova Electric Cooperative <http://cordovaelectric.com/>

Clay Koplín – Grant Administrator. Koplín has managed most of the financial aspects of the project thus far on behalf of the Cordova Electric Cooperative, serving as the project manager.

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

Katey Walter Anthony – Research Director. Walter-Anthony acts as the primary investigator, and has spearheaded the scientific goals and directions of the project. She participated in the initial on-site construction efforts and provides continual scientific expertise.

Laurel McFadden – Research Technician. McFadden, with assistance from the rest of the project team, is responsible for the implementation of the study. McFadden was a key contributor to the project development and took the lead on organization and preparation for the initial construction and setup. She is currently working on-site in Cordova, maintaining the digester experiment, including data collection, analysis, and troubleshooting. McFadden compiled the project report with input from Walter Anthony, and Cordova team members, Koplín and Low. McFadden is also drafting a Biogas construction manual and user guide for Alaskans as part of this project.

Peter Anthony – Research Technician. Anthony consulted on project development, and worked on initial site construction and digester setup. Anthony continues to provide technical expertise to the maintenance and application of digesters.

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

Adam Low – Science Teacher. Low was integral in bringing in student involvement via classroom curriculum and extracurricular projects. He was on the construction team and continues to assist troubleshooting, construction, and maintenance.

Cordova High School Students – Volunteers. The students have been highly involved with construction, feeding, maintenance, and public presentation. They include the Chemistry class students (Shannon Lindow, Craig Bailer, Taylor Kelley, Christina Morrisette, Jessica Smyke, and Danielle Hess), and the Science Club students (Craig Bailer, Danielle Hess, Ian Americus, Ben Americus, Erin Hess, Sophia Myers, Adam Zamudio, James Allen, and Keegan Irving). Ian Americus, Ben Americus, Erin Hess, James Allen, and Adam Zamudio presented at the Alaska Rural Energy Conference in Fairbanks along with Adam Low.

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

TH Culhane – Biogas Expert. With an extensive history in biogas technologies, Culhane developed the water-pressure tank design and provided extensive technical knowledge to the engineering of the project. He worked with and advised the on-site construction in January 2010 and provides expert advice from his home base in Germany.

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

Chena Hot Springs <http://www.chenahotsprings.com/>

Bernie Carl – Owner of Chena Hot Springs. Carl has been interested in deploying a digester at Chena Hot Springs, and has provided space for testing a digester in his greenhouse.

Others <http://www.cordovaenergycenter.org/>

Brandon Shaw – Website Development. Shaw designed and manages the CordovaEnergyCenter.org website, where the project is hosted. He also assisted at the initial construction site, and was integral in the assembly of the flow meter system.

ii. Narrative summary of the project status and accomplishments to date, and addressing the following questions: is the project on schedule, is the project on budget, and what actions are planned to address any project problems.

ii.a) Project Status and Accomplishments

Phase 1 of this project is defined by experimentation with a variety of microbial communities (psychrophiles, mesophiles, and mixed communities) and temperature conditions (15 °C and 25 °C), and as such is the heart of the development stage for this proposal. As this is a unique approach to the development of a cold-adapted digester, we are facing a variety of interesting challenges in bringing the experimental systems to optimal gas output. The continual benefit of this process is developing an extensive database of fundamental data on the chemical processes and gas output of this biologically-based technology, while testing the physically-engineered aspects of the constructed systems.

Our first pilot-experiment in November 2009 involved mixing different volumes of thermokarst (thaw) lake mud, in a series of ten 5-gallon buckets, to test the minimum mud-to-water ratio required for psychrophilic biogas production as a test design for larger systems anticipated in Phase 1. Conventional biogas digesters utilizing mesophiles operate with a 50:50 ratio of manure to water. Due to the time and logistical constraints of collecting mud by hammer coring in 4.5cm width barrels, we wanted to know if a less than 50:50 ratio would work in our 1000-Liter (250 gallon) Phase 1 experiment. Our November 2009 pilot study demonstrated that a 10% concentration of thermokarst (permafrost thaw) lake mud from Fairbanks mixed with water from Lake Eyak (Cordova) was sufficient to produce a flammable biogas within 2-3 days. Flammable biogas continued to be produced, to some extent, for approximately two months. Please see Appendix 1 for a summary of the pilot study.

Over the course of 3 weeks in mid-December and early January, we used a percussion corer with 4.5cm width core barrel tubes to acquire ~192 liters (48 gallons) of lake bottom sediment from Goldstream Lake, an active methane-producing, thermokarst lake near Fairbanks, to provide the source of the psychrophilic microbial community that would be the foundation of four of our 1,000-liter experimental digester systems. On January 12, 2010, we collected 240 liters (60 gallons) of fresh manure from the Northern Lights Dairy farm in Delta Junction. During January 14-19, 2010, the project team modified a Connex on site at the Cordova High School to create a temperature-controlled container for the experiment. We also constructed six digesters and filled them with mixtures of mud and manure. On January 19th, the tanks were sealed and initial physical and chemical data on starting conditions were recorded. The experimental design is shown in Figure 1.

Digester	Temperature target (°C)	Psychrophiles		Mesophiles	
		Lake sediment (L)	Manure (L)	Inoculum concentration in tap water (% of total volume)	
1	15	48			5%
2	15	48	60		12%
3	15		60		6%
4	25	48			5%
5	25	48	60		12%
6	25		60		6%

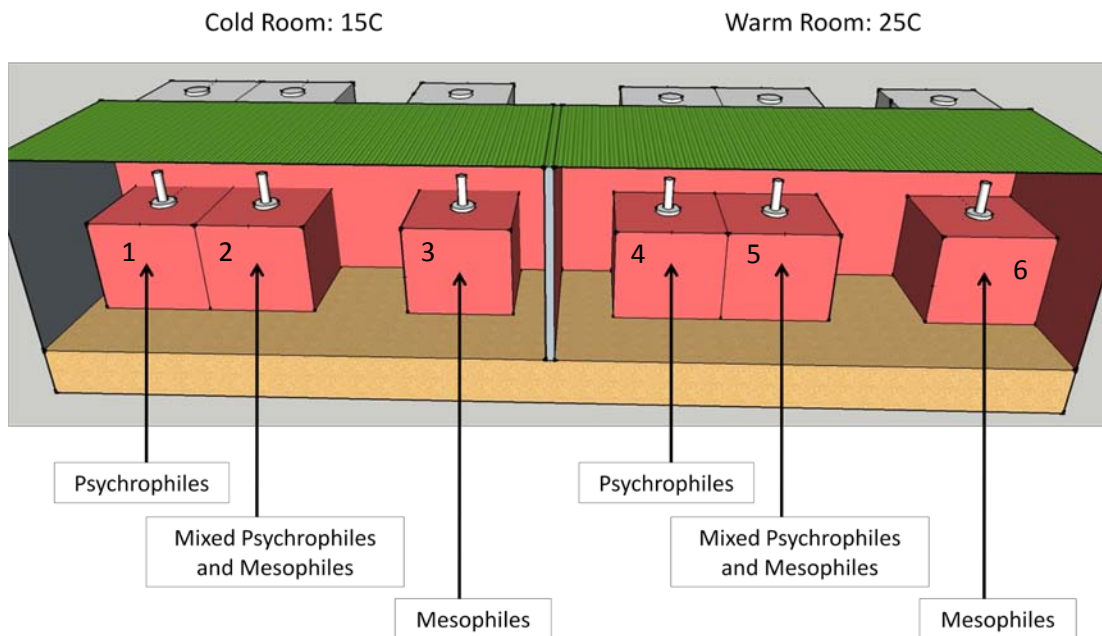


Figure 1. Experimental design for Phase 1 testing of biogas production efficiency of different combinations of psychrophilic and mesophilic methanogen communities under cold and warm temperature treatments.

The building team consisted of members of the research group from UAF, SOLAR Cities, CEC, and Cordova High School. System materials were based on 12 donated 1000-L HDPE tanks (six primary tanks for holding digester sludge and slurry (inoculum, feedstock, and water), and six additional tanks used in constructing half of the external water pressure systems), purchased pipe fittings and materials, and borrowed tools. Labor was directed by TH Culhane and Katey Walter Anthony with invaluable input, discussion, and active participation in design and construction from all team members. Primary site construction included insulating and heat-wiring a 40-ft metal Connex, which was evenly divided into the Cold (15°C) and Warm (25°C) rooms of the experiment. Voltage meters were installed to monitor the electrical input required to heat each room to the specified temperature, for later assessment of economic feasibility.

Each tank was built to hold a slurry of microbial inoculum (manure or lake sediment) and water. The contents of each tank are detailed in Figure 1. Traditional digesters are based on a 50:50 ratio of manure to water (50% inoculum). The ratios used in this experiment are significantly lower, mainly due to time and transport constraints on the amount of material that

is required to power 6 tanks. The amounts of sediments used are within the same order of magnitude as the 10% inoculum concentration that yielded biogas in the pilot experiment described in Appendix 1.

The slurry ratios used in our six tanks is significantly lower than the standard 50:50 ratio of manure to water used in traditional digesters. Although tanks with these ratios can still produce biogas, it could take longer to build a significant population of methanogens. Most methanogens have a replication turnover time of roughly 30 days (Gerardi 2003). Our tanks likely started with a low number of microbes (more on this issue in “ii.d Hurdles and Solutions, 2) Low microbial population size”).

Following the sealing of the tanks on January 19, 2010, baseline chemical and environmental properties were measured and recorded on a regular basis (approximately 3 times per week). Initially, we conducted daily “flame tests” to check the minimum methane content of produced gas (biogas is flammable at ~5% methane by volume mixed with air, in the presence of an ignition source). Chemical properties measured on subsamples of the liquid effluent mainly included: pH, oxidation-reduction potential (ORP), and dissolved oxygen; all primary indicators of the relative health of the microbial environment. In healthy anaerobic digesters, pH should be between 6.8-7.2. Methanogenesis is supported at ORP readings below -300mV. Dissolved oxygen (DO) should read as close to 0% as possible, denoting the required anaerobic conditions and balance of fermentation and methanogenesis. The other main environmental variable measured is temperature, both inside and outside of the tanks. Room temperature is measured via one centrally-located temperature logger in each room, while internal tank temperatures are recorded at two levels within the digester slurry via special waterproof dataloggers (approximately 30cm above the bottom of the tank and 15cm below the surface of the slurry). Loggers were set up to log data over intervals up to 6 months, allowing the tanks to go undisturbed as long as possible. Figures 2-6 show results to date of digester chemistry, internal and external temperature. Table 1 shows results of flammability tests.

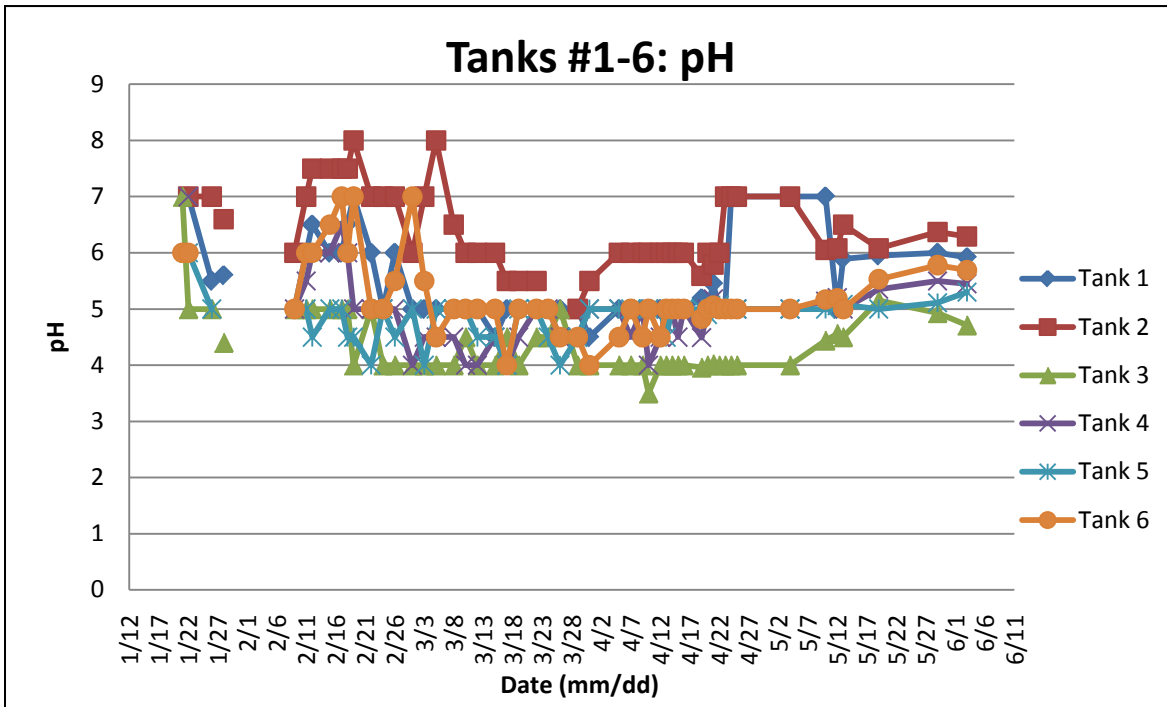


Figure 2. pH results obtained after the tanks were sealed (Jan. 19, 2010). pH declined for several months, but recently began rising in response to the alkalinity additions, which began March 22, 2010. Ideally pH should be between 6.8-7.2. pH was measured with Macherey-Nagel litmus paper January 21-April 16, following which it was more accurately measured with an Oakton PC510 pH meter.

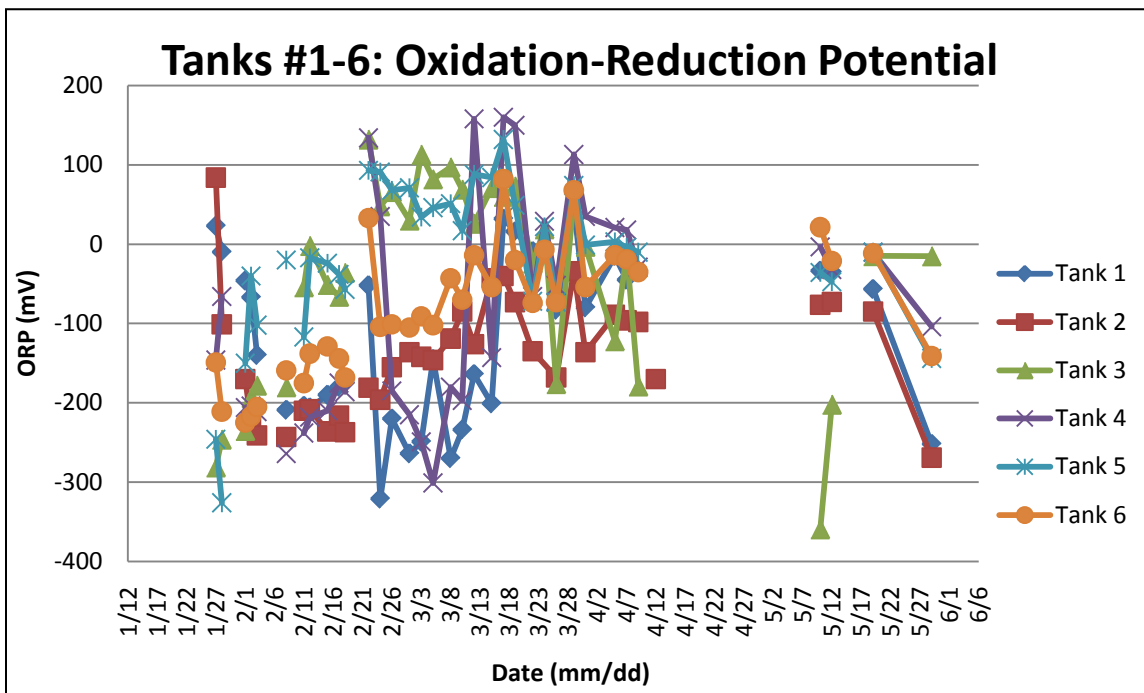


Figure 3. Oxidation-reduction potential (ORP) indicates the availability of oxygen in the system. For healthy methane production, samples should have an ORP of -300. From January 21-April 9, ORP was measured with a Xplorer GLX Pasco PS-2002 Multi-Datalogger. From May 10 forward, it was measured with an Oakton PC510 ORP meter.

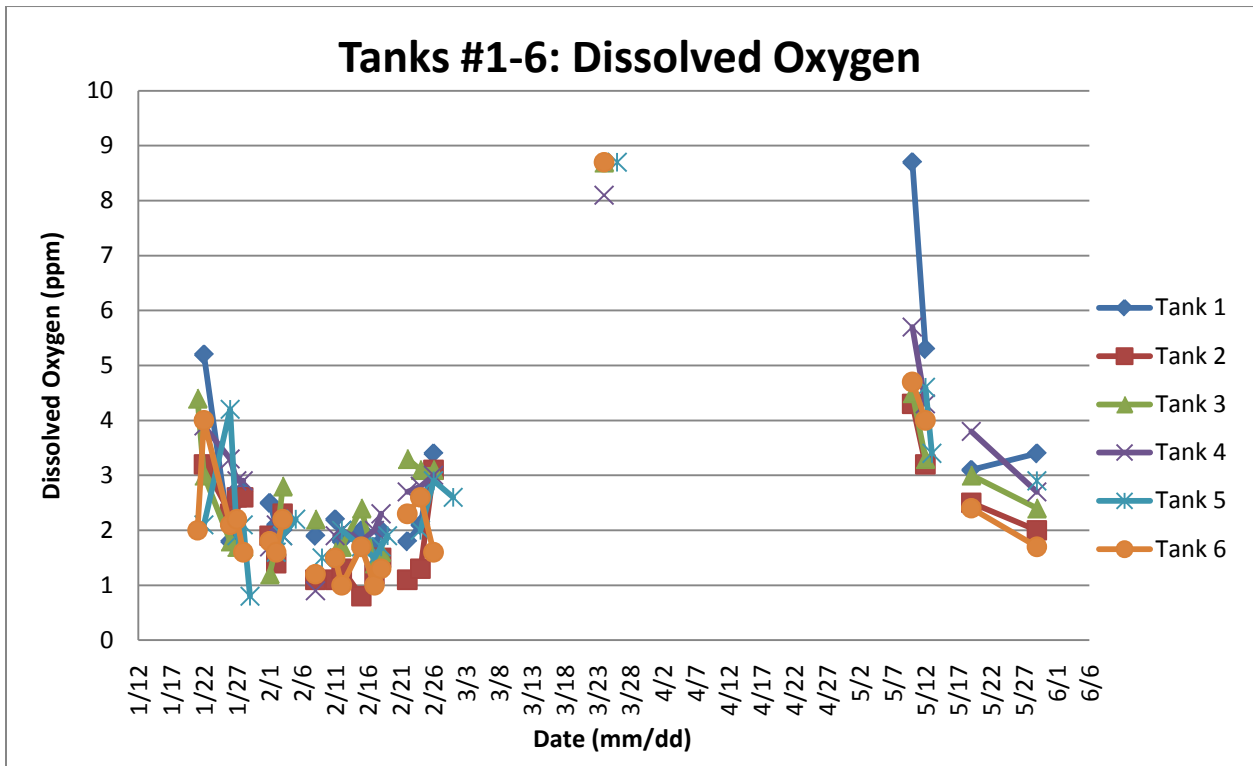


Figure 4. Dissolved oxygen (DO) readings indicate the amount of oxygen in the system. The tanks should have a DO as close to 0ppm as possible (1 ppm = 1 mg/L) . Gaps in the chart above indicate periods where our DO meter was non-functioning. The high readings in early May could have been caused by opening the system during attempts to mediate pH. DO measurements were taken with a Xplorer GLX Pasco PS-2002 Multi-Datalogger until March 24, following which they have been taken by a Hanna HI9142 DO meter.

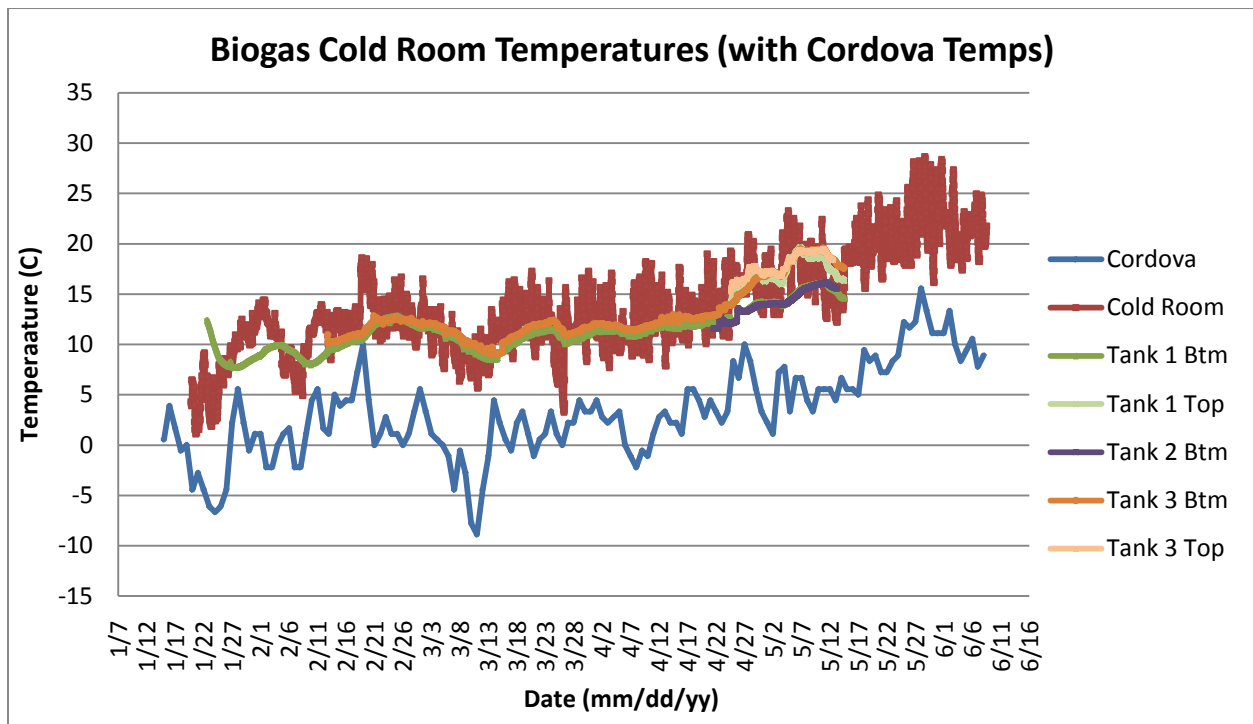


Figure 5. Mean hourly temperature of the cold room and digester tanks 1-3, and mean daily temperature recorded in Cordova. The average temperature of the cold room from January 19, 2010 through June 8, 2010, was 13.7°C. Cold room temperature has been approximately 2-4°C lower than the targeted 15°C for the majority of the study period due to the difficulties of heating a metal Connex, and due to the effects of temperature stratification within the Connex (temperatures are logged approximately 3-ft from floor level). Digester tank temperatures followed the external room temperature fairly closely, while room temperatures mimicked patterns in external environment. Tank temperatures have not been downloaded since May 12 in an effort to maintain the anaerobic environment in the tanks (accessing the temperature loggers requires opening the tanks to the air). According to the patterns we have seen thus far, though, we could predict an increase in tank temperatures following the increase in room and environmental temperatures. Biogas project temperatures are measured with Hoboware U22-001 Water Temp Pro V2 loggers recording hourly.

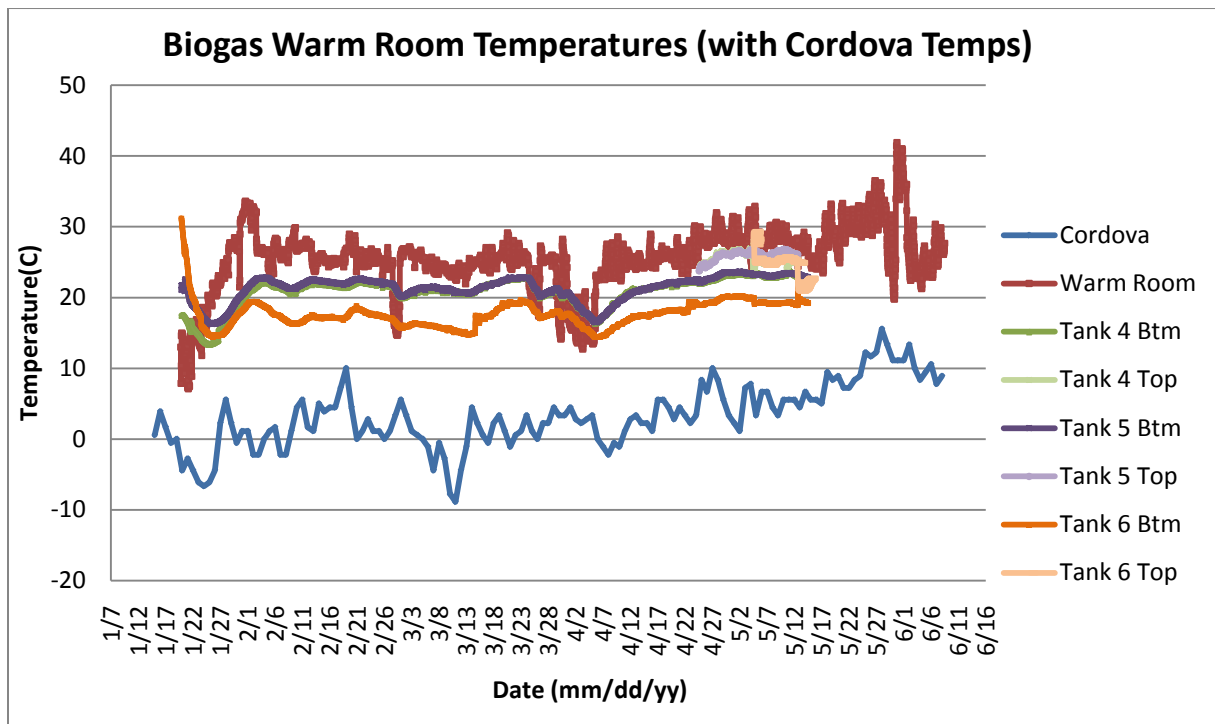


Figure 6. Mean hourly temperature of the warm room and digester tanks 4-6, and mean daily temperature recorded in Cordova. The average temperature of the warm room from January 19, 2010 through June 8, 2010, was 25.5°C. Digester tank temperatures were approximately 5°C lower than the external room temperature. Thermal stratification in tanks was observed with warmer temperatures at the top of all tanks and colder temperatures at the bottom of the tanks. Tank temperatures lower than room temperatures are likely due to heat conduction through the poorly insulated Connex floors and wall. Tank 6, the coldest tank, touches outside walls on two sides (Fig. 1). Tank temperatures have not been downloaded since May 12 in an effort to maintain the anaerobic environment in the tanks. According to the patterns we have seen thus far, however, we could predict a general similarity in tank temperatures following the rise and fall in room and environmental temperatures. Biogas project temperatures are measured with Hoboware U22-001 Water Temp Pro V2 loggers recording hourly.

Table 1. Results of produced gas flammability tests. Positive results of the flammability test indicated usable biogas. For technical and safety reasons, flame tests were not performed after flow meters were installed on 2/18/2010.

Tank	First positive flame	Last confirmed flame
1	1/31/10	2/18/10
2	NA	NA
3	1/22/10	2/1/10
4	2/1/10	2/18/10
5	1/21/10	2/9/10
6	1/26/10	1/26/10

Our most exciting result to date is the speed at which the tanks began to show flammable biogas. Tank #5 flamed after only 2 days, which was surprising considering the typical 30 day waiting period observed with most digesters post-initiation in other projects (GTZ 1999). Gas from tank #3 was flammable on the 3rd day of the experiment. Photos in section iii) show examples of flame test results. Tanks were filled with warm (approximately 20°C) water from the high school gymnasium. The combination of initial warm temperature together with residual sugar in the tanks leftover from fish product storage served as a high-energy substrate likely facilitated the rapid response of microbes in both the manure and lake sediment to produce biogas. Despite some fluctuations in tank temperatures around the targeted 15°C and 25°C levels (Figures 5-6), all tanks except #2 showed flammable gas within two weeks. As per conventional procedure, once flammable biogas was demonstrated on all tanks (February 15, 2010), we commenced full feeding procedures.

Our goals with the feeding procedure were to provide an equal volume of homogenized food-water slurry to each tank daily. In conventional biogas systems, a 1000L system is expected to digest 1kg of organic food waste daily, producing roughly 1,000L of biogas (Samuchit Enviro-Tech Pvt. Ltd.). In accordance with conventional digester protocols, we fed each tank a 2kg slurry consisting of 1kg wet food weight plus 1 kg water. The feeding procedure included collecting and blending food scraps from the high school cafeteria to produce 6 equal portions of food batch with equal 1:1 ratios of blended food and water. A 20-ml subsample of each food batch was collected and stored frozen for later carbon and nitrogen analysis.

On February 18th, Sierra Instruments Top-Trak 820 Series Mass Flow Meters were installed on all systems. Because the electronic meters were installed in line, we could no longer conduct flame tests in the same fashion on the gas discharge tube. Flow meters recorded gas output in a raw voltage format every 5 seconds. The gas flow is measured according to heat transfer and the first law of thermodynamics. The gas flows through two paths in the machine, one of which causes a small pressure drop in the other. In the sensor tube, a constant amount of heat is directed into the gas stream. The difference in the temperature between two resistance temperature detectors gives an output signal that is linearly proportional to the gas mass flow (Sierra TopTrak Manual). Due to the high volume of data and limited capacity of the data logging memory, gas flow loggers must be downloaded every 24 hours and stored on a computer. Post processing flow data includes a custom-written Visual Basic code that compiles 5-second datapoints into hourly averages, which are then more easily converted to daily output rates. Gas flow has been measured and processed continually since Feb. 18, 2010. Results to date are shown in Figure 7.

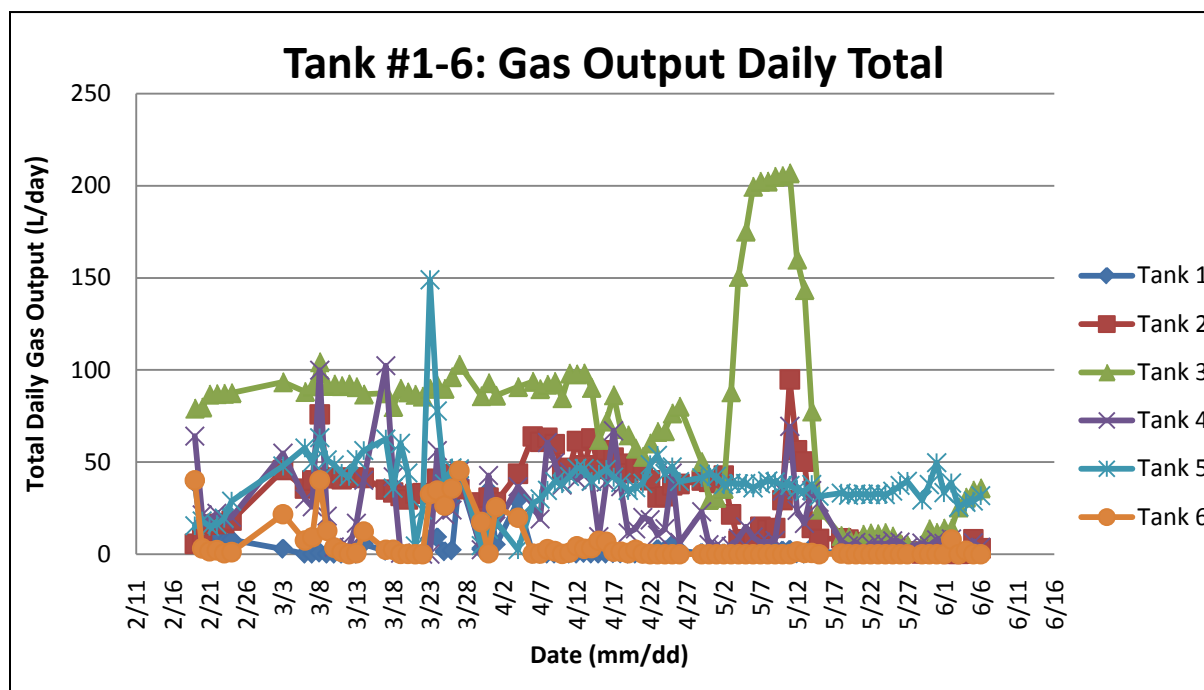


Figure 7. Mean daily gas flow rates from digesters. For an optimally operating biogas system, daily flow rates should be approximately 800-1000L/day. Regular feeding began on February 15 and was stopped on March 21. Although gas is being produced, due to the low pH and high ORP levels, it is unlikely that the gas has high methane content. Spikes seen in mid-May are a result of chemical mediation. It is unknown, without analysis of gas samples, whether that increased gas output is a sign of increased biogas (high methane) production, or production of byproducts to the reaction.

In mid-March a number of problems were elucidated. Digester slurry chemistry measurements indicated declining pH on all tanks, which combined with weak flow meter data (optimal tank production is on the order of 1000Lgas/day, whereas we were seeing 50Lgas/day, max) suggested that the tanks were no longer producing useable biogas. Biogas production involves fermentation reactions, through which the microbial communities produce CO₂, volatile fatty acids (VFAs), hydrogen, and other trace gases, some of which are precursors to methane. However, when fermentation reactions exceed methanogenesis, the buildup of fatty acids can lead to low pH conditions. Under conditions of low pH, redox above -300 mV, and the presence of oxygen, methanogens do not produce methane. We hypothesized that over-feeding may have led to the high production of fermentation products, including volatile fatty acids, causing the decline in pH. Although we did show positive flammability of produced gas early in the experiment, it is possible that variations in temperature, sugar content adhering to the HDPE tanks, or other variables contributed to an atypical spike in gas production immediately after sealing the tanks while pH was still close to neutral.

Our initial feeding protocol was time intensive and considered by the Cordova High School students to be too 'gross' for a lunch hour activity. The students subsequently re-engineered the feeding procedure to involve a faster distribution processes. As the feeding procedure was entirely the students' responsibility (as long as scientific standards were met, observed by their teacher or the on-site technician), this provided an unexpected positive highlight of the project. High school students were able to take personal role in the

engineering, leading to one student presenting their food distribution design at the Alaska State Science Fair.

However, due to the acidity of the tanks, feeding was postponed as of March 21st, and chemical mediation (adding alkalinity) to the tanks was initiated. It has been shown that a carefully mediated cocktail of baking soda, calcium carbonate (lime), and sodium hydroxide can raise the pH of biogas digesters. Table 2 shows our calculation of required alkalinity additions. Table 3 displays the schedule to date of mediation. Care has been taken to prevent tanks from going basic via this treatment, which would be a much more difficult chemical situation to fix. Measurements of pH in the sediment, manure, and mixed sediment-manure sludge at the bottoms of the tank are still around pH 7; hence we are optimistic that the methanogen population has survived this long period of low pH conditions. We are currently in the process of raising the pH, attempting to reproduce the optimal conditions for the psychro- and mesophilic methanogenic communities (pH 6.8-7.2). As there are multiple factors that can affect pH, chemicals are being added slowly to avoid over-mediation.

Table 2. Chemical mediation assessment. Slurry volumes of 500-mL were individually tested with NaOH and CaCO₃. Post-chemical pH readings are specific to the test of that particular chemical. Estimated NaOH or CaCO₃ needed to mediate an entire tank is shown in the final column.

Tank	Test Volume (mL)	Initial pH	Test NaOH (g)	Test CaCO ₃ (g)	Final pH post-NaOH	Final pH post-CaCO ₃	Estimated NaOH or CaCO ₃ (g) needed to raise ph of tank to 7.0
1	500	5.5	0.5	1	7	6.5	1000 NaOH or 2000 CaCO ₃
2	500	6	0.5	0.6	7.5	6.5	1000 NaOH or 1200 CaCO ₃
3	500	4	1	1.5	6.5	5.5	2000 NaOH or 3000 CaCO ₃
4	500	4.5	0.5	1.5	6.5	6.5	1000 NaOH or 1000 CaCO ₃
5	500	5	0.5	1.5	6	5.5	1000 NaOH or 1000 CaCO ₃
6	500	5	0.5	1.5	6.5	6.5	1000 NaOH or 1000 CaCO ₃

Table 3. Schedule of chemical alkalinity treatments. pH results highlighted in blue were measured with the Oakton PC510 pH meter. All other pH measurements were determined via litmus paper readings.

Date	Tank	pH	NaOH added (g)	CaCO ₃ added (g)
4/8/10	1	5.5	0	100
4/9/10	1	5	30	0
4/10/10	1	5	50	0
4/12/10	1	5	100	200
4/13/10	1	5	50	200
4/14/10	1	5	40	200
4/15/10	1	5	0	220
4/16/10	1	5	0	250
4/23/10	1	5.45	0	0
5/14/10	1	5.95	200	0
6/5/10	1	6.14	250	300
6/7/10	1	6.5	250	0
TOTAL	1		970	1470
4/8/10	2	6	0	100
4/9/10	2	6	30	0
4/10/10	2	6	50	0
4/12/10	2	6	100	200
4/13/10	2	6	50	200

Date	Tank	pH	NaOH added (g)	CaCO ₃ added (g)
4/14/10	2	6	40	200
4/15/10	2	6	0	220
4/16/10	2	6	0	250
4/23/10	2	5.79	0	0
5/14/10	2	6.08	200	0
6/5/10	2	6.29	250	300
6/7/10	2	6.5	250	0
TOTAL	2		970	1470
4/8/10	3	4	50	0
4/9/10	3	4	0	60
4/10/10	3	3.5	50	0
4/12/10	3	4	100	200
4/13/10	3	4	50	200
4/14/10	3	4	40	200
4/15/10	3	4	0	220
4/16/10	3	4	0	250
4/23/10	3	4.02	0	250
5/14/10	3	4.56	200	0
6/5/10	3	4.71	250	300
6/7/10	3	4	250	0
TOTAL	3		990	1680
4/8/10	4	4.5	0	50
4/9/10	4	5	30	0
4/10/10	4	5	50	0
4/12/10	4	4.5	100	200
4/13/10	4	5	50	200
4/14/10	4	5	40	200
4/15/10	4	4.5	0	220
4/16/10	4	5	0	250
4/23/10	4	5.18	0	250
5/14/10	4	5.20	200	0
6/5/10	4	5.45	250	300
6/7/10	4	5.5	250	0
TOTAL	4		970	1670
4/8/10	5	5	25	0
4/9/10	5	5	0	60
4/10/10	5	5	50	0
4/12/10	5	4.5	100	200
4/13/10	5	5	50	200
4/14/10	5	5	40	200
4/15/10	5	5	0	220
4/16/10	5	5	0	250
4/23/10	5	5.07	0	250
5/14/10	5	5.08	200	0
6/5/10	5	5.24	250	300
6/7/10	5	5	250	0
TOTAL	5		965	1680
4/8/10	6	5	0	50
4/9/10	6	4.5	30	0
4/10/10	6	5	50	0
4/12/10	6	4.5	100	200
4/13/10	6	5	50	200
4/14/10	6	5	40	200
4/15/10	6	5	0	220
4/16/10	6	5	0	250
4/23/10	6	5.06	0	250
5/14/10	6	5.19	200	0
6/5/10	6	5.69	250	300
6/7/10	6	6	250	0
TOTAL	6		970	1670

The total amount of chemicals added to the tanks thus far is more than what was estimated in Table 2. However, pH in the tanks has not yet reached an optimal level. It is possible that acids are being continually produced by residual organic substrates in the tanks. It is also possible that the test samples used to produce the results shown in Table 2 were not representative samples for the tanks. This could be due to stratification; we have already seen thermal stratification in the tanks, we may suspect chemical stratification as well. In either case, more base addition than originally estimated may be necessary to bring pH up to desired levels.

Figure 8 shows the water pressure systems designed to store and provide pressurized gas in Phase 2. As biogas is produced from the slurry in the primary tank, it is forced through the primary gas outlet into the gas storage tank, which is filled with water with a pH of 3-4 to prevent dissolution of CO₂. The pressure of the gas forces the water out through the water transport into the pump bucket. A pump then moves the water into the water storage tank. When the biogas is ready to be used, the valve between the water storage tank and the gas storage tank is opened, causing the water to flow back into the gas storage tank, forcing the biogas out at pressure from the final gas outlet. We have already assembled this water pressure system for three of the digesters (standing outside the Connex, Figure 1); however we will postpone usage of the water-pressure component of the digester system until we have higher levels of flammable biogas production (or until we have finished phase 1, where our priority is to get accurate measurements of biogas production rates, using the flow meters).

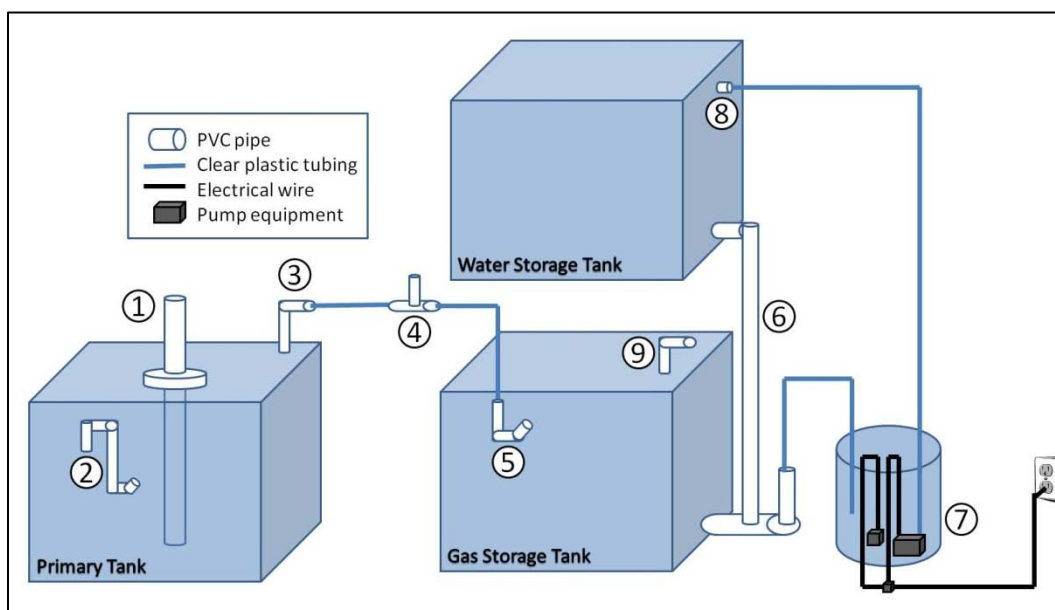


Figure 8. Water pressure system for storing and dispensing pressurized biogas. System components include: 1) Feeding tube 2) Effluent pipe 3) Primary gas outlet 4) Flame tester 5) Gas inlet 6) Water transport 7) Pump bucket 8) Water inlet 9) Final gas outlet

ii.b) Health and Safety

Conventional biogas digesters are typically considered safe and are kept in and around homes. However, there are some safety issues that are important to be aware of, especially while conducting experiments with younger students.

Flammability/explosions: Biogas is flammable. Methane is explosive at a concentration of 5-15% in atmospheric air. It is important that the biogas digesters do not have any leaks, especially if they are in an enclosed space, as they are in the Connex.

To prevent safety hazards due to flammability, our tanks are tested for leak points by immersing joints in soapy water and periodically squirting soapy water on the joints to watch for bubbling. All gas produced flows out of the Connex via the gas outlet pipes. Biogas is not allowed to be released within the Connex. Ventilation holes have been drilled into the Connex in the ceiling to allow any unintentional methane to escape (methane, being lighter than air, will rise to the ceiling). Students are not allowed to bring any ignition source (such as a lighter) into the Connex. Occasional flame tests conducted by the on-site technician are done outdoors and without students present. Students are also required to work in pairs to avoid accidents.

Hydrogen Sulfide (H₂S): Hydrogen sulfides can be produced as a side product of fermentation. The gas is flammable and toxic. At higher concentrations, or prolonged exposure to low concentrations, it is a mucus membrane irritant. Exposure can lead to headaches, nausea, and in extreme cases, pulmonary edema, heart irregularities, and unconsciousness.

We have installed hydrogen sulfide detection badges in the rooms to monitor higher levels of H₂S (at low, non-toxic levels, hydrogen sulfide can be detected by its smell of rotten eggs).

Ventilation: The build-up of certain gases in an enclosed space can be toxic. Biogas digesters produce methane, carbon dioxide, hydrogen sulfide, and other gases which can be deadly at high concentrations.

As with the flammability issue, tanks are tested for leaks and opened only occasionally when the Connex doors are wide open. Ventilation holes in the ceiling allow lighter gases to have an escape outlet. In addition, the Connex is flushed at least partially once a day, when the doors are opened during the flow meter download process. General safety procedures also include students being required to work in pairs, and having the Connex locked when a supervisor is not present. We are also in the process of coordinating an environmental health and safety assessment of the Connex site with the Cordova fire department.

ii.c) Schedule of project

The project, according to the broad outline in the proposal, is technically on schedule. Phase 1 is well underway. Construction of digesters is complete. Initial biogas was produced. Now we are working on raising pH in order to return digester conditions to those optimal for methanogenesis. When methane (biogas) production starts again, we expect to begin a more comprehensive analysis of the efficiency of psychrophilic vs. mesophilic methanogens in biogas production.

ii.d) Project budget

As of May 31, 2010, the project timeline is 30% complete. The UAF budget is on track with the project schedule, neither over nor under budget. This is somewhat to be expected as the UAF budget is primarily labor and is fairly predictable and manageable. Originally we planned for the UAF team to operate through part-time technical support to the project including regular site visits to Cordova; however, complications of acidification of tanks and more rigorous remediation necessitated the move of a full time UAF technician (Laurel

McFadden) to the site. On-sight full time UAF technician salary until June 2010, followed by part-time support thereafter, will require re-budgeting a fraction of the PIs salary to technician salary. UAF will also need to redirect funds within its sub-award towards contractual services. The equipment costs have been a little higher in some areas (instrumentation) and compensated in others. The grant match funds were reported as approximately on budget, the detail will be available in the next report. Lesli Walls will also submit a separate financial report to the Denali Commission.

The CEC and Cordova Schools budget is approximately 10% over, but the match is over approximately 40%. The CEC budget was primarily for materials. The additional insulation, wood, and hardware necessary to create a climate controlled environment for the project negatively impacted the budget. This was compensated for by reducing the plumbing and feedstock supplies portion of the budget. Since the equipment costs represent “start up” costs, they are more heavily weighted on the first portion of the project, so it is appropriate that over 40% of the budget has been consumed at this time. The Cordova Schools budget is primarily for travel and dissemination of project results. Since travel and showcase events are discrete events representing most of the cost, the budget consumption has been high for the presentations to the Alaska Power Association in Juneau in February, 2010 and at the Rural Energy Conference in April, 2010. This travel represents more than half of the project related travel, but has consumed less than half the total budget. The level of effort applied to the project by both the High School teacher and the students has been much more enthusiastic than anticipated, as reflected in the matching hours.

In summary, the UAF and CEC/Cordova Schools budgets are within expectations for this phase of the project. No budget overrun is expected at this time.

ii.e) Hurdles and solutions

Project problems and solutions were mentioned in ii.a, and are outlined in more detail here.

Lack of biogas production – Traditionally, biogas production requires a start-up time of 1-3 months following digester construction. Apart from the immediate production of flammable gas within days of start-up, which was most likely the result of breakdown of residual sugars in the digester tanks, we have not yet confirmed production of biogas. We speculate several causes:

Cold temperature treatments. Problem: If traditional (warm climate) digesters require 1-3 months for establishment of microbial communities in digesters to produce biogas, a process that requires replication of microbial cells on the order of days to weeks, then at colder temperatures we would expect a longer start-up phase. **Solution:** The solution is to continue to maintain ‘cold’ temperature treatments and wait for biogas production, since the response of psychrophiles to cold temperature is the purpose of the Phase 1 study.

Low microbial population size. Problem: Traditional digesters are constructed with a 50:50 manure to water ratio, with manure containing a large number of microbes required for fermentation and methanogenesis. Due to logistical constraints on lake sediment acquisition by the slow method of percussion coring lake sediments in narrow tubes, our digesters contained a much lower ratio of microbial inoculum (approximately 2.5:50 sediment:water; 6:50 sediment+manure:water; and 3:50 manure:water). Beginning

with a lower concentration of microbes we would expect an even longer start-up period for cell replication and growth of the microbial population. **Solution:** We collected another 96L of mud and 120L of manure to re-inoculate, at a higher concentration, tanks #4 and #6 (bringing the concentrations in those tanks to a total of 7.5:50 mud:water and 9:50 manure:water, respectively). As our primary interest is the biogas production of psychrophiles versus mesophiles, we will focus on those two tanks to encourage the biogas production. We will continue to maintain the other tanks as well. Since we have introduced the increased substrate containing additional microbial populations, tank #4 has shown some increase in gas output, but tank #6 continues to show almost no activity. This could suggest that #6 continues to be overly acidic, while tank #4 has begun to recover and utilize a larger methanogenic community.

Hydraulic retention/residence time. Problem: Feeding digesters involves adding a blended food/water slurry and removal of an equal volume of microbe-containing effluent. Depending on the volume of the digester tank and turnover time of microbial cells, the feeding process could lead to significant dilution of the digester slurry's microbial population by removal of effluent. Residence time is defined as the capacity of a system to hold a substance divided by the rate of flow of the substance into the system. Adding 2L of microbe-free slurry to a 1000-L tank daily results in a 500-day retention time. A slow replication rate of microbes could exacerbate the problem if low microbial retention and dilution. **Solution:** To prevent the removal of microbes, food can be blended with effluent instead of water. Although some effluent must still be removed to be displaced by the food mass, the microbial waste will be reduced. Feeding must also be started slowly, with small amounts, to ensure that the system can handle the amount of material and not over-produce materials to an inhibitory level. Finally, many microbes require a surface to grow their films on. On May 4, we hung socks containing mud from the top of tank 4, to increase the surface area for microbial colonization.

Low pH. Problem: Methane (the flammable component of biogas), is produced by a consortium of microbes through multiple processes operating in sync with one another, including fermentation and methanogenesis. In step one, fermentation processes generate methane precursors, many which form acids (volatile fatty acids, etc.). In step 2, a separate set of microbes (methanogens) utilize precursors to produce methane, but optimally under pH conditions of 6.8-7.2. Overfeeding of organic substrates can favor the first step, leading to the buildup of organic and carbonic acids and conditions of low pH. Daily feeding of a large volume of organic substrate, especially relative to the small volume of microbe-containing manure and sediment in our digesters, led to acidification of the water column in our tanks. Fortunately, subsamples of bottom-sludge revealed near-neutral pH (Table 5). Typical lake sediment pH measured in thermokarst lakes ranges between 7-8 (pers. comm. Katey Walter Anthony). Typical cattle manure pH is 7.0 (Leggett et al., 1996).

Table 4. pH results found in tank sludge. As the bottom sludge revealed a pH closer to 7 than the effluent, we believe the microbial population should still be viable.

Date	Tank	Sludge pH
4/21/2010	1	6.66
4/21/2010	2	6.30
4/21/2010	3	6.53
4/21/2010	4	6.52
4/21/2010	5	7.56
4/21/2010	6	7.22

Solution: Once we recognized that the low pH condition was not changing towards neutral on its own through microbial processes, we ceased feeding the tanks. This is the recommended solution for the problem of ‘sour’ tanks in conventional biogas production procedures (Gerardi 2003). We also determined the quantity of alkalinity that needs to be added back to the tanks to raise the pH by adding alkaline chemicals to beakers containing subsamples of sludge and slurry and then scaling quantities to the volume of the digester tanks. We are in the process of restoring conditions of neutral pH by gradually increasing alkalinity and patiently waiting for organic acids in the tanks to be consumed by resident microbial communities. pH trends to date can be seen in ii.a) Fig. 4. Since initiation of chemical mediation, the pH has increased in all tanks. Except for tanks 1, 2, and 6, the pH is still below 6 in all digester effluent. We are continuing with chemical treatment. . Once we have reached the targeted pH 6.8 and observed flammable biogas, we will resume feeding tanks at a slower initial rate with the goal of building up to the targeted 2 kg per day (1 kg food + 1 kg water).

Temperature fluctuation. Problem: Methanogens are sensitive not only to a general temperature range, but also to changes within their acceptable range. Most mesophiles and psychrophiles cease functioning with temperature variations of +/-2°C within an hour (Gerardi 2003). As seen in ii.a) Fig 5-6, there is some temperature variation within all six tanks. Although daily temperatures are fairly stable, there are some cases in which the temperature changes a couple degrees within a day. This is probably not enough to affect the methanogens, but it is possible with a jump of more than a few degrees the microbial communities could be negatively affected. **Solution:** Although temperature variability within treatments is not ideal, we hope the small changes do not have a significant effect, especially when spread over time. However, temperature fluctuation can affect the metabolic rate of bacteria. We are closely monitoring temperature with dataloggers. We can correlate increases or decreases in gas production to possible temperature variability.

Lack of Mixing. Problem: Intended for construction and use by residential Alaskans, our tanks are designed to be non-technical and easy to build with minimal specialized materials or engineering experience. The digesters do not have a built-in way of internally mixing the slurry. It would be ideal to mix the contents of the primary tank, to allow food to reach the entire microbial community, prevent stratification, and prevent scum build-up. Although food does naturally migrate through layers of sludge to feed the lower microbes, it is a slower process without mixing. Our systems cannot currently be mixed without opening the tanks, which introduces atmospheric air and that can contaminate

the slurry with the introduction of oxygen. **Solution:** It may be possible to install a simple mechanical mixer, perhaps attached to the base of the feeding tube, which could be rotated after feeding to mix the slurry. However, considering the density of the sediments in the psychrophilic tanks, this may not be realistic until the tanks are eventually based on pure microbial inoculations (rather than sediment-based inoculation).

Chlorine content. Problem: Many city water resources, including those in Cordova, are treated with chlorine to disinfect the water for drinking. As city water is the easiest available water resource for making the primary tank slurry, some chlorine was introduced to the slurry in the >900 L of tap water at initial setup and subsequently with the feeding. Chlorides can destroy microbes, which makes it dangerous and possibly detrimental to our methanogens. **Solution:** Although it is logistically very challenging, digester tank water could be based on local lake, stream or river water rather than city-treated chlorinated water. This may be a more viable solution for single-household units, rather than our 6-tank experimental system. Thus far, it is very difficult to say whether the chlorinated water has had a significant effect on our tanks. We tested the use of chlorinated tap water vs. non-chlorinated Lake Eyak water in the November pilot study and found that the High School tap water did not prevent biogas production. Given that we continue to observe microbial activity, we can conclude that we have not decimated the microbial community in the 1000-liter digesters either.

Scum and foam. Problem: As the microbes will only digest certain materials, an overfeeding of fatty acids, combined with other environmental conditions such as under-mixing, stratification, and temperature fluctuations, can lead to the production of foam and a scum layer. Food types that lead to scum build up have high grease content or tough vegetable matter. This scum can block inlet and outlet pipes, causing problems in utilizing or measuring gas production. **Solution:** To prevent scum, a balanced food source should be fed to the tanks, minimizing greasy and tough (woody, fibrous) food types. If an extreme amount of scum has built up, the tank can be opened to break up the film.

Feeding procedure – Cordova High School students re-engineered the distribution design to shorten time commitment for preparing organic substrates and feeding digesters. (Please see section ii.a).

Balance of responsibilities. Problem: The project was originally designed to be constructed by the full team on-site in Cordova in early January, and then to be maintained by Cordova High School students for the duration of the project with occasional (2-3 yearly) site visits by UAF technical staff for troubleshooting and advanced chemical monitoring. Although construction was completed as planned, a number of unanticipated problems have required the presence of a full-time onsite technician (Laurel McFadden). Chemical imbalances, discussed above, led to the failure of the systems to produce biogas. Monitoring, standard chemical measurements, mechanical maintenance, and feeding took significantly more time than anticipated. Although this was partially alleviated when Cordova High School students realized the extent of their time commitment and sought to streamline the feeding process, the chemical treatments and troubleshooting were beyond the scope of the Cordova contingent. **Solution:** McFadden moved to Cordova to monitor the project full-time in April. Although

solutions to many problems have either been found or are in progress, technician time represents a significant unanticipated expense to the project. It is still anticipated that, with the knowledge evolving from this extensive troubleshooting, extensive technician time should not be required for systems in community use. It is also true that we are trying to maintain certain scientific standards, and careful measurements, which are atypical of traditional digester use (contributing to increased time commitment requirements). The project consists of experiments that have not been done before, and thus has higher risk for more technical time needed for troubleshooting. It is hoped that most issues will be solved within the next month or two. As of early June, 2010, McFadden's will work on half time salary for this project. Cordova High School volunteers will be needed for feeding and maintenance for the duration of the project, as originally planned.

Positive accomplishments:

Proven flammability – One of the primary goals of this project was to determine if the psychrophiles that produce methane in thermokarst lakes could be harnessed in an artificial environment to produce biogas. With the initial (30 days) of biogas production through which psychrophiles (and mesophiles) generated biogas using residual sugar in the digester tanks as a substrate, we proved that this is possible. The pilot study also proved longer-term biogas production by thermokarst-lake microorganisms.

Student education - This project has provided an opportunity for a high level of educational enrichment across a broad group of students at Cordova Junior High and High School. The students involved can be broken into three groups: the general student body, the students in science club, and those enrolled in chemistry class. The middle school and high school students eating lunch in the cafeteria were aware of the project and its purpose each day as they made a choice to recycle their food scraps. As with many high school fads, recycling food became the cool thing to do. Students at Cordova Jr./Sr. High have gained experience about the reality of 'doing real science' and alternative energy development as they followed the project through their friends' and classmates' deeper involvement.

The science club is made up of high school students who volunteer for this extracurricular club. They were willing to commit to the "maintenance" of the digesters for the course of the two years, and volunteer to collect food, process food, and feed the digesters. As a group they worked on the various construction events, and individually they worked to make sure that the food scraps in the cafeteria were collected, processed, and fed to the digesters in a scientifically accurate manner. Three science club students were able to write up various aspects of the biogas digester project and present it at the Alaska State Science and Engineering Fair. About half of the science club students were able to travel to Fairbanks to give an update on the project at the Alaska Rural Energy Conference.

Students enrolled in the chemistry class had perhaps the greatest benefit from the methane digester project because of the level of buy-in and the structure of the course. Initially it was the chemistry class who researched biogas digesters, and prepared movies for presentation to the Denali commission. These students were committed to the project because they asked to be. This group played an important

role in the construction of the digesters, and in the many small engineering problems that arose. This group took many of the chemistry measurements and spent a considerable amount of time learning about the meaning of the data. They also had the opportunity to travel to Juneau to present to the Alaska Power Association and visit several members of the legislature.

Community outreach – We have had the opportunity to present our 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 Forum on the Environment and the Alaska Rural Energy Conference. Public response has shown community interest in and inspiration by our non-technical, low-impact, greenhouse mitigating technical development. Five Cordova High School students traveled to present at the Alaska Rural Energy Conference in Fairbanks. Titles of our project presentation at the Alaska Forum on the Environment and Alaska Rural Energy Conference were:

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

Walter Anthony, K., Culhane, TH., Koplín, 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.

Website development- Website developer Brandon Shaw designed a site (www.cordovaenergycenter.org) for the Cordova Energy Center, the venue at which the biogas experiment has been conducted. The website is an online location where students and collaborators can post questions, observations, results, general information, and instructional videos. While still in development for ease of use, it is an excellent platform for public dissemination of information, global communication of observations and results among team members, and troubleshooting forums. The Cordova High School Students have produced a number of films to post on the site, detailing their involvement in the project and providing video instruction for many aspects of the project’s construction and maintenance.

iii. Pictures of before and after progress, or photos that are representative of the funded activity, to the extent possible (digital format with a short description of the activity and names of those in the photos).



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 Connex in first stages of construction behind CDHS, 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.



The dividing wall between cold and warm rooms goes up, while electrical wiring is installed.



Students prepare insulation panels to fit around primary slurry tanks.



McFadden, Shaw, and Culhane place fittings on water pressure systems.



Working with water transport pipe fittings while snowing (Jan. 2010).



Katey Walter Anthony distributes manure and sediments into the primary tanks.



Feeding tubes are fit with internal temperature dataloggers.



First biogas flame is observed on January 21, 2010.



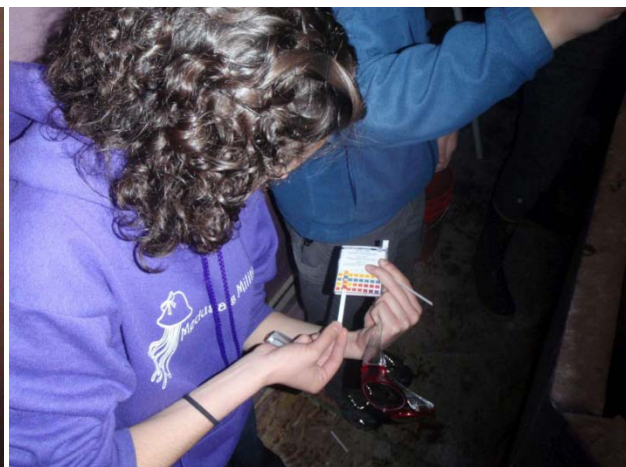
Materials for installing flow meters.



Shaw wires flow meters to a datalogger and computer.



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



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



Food processing trailer, including “sink” with installed food blender (underneath bucket).



CDHS student-designed food dispersal system, to insure even distribution of food batches.



Testing acidic effluent for amount of mediating chemicals needed to be added.



Adam Low and CDHS student re-inoculate tank with new manure.



Sybille Culhane, Killian Culhane, and Peter Anthony work in the Connex.



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

Appendix 1

In November 2009, we conducted a pilot experiment to determine the minimum ratio of lake sediments to water required to sustain biogas production. The experiment consisted of ten 5-gallon buckets, with varying ratios of mud to water. Other experimental variables included temperature (warm vs. cold), water source (Lake Eyak vs. tap water), organic food stimulus (sugar at different levels, potato chips, or none), and substrate for increasing surface area for microbial growth (fish net, wood chips, or none) (Table 1).

Table 1. Pilot study set-up. Ten buckets with varying mud-water ratios were tested for gas production under a variety of conditions.

Bucket	Treatment	Temperature on 11/27/09	Mud (%)	H2O (%)	Mud (L)	H2O (L)	H2O source	Air headspace (L)	Sugar to balance O2 dissolved in water (g)	Sugar to balance O2 in headspace (g)	Extra 'stimulus' sugar (g)	Total sugar (g)
1	large M/W ratio	classroom (~25 °C)	90	10	18	2	Eyak	2	15	280	0	295
2	large M/W ratio with extra sugar	classroom (~25 °C)	90	10	18	2	Eyak	2	15	280	500	795
3	small M/W ratio	classroom (~25 °C)	1	99	0.2	19.8	Eyak	2	148.5	280	0	428.5
4	Medium M/W ratio with no sugar	classroom (~25 °C)	10	90	2	18	Eyak	2	0	0	0	0
5	Medium M/W ratio	classroom (~25 °C)	10	90	2	18	Eyak	2	135	280	0	415
6	Medium M/W ratio with pine shavings (~1 L volume) as surface area for bacterial growth	classroom (~25 °C)	10	90	2	17	Eyak	2	127.5	280	0	407.5
7	Medium M/W ratio with tap water	classroom (~25 °C)	10	90	2	18	Cordova High School tap water	2	135	280	0	415
8	Medium M/W ratio with fish net (~1 L volume) as surface area for bacterial growth	classroom (~25 °C)	10	90	2	17	Eyak	2	127.5	280	0	407.5
9	Medium M/W ratio with cold temp	energy center (~-4 °C)??	10	90	2	18	Eyak	2	135	280	0	415
10	Medium M/W ratio with 415g unsalted potato chips	classroom (~25 °C)	10	90	2	18	Eyak	2	0	0	0	415 g unsalted potato chips, no sugar

M/W = mud/water

Setup

The lake sediments used in this pilot study were collected via piston and percussion corer from Goldstream Lake near Fairbanks on November 3-4, 2009. As it is a very slow process to collect mud, we were interested in knowing what ratio of sediments to water would be economical for a psychrophile-run digester. The buckets were designed to be glued shut and inverted (to prevent any air from entering the bucket once they were sealed), with a rubber stopper installed in the base to allow sampling of the accumulated gas in the headspace. Buckets 1-2 were based on a large mud to water ratio (9:1), bucket 3 on a very low mud:water ratio (1:99), and buckets 4-10 based on an economically mid-range estimate of a mud:water ratio (1:9).

All buckets except #4 and #10 were given an amount of sugar calculated to allow the aerobic microbes to quickly digest the dissolved oxygen in the water and the oxygen in the headspace of the buckets (based on the amount of glucose needed to balance a mol or L of oxygen in water or air, respectively). Bucket #4 was used as a control and given no sugar at all, while #10 was given a comparative mass of potato chips instead of sugar to test sugar versus carbohydrates as an impetus for oxygen consumption.

Bucket #2 was given extra sugar as a test stimulus for methanogens post-oxygen consumption. Bucket #7 was mixed with tap water instead of lake water, to test if there was a noticeable difference between the two water sources to the microbe's gas production. Bucket #9 was kept at a relatively cold temperature to compare to the other warmer tanks. Buckets #6 and #8 tested two types of bacterial growth substrates: sawdust and fishnet, respectively. It has been argued that methanogens will have increased growth if given a surface area on which to colonize (Geeta et al., 1986).

Results

Less than 48 hours after sealing the buckets, on November 28 it was found that buckets #1 and 2 had exploded from gas pressure (Figure 1). This confirmed that the lake sediments contained a viable bacterial population, and that the large ratio of mud to water could be used. Bucket #10 was also found to be severely distended, suggesting that a medium ratio with a food source was also a usable option. This was confirmed on November 30, when buckets #7 and 10 exploded. The extreme gas production in #7 suggested that the water source did not have a significant effect on gas production. Bucket #8 was found to be distended, although the short time period in which the gas was produced suggests that at that point, the fish net growth medium had had little to no effect on the bacteria (given that the bacterial reproduction rate is on the order of 30 days, increased colonization space would have no consequence in 3 days).



Figure 1. Buckets #1-8 and 10 in the 25°C room, showing exploded buckets #1 (back left) and #2 (front) on November 28, 2009.

The mud from Buckets #1 and 2 were used in a small construction experiment by Cordova High School students on December 4, as it had been proven that gas could be produced at a medium ratio (no need was seen to maintain the high-ratio buckets, considering the difficulty of obtaining the mud). All of the remaining buckets were placed in a semi-heated building (approximately 4°C) until January 18th, 2010, when construction on the main experimental tanks began. The buckets were each punctured and the escaping gas was ignited to confirm that the gas produced was biogas. There was positive ignition on all buckets #3-10. Although by that date (2 months post-sealing) no definitive comparison could be made about the total volumetric gas production from each bucket. We concluded that a variety of sediment to water ratios could produce biogas. Based on this pilot experiment, we determined that a minimum 10% sediment ratio was sufficient to power a 1,000L digester system.

Problems

Although the buckets did show positive biogas production, an error in the sugar calculations may have skewed our results. Due to an extreme over-estimate of the amount of sugar it would take to consume the oxygen in the water and the air headspace, it is possible that the explosions seen in buckets #1, 2, and 10 could be attributed to an overabundance of glucose, and such an immediate gas production would not normally be expected.

It is interesting to note that although left alone for 2 months, without being fed, the buckets continued to produce biogas. This could suggest that over-fed digesters will eventually recover, if left alone.

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