Cordova Psychrophiles Bio-Digester

Benefit-Cost and Sensitivity Analysis

December 2012

Prepared by:

Sohrab Pathan, Alejandra Villalobos Meléndez
and Ginny Fay

Institute of Social and Economic Research
University of Alaska Anchorage
and
Alaska Center for Energy and Power
University of Alaska Fairbanks

Prepared for

Denali Commission

Table of contents

List of Tables

Suggested Citation

Pathan, S. and Villalobos-Melendez, A. and Fay, G. 2012. *Cordova Psychrophiles Bio-Digester - Benefit-Cost and Sensitivity Analysis*, Technical Report, Institute of Social and Economic Research, University of Alaska Anchorage, prepared for the Denali Commission, 12 pages.

Introduction

Cordova is located in southcentral part of Alaska, 150 miles southeast of Anchorage, and can be accessed only by boat or plane. The average winter temperature[1] varies from 17° F to 28° F (-8° C to -2° C) and the average summer temperature varies from 49° F to 63° F (9° C to 17° C).[2] To support Cordova's ongoing energy independence efforts , the Denali Commission approved a science project for the Science Club students at Cordova High School using Emerging Energy Technology Funds to develop a bio-digester that uses psychrophiles, a cold climate bacteria, that can reproduce in very cold temperatures, as low as 19° F (-7.5° C).[3] Use of psychrophiles in a bio-digester in Cordova is a new technology that aims to produce low cost biogas for Alaskans who live in extreme cold temperatures. The production of biogas varies significantly depending on ambient temperatures. The cold climate application of this technology is in its research and development (R&D) phase, which makes in-depth economic analysis challenging as there is little cost information and many parts for the application of the technology have to be custom build. This paper describes a preliminary economic analysis of the Cordova project. In order to provide a study at this early stage in technology development, the analysis was prepared using a combined benefit-cost and sensitivity analysis to show the impacts of variations in methane output, and diesel fuel and propane prices. For this preliminary analysis we compared the bio-digester technology against diesel and propane fuel alternatives.

Economic Assumptions

(1) Since the application of this technology in Alaska is still in R&D phase, the analysis assumes a conceptual prototype bio-digester, based on the laboratory scale system demonstrated in this project. Design of the digester is project specific and the concept for this digester was developed from lessons learned from the demonstration field testing phase of the project.

(2) With proper operations and management, the bio-digester should operate approximately ten years.

(3) Real discount rate of 3%

(4) Actual microbial metabolic rates were tested at 15°C and 25°C in Cordova. At 15°C and 25°C the bio-digester produces 50 liters and 350 liters per day, respectively. The 15°C temperature was used to test the production on psychrophilic temperature range and 25°C was used to test the production on mesophilic temperature range.

---

[1] Alaska Community Database, Community Information Summaries (CIS), http://commerce.alaska.gov/dca/commdb/CIS.cfm
[2] Temperature conversion from Fahrenheit to Celsius : National Weather Service Forecast Office, Buffalo, NY. http://www.wbuf.noaa.gov/tempfc.htm
[3] National Center for Biotechnology Information (NCBI), http://www.ncbi.nlm.nih.gov/pmc/articles/PMC290156/pdf/jbacter00504-0093.pdf

(5) The assumption is that the bio-digester is located in a pre-conditioned space with no additional energy costs associated with space heating. The insulation cost is assumed to be 2% of the total project cost[4] and goes to increase weatherization of the preconditioned space.

(6) The price projection of propane was done using propane prices as published by the University of Alaska Fairbanks, Cooperative Extension Service Food Survey.[5] All base prices are for year 2010. The base price was $4.23 per gallon for propane and was set to increase over time at 4.5%, the average percentage increase from 2007 to 2010. Two diesel fuel price projections, medium and high, were used based on published projections by ISER.[6]

(7) Cost for food wastes is assumed to be zero since those can be collected from the neighborhood with minimal labor cost.

(8) Labor cost is assumed to be $7.75 per hour since this is the minimum wage rate in Alaska.[7]

(9) O&M costs are projected to increase 2.5% per year, the average percent change of Anchorage CPI over last twenty years (from 1991 to 2010).[8]

A summary of the economic assumptions is presented below:

Table 1. Summary of Economic Assumptions

Project Lifetime	10	years
Real Discount Rate	3	%
Biogas Production	350	liters per week at 15^{o} C
	2,450	liters per week at 25^{o} C
Labor Cost	$7.75	per hour
Propane Price Escalation	4.6	% per year
Costs for Food Wastes	$0.00	per year
O&M Cost Escalation	2.5	% per year

[4] Casey Pape of UAF was the project manager and Cordova Electric liaison. The cost was based on his work experience on the project.
[5] University of Alaska Fairbanks, Cooperative Extension Service - Food Survey. Survey data is available at http://www.uaf.edu/ces/hhfd/fcs/
[6] Fay, G. and Villalobos Meléndez, A. and Pathan, S. 2011. Alaska Fuel Price Projections 2011-2035, Technical Report, Institute of Social and Economic Research, University of Alaska Anchorage, prepared for the Alaska Energy Authority, 13 pages.
[7] Alaska minimum wage rate is available at http://www.dol.gov/whd/minwage/america.htm#Alaska
[8] Consumer Price Index for Anchorage Municipality & US. State of Alaska Department of Labor and Workforce Development. Data is available at http://www.labor.state.ak.us/research/cpi/cpi.htm

Benefit-Cost Analysis and Sensitivity Analysis

Methane production levels from a bio-digester differ significantly depending on ambient temperatures. Methane production levels determine the amounts of fuel potentially displaced. Hence this analysis' benefit cost ratios are based on two different ambient temperatures: 15°C and 25°C, and fuel price projections for two types of fuel: diesel ($ per gallon) - medium projection, diesel ($ per gallon) - high projection, and propane ($ per gallon).

Estimates of displaced fuel quantities are based on methane production at the two temperature levels previously discussed. The following heat values were used: Methane: 1 cubic feet = 600 Btu, Diesel: 1 gallon = 138,690 Btu, and Propane: 1 gallon = 92,500 Btu or 1 cubic feet = 2,500 Btu. [9] Energy content for pure methane is 1,000 BTU / cu ft, but biogas typically has 60% methane.[10] Table 2 shows biogas production in Btu, gallon, cubic foot, and liter at different temperatures.

Table 2. Estimated Annual Biogas Production in different physical units

Temperature	BTU	Gallon	Cubic Foot	Liter
15° C	385,636	4,808	643	18,200
25° C	2,699,453	33,656	4,499	127,400

Higher temperatures translate into higher bio-gas production. Hence, displaced fuel quantities are lower at low temperatures and higher at higher temperatures for all fuel types. The amount of annual diesel displacement is three gallons at 15° C and 18 gallons at 25° C . Propane displacement also shows increased fuel displacement with increasing temperature. The amount of annual propane displacement is four gallons at 15° C and 29 gallons at 25° C. Table3 shows displaced fuel quantities for diesel and propane at different temperatures.

Table 3. Estimated Fuel Displaced by the Psychrophiles Bio-Digester

Temperature	Displaced Fuel Quantity per Year	
15°C	Diesel (gallons)	3
	Propane (gallons)	4
25°C	Diesel (gallons)	18
	Propane (gallons)	29

[9] Conversion factors as published by the U.S. Energy Information Administration at www.eia.gov
[10] Baltic Biogas Bus for Baltic Sea Region, supported by the European Union: http://www.balticbiogasbus.eu/web/about-biogas.aspx

Benefit-Cost (B/C) analysis shows that B/C ratios for the Alaska application of this developing technology are low (Table 4). At 15°C, the benefit-cost ratio is 0.01 for displaced diesel with the medium-price projection and 0.02 for the displaced propane. Higher ambient temperature assumptions yield higher bio-gas production, hence B/C ratios improve marginally. At 25°C, the B/C ratios increase, but are still below one; the ratio is 0.06 for diesel at the medium price projection and 0.13 for propane. Table 4 shows B/C ratios are below one for both two temperatures and all levels of biogas production.

Table 4. Benefit-Cost Ratios Estimated for the Psychrophiles Bio-Digester

Temperature	Fuel Type	B/C Ratio
15° C	Diesel - medium projection	0.01
	Diesel - high projection	0.01
	Propane	0.02
25° C	Diesel - medium projection	0.06
	Diesel - high projection	0.09
	Propane	0.13

Factors driving the Benefit Cost ratio

In all scenarios analyzed, the B/C ratio is below one. Two important factors affecting the outcome are the early research and development stage of the technology and low levels of bio-gas production at low temperatures. This is evident when reviewing the cost drivers. Although the estimated total capital costs for this technology are relatively low compared to other alternative technologies, labor costs associated with the project are a major cost.

In the beginning year, the operation and maintenance (O&M) cost is only about one third of the total costs and labor to feed the system is 70% of all O&M costs. In the first year of operation, capital costs were the highest share of the total cost at about 68%; however, the labor portion of capital costs – research/consultation for system design – is a major portion of the capital cost, about 33%, similar to the tank cost. If this was an off-the-shelf residential technology, it is likely that capital cost and consultation labor would be a significantly lower portion of the total costs resulting in higher B/C ratios.

Since capital cost is one time investment at the beginning of the project and labor and O&M costs occur every year during the lifetime of the project, the cost ratios show a little different picture when the lifecycle cost is calculated for the capital cost and labor and O&M costs. Capital cost is only 18% of the total cost and labor and O&M cost is 82% of the total lifecycle cost of the project. Appendices E, F, and G show what the values of capital costs, O&M costs, and total costs must be to result in B/C ratios of 1. In addition, although psychrophiles are a potential option to produce higher amounts of bio-gas in arctic conditions compared to traditional bio-gas technologies, the production level were still too low for project viability. To have a higher B/C ratio under the scenarios analyzed, higher levels of production – and higher temperatures- are necessary.

Conclusion

Operating a bio-digester in an arctic environment remains challenging. In order for a psychrophiles bio-digester to be cost effective, a number of factors are necessary such as higher ambient temperatures (e.g. 25 ^{o}C) which need to be controlled on a regular basis, higher prices of displaced fuels, and lower capital, construction, and labor costs. Therefore, based on this economic analysis, the psychrophiles bio-digester is not a cost effective system to produce energy and/or to reduce energy costs for rural Alaskans. Although, this technology is likely to remain in the R&D phase in the near future, technological advancements in the future may improve the cost effectiveness of this technology if they lead to savings in the costs drivers discussed in this report.

References

Alaska Department of Commerce, Community, and Economic Development. (2010). *Alaska Community Database Community Information Systems*. Retrieved from http://commerce.alaska.gov/dca/commdb/CF_CIS.htm

Bartok, Jr., J. (2004, December). *Approximate Heating Value of Common Fuels*. Retrieved from http://www.hrt.msu.edu/energy/pdf/heating value of common fuels.pdf

Fay, G. and Villalobos Meléndez, A. and Pathan, S. 2011. Alaska Fuel Price Projections 2011-2035, Technical Report, Institute of Social and Economic Research, University of Alaska Anchorage, prepared for the Alaska Energy Authority, 13 pages.

Ingraham, J. (1958, February 21). *Growth of Psychrophilic Bacteria*. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC290156/pdf/jbacter00504-0093.pdf

Natural Resources Conservation Service. (2005, July). *Anaerobic digester - controlled temperature*. Retrieved from http://www.biogas.psu.edu/pdfs/SafetyPg2&4NRCS

National Weather Service Forecast Office. (2008, January 20). *Fahrenheit to Celsius converter*. Retrieved from http://www.wbuf.noaa.gov/tempfc.htm

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 North Carolina State University Cooperative Extension. (2012, January 24). *Conversion Factors*. Retrieved from http://www.bae.ncsu.edu/programs/extension/manure/awm/program/barker/a&pmp&c/conversion.htm

Oregon Department of Energy. (n.d.). *ODOE: Bioenergy in Oregon – Biogas Technology*. Retrieved from http://www.oregon.gov/energy/renew/biomass/biogas.shtml

State of Alaska, Department of Labor and Workforce Development, Research and Analysis. (2010).*Consumer Price Index for Anchorage Municipality & U.S.*. Retrieved from http://www.labor.state.ak.us/research/cpi/cpi.htm

U.S. Energy Information Administration. (n.d.). *Energy Calculators*. Retrieved from http://www.eia.gov/kids/energy.cfm?page=about_energy_conversion_calculator-basics

United States Department of Labor. (n.d.). *Wage and Hour Division (WHD)Minimum Wage Laws in the States*. Retrieved from http://www.dol.gov/whd/minwage/america.htm

University of Alaska Fairbanks, Cooperative Extension Service (2011, December 02). *Alaska Food Cost Survey*. Retrieved from http://www.uaf.edu/ces/hhfd/fcs

Appendix A. Estimated Present Values for the Psychrophiles Bio-digester

	Displaced Fuel Cost ($)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	PV of Benefit (in 2010 $)
15° C	Diesel - medium projection ($)	8	9	9	9	10	10	10	10	11	11	$ 83
	Diesel - high projection ($)	9	11	13	14	15	16	16	17	17	18	$ 124
	Propane ($)	18	19	20	21	22	23	24	25	27	28	$ 192
25° C	Diesel - medium projection ($)	57	63	65	66	68	69	71	73	75	77	$ 580
	Diesel - high projection ($)	63	79	94	101	106	110	114	118	121	125	$ 867
	Propane ($)	129	135	141	148	155	162	169	177	186	194	$ 1,347

Appendix B. Fuel Price Projection

Fuel Price Projection	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Diesel ($ per gallon) - medium projection	3.26	3.58	3.71	3.78	3.87	3.96	4.06	4.17	4.28	4.39
Diesel ($ per gallon) - high projection	3.62	4.54	5.34	5.79	6.04	6.27	6.49	6.73	6.93	7.11
Propane ($ per gallon)	4.42	4.63	4.84	5.07	5.30	5.55	5.81	6.08	6.36	6.65

Appendix C. Anchorage CPI

Year	Percent Change from Previous Year	Year	Percent Change from Previous Year
2010	1.8	2000	1.7
2009	1.2	1999	1.0
2008	4.6	1998	1.5
2007	2.2	1997	1.5
2006	3.2	1996	2.7
2005	3.1	1995	2.9
2004	2.6	1994	2.1
2003	2.7	1993	3.1
2002	1.9	1992	3.4
2001	2.8	1991	4.6
Average =2.53			

Appendix D. Conversion Factors

Heat Value for Methane	1 cu ft	=	600	BTU
Heat Value for Diesel	1 gallon	=	138,690	BTU
Heat Value for Propane	1 gallon	=	92,500	BTU
	1 cu ft	=	2,500	BTU

1 Liter	=	0.04	cubic ft
1 Liter	=	0.26	gallon

Appendix E. Goal Seek for B-C ratio of 1 with Different Capital Costs

To get the B-C ratio 1, with PV of labor and O&M cost constant at $8,256, PV of capital cost has to be equal to the following values which are lot lower than $1,788

Fuel Type		B/C Original	B/C Goal	PV of Capital Cost
15° C	Diesel - medium projection	0.01	1	$(8,173)
	Diesel - high projection	0.02	1	$(8,132)
	Propane	0.03	1	$(8,064)
25° C	Diesel - medium projection	0.10	1	$(7,677)
	Diesel - high projection	0.14	1	$(7,389)
	Propane	0.22	1	$(6,909)

Appendix F. Goal Seek for B-C ratio of 1 with Different Labor and O&M Costs

To get the B-C ratio 1, with PV of capital cost constant at $1,788, PV of labor and O&M cost has to be equal to the following values which are lot lower than $8,256

Fuel Type		B/C Original	B/C Goal	PV of Labor and O&M
15° C	Diesel - medium projection	0.01	1	$(1,706)
	Diesel - high projection	0.02	1	$(1,665)
	Propane	0.03	1	$(1,596)
25° C	Diesel - medium projection	0.10	1	$(1,209)
	Diesel - high projection	0.14	1	$(921)
	Propane	0.22	1	$(442)

Appendix G. Goal Seek for B-C ratio of 1 with Different Total Costs

To get the B-C ratio 1, PV of total cost has to be equal to the following values which are lot lower than $10,045

Fuel Type		B/C Original	B/C Goal	PV of Total Cost
15^{o} C	Diesel - medium projection	0.01	1	$83
	Diesel - high projection	0.02	1	$124
	Propane	0.03	1	$192
25^{o} C	Diesel - medium projection	0.10	1	$580
	Diesel - high projection	0.14	1	$867
	Propane	0.22	1	$1,347