Denali Emerging Energy Technology Grant:

"Improving Cold Region Biogas Digester Efficiency"

Year 1 Quarterly Report, Q4 – December 12, 2010

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i. Y1Q4 Summary The project is on target with regards to progress in Phase 1.

Since the Y1Q3 report, the project has been focused on resuming and improving a consistent and regimented feeding schedule in efforts to closely track changes in gas production and efficiency of conversion of food-to-biogas. We are pleased to report that we still observe healthy, flammable biogas production in our psychrophile-only tanks in both the 25°C (tepid) and 15°C (cold) rooms and in the mesophile+psychrophile tank in the 25°C room. Currently, we do not see any activity among either of the mesophile-only tanks though nominal amounts of gases are still reported flammable. **These findings support our initial hypothesis very well, that the psychrophile and mixed cultures would produce more biogas than the conventional manure-cultures at the relatively cool temperatures of 15°C and 25°C.**

Recent installation of several water traps downstream of the gas flow meters provided a useful visual reference for project observers. They serve additional purposes of (1) aiding in gas sample collection for CH_4 concentration analysis and (2) aiding in smoothing out flow-data measurements. These traps, outfitted with tipping cups and data loggers were also intended to serve a third purpose as a secondary gas-flux monitor in efforts to serve as a check on the Sierra instruments. The data loggers failed shortly after weather conditions in Cordova began to deteriorate. While it was unfortunate to lose the tipping-cup logger data, we nonetheless found other ways to obtain the desired information on gas production rate. **One of the strongest achievements of this quarter was achieving a good understanding of digester daily gas production (see results below).**

The internal chemistry of the digesters has remained for the most part stable, though Tank 1 has exhibited a noticeable drop in pH (currently 6.2). In response, we have temporarily ceased feeding Tank 1 in effort to allow the tank time for metabolic recovery. For the remainder of Phase 1 we will continue to raise the feeding rate of the digesters (with the exception of Tank 1) to determine their maximum biogas production rates. Our goal is to determine how close our cold-adapted systems (15-25 deg C) can come to reaching the same gas production rates of conventional (warm 37-40°C) biogas systems of the same household scale. The production target is 1,000 liters per day on a 2kg per day feeding regime, comparable to warm climate digesters of the same household scale. Currently, we are feeding the digesters on a 1kg per day regime and are observing a maximum gas production of around 130L/day for any one given digester. The project team is eager to see if increased feeding will improve total daily gas output. This information will be necessary for commencement of Phase 2, demonstrating the use of biogas to power gas-powered technologies.

New components of Cordova High School student participation involve construction of a greenhouse to test the potential use of biogas slurry as a liquid fertilizer for food production and Student Craig Bailer's science fair project on a heat exchanger for use to the digester project during Phase II. Bailer also maintained chemistry and flow meter measurements while the UAF-technician Casey Pape was away from the project, showing enthusiasm and determination in order to preserve the integrity of the experiment while Pape was away. Both Bailer and Cordova High School teacher Adam Low exceeded expectations in their ability to maintain the project and in demonstrating the school's interest in the projects' success.

The project was recently featured by New Scientist Magazine in an article entitled, '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.

ii. Schedule and milestone information

The project continues to closely follow the original outlined plan:

- Construct Digesters for Phase 1 by December 15, 2009 – Completed January 21 2010
- Begin Data Collection by February 1, 2010 – Ongoing, commenced January 18, 2010
- June 25-27, 2010, project meeting onsite in Cordova (all team members present); High school student presentations
- Perform mid-term Analysis of Data by July 30, 2010 – Completed informally internally as a project team, and formally in Quarterly reports 2 and 3.
- Year 1 Q4 Report due December 15, 2010
- Phase II Scoping Deadline January 25th 2011
- Phase I Report, including analysis of all Phase I data, due February 28, 2011
- Year 2, Q1 Report due March 15, 2011
- Year 2, Q2 Report due June 15
- Year 2, Q3 Report due September 15
- Final project report due September 30, 2011

ii.a) Personnel:

Cordova Electric Cooperative http://cordovaelectric.com/

Clay Koplin – Grant Administrator. Koplin has managed most of the financial aspects of the project thus far on behalf of the Cordova Electric Cooperative, serving as the project manager. Koplin serves 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 acts as the primary investigator, and has spearheaded the scientific goals and directions of the project. She provides continual scientific expertise and project management. She contributed to the data analysis, interpretation and writing of this and previous reports.

Casey Pape – Research Technician. Pape joined the project in early September, 2010, to replace Laurel McFadden as the primary project technician. Pape is currently working on-site in Cordova, maintaining the digester experiment, including data collection, analysis, and troubleshooting. After returning to the project on December 6, 2010, Pape led the preparation of the current quarterly report with assistance from other team members. In his absence, Adam Low, along with help from Cordova High School science club students were able to maintain feeding and measurements at the Cordova site. Pape plans to remain with the project until its completion in September 2011.

Dane McFadden – Project Intern. Currently an undergraduate at Stanford University, Dane McFadden helped maintain digester performance over the summer. Job responsibilities included: maintaining daily gas data collection, feeding, chemistry measurements and gas sampling. McFadden will be using his experience here in Cordova as his required internship at Stanford University and will generate an intern project report which will be submitted to the PI, the Denali Commission, and to Stanford University.

Laurel McFadden – Research Technician. McFadden, having begun a graduate program at UAA in mid August 2010, now consults on the project. McFadden was a key contributor to the project development and took the lead on organization and preparation for the initial construction and setup. McFadden completed the first draft of a Biogas Handbook for Alaskans, which will be submitted as a deliverable in final form to the Denali Commission by the end of the project.

Peter Anthony – Research Technician. Anthony consults on the project and continues to provide technical expertise to the maintenance and application of digesters. He participated in the on-site project meeting in June 2010 and provided recommendations for simplification and winterization of the gas collection system in preparation for Phase 2. Anthony conducted the gas chromatography analyses of biogas composition for this report.

Jeffrey Werner – State FFA Director. Werner is looking into using the effluent from anaerobic digesters as a liquid fertilizer for agricultural crops. Located at the horticultural center at UAF, Werner remains enthusiastic about the possibilities of the potential uses of the once thought of waste product.

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. Low has been in charge of maintaining a consistent feeding regime and guiding student involvement with the project. While Pape was away from the project, Low had the added responsibility of maintaining gas flow and chemistry measurements as well as general troubleshooting. Additionally, Low has been working with science club students to set up a greenhouse experiment in which to test effluent samples for their potential use as a liquid fertilizer. Low also assisted in collecting and shipping effluent samples to other project colleagues in Germany in efforts to greater proliferate psychrophilic digester technology.

Cordova High School Students – Volunteers. The students of Cordova High School have been highly involved with construction, feeding, maintenance, 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). Ten students now share the responsibility of feeding the digesters on a daily schedule.

Student Craig Bailer in particular has been of great help to the project. Bailer maintained chemistry measurements while the UAF-technician (Pape) was away and proved to be more than competent at updating records as well as downloading flow data. In addition, Bailer has been assisting Low with other experiments in the Cordova Energy Center in preparations for Phase II of the project. In particular, Bailer has been working on a type of heat exchanger as part of a potential science fair project with the aim that it may be of use to the digester project during Phase II.

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. Recently, Culhane has asked to acquire a 2 L sample of psychrophilic effluent in efforts to test the success of psychrophilic digesters in different locations in Europe, Asia and Africa with different weather patterns and climate regimes as part of a tangential outreach project that Culhane and Walter Anthony have, funded by the National Geographic Society and Blackstone Ranch.

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 expressed interest in deploying a digester at Chena Hot Springs, and has offered 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.

Keywords: Biogas, anaerobic digester, reactor, psychrophiles, mesophiles, methane, etc.

iii. 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.

iii.a) Project Status and Accomplishments

The project is on target in Phase I of the original research proposal. Phase I involves the testing of several different blends of methanogenic microbial populations (mesophilic and psychrolphilic) in order to examine different characteristics of digesters that operate in cold environments. The primary goal of Phase I experiments are to construct and monitor six different anaerobic digesters and to try to maximize the amount of gas that can be produced in depressed temperature climates (see original research proposal for more details on Phase I goals and objectives).

We are pleased to report that several of the tanks are producing biogas from food waste material at high levels. Currently, we are observing flammable biogas production in Tanks 1, 4 and 5 in large quantities (up to 130 L/day). Only Tank 6 is no longer observed to be producing biogas at observable levels, despite no change in pH. Tanks 2 and 3 have not been producing gas in previous quarters and are no longer being fed. Gas contained in the headspace of Tank 6 may contain methane, but gas production in this tank is nominal (<1L/day). We have remediated many of the problems elucidated in the last quarterly report (see Y1Q3 report).

In the fourth quarter we have begun pilot-level experiments for Phase II, while at the same time maintaining the Phase I study through completion in effort to improve yield and efficiency. The Cordova High School students have taken the lead on a greenhouse pilot study to test the potential for digester effluent to serve as a liquid fertilizer in food production. Casey Pape is leading the project team in preparations for Phase II, to find usable applications for biogas produced from the anaerobic digesters. In the second year of the project, Phase II research will also incorporate data collection on the time and effort required to build and maintain biogas digesters; provide data to inform economic assessment of biogas technology in Alaska; and produce a Do-it-Yourself Biogas Handbook for Alaskans.

Flammable biogas

Previous analysis of gas composition on a Shimadzu 2014 gas chromatograph equipped with a flame ionization detector revealed that CH_4 concentrations in gas flowing from the digester tanks is up to 82% by volume (see Y1Q3 report). Composition data does not exists for current or catalogued biogas samples since the third quarter, but biogas from all producing tanks demonstrates positive flame test (Table 1.). Typically, conventional biogas reported in the literature is 40-60% CH_4 by volume. It is possible that with our increase feeding rates and increased gas production rates, we will observe among collected samples a decline in CH_4 content associated with rebalancing of fermentation and methanogenesis and in variation with feedstock quality. Future gas analyses will need to be performed to complete a time series of gas composition for assessment of digester behavior over time; however, these analyses will most likely be held off until the Phase I Report.

Flame tests show that Tanks 1, 4, 5, 6 has been producing flammable gas (Table 1). Methane-rich gas from Tank 4 was previously being diluted by air through a discovered leak in the in the secondary holding tank (water-pressure system). The secondary tank was removed and biogas began showing positive flame once again. Due to too low of gas flow rates, gas from tanks 2, 3 and recently 6 is not being collected and we have little or no data on its composition.

Table 1. Results of produced gas flammability tests. Positive results of the flammability test indicated usable biogas. Flame tests are still conducted on Tanks 1, 4, and 5. Tank 4, which was not showing positive flame tests at the time of the last quarterly report (probably due to a leak identified in the secondary gas holding tank), is now demonstrating positive flame.

Tank	First positive flame	Last confirmed flame
1	1/31/10	12/10/10
2	NA	NA
3	1/22/10	2/1/10
4	2/1/10	12/10/10
5	1/21/10	12/10/10
6	1/26/10	9/18/10

For more information about GC analysis and this project please refer to *Project Status and Accomplishments* of the Y1Q3 report (section iii.a)).

Resumed feeding of digesters to increase gas production

As of September 27, 2010 the digesters have been fed on a consistent basis for the first time since the decision to stop feeding them on March 22, 2010 as part of pH remediation. Today, the time required to perform feeding has been greatly reduced due to the methods specified in the Y1Q3 report (see Y1Q3, Appendix 1). Using pre-printed labels for 1 gallon Ziploc bags, a 2 person team is able to process five to six days of food in under 2 hours using the before mentioned protocol. The bags are then weighed, sampled and stored in a large industrial freezer in the science classroom to be brought out the day prior to feeding. Once a team has fed the digesters, the next day's frozen food slurry is placed inside the Connex '25°C-room' to thaw. Actual feeding of the digesters takes less than five minutes and students have been asked to note that all valves and doors are open/shut properly prior to exiting. The benefit of processing large batches of food using this method as opposed to daily collection and processing is not only good from a scientific perspective as there is more consistency between batches, but has also resulted in saving Low and students considerable amounts of time as well as improved student and teacher moral (ref. Adam Low).

The project now feeds almost entirely in accordance with the original project proposed rate (1kg food + 1kg water). Only Tanks 1, 4, 5, and 6 are being fed currently as these tanks are the only ones to demonstrate active methanogenesis. At the end of September, for one week the digesters were fed in equal parts (1:1), totaling 500g of food combined with 500g water at every other day intervals. The following week the same amount of food and water was added at every day intervals. During the week of October 11-17th, the tanks once again resumed a conventional feeding regime according to the original project proposal (1kg food + 1kg water). Chemistry and gas measurements were closely monitored in order to detect any changes that result from increased feeding. By mid-November it became apparent that Tank 1 was beginning to exhibit a decline in pH once again despite other tanks maintaining consistent pH. Once the pH dropped below 6.5 it was recommended that Tank 1 feeding cease all together in order to prevent digester "crash" and has remained that way until it can recover on its own (currently 6.2, as of 12/07/10) (Figure 1.). It is probable that the drop in pH occurred because acetogenic activity had been exceeding methanogenic activity. This effect could be accelerated by the lower temperature and slower metabolism of Tank 1 compared to other tanks '25°C -room' tanks which have had more stable pH. All tanks which are currently or were (Tank 1) on a feeding regime continue to produce measurable quantities of biogas with the exception of Tank 6. Feeding of Tank 1 will resume once its pH has returned to a desirable level (≥6.5)(Gerardi 2003).

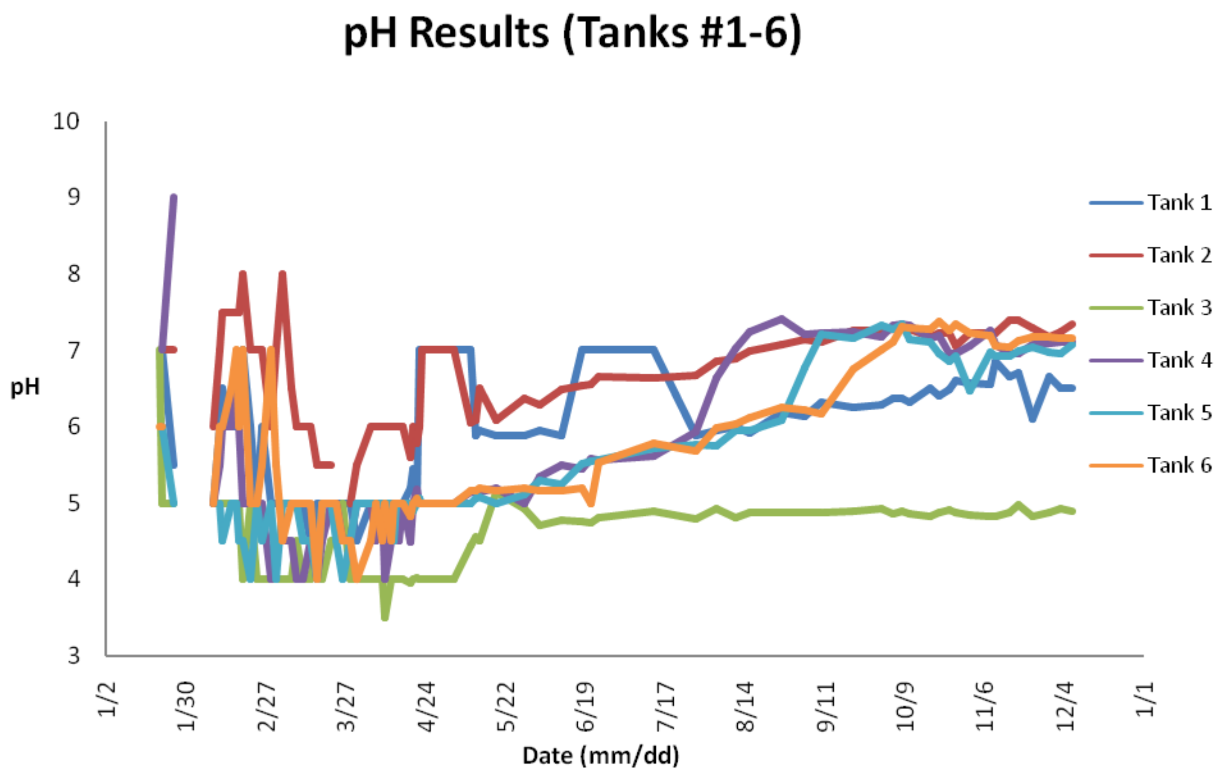


Figure 1. pH results indicate that Tank 1 has been becoming slightly acidic since the last quarterly report (currently 6.2). Daily feeding has been halted to allow the pH to on its own without seeking chemical remediation treatments. pH was measured with Macherey-Nagel litmus paper January 21-April 16 2010, following which it was more precisely measured with an Oakton PC510 pH meter.

In accordance with restoration of biogas digester conditions, we also observed changes in dissolved oxygen and redox within tanks. Both dissolved oxygen (DO) and redox levels declined to anaerobic levels favorable to methanogenesis although recent DO measurements appear to be off due to instrument error (See data figures in Appendix 1).

Gas flow measurements

At the time of the last quarterly report, it was not known with certainty whether or not the project's Sierra Instruments Top-Trak 820 Series Mass Flow Meters (installed February 18, 2010 to maintain continuous mass flow measurements of each tank), were recording properly. Due to the low reported flow rates and inconsistency in the data record (Figure 2), researchers suspected that either the flow meters were not recording accurately or that methodology for summarizing the raw data was inaccurate, leading to false low values. The information presented in Figure 2 was derived from the product of averaging daily flow rates which were then multiplied to obtain daily totals. Though generally this is an acceptable method and is appropriate for obtaining estimates of daily gas totals it does not represent the actual total sum or quantity of gas produced by the digesters and recorded by the flow meters. Additionally, the metabolic rate of each digester appeared to be too low to regisgter gas flows accurately by the

Sierra flow meters. The flow meters were calibrated by the manufacturer for a faster flow rate than our real-time biogas production. Finally, it was feared that data may be lost while the project technician was away over the course of the quarter as flow data required daily downloading and monitoring. In order to resolve this issue and settle any further concerns regarding gas production, the project team constructed a series of tipping cup bubble traps with event data loggers that were intended to serve as a secondary measure of gas produced and act as a water trap ensuring unidirectional gas flow. Unfortunately, flow dynamics and weather conditions prevented these traps from working as they were intended, but still aided the research team in developing an understanding of total gas flux amounts.

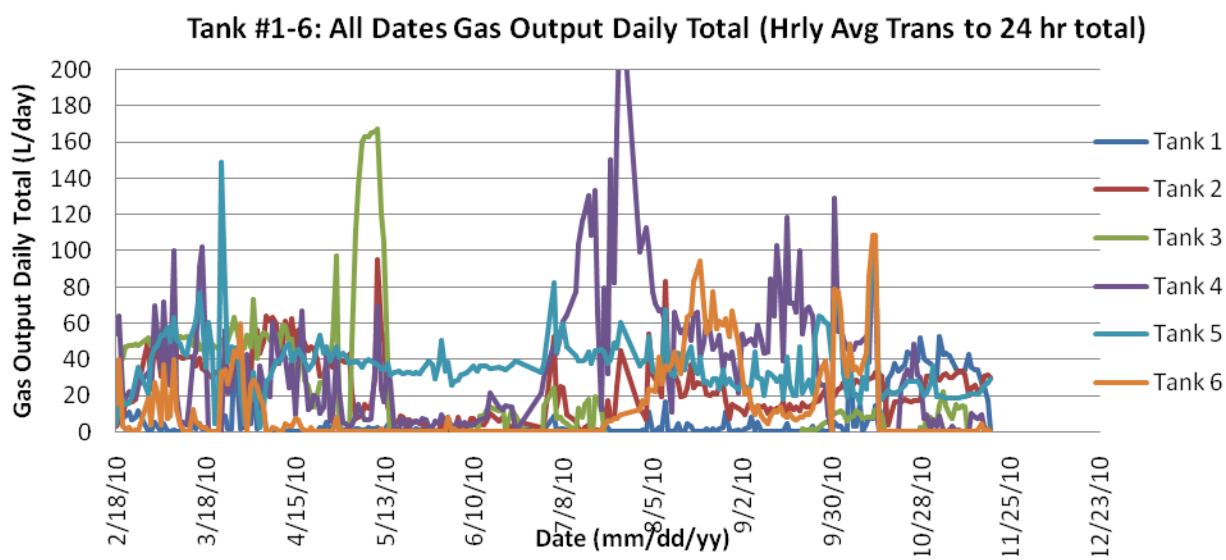


Figure 2. Mean daily gas flow rates from digesters. The flow meters averaged flow over a defined unit of time (hours in this case) rather than totaling the gas moving across the meter. The noticeable drop in gas flow on Oct. 15, 2010 and subsequent consistency of the data corresponds to the installment of water/gas traps which serve both as a secondary measure of the gas and as a passive one-way check valve. Measurements were obtained with Sierra Instruments Top-Trak 820 Series Mass Flow Meters and were calibrated by the manufacturer. It should be noted that the flow-meter on Tank 3 was apparently miscalibrated, a correction factor has been applied to report observed values.

Pape constructed four tipping-cup gas traps following the design used in lakes by researchers in the Walter-Anthony lab (Walter Anthony et al. 2010). The devices operate by recording tipping events of gas flux using falling edge magnetic-trigger switches. Essentially, gas from each one of the tanks would be diverted into an inverted cup, once the cup filled to a calibrated level it would tip, releasing the gases to the atmosphere (Appendix 2). If the amount of gas flux from a tank is low enough, the cup should tip episodically, only when the cup has filled to the calibrated level. As the tipping event occurs the motion of the cup passes by a magnetic switch which closes momentarily, causing a logger device to record the event. The devices were constructed in a glass 30Gal aquarium to allow for easy maintenance and public viewing (Appendix 2). The water used to maintain the tipping cups also served as a type of passive check valve, only allowing gases to travel out of the tanks inside the Connex. Therefore, any measurement recorded on a Sierra flow meter that that did not correspond directly with a bubbling event or reported a negative number could thrown out or ignored as a misread on the flow meter.

The traps were calibrated and deployed on October 15, 2010 and are marked by a noticeable drop in gas flow as the pressure in the tanks had to build to overcome the hydrostatic pressure of the aquarium (Figure 2). Once the pressure inside the tanks accumulated enough to overcome the height of the water column, the tanks began bubbling biogas into the automated tipping cups. One of these events was witnessed by CHS student Craig Bailer and documented in the project notebook. The observer noted that the bubbling event was from Tank 4 in which bubbles were seen filling the tipping cup, over powering it and causing it to remain in the open position for the duration of the event. This phenomenon was not anticipated by the trap designer and future note should be taken before attempts to build additional traps are made. Additionally, it was discovered that moisture had penetrated the Hobo pendant loggers intended to record tipping events and rendered them unreadable. This came as a surprise to the project team as the devices are used commonly within the scientific community and should not have failed in this or any similar application. The loggers are now being sent into Onset in an effort to uncover why they failed during their time of deployment. Though the information could not be gathered from the tipping cups as anticipated, the project team developed an alternative approach to measuring biogas flux using both the Sierra flow meters and the installed bubble traps which served to validate our measurements of biogas production.

Upon returning to the project on December 6, 2010, project technician Casey Pape contacted Sierra instruments about some of the difficulties encountered from using the Top-Trak Mass Flow meters. Jack, from technical services was very helpful in identifying what intended flow rate our units had been calibrated to as well as provide useful information about possible problems that may encountered from measuring gases with high water vapor content like that found in biogas. Jack explained that the flow meters employed at the site had been calibrated at a gas flow level at best around 3 std. L (that is, as if it was an ideal gas at 1 bar, 273.15K) per minute. Once it was realized that the biologic/ metabolic rate would be much lower than the calibrated level, Jack agreed that measuring flow rates that low with instruments calibrated for 3 std. L/min (SLPM) would be a challenge. It was therefore determined of great interest to increase the flow rate through the tanks and subsequently the flow meters. No advice was given on how to fix the miscalibrated devices aside from sending them in. Once it became known that increasing the flow rate may provide more accurate measurements Pape considered closing each of the tanks and letting them build pressure, then opening the tanks to release pressure may provide more definite measurements of gas production. Preliminary tests have been promising as tank pressure is being released four times a day (every six hours) shows very strongly in the flow data (Figures 3 and 4). This technique has been very helpful also in providing a visual representation of tank metabolic rates. The tanks that have the highest production rate demonstrated visually more biogas both through the increased duration of the pressure release and through observed bubbles witnessed from outside the Connex (Appendix 2).

Bleeding the tanks on a regimented schedule as described above has aided researchers in both reducing the size of data files necessary for performing data translations and serving as a check against improperly calibrated meters. The Sierra flow meters record upwards of 16,000 measurements in a day and it is of great interest to be able to reduce the size of data files in order to reduce the number of unnecessary computations. By releasing all of the gas accumulated over the course of a day in short bursts like those observed in Figure 5 it was much easier to perform summary statistics and integrate the data to obtain the total amount of gas that traveled through the flow meter over a given period of time. By integrating the data we hope to check our data against the previous method for obtaining daily gas totals (Figure 2) to assure consistency and validity of the method. All data results will be included in the final Phase I Report as there was not enough time to include within the timeframe of this report.

Table 2. Total amount of biogas produced on 12/10/2010. According to the information below, Tank 5 (25°C room, psychrophiles+mesophiles) is currently producing the greatest amount of biogas at 133.6 L/day though it is suspected Tank 4 (psychrophiles only) was producing the most at one time. Tank 4 has been the most bloated of all the tanks and it is believed to have recently begun to leak. The leak was located and fixed December 13, 2010 as of 3:05pm and we would expect to see a slight increase in the amount of biogas observed. All valves were closed on Tanks 2 and 3.

Total L/day (Data from 12/10/2010)

Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6
28.2	0.0	0.0	125.8	133.6	0.4

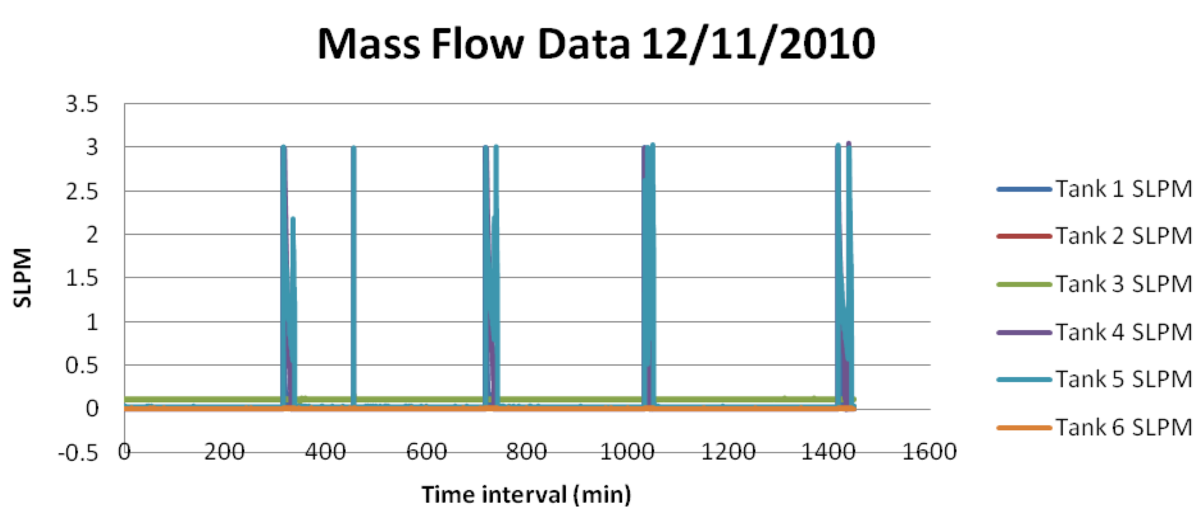


Figure 3. Flow rate data for all tanks taken from Top-Trak 820 Series Mass Flow Meters on 12/11/2010. The peaks correspond to moments when the tank valves were opened and gas was allowed to bubble through the water traps located outside of the Connex. The pressure in each of the tanks was bleed intentionally every 6 hours to release pressure build up though there is fifth peak which corresponds to CHS students opening the tanks briefly to perform the day's feeding. Values are recorded in SLPM.

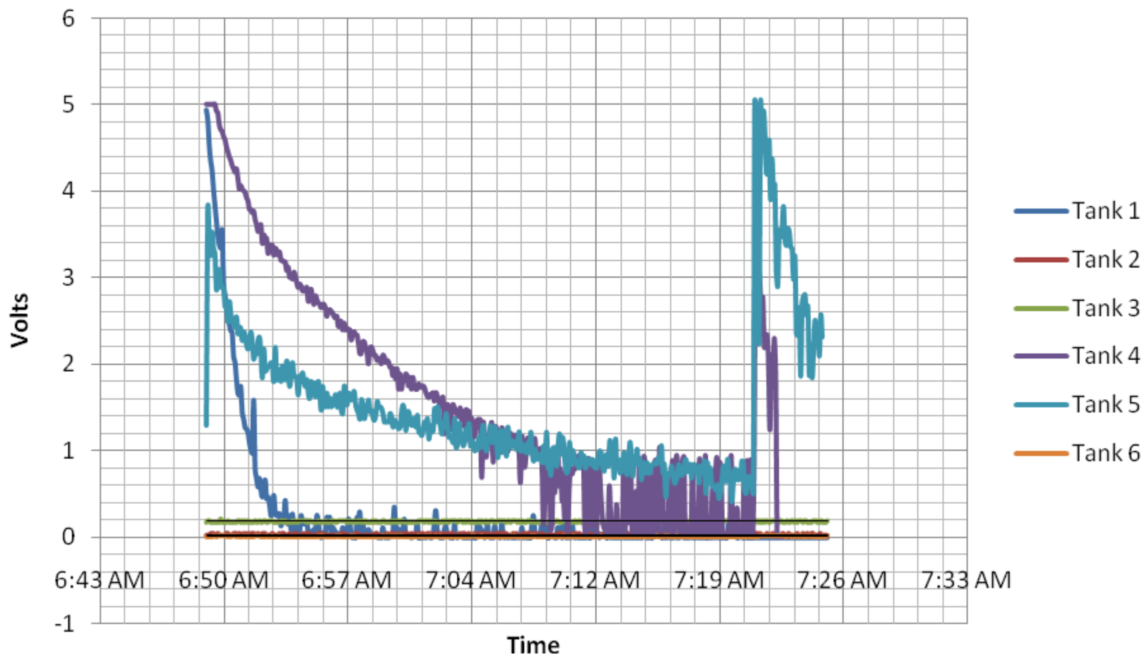


Figure 4. Example of an individual pressure release event. The shape of the curve generated generally follows the shape of an isotherm as would be expected of an ideal gas. The area under the curve corresponds to the total amount of biogas that passed through the flow meter. Data was obtained from Top-Trak 820 Series Mass Flow Meters on 12/10/2010 and is presented in Volts. The second peaks found among Tank 4 and Tank 5 correspond to the technician opening the valve again in effort release all of the excess pressure in the tank.

More analysis needs to be done in order to determine if previous data can be improved through integration and if water traps stabilize the data without causing any negative effects.

Temperature control in the Connex

Temperature remains one of the most imporant factors that influences methanogenic metabolic rate (House 1978). The Connex used to house the digesters was designed by the project team to maintain two rooms at separate cold (15 °C) and tepid (25 °C) temperatures (as opposed to conventional biogas 37-40 deg C, 'warm' temperatures). The temperature is visually monitored by digital thermometers (less accurate) and recorded by (more accurate +/-0.47°C , Drift +/-0.1 °C/yr) dataloggers suspended in both rooms as well as inside the slurry of each digester. Several dataloggers, suspended at different depths within some of the tanks, have not been downloaded since May 12, 2010 in an effort avoid opening the lids of the tanks and preserve the current anaerobic conditions of the experiment. Summary data from all tempertature loggers over the course of the experiment are illustrated in Figure 5.

A major goal of this study is to control a narrow temperature range in which the microbial communities were exposed to. Daily fluctuations occur as a result of opening the Connex to download flow meter data, but is not considered to be of major concern to tank health as the large volumes of water in the tanks makes them relatively thermally stable. Of greater concern is the tendency of the Connex temperature "drift" with changes in local environmental conditions and Cordova weather (Figure 5). As temperatures in Cordova have dropped to wintertime values so too has the average temperature of the Connex and hense the digesters as well. Average temperature of the 'Cold Room' Connex since Sept 30, 2010 was 10.8 °C. Average 'Tepid Room' temperature was recorded at 23.1°C for the same period. Cold room variation is expected to be greater than the tepid room as the cold room is disturbed daily in order to download our gas flow data. Due to the thermal mass of the tanks and water's high heat potential, the digesters tend to resist daily changes in temperature; however, if temperatures remain on average at low values (Figure 5) then it is likely that the temperatures of the digesters have also dropped below set targets. Currently the project obtains it's energy and electricity needs through use of extension cables run from the school to the Connex. Unfortunately, high exposure to student traffic sometimes results in these connections becoming severed and Connex temperature declines as a consequence. The most recent case discovered by the project team was on December 13, 2010. Signs have been replaced in an effort to detract passers by from possibly disconnecting experiment power cables. More analysis will need to be done to tract the changes in gas production as related to changes in digester temperature.

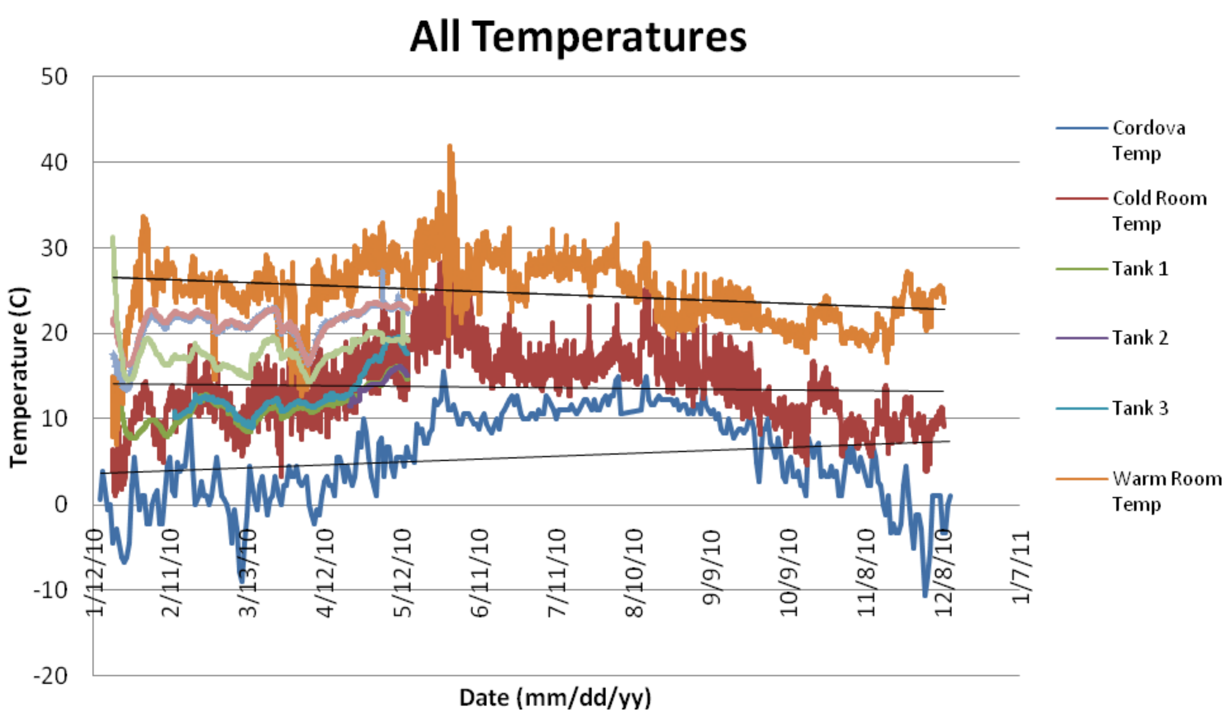


Figure 5. Mean hourly temperature of the data loggers in the Connex cold and tepid room, and mean daily temperature recorded in Cordova. As the temperatures in Cordova began to drop from temperate summer conditions, the Connex experienced a noticeable and unfavorable drop in temperature. Temperatures are still below their "set" values (of 15°C and 25°C respectfully), both rooms will need further heating inputs to meet project targets. Individual 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). Biogas project temperatures are measured with Hoboware U22-001 Water Temp Pro V2 loggers recording hourly.

Removal of the outdoor water pressure system

Appendix 2 depicts the site in its current state. The outdoor water-pressure system that was installed at the project in January 2010 by T.H. Culhane was adapted by the Alaska team members from other versions built in tepid-climate regions. At the time of the last quarterly report it was determined that these secondary containment systems did not meet the needs of project nor were they appropriate for the given conditions found here in Cordova. The average temperature in Cordova since September 30, 2010 has been 2.3 °C, with freezing events occurring often. The use of water in the old containment system would have presented a significant problem in case of a freezing event as joint stress caused from the expansion of freezing water was known to cause leaks in the past and would further bring to tank integrity into question.

All outside tanks have been removed as of October 12, 2010. Remaining salvageable parts have been inventoried and stored inside of the Cordova energy center to possibly be used again during the Phase II study. The LDPE tanks that were once used for the containment system are now stacked near the Connex with the exception of the Tank 1 floating barrel system which is still located in its original position against the Connex. None of the tanks are currently connected with any type of gas containment system and all gases are simply being vented to the atmosphere at this time. We will once again pursue a suitable containment system with the goal of utilizing the biogas to fuel a gas-powered technology in Phase II.

Cordova High School students brainstorming for Phase II

During the third quarter, it became of interest to team members to test digester effluent for its use as a nutrient-rich liquid fertilizer. Since the last report, Cordova High School teacher Adam Low spearheaded efforts with students to test effluent samples in a controlled greenhouse experiment (Appendix 3). The greenhouse experiment is currently set up within the Cordova Energy Center and employs the use of heaters and florescent lighting in order to support plant growth despite the local weather conditions of Cordova. Students worked with Clay Koplin and Adam Low to set up experiments testing effluent from Tank 4 as an organic plant fertilizer. Students are currently growing lilies, carrots, lettuce, radishes and cilantro. By planting these food crops in both nutrient enriched and poor soil(s) students are hoping to identify a difference in responsiveness to the nutrient rich effluent.

Additionally, the students in CHS Science club have also taken home dropper bottles of effluent from Tank 4 and are using this as a concentrated plant food on various house plants in their homes. In the next quarter, as the project begins to move into Phase II, more research will be conducted around potential use of biogas for increasing greenhouse efficiency. Namely, it is of interest to see whether or not current digesters can produce enough biogas that can be burned or 'flared' in order to sustain elevated temperatures and CO_2 concentrations within the greenhouse.

iii.b) Health and Safety

Conventional small-scale anaerobic digesters are generally considered to be non-hazardous when given proper ventilation and maintenance. Still anaerobic digesters are used for the synthesis of combustible gases and have some safety concerns associated with them.

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.

In order to prevent potential sources of flammability, the digesters should be checked for leaks regularly. The use of soapy water can help to positively identify leaks at seems and joints where small leaks may not be audible or visible to the naked eye. These checks should be preformed fairly regularly as the tanks are constantly experiencing stresses from both operation and the varying weather of Cordova. Periodic room air will be sampled and analyzed on the gas chromatograph in the Anthony lab at UAF for quantification of background levels in the Connex. We will investigate options for acquiring gas detection alarm systems for the Connex.

Signs are clearly posted inside of the Connex that explain(s) the presence of flammable gas and expressly prohibits the use of open flames inside. More signs should be visible from the outside, however, both to warn the general public of the danger, but also to encourage curiosity about the study. All students and researchers should wear proper safety glasses when conducting flame tests or working with pressurized digesters.

There are several options available for the detection and alarm of dangerous concentrations of flammable gases. Current detectors can sample gases for flammable elements through either use of catalytic beads or infrared technology. For our purposes it would probably be best to investigate infrared options as they would be less likely to experience failure due to potential catalyst poisoning. Several companies make detectors that measure the lower explosive limit (LEL) of flammable gas mixtures. These detectors measure a range of different gases and are not selective to just methane. We will explore possibilities of acquiring a flammable gas detector for the Connex.

Hydrogen Sulfide (H_2S): 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 and is considered a broad-spectrum poison. 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 H_2S (≥10ppm). So far all badges indicate the rooms contain nominal H_2S levels.

Carbon Monoxide (CO): There is no mechanism for the formation of CO gas within the methane fermentation pathway and is not of major concern in this study. Carbon monoxide can be formed through improper combustion and should be taken into consideration whenever combusting biogas in a poorly ventilated area.

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.

Though the tanks are checked often for leaks, the inside of the Connex container has a very noticeable smell reminiscent of manure. The air is cycled daily to a certain extent when the Connex container is opened for daily download of the gas flow data. Tubes are connected to the tanks to allow lighter than air constituents escape the container. **The Cordova fire department has visited the site and tested it for noxious gases. The results of the fire departments' testing came up negative for any toxic gases.**

iii.c) Schedule of project

The project is still on schedule as defined by the original project outline. Phase I of the study is still of major importance to the project and should be continued, possibly through until the project's completion. We plan efforts to begin Phase II of the study at the start of 2011 to incorporate the practical use of digester biogas and effluent waste products.

iii.d) Project budget

Project costs as of Oct. 30, 2010 for the project are $110,186.38. This represents 40% of the $250,910 budget. As of Oct. 30, 2010, the project timeline is approximately 50% consumed. The project is running just below budget through Q4 of 2010. The CEC match portion of the project is $15,882.79 as of Oct. 30, 2010. Cordova Schools match have not been computed recently, but had exceeded $50,000 as of June 2010. UAF match has not been computed recently, but had exceeded $3,000 as of June 2010. The Cordova Schools expended a large number of labor hours during this quarter, but total match as of Oct. 30, 2010 was in excess of $69,000 or 70% of the $98,500 match requirement even without recent Cordova Schools and UAF grant matching activities included. In summary, grants costs are slightly under budget as of October 30, 2010, and matching requirements have met 70% of the project requirements through 50% of grant completion. At this time, the budget is not expected to exceed the grant, and the matching contribution is expected to significantly exceed the grant requirement.

iii.e) Hurdles and solutions

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

Lack of confidence in biogas measurements: Due to offsets between the flow meter calibration levels and our gas production rates, we were not able, until this report, to provide the true values of biogas produced. Previous values represented averaged daily flow rates as opposed to cumulative daily gas production. Though this is generally an acceptable method for smoothing out noise in any data set, the true biogas production rates were underestimated. **Solution:** Casey Pape determined a new method to achieve our goal of daily gas production determinations by closing tanks, allowing them to swell with produced gas, opening the valves over a short period of time to allow high rates of gas flow within the level of the flow meter calibration. We will now start reporting total values of gas produced and make an effort to correct errors in the data that may be attributed to false readings on the Sierra instruments rather than actual biogas being produced.

Low biogas production: In order to be of any practical use to the general public - a major goal of the study - an anaerobic digester would have to consistently produce relatively high amounts of methane (on the order of 1000 L/day). Since we began consistently feeding in September, there has been a greatly noticed increase in the amount of biogas produced, though perhaps not noted in the flow data. As of 12/11/2010, Tank 1 reported producing 30 L/day, Tank 4 about 125 L/day and Tank 5 at about 130 L/day. These numbers are still below target values; however, we are excited to be once again seeing flammable biogas in any significant quantity. It is possible that increased feeding could aid the digesters more, but this is so far untested as we are currently feeding at the original proposed rate, which is half the rate used in warm temperature conventional biogas systems.

(1) Low pH. Problem: pH has stabilized in all tanks except Tanks 1 (6.2, Figure 1) and 3, which are currently lower than that which is ideal for supporting active healthy methanogenesis (Gerardi, 2003). It is probable that acetogens out-produced methanogens once the temperature began to drop within the cold room of the Connex. It is very important that team members do not to allow tanks to drop too far below their marginal pH values as it can result in needing chemical remediation which is time intensive in both labor inputs as well as time taken by the digester to recover. **Solution:** Feeding has been halted on Tank 1 in the short-term in order to asses if the pH can be restored on its own as methanogens begin to consume the VFA's and acetate within the digester which are responsible for its lowered pH. Tanks 2 and 3 have not been feed for the duration of the quarter. If the digester can recover on its own that is a very important finding as it indicates the microbial consortium functions a type of "biological buffer" and are able to sustain their own chemistries if caught early enough and given enough time to recover. Tank 1 is still producing measureable amounts of biogas and it will be interesting to observe how the production rate changes in the near future as it could be due to changing pH or to relative nutrient availability.

Other potential considerations:

The following factors are important considerations that generally can lead to problems in biogas technology. While we have no reason to think that any of these factors is causing a problem in our systems, for the sake of thoroughness, here we evaluate each as a potential problem in the context of our study.

Temperature fluctuation. Problem: It is a major goal of this study to preserve the 'cold' (15°C) and 'tepid' (25°C) conditions as was defined in the original project proposal for the purpose of incubation of microbes. The Connex constructed for the project is insulated with R-10 pink foam insulation, but has poor seals and air spaces that cause it to have a heat/cooling regime that mimics that of the local environment of Cordova. Over the course of this quarter, average temperatures for both 'cold' and 'tepid' rooms was 4.2°C and 1.9°C below target values respectively. This is not ideal and will need to be better monitored in the future as our impression of the day to day gas production is that it should be consistent if temperature and food inputs are maintained at a constant level. **Solution:** Although temperature variability is undesirable, we have tried to correct it each time it comes to the team's attention that it may be an issue. Currently there are no outdoor outlets for the project to plug into and makes getting needed power out to the Connex an arduous process. Circuit overload is of great concern as the temperatures have become colder. The projects' heating needs are entirely met by electrical heaters and the project currently employs the use of 5 electric radiant heaters. The project team will have to be more careful in the future to make sure heaters are working properly or have not been unplugged by curious passersby or malcontent youth.

Logistical and management concerns:

Digester/tank and fittings integrity. Problem: Generally speaking, the more holes and fittings installed on a digester or any gas-holding container increases the chance for a leak to develop. When designing systems intending to carry gas (especially flammable gas), it is important to try and build them with as few joints and failure points as possible. Each joint or threaded fitting is a possible leak point equivalent to the circumference of the circular fitting. Summing the total linear area of all these fittings reveals the total area of open holes in the system that now have to be filled with some sort of compound or sealant in order to prevent the vessel from leaking. In this experiment, leaks have already been uncovered among the secondary gas containment systems and resulted in biogas no longer being flammable in air. Inside the Connex, this is less of a concern, but still cannot be ruled out. There are somewhere between 20-30 fittings located on each tank that must all be air tight in order for the researchers to conclude that ever mole of gas is being measured. Additional fittings exist on each tank, but aren't necessarily exposed to an air-gas boundary. This is an issue, but for the most part tanks demonstrate the ability to maintain positive pressure and are thought to be mostly air tight, though minute leaks have been discovered on Tank 4. Tank 6 is not producing biogas that we can record, but we are not sure as to whether or not it can maintain positive pressure. **Solution:** Soapy water does help to uncover leaks where they are suspected; however, small leaks may still exist that are simply too small to notice. For example Tank 4 was found to have a leak, but it was less significant than the metabolic rate of its methanogens and continued to exude positive pressure. If a tank can't exert positive pressure then it is unlikely that soapy water would uncover a leak as there has to be some significant Δ in pressure in order to observe gas exchange between the tank and the atmosphere. In this case, increased pressure is the best way to uncover if there is a leak or not. In the last remaining part of Phase Pape we will try and demonstrate that all tanks have the ability to maintain positive pressure and therefore lack of biogas can be attributed to the chemistry of the tanks and not tank fitting soundness.

Balance of responsibilities. Problem: The project is designed to be conducted in tandem between Cordova High School students and staff as well as the University of Alaska, Fairbanks. Collective effort between both parties is necessary in order to maintain the project and pursue additional research and development during the Phase II study. Students are very capable of feeding and maintain digesters from day to day, but both students and staff are ill-equipped to combat many of the more technical problems that arise due to the nature of an experiment of this type. **Solution:** The project full-time technician (Casey Pape) has recently returned from prior work commitments will now be solely committed to this project both in research and practical development. Adam Low and CHS students have done a wonderful job filling in for Pape while away. Students are eager to learn more from the project and help in any way they can. It will be an educator's challenge to come up with more challenging and constructive projects for students to include themselves in during the next phase of the project.

iii.f) Positive accomplishments:

Biogas production- high methane and 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 production of biogas from both psychrophilic and mesophilic microbes we proved flammability possible (refer to Y1Q2 report).

Biogas from conventional anaerobic digests typically contains methane content between 40-60%. Recently it has been discovered that our biogas contains increasingly high concentrations of methane (50-82%). We suspect that the increased methane concentration(s) observed in our tanks are the result of using psychrophilic methanogens whereas typical anaerobic digesters commonly use mesophilic bacteria and archea found in bovine and animal manure. Additional measurements of gas content are needed to confirm consistency in this trend. Stable isotope analysis could also help distinguish pathways of methanogenesis in the manure-vs.-psychrophile tanks. If this high CH_4-content of psychrophilic biogags holds constant, then this is an important finding as it implicates the use of psychrophilic methanogens for improving the energy content of biogas as opposed to more common mesophilic anaerobic digester systems.

Successful Chemical Remediation of Digester Tanks – As mentioned before in section iii.a) early in the experiment, observed declining pH was foreseen as a potential threat to the digester(s) microbial health and action was taken to restore pH to previous levels. Ideally, digester psychrophilic and mesophilic-communities perform under optimal conditions at a pH of around 6.8-7.2, observing tank pH(s) much lower than this (pH 3.5 – 6) was an indication that the tanks were acidifying and VFA's were likely being produced in large quantities. From this point chemical remediation was determined necessary to stop the digesters from potentially "crashing" or "souring" from prolonged exposure to low pH.

Remediation was performed in two steps. The first step involved stoppage of the initial feeding schedule as specified in the project proposal. Stopping feeding was a necessary step as it was essential to minimize the amount of variability in the tanks while alkalinity was restored. The second step entailed adding calculated quantities of Calcium Carbonate, Lime, and Sodium Hydroxide in order to bring the pH back to the initial conditions. Care had to be taken to restore the pH in a gradual manner as to not "shock" the microbial communities. Slow remediation was also essential as over treating the tanks could cause them to become too basic, as anaerobic digester bacteria are particularly sensitive to increased ammonium concentration and this is to be avoided as even slightly basic tanks can cause total failure of mesophilic communities (comm. TH Culhane). All digesters are now at relatively stable pH values with the exception of Tank 3.

Proven High Methane Content of Biogas – Recent GC analysis of gas samples collected from tanks 1, 4, 5, and 6 shows high levels of detected methane in most cases. Preliminary analysis shows that methane concentrations have increased since the onset of Phase I research. To some extent this is an indication that we are observing healthy proportions of microbes in several tanks enough to support active methanogenesis. More work will have to be performed on the GC in order to understand long term trends and behavior of our tanks, but at first look the results seem promising.

Student education – This project has the fortunate opportunity of involving High School students in a primary scientific study. Cordova High School students have the unique ability to see some of the technical aspects and complications that go along with scientific research. The science club and chemistry class provide an excellent platform to organize student involvement. Previously, students have had the opportunity to troubleshoot and take the lead on feeding procedures for the project resulting in several very clever and innovative ideas being implemented.

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. 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., 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.

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.

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
Unfortunately no final reference was made to the Denali Commission as the funders of this research. Interviewees informed the writer of the funding source, but did not have the opportunity to ensure that the information was included in the printed article.

We are pleased to announce that we will be presenting this research at the 2011 Alaskan Forum for the Environment. Pape will be presenting on the project along with aid and support from Science club students. Held in Anchorage from Feb. 7-11, 2011, our presentation will revolve around technical aspects of the project as well as student involvement. CHS Students were not at first able to attend the conference due to lack of funding from the Cordova School District; however, have recently been invited by the Forum as part of the 'Youth Track'. The Forum has provided funding for air travel and lodging for two students and one adult chaperone.

Last year the chemistry students took a class trip to the Alaska Power Association in Feb. 2010. Students C. Bailler, D. Hess, C. Morrissett, J. Smyke, S. Lindow, and T. Kelley presented on the project and it was received well among those who attended the meeting. The project teams intends to present at next years' Alaska Rural Energy Conference in Juneau, Sept. 27-29, 2011.

Biogas Handbook for Alaskans- McFadden completed the first draft of a Biogas Handbook for Alaskans, an instructional booklet specific to biogas production and applications for Alaskan communities. The Handbook will continue to be revised, and submitted as a deliverable in final form to the Denali Commission by the end of the project.

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 provides a venue for students and community members to obtain information about the project and how to get involved. It is important to update the website often as a means to show visitors that the project is still underway, that is still producing results and that people are still encouraged to get involved.

References:

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

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

Walter Anthony, K. M., D. A. Vas, L. Brosius, F. S. Chapin III, S. A. Zimov, Q. Zhuang (2010) Estimating methane emissions from northern lakes using ice-bubble surveys. *Limnology and Oceanography: Methods*, in press.

Appendix 1.

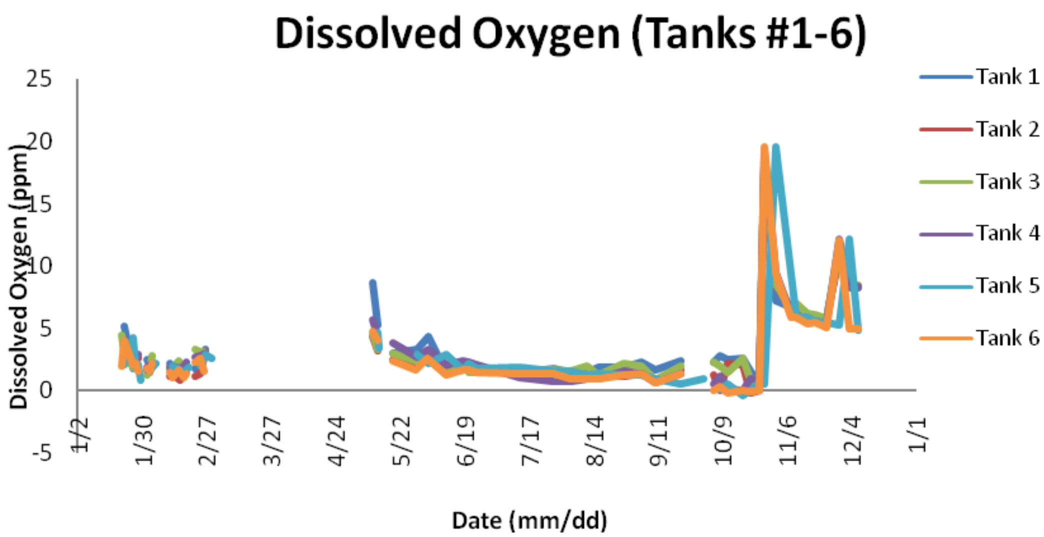


Figure . DO measurements were taken with a Xplorer GLX Pasco PS-2002 Multi-Datalogger until March 24, following which they have been taken by a Hanna HI9142 DO meter. As of October 1, 2010, the Hanna instrument could no longer be calibrated properly. All DO measurements from 10/1/2010 until present are suspected to be inaccurate due the malfunctioning instrument. Methods/steps to restore proper function to the Hanna HI9142 DO meter is/are discussed in the *Hurdles and Solutions* portion of the report (section ii.e)).

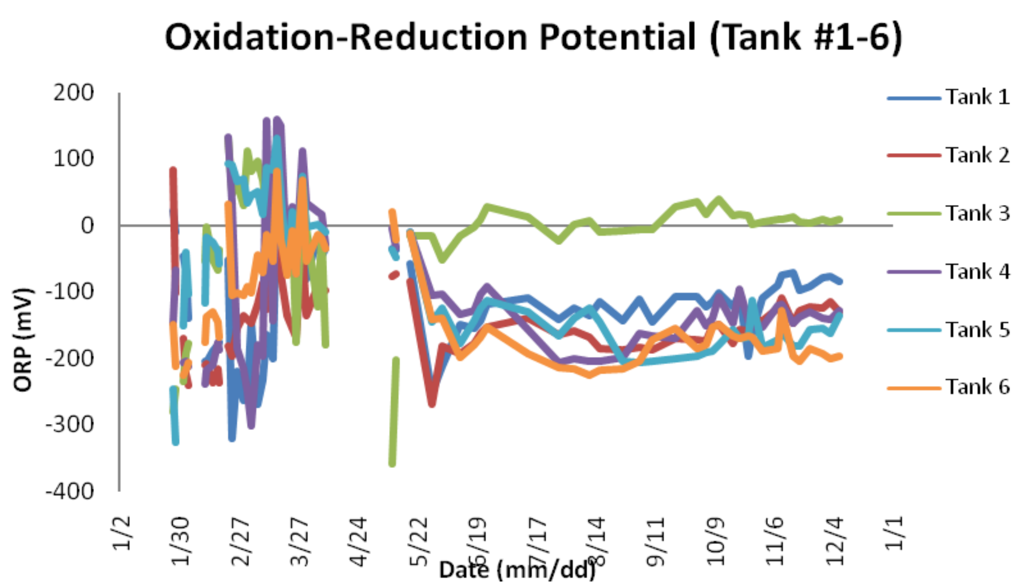
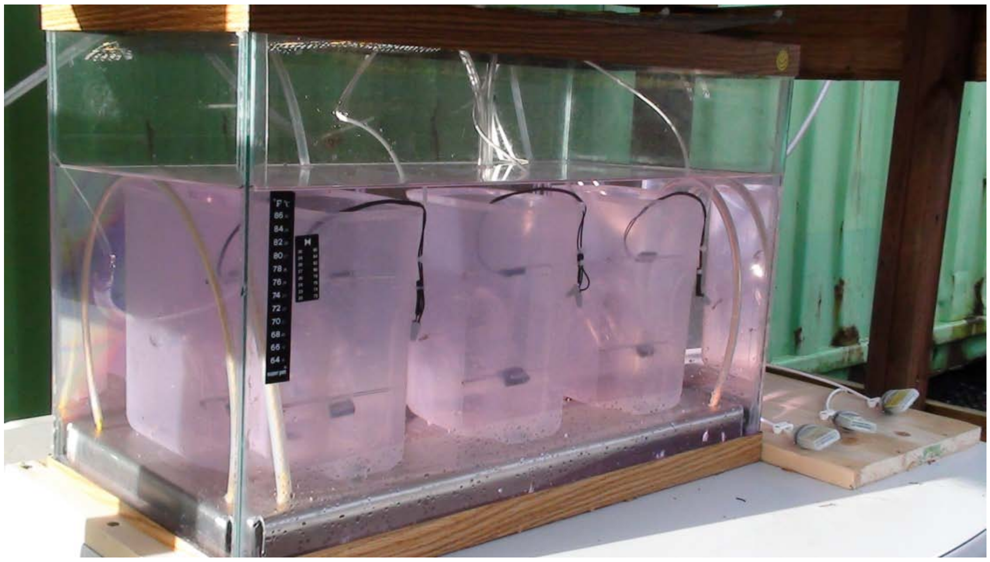


Figure . Oxidation-reduction potential (ORP) indicates the availability of oxidative molecules and ions in the system. ORP is a valuable measure as it determines the likelihood that bacteria will follow the methane fermentation pathway. For healthy methane production, samples should have an ORP of -300. 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.

Appendix 2.



Automated bubble traps were installed on 10/15/2010 in an effort to monitor total gas flux from digesters 1, 4, 5, and 6 in a to 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 is now used periodically to prevent freeze up.

Here the water traps are observed in action during one of the four daily pressure releases of tanks 1, 4, and 5. Tank 6 (on the right) has not demonstrated gas production since the water trap was installed.

Teacher Adam Low is pictured obtaining a sample of gas from Tank 4 in order to demonstrate its flammability to students in his Chemistry class.

Appendix 3.

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

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

Lilly starts contained within the greenhouse aim to see if effluent samples grow faster or slower given the same conditions as starts with only light and water inputs with minimal nutrient content

Effluent samples taken from Tank 4 have been disseminated among Science club students to be used for their own experiments with the anaerobes. Students now have the ability to test the nutrient potential of the effluent as well as pursue individual experiments. Samples contain active cultures as demonstrated in the picture (right)

Student Craig Bailer's heat exchanger experiment to be presented in the annual Alaska State Science Fair. The heat exchanger idea is being explored as it may be of use to the biogas project during Phase II.

25°C room showing active (Tank 4 and 5) and inactive (Tank 6) tanks. Outside the Connex, a water trap allows for a constant pressure to exist within the tanks (approx 0.65 psi). Active tanks can be identified by their tendency to bloat due to the positive pressure exerted by gas produced during methanogenesis.