

Denali Emerging Energy Technology Grant: “Improving Cold Region Biogas Digester Efficiency”

Phase I Data Report – March 15, 2011



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Motivation

Rising costs of fuel and increasing energy demand are incentives for Alaskans to diversify their energy portfolio. In the current world's energy economy, recent reports have emphasized the important role that low-technology energy production will likely play in the future. In Alaska this presents an attractive option for rural communities that have tremendous heating and fuel costs due to the remoteness of their location. Anaerobic digestion, which has been used for centuries in China and India and more recently in other countries such as Europe and the United States, presents a potential solution to help meet Alaska's energy needs. Though the technology has typically been limited to warm, equatorial regions of the planet, recent findings in lake ecosystem research demonstrated that certain forms of cold-tolerant bacteria (psychrophiles) produce methane at near zero degrees Celsius temperature conditions, posing an interesting possibility for biogas production technology even among climates found in Alaska. The objectives of this project are to: determine the potential for psychrophilic methanogens extracted from Alaskan lake sediments to improve biogas production efficiency in small scale digestors at cold temperatures; produce a renewable and alternative fuel through biogas production in Alaska; reduce the release of potent greenhouse gases; and implement dwelling-size applications of biogas to evaluate the potential for its acceptance and sustainability for widespread application in Alaska.

Phase I Summary

The primary objective of the Phase I study was to determine the optimal gas production rate at which small-scale psychrophilic digestors could be expected to perform within Alaskan climates and to compare biogas production efficiency under these conditions with that commonly observed in the tropics, where digestors are a mainstream form of energy production. In Phase I, six different digester vessels (incubated at 15°C and 25°C) were fitted with data logging devices, gas collection systems and were kept within a semi-temperature controlled environment to test the effects of temperature on the various microbial consortia (mesophiles vs. psychrophiles) within the reactors. We monitored the following variables throughout the study: room and digester temperatures, dissolved oxygen, pH, gas composition, flammability, and gas production rates. Using a feeding or loading rate of 2kg of substrate per day (1:1 food and water), researchers aimed to determine how close cold-temperature biogas production by psychrophiles, mesophiles and mixed cultures could come to the efficiency observed with small-scale warm-temperature biogas production in India, which is approximated at 500g CH₄ (around 800 Liters or 28 cubic feet @ 30°C) per day (Karve, A.D.,

2011). Currently, our highest sustainable production based on only 1 kg of food substrate (dry weight) per day is <140g of CH₄ or 230L/day, which is roughly 30% warm-climate digester efficiency of comparable digestors in India. The maximum biogas production rate observed on a single day at any point during this study was 433 L/day.

Results from Phase 1 supported our initial hypotheses. We found that biogas production was higher at 25°C than at 15°C, and that cold-tolerant microbial populations derived from thermokarst lake sediments produced more biogas than warm-loving manure-derived microbes at low temperatures.

Overview of report

The research aims of this two-phase, two-year study are to uncover and understand the potential role that small-scale anaerobic digester technology could play in Alaskan homes as well as what limiting factors determined gas production. In addition to testing hypotheses related to temperature and microbial communities, the objective of Phase I was to determine the optimum daily gas production for small-scale (1000 L) anaerobic digestors within a climate region typical of those in Alaska.

Housed at a public high school in Alaska, the project is a collaborative effort among a public utility (the Cordova Electric Cooperative), Cordova High School, and the University of Alaska, Fairbanks. While the project was originally intended to be maintained largely through hands-on activities by the high school students, researchers from the University of Alaska, Fairbanks have been on-site since April 2010 in order to help facilitate data collection and daily operation of the experiment. Their role has largely been to ensure that the above questions are answered both expediently and with as much accuracy as possible.

Contained within this report are the activities and findings from Phase I, or the first year of the two-year project, including a summary and analysis of digester chemistry and physical parameters that we monitored as well as biogas production under the experimental treatments of temperature and microbial consortia.

Being a first generation study on an unproven technology in Alaska, the project team encountered significant obstacles at various points throughout year one. Not surprising, as each obstacle had to be remedied, the project team learned from the difficulties encountered within the first year. Lessons learned are shared in the report and will also be included in the final handbook presented at the projects' end.

After overcoming hurdles related to optimizing biogas production and ensuring quality flow measurement data (Appendix A), we engaged in Phase 1.5 during Jan. 17-Mar. 10, 2011. The objective of Phase 1.5 was to obtain intensive, high-quality flow data on the six digestors in

order to draw final conclusions about gas production optimization achieved in this study. Research performed in order to understand optimum feeding rate, temperature affect, and biogas production have been mostly exhausted at this point and research interest have been largely. Findings from the Phase I (including Phase 1.5) study are presented in next section of this document.

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iii. Phase 1.5 Study and Results

In December 2010, we achieved high quality gas flow data on the biogas digestors following methods determined by Casey Pape (Y1Q4, section iii.a); however, some of the digestors were discovered to have leaks and the period of gas collection was only three days (sample n=3). The

purpose of Phase 1.5 was to expand the high-quality gas flow measurements after fixing leaks in order to compare biogas production rates among the six experimental digestors over a 10 day observational period. The method required an intense amount of researcher involvement, (measuring gas flow every eight hours, 24 hours per day), and was therefore only able to be performed when personnel could be close enough to the project to tend to each tank. Figure 1 (below) is a summary of the all the data collected on biogas production during Phase 1.5. These data are our most accurate account of daily biogas production during the project.

The method involved with Phase 1.5 was straight forward. In the Y1Q4 Report, we determined that the average biologic rate of any given reactor was below that of the calibration limit on our Sierra gas flow meters, prohibiting accurate gas flow data collection. The low values being recorded on the devices were causing misinterpretations of the data. In order to remedy the problem of low gas flow rate, Casey Pape determined that closing off the tanks, allowing them to build pressure and then vent at set intervals was the best way to measure daily gas production. The valves on each of the tanks were turned into the “closed” position, allowing the tanks to accumulate biogas in the headspace above the reactor fluid. After eight hours, we opened the valve to allow the pressurized biogas to escape through the Sierra flow meters. The tanks were vented every eight hours to avoid over-pressurization. Daily feeding typically corresponded to right after a mid-day venting so that food contents could be easily added without encountering significant backpressure from the closed-off tank. For any additional information concerning methodology for the above mentioned sampling protocol, please refer to the Y1Q4 report.

Table 1. Biogas summary data for Phase 1.5. The numbers represent average, un-normalized gas production for each tank within a 24hr period. Gas production results normalized by the volume of biogas slurry inside each tank are provided in (Table 4). On several occasions, gas pressure contained in the headspace of the reactors caused tanks to expel some of their liquid contents from the tanks. Dates of occurrences of tanks spills are both documented and undocumented as students may not have reported a spill during several instances when researcher and teacher support was not available. Tank(s) # 2 and 3 valves were closed and were not observed to have produced gas above nominal levels for the entire period. Any noise recorded by the Serria Top-Track 820 mass flow meters was given a value of zero.

Date	15°C Room			25°C Room		
	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6
12/11/2010	28.3	0.0	0.0	126.6	151.4	0.4
1/17/2011	19.7	0.0	0.0	207.5	145.0	23.9
1/18/2011	21.2	0.0	0.0	257.1	162.9	27.5
1/19/2011	32.0	0.0	0.0	201.9	196.8	41.3
1/20/2011	48.8	0.0	0.0	330.2	318.0	90.8
1/21/2011	27.6	0.0	0.0	165.8	191.6	88.6
1/22/2011	40.0	0.0	0.0	237.8	279.9	207.9

1/23/2011	59.0	0.0	0.0	346.0	320.1	263.9
1/24/2011	49.7	0.0	0.0	141.0	169.1	115.1
1/26/2011	46.2	0.0	0.0	357.9	433.0	331.7
1/29/2011	35.2	0.0	0.0	175.3*	182.6	144.9
1/30/2011	35.2	0.0	0.0	175.3	182.6	144.9
1/31/2011	63.1	0.0	0.0	154.5	169.2*	136.1
2/1/2011	47.3	0.0	0.0	181.8	214.8	170.8
2/2/2011	46.4	0.0	0.0	179.0	235.7	150.1
2/3/2011	42.2	0.0	0.0	147.5*	140.3	101.8*
2/4/2011	33.3	0.0	0.0	231.2	230.5	220.2
2/25/2011	27.8	0.0	0.0	91.1*	147.9	113.4
2/26/2011	0.8	0.0	0.0	149.7	166.2*	157.0
2/27/2011	27.3	0.0	0.0	140.8	182.3	155.9
2/28/2011	51.2	0.0	0.0	140.5	190.6	162.5
3/1/2011	21.5	0.0	0.0	165.8	209.8	180.6
3/2/2011	40.6	0.0	0.0	155.3	186.5	168.6
3/3/2011	27.7	0.0	0.0	136.7	173.9	157.2
3/4/2011	24.4	0.0	0.0	144.5*	163.3*	163.2
3/5/2011	31.6	0.0	0.0	145.9	184.5	160.8
3/6/2011	17.9	0.0	0.0	152.4	196.8	165.1
3/7/2011	33.1	0.0	0.0	146.1	182.2	165.1
3/8/2011	38.9	0.0	0.0	162.6	203.0	145.9*
3/9/2011	37.4	0.0	0.0	166.3	198.1	157.1
3/10/2011	35.2	0.0	0.0	215.0	265.5	255.3
Average	35.2	0.0	0.0	184.8	205.6	147.3
Standard Dev	13.0	0.0	0.0	63.6	61.9	69.6
Total	1090.6	0.0	0.0	5729.0	6373.9	4567.6

* Days in which a documented leaks occurred (volume released is not known)

Biogas Production (Dec. 11, 2010 - Mar. 10, 2011)

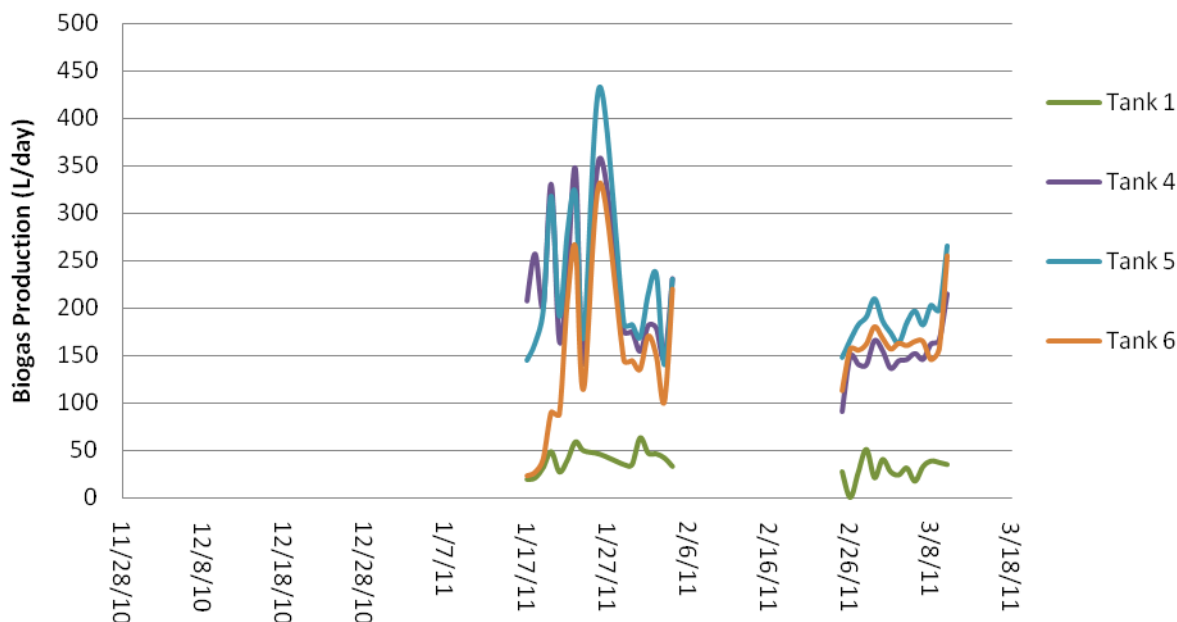


Figure 1. Graphical representation of un-normalized data presented in Table 1. Biogas production shows marked increase from the beginning of the week (01/17/11) and the end (01/23/11). Continuous gas flow data collected on all digestors from February 18, 2010 to the present are not shown due to uncertainties in their calibration.

Feeding during this period was not altered in any way. Tanks 4, 5 and 6 were fed daily according to the original protocol of 1 kg of dry-weight food mixed with 1 kg of water, Tank 2 was fed 0.5kg of food (dry-weight) and 0.5kg of water, and Tank 1 was not fed at all during Phase 1.5 due to low pH conditions.

Gas flow rates were lower during the March 2011 observation period compared to flow readings taken in January 2011, despite the existence of leaks in the tanks in January 2011. We will explore potential explanations for this observation in the next section of this report. All other measurements were maintained during the Phase 1.5 study. We measured tank chemistry and temperature weekly as well as collected samples for gas composition analysis.

Chemistry Results

Some chemical variables that serve as important indicators for assessing the health of anaerobic digestors include pH, redox potential (ORP) and dissolved oxygen (House, 1978). Of these, pH is a very useful benchmark used to determine microbial consortium activity and dynamics within the tank. Tank acidity plays a significant role as active methanogenesis only occurs between a narrow range of pH between about 6.5-7.5 with effective cessation of methanogenesis for pH <6.5 (Gerald, 2003). Figure 2 illustrates changes in pH among all the tanks over the entire course of the experiment.

pH Results (Tanks #1-6)

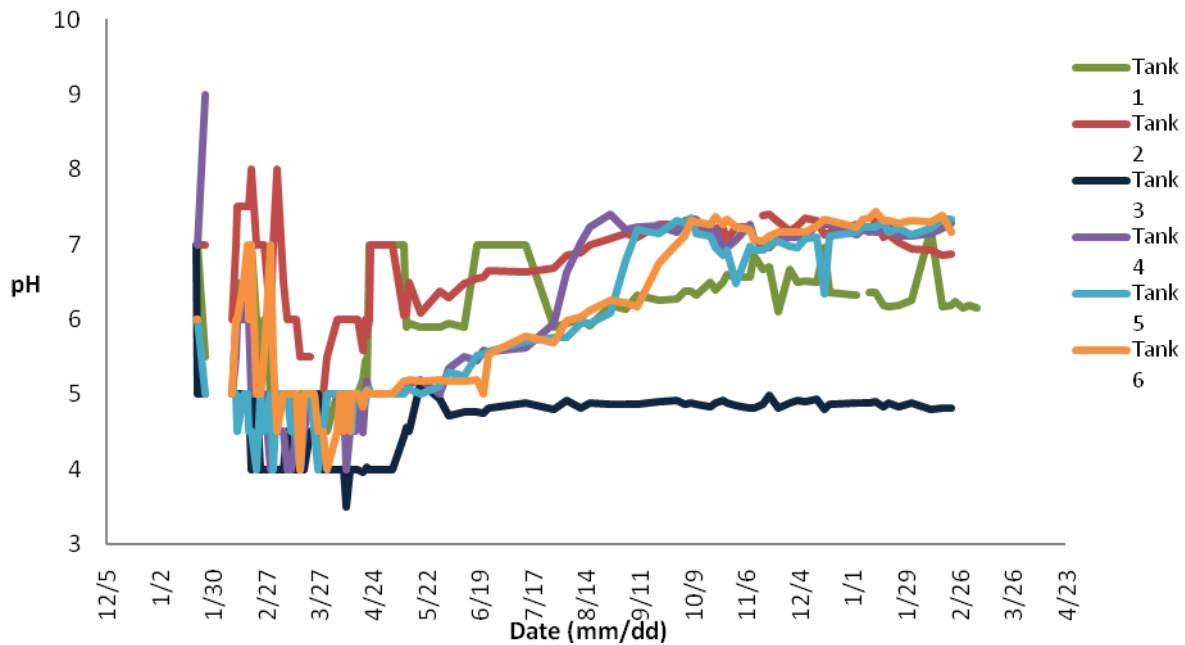


Figure 2. Results indicate that the pH in Tank 1 fell slightly since Y1Q3 report (currently pH 6.1). We halted daily feeding to allow the opportunity for pH to recover on its own, without reverting to chemical remediation treatments. pH was measured with Macherey-Nagel litmus paper January 21-April 16 2010, and with more precision using an Oakton PC510 pH meter since April 17, 2010 until the present.

Table 2. Current pH values among all tanks. During the projects' first year pH values fluctuated greatly. Since the initial acidification was observed and later remedied pH values have been closely monitored among all the tanks in order to prevent future relapse. Currently, the 25°C room digestors are at higher pH values than any of the 15°C room reactors.

Tank	Date of lowest recorded pH	pH value	Date of last sample	pH Value
1	3/31/10	4.5	03/07/11	6.1
2	3/29/10	5.0	03/07/11	6.7
3	4/29/10	4.0	03/07/11	4.7
4	4/19/10	4.4	03/07/11	7.1
5	4/19/10	4.9	03/07/11	7.1
6	3/17/10	4.0	03/07/11	7.0

Another key indicator of tank health and productivity is oxidation-reduction potential (ORP). In essence, ORP serves as an indicator for the likely pathways that electrons will follow in a chemical reaction. Since the target complex of this study is the formation of methane - the

most highly reduced hydrocarbon known (i.e. four hydrogen atoms bonded to one carbon atom center) - conditions that favor oxidative pathways are undesirable. Methane formation occurs at highly negative ORP conditions near -300mV (Geraldi, 2003). ORP has been closely monitored throughout this experiment in order to determine if conditions within the reaction vessels are conducive to supporting active methanogenesis (Figure 3).

Oxidation-Reduction Potential (Tank #1-6)

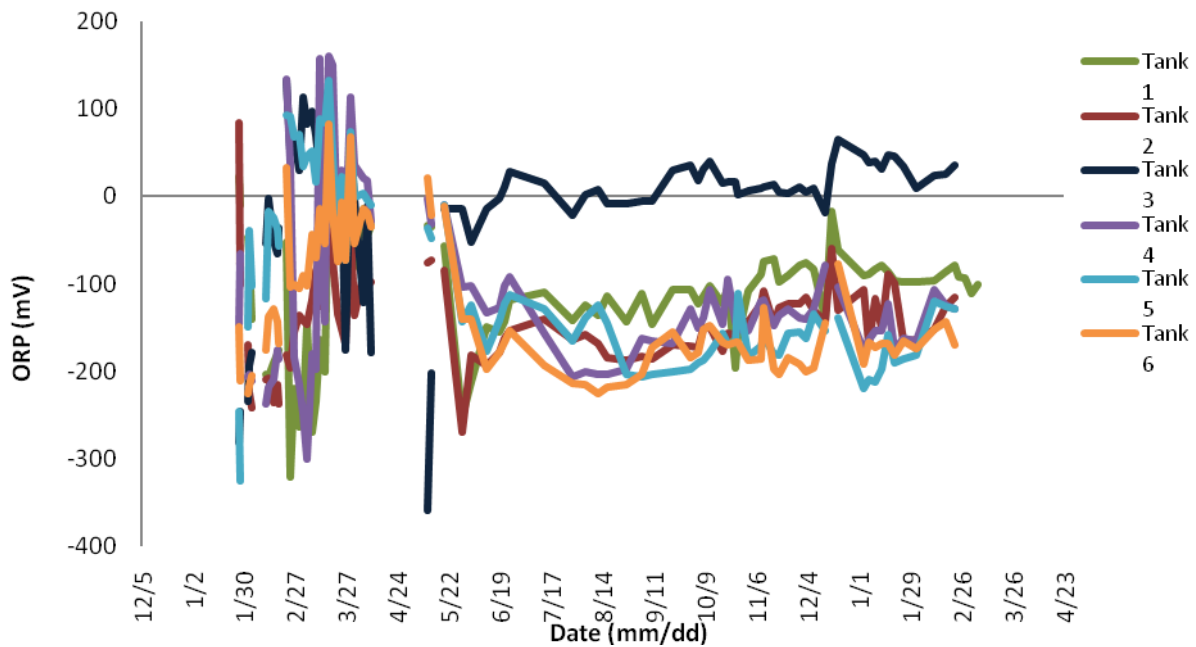


Figure 3. Oxidation-reduction potential (ORP) indicates the availability of oxidative molecules and ions in the system. ORP is a valuable measure as it determines the likelihood that bacteria will follow the methane production pathway. For healthy methane production, samples should have an ORP of -300mV. From January 21-April 9, ORP was measured with an Xplorer GLX Pasco PS-2002 Multi-Datalogger. From May 10th 2010, until present it was measured with an Oakton PC510 ORP meter.

Dissolved oxygen is used to determine if any air is penetrating the system. Anaerobic (zero-oxygen) conditions are desirable in digestors for several reasons. First, oxygen is a strong electron acceptor, so in the presence of oxygen, high redox conditions occur and methane production is unlikely. Molecular oxygen is highly reactive and, when given the chance, will react more readily than the enzymatic pathways supported among methanogens. In essence the reaction will just take an easier route and volatile carbon molecules will tend to oxidize rather than be reduced to form methane. Second, oxygen is toxic to some anaerobic bacteria present within the same media. Figure 4 presents recorded values of dissolve oxygen during this experiment and serves as a relative measure for how stagnant the tanks are.

Dissolved Oxygen (Tanks #1-6)

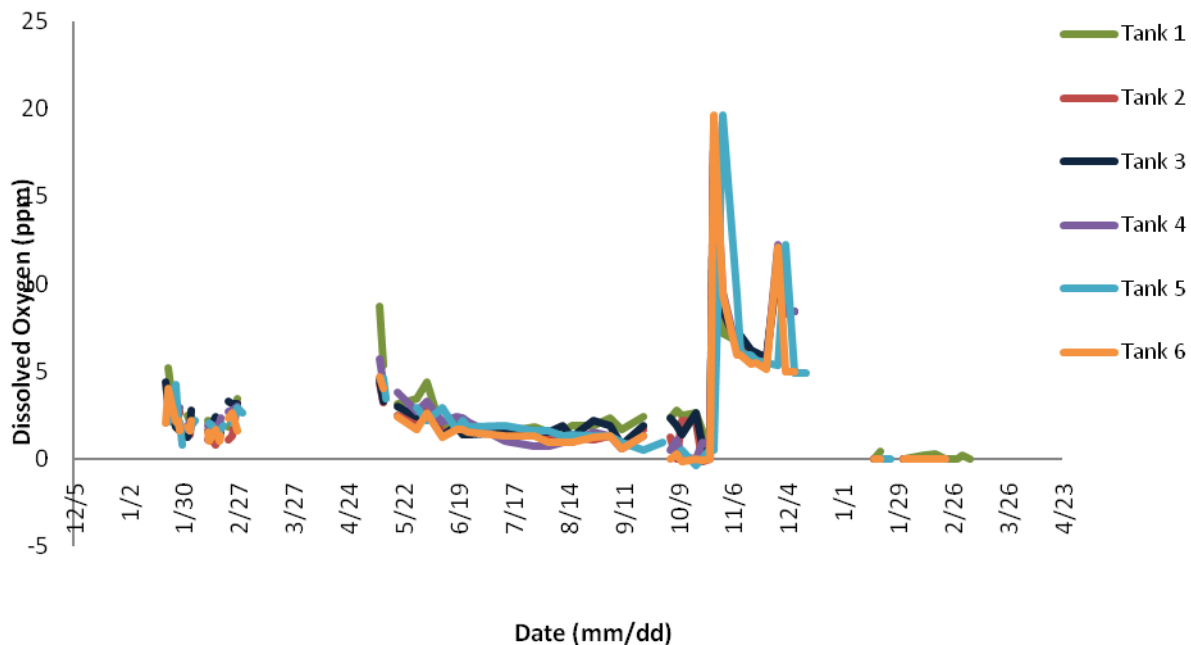


Figure 4. DO measurements were taken with an Xplorer GLX Pasco PS-2002 Multi-Datalogger until March 24, following which they have been taken by a Hanna HI9142 DO meter. As of October 1, 2010, the Hanna instrument could no longer be calibrated properly. Proper function was restored after servicing the instrument in December 2010.

Temperature Data

Factors that influence methanogenesis are not always chemical properties. In fact, physical properties can largely affect biogas production and tank microbial activity. Other factors that limit or effect biogas production are surface area, dissolved organic solids, nutrient mixing/cycling, etc. Of these physical conditions, the variable that is easiest to measure and quantify its effects on gas production is temperature.

Temperature, more than any other factor has perhaps the greatest and most direct influence on biogas production rate in an anaerobic digester. The amount of biogas produced via methanogenesis is proportional to the ambient temperature of the vessel. Temperature plays directly into the relative activity of the enzymes within methanogens and their ability to overcome the activation energy required to drive a reaction to completion. Simply put, relatively warm temperatures increase the energy of molecules within the reactor and bring them closer to the energy barrier required to cause them to react.

The project team has tried to limit the amount of temperature variation between the different rooms in effort to maintain steady reaction conditions throughout this experiment. Within both rooms, temperature data was closely monitored in order to correlate any changes in biogas production to possible changes in room temperature. Figure 5 illustrates the variation in temperature between the “ideally” 15°C and 25°C rooms with average daily Cordova outside

temperature superimposed to shed light on environmental conditions at any given time. Individual tank temperatures have not been downloaded since May 12, 2010. Temperature data loggers are still located inside each of the tanks; however, data have yet to be downloaded in order to avoid opening the tanks and exposing them to air. We will download the individual tank data at the end of Phase II for inclusion in the final project report.

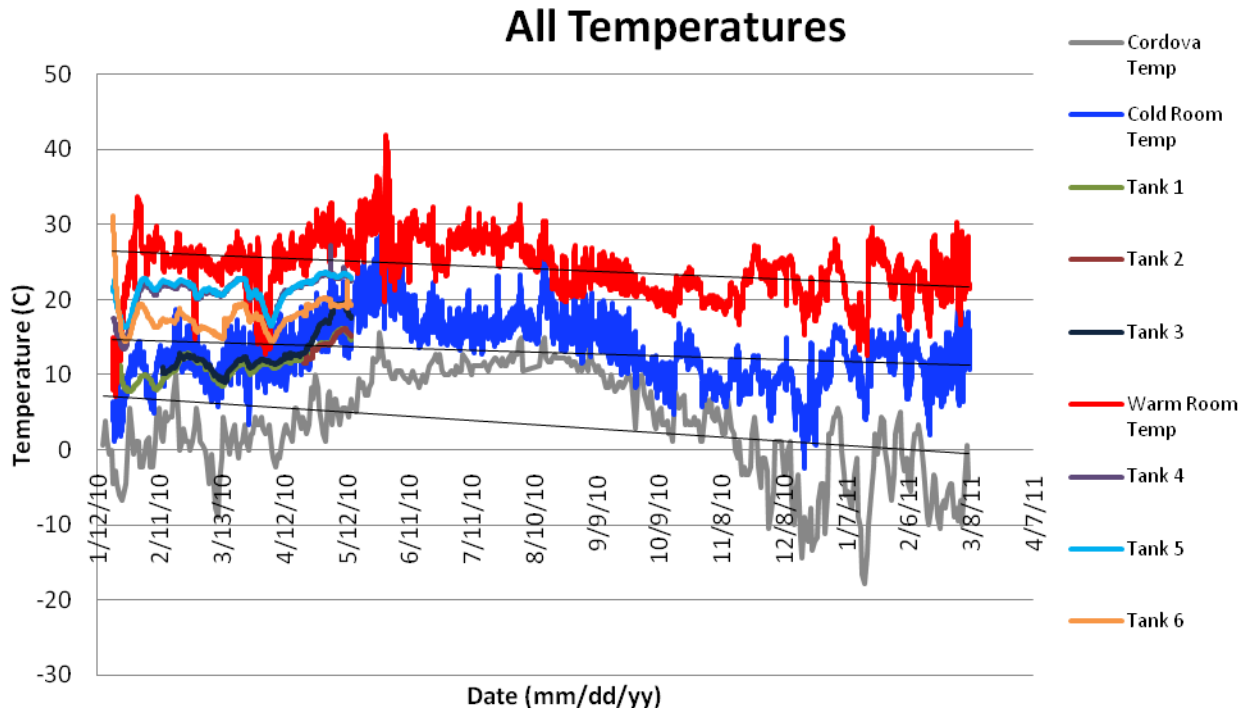


Figure 5. Mean hourly temperature of the data loggers in the Connex cold (15 °C) and tepid (25 °C) room, and mean daily outdoor temperature recorded in Cordova. As the temperatures in Cordova began to drop from at the end of summer, the Connex experienced a noticeable and unfavorable drop in temperature. Temperatures are still below their “set” or target values (of 15°C and 25°C respectfully). Both rooms need further heat sources to meet project targets. Biogas project temperatures are measured with Hoboware U22-001 Water Temp Pro V2 loggers recording hourly. Cordova temperature data was obtained from online sources (source: wunderground.com).

Here we presented the raw experimental data that were either recorded during year one, measured onsite, or obtained from other online databases. In the next section of the report, these graphs and tables will be explained in detail and their most valuable information will be examined to better enhance reader comprehension of the presented research.

iv. Discussion

In this section we (1) discuss results obtained during Phase I, and (2) assess biogas produced with respect to its energy potential based on initial gas composition data.

The protocols described for Phase 1.5 greatly increased the level of accuracy in our daily gas flow measurements. Previous data obtained during year one were highly variable and consistently underestimated the daily quantity of biogas produced. The challenge to a great extent came from initial research prior to beginning the experiment, when researchers had to assume or more or less predict what the gas production was likely to be at the stage of requesting manufacturing of the flow meters. In essence the production rate was overestimated and therefore the flow meter instruments on site were not properly calibrated to register real-time production rates. Re-calibration was questionably cost and time-prohibitive. Measuring biogas production is generally difficult due to the challenges presented by the low flow and low pressure nature of small-scale biogas outside of the laboratory. Many if not all of these problems went away once the tanks were sealed and vented on a fixed schedule; however, one new problem did become apparent soon after this method was adopted. The problem had to do with the increased likelihood of pressure buildup which would accumulate in the headspace of the tank and cause a tank to overflow if left unattended for too long.

Several overflow events were documented among the tanks following the initial, first week of Phase 1.5. Other overflows both documented and undocumented may have occurred and are suspected to have obscured later flow measurement data. Initially, Phase 1.5 data suggested that Tank 4 (*psychrophiles* only, 25°C) was the most productive tank, but later data shows tank(s) five and six are currently overproducing that of Tank 4. Recently, upon measuring the tank volume, it became very clear to researchers that the volumes were no longer equal among all of the tanks and that indeed overflows were likely suppressing the data obtained from direct flow measurements (Table 3). The gas flow measurements made for this period have to therefore be corrected as tanks with decreased amounts of liquid media means the tanks have less food available to produce biogas from, have fewer microorganisms to consume and produce gas and less liquid surface area environment in order to perform reactions converting of food to gas.

If we assume that biogas production is directly proportional to the reactor fluid (1:1), we can derive theoretical production relationships between tanks by performing a simple ratio calculation. By doing this, we can normalize each of the tanks average production to what it would be if the tanks were at 1000L scale. Each tank used in the experiment are 1.0 m³ and therefore we obtain the current volume within each tank by simple multiplying the existing height of the water level within the tanks by 100 (Table 3). From here some simple arithmetic provides us with biogas production rates that are more in line with the data obtained initially (Figure 6). The information presented in Table 4 is therefore the production rates of each tank at the 1000L scale.

Table 3. Current water levels among the different tanks in both the 15°C and 25°C rooms. For each tank, the experiment aimed to test biogas production at the 1000L-scale. Biogas production presented without taking into account the decreased volume of the tanks is inaccurate in that they will misrepresent the actual likely production rate.

Tank #	Date	Water Height	
		(in)	(cm)
1	3/7/2011	34	86.4
2	3/7/2011	31.75	80.6
3	3/7/2011	N/A	N/A
4	3/7/2011	26.25	66.7
5	3/7/2011	30.5	77.5
6	3/7/2011	33.5	85.1

Table 4. The information in this table is the adjusted data presented in Table 1. Information here takes into account the decreased level of each tank and normalizes it to the 1000L-scale. The normalized data are a more accurate representation of gas production within the tanks.

Gas Production Summary Data (Adjusted values)						
Date	15°C Room			25°C Room		
	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6
2/25/2011	32.2	0.0	0.0	135.3*	190.9	133.3
2/26/2011	0.9	0.0	0.0	222.4	214.5*	184.5
2/27/2011	31.6	0.0	0.0	209.1	235.3	183.2
2/28/2011	59.3	0.0	0.0	208.7	246.1	190.9
3/1/2011	24.9	0.0	0.0	246.3	270.8	212.3
3/2/2011	47.0	0.0	0.0	230.7	240.7	198.2
3/3/2011	32.0	0.0	0.0	203.1	224.5	184.8
3/4/2011	28.3	0.0	0.0	214.7*	210.8*	191.8
3/5/2011	36.6	0.0	0.0	216.8	238.2	188.9
3/6/2011	20.7	0.0	0.0	226.3	254.1	194.1
3/7/2011	38.4	0.0	0.0	217.1	235.1	194.0
3/8/2011	45.0	0.0	0.0	241.5	262.0	171.5*
3/9/2011	43.3	0.0	0.0	247.0	255.7	184.6
3/10/2011	40.8	0.0	0.0	319.4	342.8	300.0
Average	34.4	0.0	0.0	224.2	244.4	193.7
Standard Dev	13.8	0.0	0.0	38.7	35.5	35.3
Total	481.1	0.0	0.0	3138.6	3421.4	2712.1

* Days in which a documented leaks occurred (volume released is not known)

Biogas Production 1000L-scale (Adjusted values)

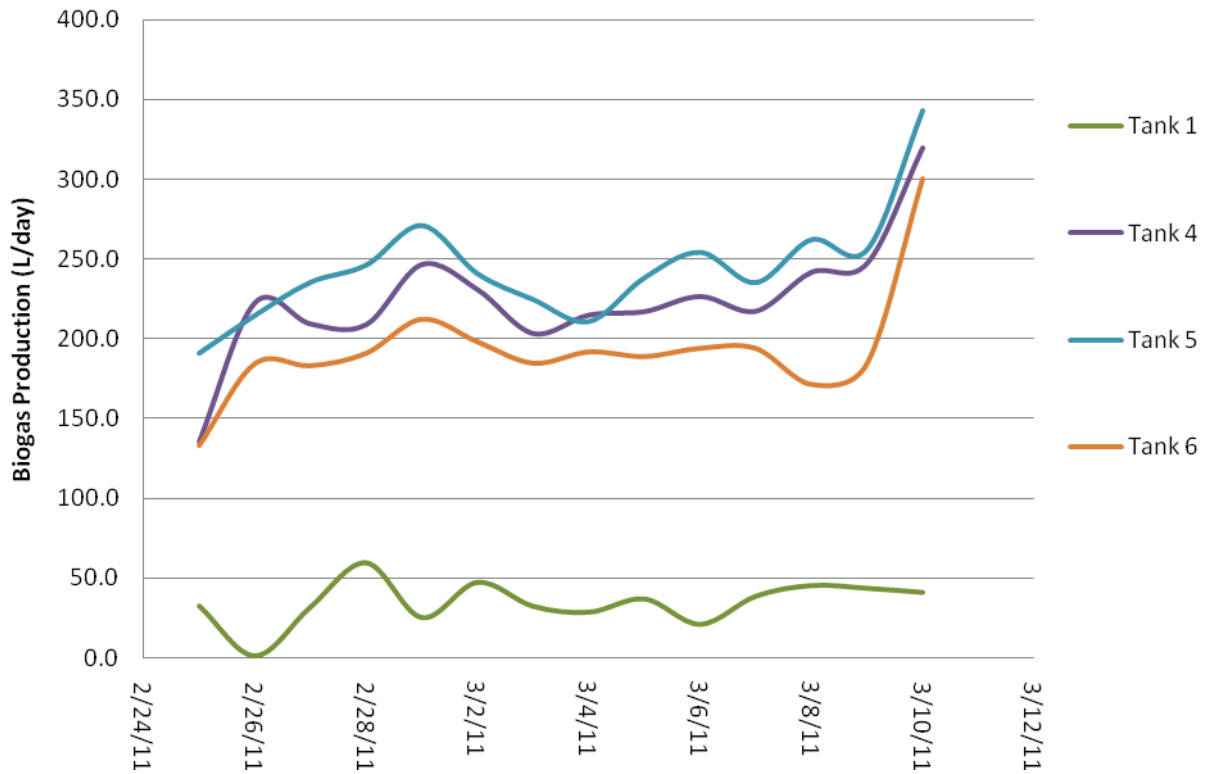


Figure 6. Graphical representation of the adjusted data presented in Table 4. Trends are more representative of the observations made by researchers on location. Tank overflow is suspected to be a plausible explanation at this time for why the recorded biogas production observed a large decrease from previous measurements in January 2011.

Biogas Production - Dec. 11th, 2010 to Mar. 10th, 2011 (Adjusted Values)

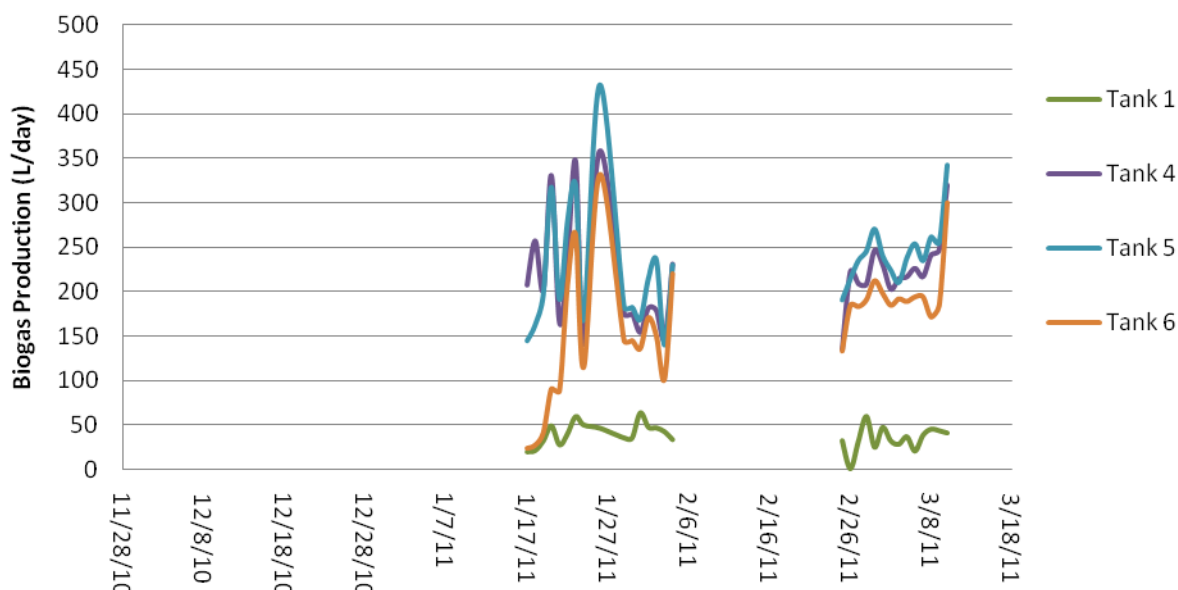


Figure 7. Phase 1.5 biogas production including the corrected data from Figure 6.

Table 5. Summary statistics for the Phase 1.5 study with adjusted values incorporated. These numbers represent the likely optimum daily output of small-scale biogas digestors of in regions in Alaska.

Gas Production Summary Data (Adjusted Stats)						
	15°C Room			25°C Room		
Stats.	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6
Average	37.3	0.0	0.0	217.9	230.5	160.4
Standard Dev.	13.1	0.0	0.0	58.7	63.1	75.4
Max. Daily Rate	63.1	0.0	0.0	357.9	433.0	331.7
Total	1156.2	0.0	0.0	6755.0	7144.7	4972.0

In summary, digester results suggest that we have obtained understanding of the typical rate of biogas production that can be achieved at low temperature conditions. The results support our original hypotheses that psychrophilic methanogens were more productive than mesophilic microbes at low temperature conditions of this study. Thermodynamic constraints of temperature on metabolism, despite adaptations to cold in psychrophiles, nonetheless suggest that cold-temperature biogas production (20-25 °C) is roughly 60% less efficient than conventional warm temperature (40°C - 60°C) biogas production.

iv. a) Chemical Properties that Affect Biogas Production

It is well documented in the literature that several chemical factors can indicate to a large extent, the general health of an anaerobic digester. Though the bacteria tested in this experiment have adapted to living in colder climates (*psychrophilic*), they still share many

similarities with *mesophilic* and *thermophilic* methanogens therefore have similar chemical fingerprints. Often methanogenesis can be sustained continuously if when a tank starts to diverge from the ideal appropriate action is taken to remedy it. If certain chemical signatures and early warning signs are heeded in time, often no additional labor inputs are needed in order to remedy the issue. Many of the lessons learned from first-hand observation of the project will allow future projects to avoid similar hang-ups and setbacks. In this study, there were four chemical factors that were used to monitor the experiment and ultimately digester health. As mentioned in the introduction and in the results section of this report, the four variables that were monitored throughout the Phase 1 and 1.5 studies were: pH, ORP, dissolved oxygen and biogas composition analysis (Gas Chromatography).

pH

Tank acidity or pH was arguably the most predictive chemical factor of tank microbial activity and methanogenic health. Methanogenesis requires multiple pathways and depends on symbiotic relationships between microorganisms in order to decompose complex organic compounds and produce methane (see Y1Q2. Status Report). If these different microbes get out of sync with one another possible “crashes” or destruction of the methanogenic communities can occur. These crashes are labor intensive and require lots of downtime (time spent not producing gas) in order to correct. A declining pH is a textbook warning sign that the system is currently experiencing an imbalance in microbial activity. When this happens the best thing to do is stop feeding the tanks as more food inputs are likely to exaggerate any current trend.

In our experience, there was a well documented acidification among all the tanks following the initial sealing of the reactors back in February 2010 (Figure 2). In order to remedy the problem before causing a total system “crash”, intense amounts of labor inputs and careful monitoring were required to nurse the experiment back to its originally intended performance levels. For our project team this materialized in dedicating a full-time research staff position (performed by Laurel McFadden) in Cordova as well as halting all feeding regiments until June of 2010.

From this acidification incidence, the research group learned and experienced the importance pH markers have on tank performance. It is known among the literature that the pH levels below about 6.5 ($\text{pH} < 6.5$) results in cessation of active methanogenesis (Geraldi, 2003). Therefore it is recommended that anytime a pH is observed below 6.5 all feeding should be halted immediately to prevent irreparable damage to the system. Following the initial acidification and remediation of the experiment in Cordova, only one other tank has been noted to demonstrate an acidification-type trend. Tank 1 is currently thought to have acetogenic activity “out produce” methanogenic activity as its pH is below the minimal 6.5 benchmark (currently 6.1). Figure 2 presents a slight decrease in pH for Tank 1 at lower temperature where tanks being fed the same amount in the 25°C room experienced only nominal decreases in pH. The decision to stop feeding the tank was made in December of 2010 and the tank is being tested to see whether or not it returns naturally to neutral pH without assistance. The tank is still producing biogas and samples are being collected for further analysis (Figure 1).

ORP

Ideally, for methanogenesis to take place, ORP values should be as close to -300mV as possible. ORP serves as an indicator for the relative path an electron is likely to travel during a reaction. A more positive ORP indicates that oxidative potential is high and that any organics contained within the reaction vessel are more likely to be oxidized rather than reduced. Likewise, a low or more negative ORP can indicate that conditions are favorable for reduction reactions to occur. This is important because methane is the most highly reduced form of any hydrocarbon.

Figure 3 above shows that only tank with a high (positive) ORP is tank 3. Tank three has been thought to be relatively inactive for some time as its combined ORP value and low acidity are probable indicators that the tank does not support active methanogenesis. Why Tank 3 didn't recover like the rest of the reactors remains somewhat of a mystery at this time.

Dissolved Oxygen

DO is a useful indicator of potential air leaks into the reaction vessel. For an experiment such as this where the objective was to cultivate and maintain a stagnant pond environment, DO values were expected to remain consistently low. We observed consistently low DO values, especially when our DO meter was properly functioning.

Gas Chromatography

Gas Chromatography (GC) analysis is an important research tool. Gas samples which have been collected periodically throughout the project can be used to determine the energy content of the gas produced. We currently have a large catalogue of samples that need to be run for GC analysis though preliminary results have indicated high concentrations of methane production in the past (as high as 82%). Please refer to the Y1Q3 report for more information. Typical CH₄ concentrations observed in biogas production from household wastes are 50-60% CH₄ (Frederic, 2009). If the CH₄ concentration of biogas produced in our digestors is above this, then the energy content of the gas will be substantially higher, and potentially comparable to that of the warm temperature biogas digestors in India.

iv. b) Physical Properties that Affect Biogas Production

Environmental or physical properties that affect the rate of biogas production can range in importance from having little to no affect to those which profoundly impact the amount of biogas that can be produced within an anaerobic digester. Various physical properties that can influence biogas production include: Surface area, barometric pressure, mixing, and temperature control.

Undoubtedly, temperature plays the biggest role in biogas production.

iv. c) Feeding and Loading Rates

Another important variable thought to greatly impact biogas production is feeding rate. To date, no variable feeding regime has been tested to assess what affect feeding rate has on biogas production.

We have determined through close observation of the 15°C and 25°C room that we are probably at or exceeding the maximum feeding rate. For example, Tank 1 has not been feed any additional feedstock and has maintained a daily average gas output of around 30 L/day (Table 1). Additionally, even at our highest observed production rates in January 2011 the gas produced never exceeded beyond 25% conversion efficiency for any of the tanks. At this time we do not think that increased feeding rate would have benefited the research or that higher production rates would have been uncovered. We will elaborate more on this in the *Feeding and Loading Rate* subsection later in the discussion.

iv. d) Current Project Energy Potential

Based on the summary information provided in Table 5 as well as preliminary GC data, the maximum daily BTU rating (the energy equivalent of gas produced) for the digester tanks was between 3000-10,000 BTUs per day (Equation 1).

Equation 1. Rating BTU content of biogas

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

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

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

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

* [MSDS for Methane](http://msds.airliquide.com) (source: encyclopedia.airliquide.com)

It is important to note that these values are theoretical based on the averaged and highest recorded data collected among tanks. Efforts to actually measure BTU content of the gas have not been conducted beyond simple tests to boil water or demonstrate positive flame tests.

v. Conclusion

Determining the potential of psychrophiles extracted from thermokarst lake sediments to produce biogas at low temperatures was the ultimate goal of this study of Phase I. We were interested to learn how close cold-adapted microbes could come to the efficiency levels of biogas production commonly observed among low-tech anaerobic digestors in warmer

equatorial regions of the planet. Digestors of this type (or at least similar to the ones duplicated in this experiment) have been reported to produce on as much as 1000L of biogas per day using a similar feeding regime like the one detailed in this experiment. In many developing countries, China and India mostly, this amount of gas can provide a single family dwelling with the fuel needed for cooking or other comparable useful task in which a conventional fuel source is not available or likewise, hazardous to public health. Here in Alaska, a similar line of logic was used to justify this project as many of the remote villages and communities common throughout the State could greatly benefit by this technology. Results of our Phase I experiment showed that cold-adapted microbes and mixed microbial communities produced only ~30% of the biogas that analogous warm-climate digestors produce in the tropics. These results most likely lend insight to the limits of cold-temperature metabolism, even among microbes adapted for cold-temperature processes.

In the project's second year of study, the team will concentrate efforts on deploying the digestors used in this experiment for common Alaskan-type applications. The Phase II study will incorporate the information gathered from both Phase I and 1.5 studies as well as economic and other data in order to make ultimate recommendations about the likely future of this technology in Alaska. We will produce a "how to" guide book for Alaskans interested in the small-scale technology. We will also pursue research into future scaling and commercial-type projects. The "how to" guide will materialize into a handbook on building small-scale anaerobic digestors and will instruct Alaskans on all the necessary components required to build and deploy digestors of their own. Data gathered from Phase I as well as economic and labor costs studied during Phase II will be integrated into the final report with the aim of presenting final recommendations for the technology's future role in Alaska's ever-widening energy portfolio.

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Appendix

Summary of hurdles and solutions

Significant obstacles overcome during Phase I to maintain experiment conditions necessary to determine optimal gas output were tank acidification due to overfeeding, achieving a consistent feeding schedule with the high school students, obtaining high quality measures of gas flow, and structural integrity of tanks (e.g. joint fittings and seals).

Tank acidification due to over feeding: Originally, the project was intended to be monitored almost entirely by Cordova High School students. Under supervision of their science teacher, Adam Low, students were meant to feed tanks and record gas production while maintaining communication with UAF personnel and CEC who were also responsible to the project. However, complications arose soon after the tanks were sealed February 19, 2010, as each of the six reactors began to notably acidify. Tank acidification is quite common among startup digester projects and had to be remedied before tank pH became too low for methanogenic microbial communities. As a result, a full-time position was created for UAF personnel (Laurel McFadden) moved to Cordova in order to handle some of the chemistry and logistical difficulties encountered during the early stages of Phase I (for more information regarding remediation, please see Y1Q2 report). Laurel achieved successful remediation via chemical treatments in the digestors by June 2010 at which time feeding was partially resumed.

Turnover of personnel: The CHS school year commenced in September of 2010, and with it a consistent feeding schedule. Casey Pape, a new UAF technician was brought to the project to replace Laurel McFadden, who left to begin graduate school in September 2010. Upon Casey's arrival and careful monitoring of gas flow, we started to observe significant biogas production in nearly all tanks.

Tank pH: Tank pH has stabilized (with feeding) among all digestors since the initial acidification was remedied, with the exception of Tank 1 (currently 6.2). The declining pH in Tank 1, below levels conducive to methanogenesis (>6.5), began occurring in November 2010 and led researchers to stop feeding the tank. We suspect that the reason for this pH decline was an imbalance between acetogenic and methanogenic microbial processes within the reactor at the low temperature level of Tank 1 (≤ 15 °C). At low temperatures, acetogenesis can exceed rates of methanogenesis, resulting in the buildup of intermediate metabolic acids. Tank 1 is currently producing flammable gas, but less than it was when the decision to stop feeding was made. Chemistry data has shown a stable, slightly acidic pH (Figure 2). It was believed that without additional feedstock the pH may restore naturally to desired levels, however, this has not yet

been observed. Flow measurements and gas chemistry data on Tank 1 will be continually monitored despite suppressed feeding schedule in effort to maintain information about microbial activity within the reactor. In the 25°C room, tank pH remained in balance with the higher feeding rates, suggesting that the metabolic processes in Tanks 4, 5, and 6 were in sync.

Flow meter calibration: Recent analysis by Casey Pape showed that flow data continuously acquired with the industry standard Sierra 820 flow meters were inconsistent due to flow rates below the calibration limit of the meters when the digester tanks outflow pipes were left in the continuously open position. The instantaneously rate of production, or rather, the “biologic rate” of the tanks was therefore considered to be too low to be recorded by the meters. Pape corrected this problem by closing the tanks and allowing them to build pressure sufficient enough to be registered by the meters when the gas was released (see Y1Q4 report). Accurate flow measurements are now being recorded and are presented in this document (Figure 1).

Joint integrity and leaks: Finally, issues with joint integrity have hindered the ability to maintain accurate flow measurements, but researchers have since solved this problem by closely monitoring joint and fitting seals. Completed on February 25, 2011, Figure 8 shows the old and retrofitted joints and seals.



Figure 8. Pictures representing the old and newly installed gas outlet systems. The old system (left), which was originally installed on February 19, 2011, was demonstrated to have several leaks common among multiple tanks. The decision to retrofit and install the new system (right) was made on January 9, 2011, following a teleconference among project team members at the CEC boardroom and UAF. The new install was completed as of February 25, 2011.