Denali Emerging Energy Technology Grant:

"Improving Cold Region Biogas Digestor Efficiency"

Phase II Scoping Report – March 15, 2011

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i. Project objectives

The objectives of this project are to improve the efficiency of existing methane biogas digestors for operation at cold temperatures, produce a renewable and alternative fuel, reduce the release of harmful greenhouse gases, and implement dwelling-size applications to evaluate their acceptance and sustainability for widespread use in Alaska.

ii. Y1 Phase I summary

The primary objective of the Phase I study was to determine optimal gas production in which small-scale psychrophilic digestors could be expected to perform within Alaskan climates. In effort to increase digestor performance, researchers sought to test the effects of variation among two factors that determine biogas production: temperature and microbial community (*mesophiles* vs. *psychrophiles*). Six different digestor vessels (incubated at 15°C and 25°C) were fitted with data logging devices, gas collection systems and were kept within a temperature controlled environment to test the effects of temperature on the various microbial consortia within each of the reactors. We found that at the cold temperature (~15°C), the only digestor that produced biogas was the one that contained psychrophiles only. At the tepid temperature (~25°C), all digestors produced biogas; however, the psychrophile-only and mixed pscychrophile-mesophile digestors produced more biogas than the mesophile-only digestor. Using a feeding or loading rate of 2kg of substrate per day (1:1 food and water) we aimed to determine how close the cold-temperature biogas production could come to the rates typically observed among warm-climate digestors of the same household scale in India, which is upwards of 500g CH_4 (around 800 Liters or 28 cubic feet @ 30°C) per day (Karve, A.D., 2011). Our work showed that the highest biogas production rate based on 1 kg of food substrate (dry weight) per day is <235g of CH_4 or 345L/day, which is roughly 30% of the warm-climate digestor efficiency. For details of Phase I results, refer to the Phase I Final Report.

iii. Phase II Scoping

We are producing more biogas now than at any other time during the project. Collectively we produce enough gas from all tanks to begin pursuing Phase II research. **The goals of Phase II are to find useful applications for the biogas being produced and disseminate information about the technology to rural Alaskans.**

Research efforts will primarily center around four main objectives:

a. System design and robustness
b. Temperature control and insulation
c. Application of the proven technology
d. Replicability, outreach and collaboration

In keeping with the initial project proposal, during Phase II the project team will focus on deploying the current digestors to test various applications and generate materials to inform a greater community of Alaskans about the technology. Researchers will provide Cordova High School (CHS) students with support and technical expertise necessary to aid them in exploring both conventional and nonconventional uses for this project's small-scale biogas reactors. In this effort, the second phase of the project will engage the students much more than during Phase I (in which the student's main responsibilities were to feed and maintain digestors), while at the same time continuing to analyze the project from a solid scientific framework supported by UAF technical staff. Some of the challenges we face offer a wide array of science and engineering problems and provide an excellent platform for student innovation and learning. Student involvement is likely to continue through the duration of the project when students will be given an opportunity to present their research findings at the Alaska Rural Energy Conference in Juneau Sept. 27th-29th, 2011. Once the research proposal has been approved, the project team will begin pursuing Phase II projects, beginning with gas storage and current system design.

iii.a System design and robustness – gas storage

System design is an essential first step to developing small-scale digestors that operate in conditions found here in Alaska. To date, the project team has encountered and learned from several shortcomings of the current design (modeled after designs in warmer climates) that have proven inadequate for the Cordova environment. Research in this area is essential to Phase II, as researchers hope to present a proven low-maintenance design for Alaskans to mimic in their own projects. We will present this design in the final project report and in the Small-Scale Biogas Handbook for Alaskans.

When the project digestors were initially deployed at CHS, the vessels included an elaborate "passive" gas pressure system introduced by Thomas Culhane of Solar Cities that was intended to both collect and pressurize gas for use. Within its first year of deployment the system failed due to winter freezing conditions and was disassembled. It was determined that the water used to maintain the pressure would quickly freeze if stored outdoors during winter; and that the 1,000L system was probably too large for practical indoor use. A waterless gas collection system would be more practical for Alaskan residences than the water-pressure systems implemented in warmer regions. Efforts to counter this issue may be solvable with bladder-type or rubberized gas collectors, or with a secondary telescoping system similar to that used in primary digestors in India (ARTI website, www.arti-india.org). Gas collection bladders have been demonstrated in similar projects in China, India and would make an ideal collection system for Alaskans as well (Figure 1).

Figure 1. Typical small-scale gas collection systems. Left) a bladder-type collector is ideal for both minimal transportation cost and waterless deployment (source: www.sijiabiogas.com/en). Right) typical telescoping digestor design that uses articulating top tank to contain headspace gas produced by the lower unit (source: www.sijiabiogas.com/en). Both designs are common among rural anaerobic digestors in both China and India.

The advantages and disadvantages of various gas collection and dissemination systems for use in Alaska are provided in Table 1. The emphasis in design is in robustness and minimal need for maintenance once deployed. Designers must build systems (reactors and collectors) that can withstand the seasonal variation and stresses that are common for Alaskan environments. Ideally, gas pressurizing systems would be to some extent passive or human powered to a large degree to reduce energy losses through compression (e.g. compressor pump flywheel linked to an exercise bike, etc.). Joint integrity is also something to be considered as the likelihood of a leak developing in a digestor or gas collector is directly proportional to the number of connections a tank has. So far the team has documented several leaks within the current design among multiple tanks and will have to design better models that do not incorporate so many fittings – both costly and unnecessary to digestor performance.

Table 1. Gas collector systems and possible pros and cons for Alaskan applications.

Gas collection-dispersement system	Advantages	Disadvantages
Water-pressure tanks	None for Alaska except in specific circumstances where non-potable indoor water storage is desired.	Large volume; water freezing problem; energy needed to move and transport water source.
Rubber bladder	Readily available inner tubes, so minimal fabrication/set-up time.	Time consuming to use and maintain; limited gas volume; limited pressurization; inconsistent pressure during gas usage from very high to gradual decline.
Dry, secondary telescope	Minimal maintenance, easy to use indoors or outdoors, self-pressurizing; constant output pressure until empty; similar proven technology in India and elsewhere.	More time consuming to fabricate; challenge of identifying inexpensive, suitable materials for building the telescope.

The efforts to fix the above mentioned problems within the Phase II project will include, but are not limited to:

- Reducing the number of joints in fittings in the existing tanks: Work completed on February 25th 2011
- Collect gas in rubber inner tubes to demonstrate concept. Work completed February 11th 2011
- Developing a Gas Collection System: Research to be completed by June 30th 2011
- Standardized propane tanks and compressor units to pressurize and dry biogas: Plans are tentative at this point.

iii.b. Temperature control and insulation

Despite the fact that this experiment incorporates the use of psychrophilic (cold-adapted) methanogens for increasing digestor performance at low temperatures, the performance of digestors is greatly increased for temperature-controlled reactors over those which might experience ambient outside air temperature fluctuations/decline. What this means for our research is that any efforts to advise Alaskans how to implement methane digestors on a household scale will have to take into account temperature considerations. In this experiment, electric heaters have been used in the Connex that houses the primary digestor tanks in order to maintain temperatures warm enough to sustain gas production. For most applications it is thought that these digestor vessels will be placed within a semi-heated space that will maintain year-round temperatures warm enough to sustain active methanogenesis (at least 20-30 °C; 68-86 °F). Instances in which a digestor may not be placed in a thermally heated space, other innovative ways to heat reactors will need to be considered such as thermal mass storage (i.e. ground, concrete foundation, etc.).

One instance in which alternative heating techniques may need to be considered is in instances of greenhouse applications for methane digestors. Possible ways of passively heating tanks may include pairing an anaerobic digestor with aerobic compost project(s). In this instance, heat generated from the aerobic metabolism of soil bacteria could be used to heat an anaerobic tank. Other ways of heating the tanks could be explored though it is not a primary research priority at this time. We believe that suggesting alternative ways of heating tanks will inspire Alaskan innovation to develop other systems that work for their specific application.

Students may also take the lead in this effort to experiment and brainstorm inventive techniques for better insulating and adapting tanks to the Alaskan environment in which they are expected to perform.

Possible methods for insulating tanks:

- Buried designs which use ground thermal stability to regulate temperature
- Aerobic microbial pairing (e.g. using heat released from compost to insulate tanks)
- Placement in semi-heated space (i.e. crawlspace, boiler room, etc.)

iii.c. Application of the proven technology

Though it is hoped that improvements in biogas production efficiency will occur in this and future projects it is important to begin research into possible useful applications of the digestor's performance at their current level. Already we are generating high quantities of gas (around 200-345 L/tank day^{-1}), enough to begin with experiments to test its usability. There is a question of concern within our group as to what the usability of the gas is in its raw form. Though biogas has been demonstrated to power applications directly and our analysis has indicated gas of high methane content (as high as 82%) as well as flammability, we have yet to prove its use in any standard appliance or other application. It is of interest to researchers to know whether there are any complications with the gas (i.e. causes corrosion, pitting, etc.) and if additional steps need to be taken to process the gas produced (i.e. does drying the gas significantly improve BTU output?). Mostly it is important to continue pursuing uses and applications for anaerobic digestors of this scale that incorporate, but are not solely dependent on the amount of gas produced.

The project is generating gas at lower rates than conventional warm-temperature digestors based on manure: We currently produce ~345L day^{-1} reactor^{-1} @ 25 °C. This is ~30% of the efficiency of conventional manure reactors of the same size, but which require warmer temperatures (800L day^{-1} reactor^{-1} of same size @ 30°C) (Karve, A.D., 2011). The challenge to researchers in the next phase of this two-phase project is to determine if 345L day^{-1} reactor^{-1} @ 25 °C is a cost-effective means of independent and sustainable energy production for enthusiastic Alaskan households.

Applications that we wish to evaluate in Phase II:

- Provide the gas currently being produced in convenient forms to power standardized common appliances (i.e. boil water, gas cook stove, lab table Bunsen burners, high pressure containers with standardized natural gas and propane fittings, etc.)
- Test an internal combustion engine run on biogas
- Transduction or conversion of the energy produced from biogas into some other usable form (i.e. run a generator; increase crop yield to store as sugars and carbohydrates in plants)
- Provide fuel to run 2011 Science Fair experiments for students at CHS and use it as a platform to support student learning
- Use biogas production as an educational tool for students and schools as a means to reduce waste streams associated with school food and other programs
- Use biogas in a greenhouse application as a means to increase crop yield

Additional benefits of biogas digestors – liquid organic and CO_2 fertilizers

Developing and demonstrating the utility of digestors on this scale will potentially incorporate more than just the BTU rating for the amount of methane produced in each tank. For our research, students at CHS have already begun a project greenhouse with the aim of testing digestor ability to fertilize plants by both testing the effluent and increasing carbon dioxide concentration.

- Students have been working on testing tank effluent in a practical greenhouse application while UAF technician Pape will later run samples acquired from the tanks to test usable NPK ratios. This work should be completed by the end of Y2Q2.

Much of our efforts in developing applications for our current digestors are intimately tied to the amount of gas produced. That is with more gas, more studies become possible. All efforts to demonstrate applications for biogas will be completed by CHS students and teacher Adam Low. Close collaboration with UAF and CEC will be maintained. A strict schedule of project proposals and reports, including both written and film documentation will be provided to UAF by the CHS. Date of completion in these efforts is set for June 15, 2011, at the end of the scholastic year (Figure 2).

Implementation of Biogas Applications will proceed as follows: UAF will design templates for Biogas Application Proposals and Reports for use by the CHS. Casey Pape will draft the templates. Adam Low, Katey Anthony and Clay Koplin will provide input to the templates. A final draft of the templates is due March 25, 2011. The purpose of the templates is to standardize the planning and documentation of Biogas Application projects at CHS. Proposals should include a detailed plan, timeline and budget for each project. The CHS students should submit their proposals to UAF and CEC for approval. Once approved, the project should be implemented by the CHS. The CHS should collect data, photographs, interviews and film of the implantation, and turn in a report on their progress, hurdles, successes, and future recommendations to UAF. UAF will use these materials to generate reports for the Denali Commission, the Alaska Biogas Handbook, and possibly materials for the project website.

iii.d. Replicability, outreach and collaboration

It is of interest during Phase II to collaborate with an ongoing public outreach project sponsored by the National Geographic Society (NGS) to understand and test the robustness of our psychrophilic microbial communities and the ability to start up new projects. Tank effluent from a high–performance digestor (the psychrophile-only digestor #4 which contains active healthy cultures) was sent to collaborator and NGS Explorer, T.H. Culhane, in Germany in November 2010 to kick-start new digestors in Germany, Tibet, Israel and Africa. By experimenting with new projects, researchers intend to learn more about the start up time and growth of microbial communities within tanks of similar and differing sizes. Propagating technology in this way enhances collaboration and has the added benefit of building on the lessons learned from previous projects. Inoculation of new digestors with our current digestor microbes protects the environment by reducing the time, effort, and potential environmental hazards of extracting sediments from other Alaskan lakes.

ACEP Economic Feasibility Study

We will collaborate with the Alaska Center for Energy and Power (ACEP) during phase II to conduct an economic feasibility assessment. ACEP staff has agreed to assist in conducting an economic feasibility study of small-scale biogas digestor technology using our current demonstration project in Cordova. Assistance will be provided by PI Walter Anthony's lab support staff at UAF's WERC as well as CEC in Cordova. The assessment will incorporate both physical data from the current project as well as theoretical information as project expenses occurred during this project are not likely to affect second generation projects like those experienced by the target audience(s).

Scaling biogas in Alaska

We will conduct research on the topic of optimizing biogas production by scale of operation in order to make recommendations for future biogas projects in Alaska. Research will consist of investigating the structure and economics of other cold-temperature and conventional biogas operations in Scandinavia, Canada, the United States and elsewhere to determine the economy of scale for biogas. We will consult websites, peer-review literature, magazines, and phone-call interviews to learn from other successful, larger-scale projects what works and what does not work for biogas production. With this knowledge in mind, we will consider some future potential options for upscaling biogas production in Alaska, for instance for use in processing waste from fisheries, dairy farms, Chena Hot Springs and/or the University of Alaska, Fairbanks.

Small-Scale Biogas Handbook for Alaskans

Encouraging collaboration and information sharing among different start ups is a major goal of this project. By the end of this project, a detailed instruction manual for constructing small-scale digestors will be produced as a reference for people interested in replicating small-scale biogas digestors in the future. The handbook will include a summary of the findings of this study. Ideally, the booklet will not only be filled with information on how to make successful anaerobic digestors, but also contain information on how enthusiasts can collaborate and share new innovations they've developed for their own projects. Instructions will be strait forward, but also contain information regarding the technical aspects of this project. Our goal in this effort will be to thoroughly inform Alaskans on all aspects of biogas digestors in hopes that start up projects are replicated with realistic expectations of the costs and energy required for building and maintaining digestors, and to help promote their success.

The booklet will address a variety of topics to provide both a step-by-step "how to" as well as general information to encourage variety and growth of the technology. Tentative booklet chapters will address:

- General history and background of the technology
- Brief summary of the "Improving Cold Region Biogas Digestor Efficiency" project
- Chemistry and biology considerations
- Feeding and nutrient loading
- Temperature and insulation considerations
- Notes on general construction (i.e. fittings, joints, and materials)
- "How to" instructions
- References to other projects and website forums

The proposed timeline for the Handbooks follows: First draft was already submitted in August 2010 to PI Walter Anthony. 2nd draft due May 15, 2010 (to PI Walter Anthony and project team for internal review). 3rd draft due July 1, 2010 (to PIs and to ACEP for comment). Final draft due August 30, 2011.

iv. Timeline

The project is on target with the proposed schedule and budget. Researcher and student projects have already begun work into some of the above mentioned phase II activities. The timeline below summarizes the current project status as well as future goals and targets (Figure 2).

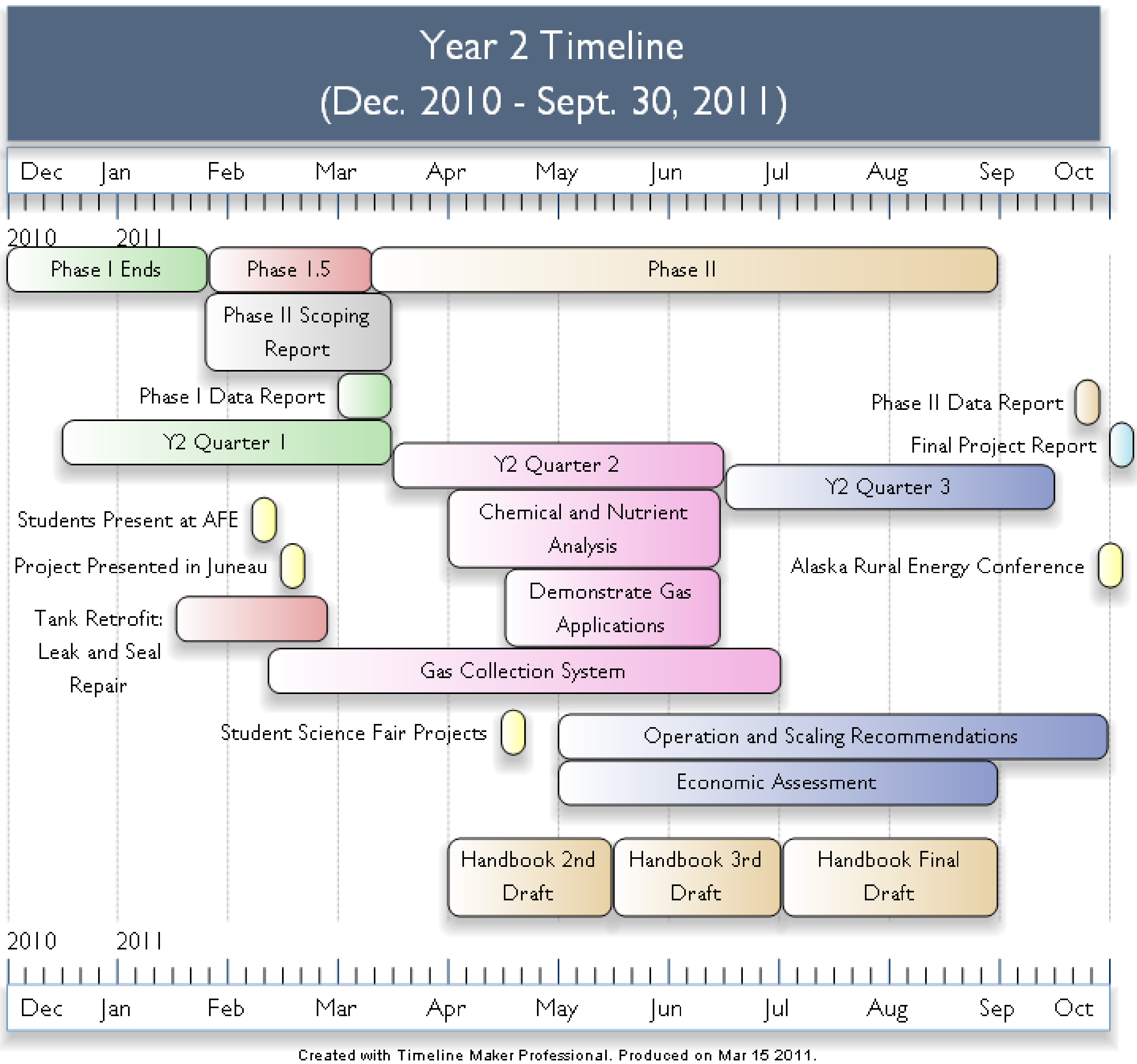

Figure 2. Project timeline including work completed and Phase II work goals. Different aspects of the scheduled work are referenced to what stage of the project which they fall under. Progress reports on each topic can be expected each quarter in which a given work priority shows overlap within that quarter (e.g. if researchers break ground on a certain work priority during Y2Q2, said work will be addressed in the Y2Q2 quarterly report regardless of its completion date in Y2Q3, etc.).