Denali Commission
Emerging Energy Technology Grant

Improving Cold Region Biogas Digestor Efficiency

Microbial-based cold-adapted alternative energy source for Alaskans

September 28, 2009

Cordova Electric Cooperative- Institute Northern Engineering UAF- Cordova Schools
Climate-limitation of conventional biogas production
Project Summary

Deploy the use of cold-loving microbes (*psychrophiles*) to improve efficiency in biogas digestors for generating cooking and heating gas for Alaskan households.
Project Management Plan

Clay Koplin
Project Manager
Cordova Electric Cooperative
Executive

Dr. Katey Walter Anthony
Principal Investigator
INE UAF

Adam Low
Director of Operations
Cordova Schools

Dennis Rose, Mgr.
Feedstock Donor
AC Value Center

T H Culhane
Expert Consultant
Solar Cities

Laurel McFadden
Peter Anthony
Technical Assistants
INE UAF

Engineers
Jack Schmid
Tom Johnson
INE UAF

High School Students
Research Technicians
Cordova Schools

Collaborators:
Autumn Bryson, Native Village of Eyak
Bernie Karl, Chena Hot Springs Resort
Technology Description

Biogas

Biogas is a flammable gas created by bacterial degradation of organic matter, roughly:

- ~60% methane (CH$_4$)
- ~35% carbon dioxide (CO$_2$)
- ~5% other gases

Biogas can be used to fuel gas-burning technologies:
- stoves
- heaters
- lights
- electrical generators
Methanogens

ARE: bacteria that produce methane (CH₄, biogas)
HOW: anaerobic process, consortium of hydrolytic and fermentative bacteria
WHERE: anywhere with the right environmental conditions and food source

Biogas production is highly dependent on:
- temperature
- pH
- nutrient availability
- carbon/nitrogen ratios
How can we use methanogens to produce a low-cost, sustainable supply of biogas as an alternative energy source?

Mimick their natural optimal environment and methanogens will naturally supply a continual source of biogas.

The beginnings of digestor technology: Ruminant digestion systems
Conventional Digestor Technology

Collect ruminant manure:
- warm-loving microbial source
- feedstock source
Mix with water and seal in primary tank
- microbes consume $O_2$ naturally $\rightarrow$ anaerobic conditions
- biogas production starts
- 2 to 4 weeks later (temperature dependent), biogas burns
Utilization:
- Direct methane to a biogas-burning technology

http://enviro-toons.com/page2.html
Basic biogas digestor design

Gas outlet with gas flow meter (to house)

(Liquid organic fertilizer)

Outlet

Gas Holder

Feedstock

Inlet

Fermenter

Appropriate Rural Technology Institute
PROBLEM #1: manure is a nutrient-poor resource

SOLUTION: supply high-quality feedstock (rich in sugar and starch) for optimal biogas production such as:

- organic kitchen, restaurant & cafeteria waste
- waste grain and flour
- fisheries and hunting offal
- green leaves
- plant oils, seeds
- rhizomes
- flowers

Carbon/Nitrogen Ratio 8-20
Efficiency $800x$ greater for quality feedstock systems

**Conventional biogas**

40 kg manure, sewage $\rightarrow$ 500 g CH$_4$
40 days

**Quality feedstock**

2 kg feedstock $\rightarrow$ 500 g CH$_4$
1 day

TH and Sybille Culhane at home with their digestor in Cairo, Egypt
PROBLEM #2: temperature limitation

The bacterial populations in ruminant digestion tracks are warm-loving microbes (*mesophiles*).

- Optimal methane production at 37°C
- Shuts down at 15°C
- Standard digester technology only works if
  - the equipment is built in warm climates
  - the equipment is kept heated, at fuel costs

SOLUTION: This proposed research— an emerging technology. Improve biogas production for people who live in cold climates by inoculating digestors with cold-loving, Arctic methanogens (*psychrophiles*).
Where do we find cold-loving methanogens?

Alaskan thermokarst-lake sediments

• Methane production at 0-1°C to 21°C
• 4x more efficient than European psychrophiles that live at 5°C
Methane emission

Peat

Methane production

Permafrost

Massive ice wedge

Dead plant & animal remains

Thaw bulb

Permafrost
Methane burning movie
Project Goals:

Improve the efficiency of existing methane biogas digestors using Alaska’s cold-loving microbes and available feedstock to:

- Produce a renewable, alternative fuel
- Reduce the release of harmful greenhouse gas
- Mitigate health and environmental safety problems associated with waste disposal in Alaska
- Increase energy independence for Alaskans
- Evaluate technology for widespread application in Alaska
Adaptations of cold-climate biogas digestor systems for Alaskans

- **appropriate microbial populations**
  psychrophiles available in mud of thousands of thermokarst lakes across Alaska

- **utilization of available food substrates**
  kitchen/cafeteria food scraps; hunting/fishing offal; leafy green vegetation; sewage (honey bucket bags); manure

- **easy, cheap construction design and materials**
  ~$300 construction cost; 750-1000-L tanks common in Alaska as water and fuel tanks; PVC and/or hose; foam insulation

- **profitable fuel offsets**

- **potential Federal tax incentives for households using biogas**

- **community outreach programs**
Alternative Designs

Simple biogas plants. Floating-drum plant (A), fixed-dome plant (B), fixed-dome plant with separate gas holder (C), balloon plant (D), channel-type digester with plastic sheeting and sunshade (E).

Source: Biogas Plants, L. Sasse, GATE, 1988

Could put tanks underground in Alaska

Or above ground with 5” of foam insulation (equivalent to >17’ below ground)
Cold-climate biogas project for Alaska

**Phase 1:** Test series of cold-adapted digestors for optimal conditions and construction

**Phase 2:** Operate gas-fueled appliances to evaluate feasibility and sustainability for widespread use in Alaska

**Location:** Cordova (rural Alaskan community), -5°C to 20°C
Stretch goal: Chena Hot Springs Resort, interior Alaska
**Phase 1:** Determine the most efficient biogas digestor system for Alaskans

<table>
<thead>
<tr>
<th>Location/Temperature</th>
<th>Feedstock</th>
<th>Microbial Community</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoors/Warm</td>
<td>Kitchen waste</td>
<td><strong>Mesophilic</strong> (warm-loving)/manure</td>
</tr>
<tr>
<td>Outdoors/Cold</td>
<td>Fisheries waste/ leafy vegetation</td>
<td><strong>Psychrophilic</strong> (cold-loving)/Alaska lake mud</td>
</tr>
</tbody>
</table>
Phase 1: Determine the most efficient biogas digestor system for Alaskans

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<td>Fisheries waste/ leafy vegetation</td>
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</table>

Basic Phase 1 Experimental Set-up with 6 tanks

Indoors: 15 to 27 °C (60 to 80 °F), Warm

Outdoors: -5 to 20 °C (23 to 68 °F), Cold

Feedstock → mesophilic → mesophilic → mesophilic → psychrophilic → psychrophilic → psychrophilic

Microbes → kitchen waste → fisheries waste/ leafy plants → kitchen waste → kitchen waste → fisheries waste/ leafy plants → alternate food scraps/fish/ plants
Project site: Cordova High School Energy Center
# Phase 1 measurements

<table>
<thead>
<tr>
<th>Variable</th>
<th>Method</th>
<th>Frequency</th>
<th>Data (units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas production</td>
<td>flow meter, digestor outlet</td>
<td>continuous</td>
<td>quantitative (liters per day)</td>
</tr>
<tr>
<td>Temperature</td>
<td>data loggers, inside/outside tanks</td>
<td>continuous</td>
<td>quantitative (°C)</td>
</tr>
<tr>
<td>Gas composition</td>
<td>syringe, evacuated vials, outlet hose</td>
<td>weekly/monthly</td>
<td>quantitative (%CH₄, %CO₂, %N₂, %O₂)</td>
</tr>
<tr>
<td>Substrate mass</td>
<td>weigh, describe, record in lab book</td>
<td>daily</td>
<td>quantitative (kg per day)</td>
</tr>
<tr>
<td>Substrate &amp; effluent quality</td>
<td>subsample, freeze, CN analyzer</td>
<td>weekly/monthly</td>
<td>quantitative (% carbon; % nitrogen)</td>
</tr>
<tr>
<td>Slurry conditions</td>
<td>Hydrolab, measure in bucket</td>
<td>weekly/monthly</td>
<td>quantitative (temp, pH, redox, DO, salinity, conductivity)</td>
</tr>
<tr>
<td>Odor</td>
<td>student observations, lab book</td>
<td>daily</td>
<td>qualitative (present/absent; pleasant/repugnant)</td>
</tr>
</tbody>
</table>
Phase 2: Deploy digestor(s) in practical household scale project(s) to operate appliances and an electrical generator to evaluate feasibility and sustainability in an applied setting for widespread use in Alaska

\[ \sim 1,200 \text{ L day}^{-1} = \text{biogas production} \]

- gas lights
  - 125-150 L day\(^{-1}\)
- hot water heater
- infrared heater
  - 200-300 L hr\(^{-1}\)
- cook stove
  - 150-300 L meal\(^{-1}\)
- electrical generator
  - 1000 L kWh\(^{-1}\)

Usage estimates from GTZ
## Phase 2 measurements

<table>
<thead>
<tr>
<th>Variable</th>
<th>Method</th>
<th>Frequency</th>
<th>Data (units)</th>
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<tbody>
<tr>
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<tr>
<td>Gas composition</td>
<td>syringe, evacuated vials, outlet hose</td>
<td>monthly</td>
<td>quantitative (%CH₄, %CO₂, %N₂, %O₂)</td>
</tr>
<tr>
<td>Feedstock mass</td>
<td>weigh, describe, record in lab book</td>
<td>daily</td>
<td>quantitative (kg per day)</td>
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<td>Feedstock &amp; effluent quality</td>
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</tr>
<tr>
<td>Odor</td>
<td>student observations, lab book</td>
<td>daily</td>
<td>qualitative (present/absent; pleasant/repugnant)</td>
</tr>
<tr>
<td>Effort</td>
<td>record time of operation/maintenance in lab book</td>
<td>daily</td>
<td>quantitative (minutes)</td>
</tr>
</tbody>
</table>
Phase 2 Stretch Goal: Chena Hot Springs Resort
**Methane Cost-Benefit Analysis Estimate**

### Installation Cost

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Cost</th>
<th>Extended</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>Plumbing</td>
<td>1</td>
<td>$100.00</td>
<td>$100.00</td>
<td>Pipes, Elbows, etc.</td>
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<tr>
<td>Vessel</td>
<td>1</td>
<td>$10.00</td>
<td>$10.00</td>
<td>Recycled Container</td>
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<tr>
<td>Blender</td>
<td>1</td>
<td>$40.00</td>
<td>$40.00</td>
<td>Feedstock Prep</td>
</tr>
<tr>
<td>Install Labor (hrs)</td>
<td>12 hours</td>
<td>$15.00</td>
<td>$180.00</td>
<td>Assume Day Labor Rate</td>
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<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td>$330.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Annualized for 5 yrs</strong></td>
<td>0.2</td>
<td>$330.00</td>
<td>$66.00</td>
<td>Annual install cost</td>
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</table>

### Benefit

<table>
<thead>
<tr>
<th></th>
<th>Cubic Feet/Day</th>
<th>Days/yr</th>
<th>Total</th>
<th>Cubic Feet</th>
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</thead>
<tbody>
<tr>
<td>Annual Methane</td>
<td>25</td>
<td>365</td>
<td>9,125</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>BTU/cubic ft</th>
<th>Cubic Ft</th>
<th>Total</th>
<th>MBTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual BTUs</td>
<td>992</td>
<td>9,125</td>
<td>9,052,000</td>
<td>9.052</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>MBTU/Gallon</th>
<th>Cost/Gal</th>
<th>Value/MBTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane Equivalent</td>
<td>0.09133</td>
<td>$4.30</td>
<td>$47.08</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Value/MBTU</th>
<th>MBTU</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Methane Value</td>
<td>47.08</td>
<td>9.052</td>
<td>$ 426.17</td>
</tr>
</tbody>
</table>

**Assumptions:**

- Optimal Methane Production 365 days a year
- Department of Energy Propane Heat Value 91,330 BTU/Gal
- Current cost of propane at pump in Cordova as of 9/12/09 $4.30/gallon plus tax
Challenges

- technology adaptation to cold climate regimes
- cultural norms: handling organic waste is time commitment, stigma in USA
- space requirement (4’ x 4’ x 8’) minimum

A successful cold-adapted digestor for use in the USA, must be:
- cost-beneficial
- easy to construct and maintain
- customizable

Potential solutions  (outside scope of this project)
- Develop design with higher financial and technological start-up costs in favor of long-term ease in maintenance
- Outreach efforts in student and community education
- Government subsidies
Ultimate benefits (this project)

1. Powers household and community technologies such as stoves, heaters, and electrical generators
2. Reduces fossil fuel demands in rural Alaskan communities
3. Reduces the need for transport of fossil fuels across Alaska
4. Produces fertilizer for agricultural efforts
5. Reduce greenhouse gas emissions to the atmosphere
6. Simple and inexpensive technology that any household can operate
7. Empowers local and individual contributions to mitigating the global greenhouse effect
8. Public health and safety: Reduce trash dispersal and organic waste in landfills and environment
9. Potentially provides a portable alternative cold-adapted energy technology (including for reindeer herders)
10. Puts Alaska at the head of cold-adapted digestors globally and makes Alaska one of the initiating areas to use digestors in the USA
11. Offsets energy and economic crises locally and globally.
2009 Emerging Explorers

TH Culhane, Urban Planner

Shafqat Hussain, Conservationist

Nathan Wolfe, Epidemiologist

Malik Marjan, Wildlife Biologist and Conservationist

Grace Gobbo, Ethnobotanist

Katsufumi Sato, Behavioral Ecologist

Beverly Goodman, Geo-Archaeologist

Katey Walter Anthony, Aquatic Ecologist and Biogeochemist

Kristofer Helgen, Zoologist

Michael Wesch, Cultural Anthropologist and Media Ecologist
<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>Methane Timeline &amp; Management</td>
<td>509 days</td>
<td>10/16/09</td>
<td>9/27/11</td>
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<tr>
<td></td>
<td></td>
<td>90 days</td>
<td>10/16/09</td>
<td>2/17/10</td>
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<tr>
<td>1</td>
<td>Startup and Commission Phase I Research</td>
<td>1 day</td>
<td>10/16/09</td>
<td>10/16/09</td>
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<tr>
<td>2</td>
<td>Planning Teleconference</td>
<td>44 days</td>
<td>10/16/09</td>
<td>12/15/09</td>
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<tr>
<td>3</td>
<td>Prepare students</td>
<td>44 days</td>
<td>10/16/09</td>
<td>12/15/09</td>
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<tr>
<td>4</td>
<td>Prepare Project Sites</td>
<td>44 days</td>
<td>10/16/09</td>
<td>12/15/09</td>
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<tr>
<td>5</td>
<td>Acquire Materials and Substrates</td>
<td>44 days</td>
<td>10/16/09</td>
<td>12/15/09</td>
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<td>6</td>
<td>Build Instrumentation at UAF</td>
<td>44 days</td>
<td>10/16/09</td>
<td>12/15/09</td>
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<td>7</td>
<td>UAF/TH Culhane site collaboration</td>
<td>10 days</td>
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<td>1/14/10</td>
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<tr>
<td>8</td>
<td>Meet Onsite - Cordova</td>
<td>5 days</td>
<td>1/14/10</td>
<td>1/20/10</td>
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<tr>
<td>9</td>
<td>Build and Commission Digestors</td>
<td>25 days</td>
<td>1/14/10</td>
<td>2/17/10</td>
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<tr>
<td>10</td>
<td>Project Startup COMPLETE</td>
<td>1 day</td>
<td>2/18/10</td>
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<td>11</td>
<td>Gas Production and Collection</td>
<td>180 days</td>
<td>2/19/10</td>
<td>10/28/10</td>
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<tr>
<td>12</td>
<td>Feed Digestors</td>
<td>180 days</td>
<td>2/19/10</td>
<td>10/28/10</td>
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<tr>
<td>13</td>
<td>Monitor and Collect Data</td>
<td>180 days</td>
<td>2/19/10</td>
<td>10/28/10</td>
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<tr>
<td>14</td>
<td>Data Analysis</td>
<td>31 days</td>
<td>10/29/10</td>
<td>12/10/10</td>
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<tr>
<td>15</td>
<td>Evaluate Data</td>
<td>15 days</td>
<td>10/29/10</td>
<td>11/18/10</td>
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<tr>
<td>16</td>
<td>Prepare Findings Report &amp; Power Point</td>
<td>15 days</td>
<td>11/19/10</td>
<td>12/9/10</td>
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<td>17</td>
<td>Cite Preferred Alternative for Ph II</td>
<td>1 day</td>
<td>12/10/10</td>
<td>12/10/10</td>
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<td>18</td>
<td>Phase I Complete</td>
<td>1 day</td>
<td>12/13/10</td>
<td>12/13/10</td>
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<td>19</td>
<td>Practical Installation - Phase II</td>
<td>25 days</td>
<td>12/14/10</td>
<td>1/17/11</td>
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<tr>
<td>20</td>
<td>Conduct Planning Teleconference</td>
<td>1 day</td>
<td>12/14/10</td>
<td>12/14/10</td>
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<tr>
<td>21</td>
<td>Meet Onsite - Cordova</td>
<td>5 days</td>
<td>12/14/10</td>
<td>12/20/10</td>
</tr>
<tr>
<td>22</td>
<td>Install Digestors and Appliances</td>
<td>25 days</td>
<td>12/14/10</td>
<td>1/17/11</td>
</tr>
<tr>
<td>23</td>
<td>Site Management and Performance</td>
<td>160 days</td>
<td>1/18/11</td>
<td>8/29/11</td>
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<tr>
<td>24</td>
<td>Feed Digestors</td>
<td>160 days</td>
<td>1/18/11</td>
<td>8/29/11</td>
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<tr>
<td>25</td>
<td>Monitor and Collect Data</td>
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<td>1/18/11</td>
<td>8/29/11</td>
</tr>
<tr>
<td>26</td>
<td>Data Analysis</td>
<td>15 days</td>
<td>8/30/11</td>
<td>9/19/11</td>
</tr>
<tr>
<td>27</td>
<td>Evaluate Data</td>
<td>15 days</td>
<td>8/30/11</td>
<td>9/19/11</td>
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<td>28</td>
<td>Interview Participants</td>
<td>15 days</td>
<td>8/30/11</td>
<td>9/19/11</td>
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<td>29</td>
<td>Closing</td>
<td>5 days</td>
<td>9/20/11</td>
<td>9/26/11</td>
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<td>9/20/11</td>
<td>9/26/11</td>
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<td>31</td>
<td>Create Post Project Review</td>
<td>5 days</td>
<td>9/20/11</td>
<td>9/26/11</td>
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<tr>
<td>32</td>
<td>Publish Project Results with Power Point</td>
<td>1 day</td>
<td>9/27/11</td>
<td>9/27/11</td>
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<tr>
<td>33</td>
<td>Present Report</td>
<td>1 day</td>
<td>9/27/11</td>
<td>9/27/11</td>
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</tbody>
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Project: Methane Timeline & Management
Date: 9/14/09
Clay Koplin
Project Manager
Cordova Electric Cooperative
Executive

• CEC managed two successful Denali Commission grants in the last 7 years
• Expert in renewable energy solutions for rural Alaskans
• B.Sc. in Engineering at UAF, Registered PE in the State of Alaska
• Native to Alaska (38 years)
• 17 Years of experience in Alaskan Rural Energy Cooperatives
• Strong Record of team leadership and community or organizational collaboration
  a) Kodiak Elks Lodge Exalted Ruler (President)
  b) Kodiak Island Borough Planning Commission & Personnel Advisory Board
  c) Marine Transportation Advisory Board Vice Chair (State of Alaska)
  d) Cordova City Councilman and Vice Mayor
  e) Cordova Chamber of Commerce Board President
  f) Cordova Ducks Unlimited Chairman
  g) Prince William Sound Economic Development Council Officer
Project Management Plan

Dr. Katey Walter Anthony
Principal Investigator
INE UAF

- Expert in cold-temperature methane production in Arctic systems (Alaska & Siberia); 9 years methane; 13 years Arctic lakes/organic materials
- Agricultural/applied methane research 2 years
- Principal Investigator, $2.6M in grants for methane-related research since 2007
- Publication of methane results (selected):
  Walter, K. M. et al. 2006, Nature 443, 71-75
  Walter Anthony, K. M. 2009, Scientific American, Nov. issue
- Alaska resident since 2000
- National Geographic Society Emerging Explorer (named in 2009)
- Public outreach (selected): NPR, History Channel, Discovery Channel, Discover Magazine, New York Times, LA Times, National Geographic, BBC
Project Management Plan

- BS Geology UAF
- MAT UAA
- 33 year life long Alaskan
- 2008 Alaska Outstanding Earth Science Teacher
- 7 years - Advisor for the Cordova High School Science Club
- 11 years teaching experience as an Alaska certificated teacher
- Led over 20 extended science field excursions around Alaska, the Grand Canyon, Hawaii, and South American mines and volcanoes
Project Management Plan

Laurel McFadden
Technical Assistant
INE UAF

• BA in Science, Technology, and Society

• Circumpolar Arctic field experience:
  Canadian Coast Guard Icebreaker Amundsen
  Weather station maintenance, elementary school
  teacher in Ittoqqortoormiit, Greenland
  Marine research technician on Svalbard, Norway
  Methane research assistant across Alaska

• Watson Fellowship recipient with focus on high-
northern communities and climate change

• Former resident of Cordova with special interest in
  addressing the energy needs of rural Alaskans

Collecting thermokarst lake sediments
with methanogens
Project Management Plan

- Expert in low-cost biogas digesters, solar hot water systems and other do-it-yourself renewable energy technologies for low income community and developing country applications

- 8 years teaching applied science (renewable energy/biofuels/biology/chemistry as a vocational/academic partnership) in the ghettos of Los Angeles. 6 years working with Muslim and Christian poor in Cairo.

- Board of Directors and instructor/designer at Egyptian Environmental Science Center 3 years

- Solar CITIES Co-founder/director, German NGO specialized in „Connecting Community Catalysts Integrating Technologies for Industrial Ecology Systems“ (most recently implemented $25,000 U.S. AID small infrastructure renewable energy grant in the slums of Cairo, Egypt)

- Publication of development work (selected):

- U.S. born citizen with experience living in and working on development projects in many cultures, with commitment to spending the time in each place necessary for project success.

- National Geographic Society Emerging Explorer (2009)


- B.A. Harvard, Biological Anthropology

Thank you

Biogas videos made by Cordova High School Energy Center Students

http://cordovaenergycenter.org/mov/TrashCanEpiphany.mov

http://cordovaenergycenter.org/mov/teamreuben1.mov