COLD CLIMATE HOUSING RESEARCH CENTER
CCHRC

Final Report to
The Denali Commission

Small-Scale Biomass Combined Heat and Power Demonstration Project

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Small-Scale Biomass Combined Heat and Power Demonstration Project

Cold Climate Housing Research Center

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Executive Summary

This is the final report on the Cold Climate Housing Research Center's (CCHRC) small-scale[1] biomass combined heat and power (CHP) research and demonstration project. The objective of CCHRC's biomass CHP project was to investigate and ultimately demonstrate a commercially ready, small-scale biomass combined heat and power system. The purpose of this investigation and related demonstration was to help distinguish whether small-scale biomass CHP units are viable options for use in Alaska's remote and rural areas as an alternative or supplement to the current use of diesel generators and diesel space heating appliances.

CCHRC investigated four main technologies to produce heat and power from biomass: gasification, the Rankine Cycle, the Organic Rankine Cycle, and the Stirling Engine. Gasification involves separating producer gas from burning biomass. The other three methods are engine cycles that can be used with a variety of fuels, which may include biomass, solar energy, geothermal heat, propane, and natural gas. None of these methods are currently commercially available in a small-scale biomass CHP unit.

CCHRC's search for a small-scale biomass CHP system began with establishing three tiers of criteria describing the characteristics of a unit that would be suitable for rural Alaska. Systems that met the first tier of criteria would be investigated for the potential to meet the following two tiers. While a CHP system that met all tiers of criteria would have been ideal, researchers were open to investigating the possibilities of CHP systems that met at least the first tier of criteria. The first tier of criteria focused on the production scale of the CHP unit and its use of woody biomass as fuel. Tier Two criteria specify that CHP units should be easy to use and maintain, have a high duty cycle and have affordable capital and operational costs. The third tier examined the CHP unit's economic development potential and its state of commercialization.

The investigation phase of the project lasted more than 3 years and encompassed several strategies. During the investigation, researchers conducted market surveys, performed in-house searches for manufacturers, and pursued partnerships with industry experts and CHP manufacturers. The first phase of the investigation included a period of background research and investigation, during which CCHRC staff researched CHP gasification units and identified companies that manufactured CHP units. Then, CCHRC issued an RFP seeking proposals for a gasification CHP with automated operation and an electric output of 15-30 kilowatts (kWe). The RFP was later cancelled when no proposals within the scope of the project were submitted. During the next phase of the investigation, CCHRC hired an independent contractor with experience in international biomass projects. The contractor identified a company, Crorey Mechanical in Oregon, and CCHRC partnered with Crorey to test and demonstrate a CHP. However, Crorey became behind schedule during the manufacturing process and the contract was terminated. Lastly, CCHRC expanded its search to include CHP units using technologies other than gasification. CCHRC staff researched small-scale biomass CHP units using ORC, Rankine, or Stirling cycle technologies. They made company contacts to identify systems that met the screening criteria and a consultant familiar with the European market was hired to help with the search. Two companies were identified that had pre-commercial CHP units that could be demonstrated at CCHRC. Ultimately though, both options were ruled out because of high costs and an uncertain commercial outlook for the products.

CCHRC's 3-year search resulted in the following conclusions:

- At the time of CCHRC's investigation there was not a commercially available small-scale biomass CHP system that met CCHRC's criteria of scale, fuel type, ease of use, duty cycle, and affordability.
- The lack of a market appears to be the largest challenge to the commercialization of a small-scale biomass CHP unit.

[1] For the purposes of this project, CCHRC defined a small-scale CHP as one capable of producing 5-30 kWe.

- Scale and fuel type drive the challenges associated with meeting the criteria of ease of use, duty cycle, and affordability of small-scale biomass CHP units.
- CCHRC was uncertain that its involvement in a pre-commercial demonstration project would lead to innovations that advanced commercialization.
- Due to the developmental stage of small-scale biomass CHP technology, parties interested in investing in such a CHP system should exercise due diligence when searching for a manufacturer as emerging technologies inherently carry more risk than established ones.

List of Acronyms

BTU	British Thermal Unit
CCHRC	Cold Climate Housing Research Center
CHP	Combined Heat and Power
kWe	Kilowatts of electricity
kWh	Kilowatt-hours
kWt	Kilowatts of thermal energy/Kilowatts of heat
ORC	Organic Rankine Cycle
RFP	Request for Proposals
RTF	Research and Testing Facility

Introduction

This is the final report on the Cold Climate Housing Research Center's (CCHRC) small-scale[2] biomass combined heat and power (CHP) research and demonstration project. This report is being formally submitted to the Denali Commission as a program funding partner; however, it is expected that other industry and state partners, technologists, academics, and the general public may find the information on the project useful.

Energy Issues in Rural Alaska

Since the mid 1980s, most remote communities in Alaska have relied on centralized diesel power facilities for electricity generation because diesel generators are available in a variety of sizes to meet demand, are reliable, and have maintenance requirements that can be met in a remote setting. In 2010, fuel oil was used to produce almost 85% of electricity in areas outside of the railbelt or Southeast Alaska where hydropower or natural gas is available (Fay & Melendez, 2011). In addition to using diesel for electricity production, rural communities rely on diesel fuel for the majority of their space heating and transportation needs. Figure 1 shows the percentages of households relying on diesel for space heating.

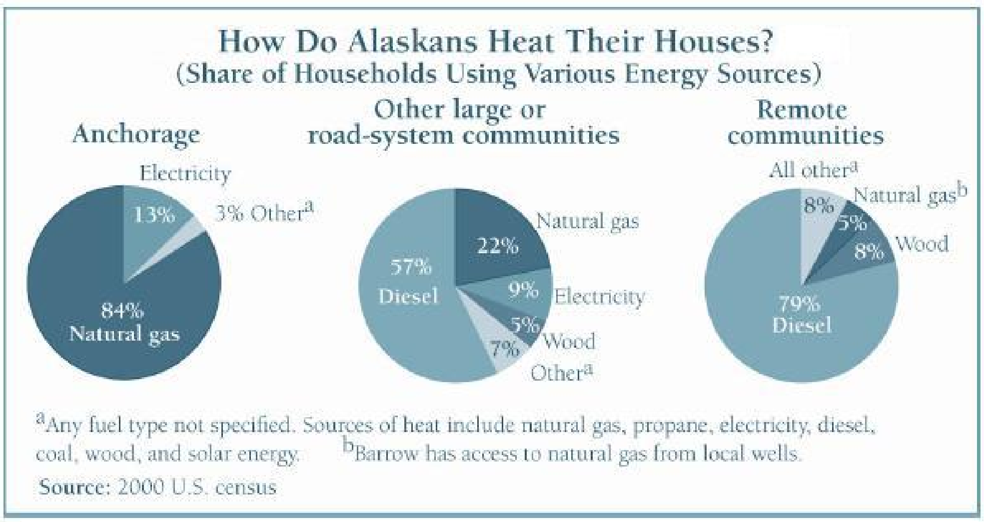

Figure 1: Many rural communities rely on diesel fuel to heat their homes. Image courtesy of (Saylor, Haley, & Szymoniak, 2008).

In rural areas diesel is typically more expensive than in urban areas because of added transportation costs and issues relating to the need for long-term storage. Many communities in Alaska require fuel to be flown in or transported on a barge. In areas of Alaska where periodic fuel deliveries are impractical, for instance during the winter, storage must be adequate to hold a significant portion of seasonal demand. For example, in western Alaska villages the added costs of delivering fuel is approximately $1.00 per gallon, with another $1.60 per gallon added to cover the costs of storage, which means that fuel that would cost $2.00/gallon at the refinery would be $4.60/gallon when sold in a community (Szymoniak, Fay, Melendez, Charon, & Smith, 2010).

A reliance on diesel and added transportation costs to rural areas result in rural Alaskans paying the highest prices for space heating and electricity in Alaska. This means that residents in rural areas spend a disproportionate percentage of their gross income on energy compared to Alaskans living in more urban areas, a disparity that is heightened during times of high oil prices. For instance, in July 2008, composite crude oil prices reached a record high of $128 per barrel

[2] For the purposes of this project, CCHRC defined a small-scale CHP as one capable of producing 5-30 kWe.

(U.S. Energy Information Administration, 2008). Figure 2 shows the results of calculations from the Institute of Social and Economic Research report on household expenditures near this time. While energy prices rose for all income levels during 2008, low-income households in rural Alaska saw the largest increase, spending up to 47% of income on energy costs (Saylor, Haley, & Szymoniak, 2008).

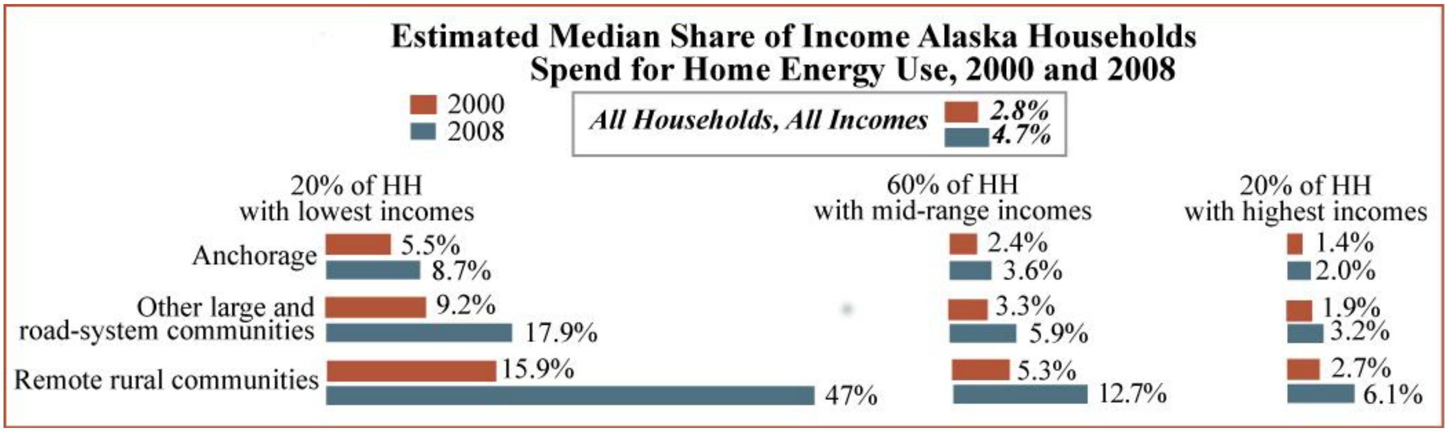

Figure 2: Residents of remote communities in Alaska spend a larger portion of their income on energy for their homes. Diagram courtesy of the Alaska Institute of Social and Economic Research (Saylor, Haley, & Szymoniak, 2008).

In the current economic environment, energy costs are rising and are predicted to continue to do so. Current reference outlook estimates place the price of a barrel of oil at $133 in 2035 in 2010 dollars, compared to the $89-per-barrel cost in December 2010 (U.S. Energy Information Administration, 2012). Volatile and/or rising energy prices will directly affect rural Alaskans who currently have few other options for space heating and electricity.

CHP in Alaska

One possible energy alternative for areas in remote Alaska with an abundance of biomass would be to use biomass to meet some of the heat and electricity energy needs either separately or combined. Technology for the cogeneration of heat and power has been in existence since the 1800s (Onovwiona & Ugursal, 2006). It is a proven technology at the industrial scale with use of biomass as a fuel, and is currently used at the residential scale using natural gas. Commercially produced small-scale natural gas systems exist that provide power down to the 0.5-1.5 kWe range, a scale appropriate for a small household (Aliabadi, Thomson, & Wallace, 2010).

Alaska has substantial biomass resources and the potential to use them for space heating and power generation. Currently, Alaska has more than 10 times the unused biomass energy resource potential than is needed to offset diesel fuel used for power production in rural Alaska (Alaska Energy Authority, 2009). A 2009 modeling study by the USDA found that the installation costs of community-scale biomass systems would be recovered within 10 years for at least 21 communities in the forested regions of Interior Alaska (Fresco & Chapin, 2009). The same study suggested the next step would be for selected communities to institute pilot projects to demonstrate the efficacy of biomass energy and provide a testing ground for improvements.

Figure 3: A biomass boiler has been installed to heat the Tok School. Photo courtesy of Alaska Gateway School District.

Using biomass products to supplement space heating and cooking through the use of wood stoves is already popular in Alaska. Larger-scale biomass heating systems also exist in some locations. As of 2009, there were community-scale biomass heating systems in Dot Lake, Tanana, Delta, and a smaller one in Craig. At that time, there was not any biomass being used for power production (Alaska Energy Authority, 2009). Since then, the Alaska Gateway School District, partnering with the Alaska Division of Forestry, U.S. Fish and Wildlife Service, and the Tetlin National Wildlife Refuge, has installed a 5.5-billion BTU steam boiler and 70 kW steam turbine generator in Tok to heat and power the Tok School with wood from forest-thinning projects and wood scraps from sawmills in the area (Rettig, 2010). The boiler is currently heating the school, and the district hopes to start the power generator in mid-2012. Also, a 400 kW CHP unit is being installed at Chena Power in North Pole. The CHP will use ORC technology to produce energy and power from cardboard, paper, and woody biomass. Small-scale CHPs have also been tested in other cold climates: The Canadian Centre for Housing Technology tested 4 different types of natural-gas fired or fuel cell cogeneration units at its twin house facility to examine the modifications necessary for homes to accommodate such systems (Manning, Szadkowski, Gusdorf, Entchev, Swinton, & Douglas, 2005).

Objective of Study

The objective of CCHRC's biomass CHP project was to investigate and ultimately demonstrate a technically viable, small-scale biomass combined heat and power system. The purpose of this investigation and related demonstration was to help distinguish whether small-scale biomass CHP units are viable options for use in Alaska's remote and rural areas as an alternative or supplement to the current use of diesel generators and diesel space heating appliances. The project was to be demonstrated at the CCHRC Research and Test Facility (RTF) in Fairbanks.

Biomass CHP System Technology

Technology exists to produce both power and heat from biomass. Biomass systems present some challenges because biomass has more variety than other types of fuel in its physical characteristics, energy content, and composition. However, producing electricity from biomass is a commercially proven option. In the United States, there are 11 GW of installed capacity, with an average plant size of 20 MW and average efficiency of 20% (Bain, Amos, Downing, & Perlack, 2003). Smaller plant sizes tend to have a higher capital cost per unit of electrical energy produced, and smaller efficiencies.

Biomass systems require a process for gathering and storing biomass, a way of delivering biomass to a combustion vessel, ash removal, and general maintenance. CHP systems often also require control systems to manage the variables between input of biomass and output of heat and electricity. For example, controls help manage temperature, pressure, fail-safe switching, and the connection to an electrical grid, battery bank or direct use.

CCHRC investigated four of the more common methods to produce heat and power from biomass during the course of this project. These methods are discussed below.

Gasification

Gasification refers to the separation and burning of gas from a biomass fire. The process of gasification has been used since the early 1800s, when it was used to produce gas for lighting and cooking. It continued to develop in World War II due to a shortage of petroleum and was used to power cars in Europe at that time.

When a wood fire burns, approximately 80% of the solid wood converts to a gas (referred to as producer gas or syngas) before it burns. The remaining wood is in the form of fixed carbon, which converts to charcoal. In an appliance such as a wood stove or boiler, the gas burns with the wood and the heat is used for space heating, and then the charcoal burns once air is available for direct combustion. During gasification, on the other hand, the producer gas is separated from the solids and is filtered for use in an engine for electrical power generation. Sometimes this technology is called “fuel-switching” because it produces a gaseous fuel from a solid one.

Figure 4: A 1941 car with a gas generator. Photo courtesy of Mattes and the Deutches Museum Verkehrszentrum.

The composition of the producer gas depends on the make-up air for the fire and on the fuel. For instance, when atmospheric gas is used, the producer gas consists of approximately 50% nitrogen. The main fuel in the producer gas is carbon monoxide, which is accompanied by methane and hydrogen. The advantage to burning this producer gas away from the original source is that it can be combusted at higher temperatures, which carries the potential for greater efficiency. The producer gas is considered a form of renewable energy and, depending on the biomass and make-up air, has about 15% of the heating value of natural gas (Alaska Energy Authority, 2009). There are four main types of gasifiers currently available:

1) Updraft: In this configuration, there is a fixed bed of biomass fuel through which air flows in a counter-clockwise configuration. This method results in a gasifier with high thermal efficiency, but typically the producer gas will have high tar content and will need to be cleaned before it can be used.
2) Downdraft: In a downdraft gasifier, the current of gas flows downward over the fixed bed of biomass. The air intake is at the top or sides of the biomass. This configuration results in lower tar levels, since the gas has to pass through the hot bed of char, where the tars are broken down or “cracked.” It also results in a gas with a much higher temperature than the updraft method.

3) Fluidized Bed: In this method, the bed consists of an inert material such as sand. It is fluidized by a stream of air, oxygen, or steam, and fuel is then fed into the system above the bed or directly into it. This method has a low operating temperature and is used mainly with fuels that form a highly corrosive ash.
4) Entrained Flow: The fuel in this method is gasified using oxygen. It requires high temperatures and pressures, which results in a high throughput and prevents the production of tar. The gas is then cooled and cleaned.

Gasifers are currently used on an industrial scale to produce electricity from fossil fuels such as coal. Many CHP units using gasification have also been installed, especially in Europe and South America, which are capable of producing several hundred kWe. In addition, very small-scale gasifier instruction "kits" are available on the Internet for homemade gasifiers. Smaller-scale gasifiers capable of providing power for a village are currently not commercially manufactured, but many companies are in the process of developing this technology.

Advantages	Disadvantages
• Gasifiers are simple and relatively inexpensive. In fact, many homemade gasifiers and experimenter's kits exist. • Gasification offers the potential for higher efficiency from burning biomass for space heating because it separates the gas from the charcoal and allows the gas to be burned at a higher temperature. • Gasifiers can be paired with existing infrastructure for heating or electricity.	• The gas quality is important. Gas that is high in tar and particulates will result in increased maintenance costs. It also affects the reliability of the system. • Currently, small-scale gasifiers with an appropriate control system for a house or village are not commercially viable.

Rankine Cycle

The Rankine cycle was invented by William Rankine in the 19th century. It converts heat energy to work or electricity and was originally used to design steam engines. Heat is applied to a closed cycle that uses water as the working fluid. In a Rankine cycle, water is heated to superheated steam in a boiler. The steam is used to turn a turbine and then releases heat while it is condensed. Electricity is produced when the turbine rotates a shaft connected to a generator. In a cogeneration system, the heat from the steam is used to heat a building instead of being rejected as waste heat. These systems may have a processor instead of a condenser to direct the heat to the location requiring space heating.

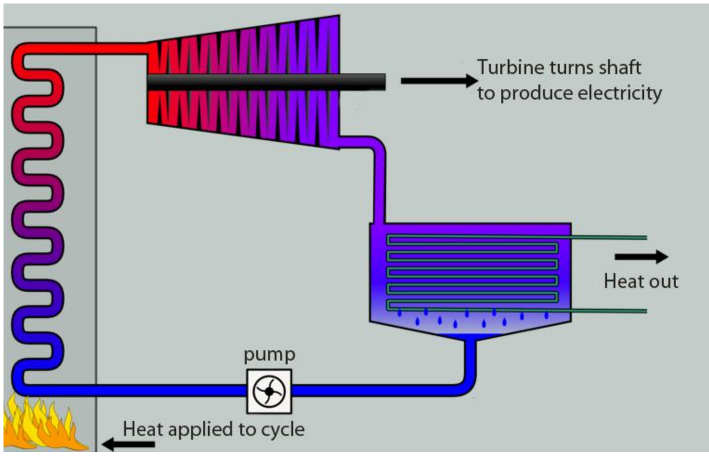

Figure 5: The closed Rankine cycle uses water as a working fluid. Diagram based on work by Andrew Ainsworth.

The Rankine cycle is used to generate more electrical power in the world than any other method (Wiser, 2000). Large-scale systems are highly regulated because of the inherent safety risks of using superheated steam to produce work. The regulation costs are mitigated by the fact that the systems produce a lot of power. A small-scale CHP unit would require a system that operated at lower temperatures so that the necessary regulations and safety risks would decrease. There are currently no small-scale systems available commercially.

Advantages	Disadvantages
• The Rankine cycle is mechanically simple and well understood, as it is used all over the world in electrical power plants. • Rankine cycles can be used with many fuel sources.	• Currently, systems that use the Rankine cycle require superheated steam as a working fluid, which mandates that facilities using Rankine cycles meet standards for safe operation. • Small-scale Rankine systems are not currently commercially available.

Organic Rankine Cycle (ORC)

The ORC is a variation of the Rankine cycle. It was developed to adapt the Rankine cycle to be used with low-temperature heat sources. The working principle of the ORC is the same as the Rankine cycle in that a working fluid goes through a closed cycle where it is vaporized, passed through a turbine to produce work, and then condensed. The turbine is used to drive a generator, which converts the work into electricity. However, instead of using water as the working fluid as the Rankine cycle does, the ORC uses an organic fluid such as a refrigerant. The advantage to using an organic fluid is that the boiling point will be lower than that of water, which allows the heat running the cycle to be of a lower temperature source. This also makes the ORC safer than the Rankine cycle because superheated steam is not used. Also, different working fluids can be used so that the boiling point is tailored to the specific application of the ORC.

Currently ORC technology is used for electricity generation from low-temperature sources, such as from geothermal heat or industrial waste heat. It is also used in some power stations to improve efficiency. A geothermal ORC power plant is currently used in Alaska at Chena Hot Springs Resort, located near Fairbanks. Some global companies that utilize ORC technology at a commercial scale include Ormat Technology (www.ormat.com), Barber Nichols (www.barber-nichols.com), United Technology Corporation (www.utc.com) and Turboden (www.turboden.edu).

Advantages	Disadvantages
• The ORC is used in industry. • The cycle is mechanically simple. • The ORC can be used with many fuel sources, including low-temperature fuel sources. The working fluid can be tailored to the heat source.	• Small-scale biomass ORC units are not currently commercially available. • ORC units do produce waste heat. When this heat cannot be used for space heating, such as in the summer, it must be discharged to an alternative heat sink.

Stirling Engine

Stirling engines were first developed by Robert Stirling in 1816 as a more efficient alternative to the steam engine. The Stirling engine is noted for its potential to be very efficient because the Stirling cycle is reversible.

A Stirling engine is another closed cycle thermal system. It differs from a Rankine cycle in that the working fluid (usually hydrogen or helium) remains in gaseous phase throughout the cycle. The cycle is used in an external combustion engine: it begins when the gas undergoes an isothermal expansion using heat from an external source. The gas transfers this heat energy to a regenerator. Then the gas is compressed, and rejects heat to an external sink. Essentially the heat is applied to

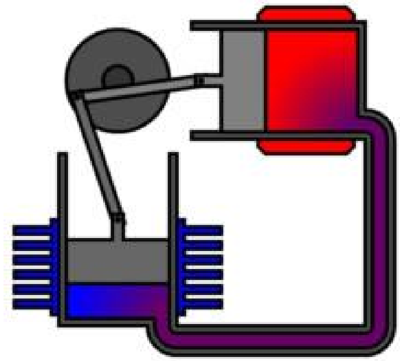

Figure 6: Expansion and contraction of the gas in this simplified Stirling Engine moves a piston. Diagram courtesy of Richard Wheeler.

one side of the engine and rejected to the other side. There is no internal burning of fuel or exhaust valves on the engine.

While Stirling engines have been in existence for almost 200 years, they are not widely used. The cycle is difficult to achieve in practice because of pressure losses in the regenerator, temperature limitations, and non-ideal efficiencies in the regenerator (Cengel & Boles, 2006). However, the engines are used in limited applications such as submarine engines, for power generation on ships, and for small power generation. Also, in recent years the engines have been in research and development for use in automobiles, CHPs, and solar power generation. There are currently companies that manufacture Stirling engines. These include Kockums (www.kockums.se), WhisperGen (www.whispergen.com), and Stirling Denmark (www.stirling.dk).

Advantages	Disadvantages
• Stirling engines can be used with many fuel sources, including low-temperature sources. Additionally, the heat source is external to the engine, so Stirling engines can be coupled to a biomass combustion unit. • A Stirling engine operates very quietly compared to other engines because there is no exhaust of the gas. • Stirling engines have the potential to be very efficient.	• Stirling engines have higher capital costs because they can be complicated to produce. • The Stirling engine is currently used only in a few commercial applications.

Project Screening Criteria

Combined heat and power systems being researched and manufactured around the world encompass a wide variety of sizes and fuels, from industrial scale heat recovery plants to household cogeneration plants that use natural gas. CCHRC's investigation focused on finding a small-scale biomass CHP that would be appropriate for providing heat and electricity in rural Alaska. CCHRC established criteria, described below, for evaluating the suitability of a small-scale biomass CHP for testing and demonstration in this project. It was not expected that a CHP would be able to meet all of the criteria; instead, researchers searched for systems that met many of the criteria or systems that showed promise for meeting the criteria in the near future.

The criteria were established in tiers to narrow the search for a CHP unit, as shown in Figure 7. Systems that met the first tier of criteria would be investigated for the potential to meet the following two tiers. While a CHP system that met all tiers of criteria would have been ideal, researchers were open to investigating the possibilities of systems that met the first tier criteria. CCHRC staff were also open to the possibility of joint research and development of a manufacturer's CHP system to make it more appropriate for the needs of rural Alaska.

Figure 7: CCHRC established 3 tiers to screen possible CHP manufacturers.

Production capacity of less than 50 kWe and 50 kWt: The CHP should be "small-scale," meaning that it would provide power and heat for a single home or cluster of homes. Ideally, such a system would produce between 5 kWe and 30 kWe and up to approximately 40 kWt (136,520 BTU/hr). For reference, the Alaska monthly household average electrical use is 641 kWh/month, or approximately 20 kWh/day (U.S. Energy Information Administration, 2010)

Use of woody biomass as the primary fuel source: CCHRC required that the source of fuel for the CHP be primarily woody biomass, although units that used cellulosic waste such as paper and cardboard as a portion of the fuel were also considered. Additionally, CCHRC considered the extent to which a unit would require a responsible party to identify, acquire, and store woody biomass in order to operate the system. Attention was also given to the amount of biomass processing required by a particular CHP unit (some require wood chips or pellets instead of cordwood) and whether the users would have access to the necessary processing equipment. CCHRC also weighed the inherent need to be able to sustainably maintain the fuel source at the required consistency over the life of the project. Woody biomass became a promising fuel source because it is a renewable resource, available in many rural locations, and can be harvested locally and sustainably. Alaska has almost 12 million acres of available forested land, with an estimated 1.9 million cords of annual growth (Alaska Energy Authority, 2009).

Easy to use and maintain: CCHRC assessed the relative effort to operate and maintain the CHP, the type and availability of parts for potential maintenance, and whether the operation and maintenance regime was likely to change over time and with use. CHP units that met these criteria would be able to be used and maintained in a rural and remote location.

Have a high duty cycle: CCHRC considered the potential duty cycle of the CHP unit. CCHRC defined duty cycle as the amount of time that a CHP is operational. Units with high duty cycles are able to produce electricity and heat a greater percentage of the time. CHPs that require frequent cleaning and maintenance are characterized as having a low duty cycle, as they must be shut down to perform required upkeep tasks. A high duty cycle indicates that the unit would be available to meet the heat and electricity needs for which it was installed and also increases the economic utility of the unit. CCHRC searched for a CHP with a duty cycle of at least 80%.

Affordable capital and operational costs: CCHRC calculated the capital and operating costs and compared them to the existing heat and electricity price profiles in rural and remote communities. CCHRC recognized that several factors would drive the actual economics of a system, so its attempt to assess economic performance was limited to determining if a system showed promise of comparable economic performance. Also, CCHRC considered whether the economics of CHP units under consideration would improve through economies of scale or technological advancement and the extent to which research and demonstration in Alaska could help compel these improvements.

Have economic development potential: CCHRC considered that the use of a CHP or several CHPs in a community could help develop the local and regional economy by redirecting money to local providers of forest industry goods and services that would otherwise leave the community in the form of diesel purchases. Also, to the extent that the CHP would reduce energy prices, users of energy would directly benefit through lower energy bills. Potential additional benefits could include reduced wildfire risk, secondary business opportunities, and a new market for lower quality logs (for a logging industry where higher quality logs are used for buildings).

State of commercialization: CCHRC considered whether the CHP unit was commercially available or whether the developer had any plans to commercialize the unit. This consideration was bound to a related consideration of whether the manufacturer of the CHP unit would be available to help resolve potential maintenance and operation issues over the life of the project.

CHP Investigation

The search for a small-scale biomass CHP conducted by CCHRC lasted nearly three years, beginning in March 2007 and continuing until the winter of 2010. During this time, researchers conducted market surveys, performed in-house searches for manufacturers, and pursued partnerships with industry experts and CHP manufacturers. The search was mainly conducted by two wood energy specialists employed by CCHRC. However, several other researchers both from CCHRC and other organizations contributed. A timeline of the search is located in Appendix A. The search consisted of the following strategies:

Project definition and scope CCHRC initially worked to identify the criteria to evaluate the suitability of small-scale biomass CHP systems for rural Alaska. The broader context of the project was to identify ways to use renewable energy to provide year-round heat and power to residences, small buildings, and small communities in Alaska so that Alaskans could reduce the high energy costs associated with living in a remote cold climate.

Background research and investigation CCHRC staff researched CHP gasification technology and companies that manufactured CHPs that might fit the criteria to be used in rural Alaska. The goal was to identify companies that had a product or concept that would be suitable for the demonstration project. Ideally, CCHRC was seeking a partnership for a demonstration and research project rather than looking to purchase a CHP. A list of companies that were located and contacted by CCHRC appears in Appendix B. These companies were identified through a review of available literature, internet searchers, word-of-mouth, and interviews with industry experts.

Request for Proposals (RFP): An RFP was issued by CCHRC in March 2007 to approximately 100 manufactures worldwide that had been identified by CCHRC during the background research and investigation. The RFP sought proposals to furnish a demonstration CHP system capable of utilizing woody biomass to generate heat and electricity at CCHRC's RTF. The preferred system would feature the following general requirements:

- Automated operation
- Electrical output of 15-30 kWe, and a minimum thermal output of 40 kWt
- Potential to utilize portions of a municipal waste stream as fuel, in addition to woody biomass
- Ability to be installed and operated in remote communities in rural Alaska on a cost-effective, low-maintenance, easy-to-operate basis

Also, the unit was to be delivered to the RTF and operated by CCHRC staff with technical support from the selected company. The intent was for CCHRC staff to develop biomass materials handling and storage solutions to facilitate the CHP's operation in Alaska. Additionally, the CHP unit would preferably be scalable from the residential size to a larger institution. Proposals that demonstrated an opportunity for research participation and partnership were encouraged.

Proposals were received for the RFP from the following companies:

- Alternative Energy Solutions, a subsidiary of Wichita Burner Inc.
- Chanderpur Works in India
- The Energy and Environmental Research Center of the University of North Dakota
- Heuristic Engineering, Inc.
- Community Power Corporation

CCHRC cancelled the RFP in December of 2007 after reviewing the proposals. The reason for the cancellation was the lack of a proposal that adhered to the desired criteria and remained within the project budget. Each proposal represented a technology or model still in some stage of pre-commercialization and at least two of the proposals were outside the specified capacity. Additionally, costs after shipping and installation were on the order of $500,000 for three of the proposed systems, and over $1 million for the remaining two.

Independent contractor CCHRC hired an independent contractor, T.R. Miles Technical Consultants, Inc (www.trmiles.com). T.R. Miles is a firm with experience in international biomass projects. Additionally, the firm is familiar with the technology currently in the market and hosts a number of biomass discussion websites. Hiring the contractor allowed CCHRC to access both American and overseas markets in the search for a CHP demonstration project partner.

Figure 8: Crorey gasifier in development during spring 2009.

In May 2008, CCHRC entered a project to test and demonstrate a CHP system manufactured by a company identified by the independent contractor. The CHP was a 25 kWe gasifier manufactured by Crorey Mechanical in Oregon. It was to include the following major components:

- Run on wood chips or pellets
- Be housed in a used shipping container
- Have a gasification reaction module that would operate at 100% duty cycle
- Have a conditioning tank, gas pump, pressure tank, and ash removal system
- Have controls that were mounted and pre-wired

It would cost up to $71,000, or approximately $2,800 per kWe. Crorey had previously field-tested units using wood pellets and coffee waste as fuel but its products had not been commercially installed. If the gasifier were operated successfully during a testing period, CCHRC had plans to develop a feedstock conveying and drying system appropriate for the Alaskan environment to facilitate placing a unit in a remote location. The CHP originally was to be delivered to Fairbanks and installed at CCHRC in October 2008. However, the manufacturer fell behind schedule as the gasification system experienced tar and gas quality issues. In April 2009, a CCHRC researcher visited the manufacturing site to evaluate the progress of the CHP construction. After this visit, CCHRC concluded that the CHP unit was still in the development phase and terminated the contract.

Expansion of search to include small-scale biomass CHPs of all technology platforms CCHRC expanded the search for a CHP to include technology platforms other than gasification. Stirling engines, Rankine engines, and ORC technologies were investigated. Another background research and investigation phase led CCHRC to hire a liaison to the European market to determine if technology was available overseas that could be brought to the United States. Many companies were identified that were looking for investors to fund a prototype of their product idea. However, this type of development was out-of-scope of the project budget. The search finally resulted in two companies that were identified as having pre-commercial CHP units that could be demonstrated at CCHRC. One of them featured a Stirling engine from a Danish company that originally was designed for solar energy; the other company had a Canadian partner and offered a Rankine cycle engine operated from a wood chip or pellet stove. Ultimately, both options were ruled out because of high costs and an uncertain commercial outlook for the products.

Conclusion

Despite a rigorous, 3-year search that used several different techniques, including contacts with over 100 manufacturers and conversations with industry experts world-wide, CCHRC was unable to find a small-scale biomass CHP system that sufficiently met its established search criteria. The following describes CCHRC's conclusions based on the results from the investigation:

At the time of CCHRC's investigation there was not a commercially available small-scale biomass CHP system that met CCHRC's criteria of scale, fuel type, ease of use, duty cycle, and affordability.

The lack of a market appears to be the largest challenge to the commercialization of a small-scale biomass CHP unit. Many companies exist with prototype designs for small-scale biomass CHPs. However, world-wide demand for small-scale biomass CHP units is limited to areas with the right combination of abundance of biomass, high costs for space heating and electricity, and the capacity to perform the harvesting, processing, operations, and maintenance needs of the CHP unit. The size and disparate nature of the market seems to make achieving a critical mass in the market difficult, thereby stalling further commercialization or the benefits of economy of scale. Although certain market forces may change, it is unclear if the market environment will transform to such an extent that a small-scale biomass CHP unit will become commercially available.

Scale and fuel type drive the challenges associated with meeting the criteria of ease of use, duty cycle, and affordability of small-scale biomass CHP units. Biomass fuel systems require fuel handling systems, longer maintenance cycles, and more complicated emission control strategies than CHP systems fueled by propane or natural gas. Additionally, unprocessed biomass fuel is not industry-regulated to a common standard, such as how diesel is regulated for consistency, so systems must account for some variation in the fuel input. At larger scales and in locations with an abundance of waste biomass, the cost of developing systems to accommodate biomass fuel can be recovered in a reasonable period of time, even with the time and monetary demands of continuous maintenance and cleaning of the system. For small-scale biomass CHP systems, technological challenges and high costs persist. These challenges may be overcome in the future, but there is currently no market force driving continuous research and development.

- In the case of gasification, the complexity of producing a consistent quality and flow of producer gas to drive the generation of electricity over long periods of time is a key challenge. Robust control systems for gasification units are still in the developmental stage. Additionally, gasification systems can be prone to tar issues that result in high emissions and high maintenance requirements.
- In the case of Rankine and ORC, the technology works at larger scales. It has also been proven at small scales using propane and natural gas fuels. However, versions that met CCHRC's scale and fuel criteria are not yet commercially available.
- In the case of Stirling Engines, the technology platform is used in small markets with non-biomass fuel types (such as in submarine engines and for power generation on yachts). Biomass systems currently feature high capital cost and are in the pre-commercial stage.

CCHRC was uncertain that its involvement in a pre-commercial demonstration project would lead to innovations that advanced commercialization. A demonstration project would help to identify technical and maintenance issues of the specific CHP unit, identify appropriate fuel-handling strategies and increase awareness of the viability of using small-scale biomass CHP in Alaska. However, accomplishing these ends does not inherently solve technical issues with a given technology. Further, CCHRC did not identify a path to work with CHP companies to resolve the known technical issues or those that would be discovered through demonstration. Regardless of whether or not technical issues were an impediment to advancing a technology to commercial status, the larger barrier to commercialization appears to be the small size of potential markets and the associated economics.

Due to the developmental stage of small-scale biomass CHP technology, parties interested in investing in such a CHP system should exercise due diligence when searching for a manufacturer as emerging technologies inherently carry more risk than established ones. Establishing and following clear objectives and a corresponding screening criteria will help filter the many CHP research and manufacturing companies to find one that will meet the objectives of the user. It is recommended to contact past customers or investigate demonstration projects to ensure that technological and maintenance challenges specific to the CHP unit of interest have been overcome. If interested parties are flexible in their search criteria, for example, if they are willing to consider a larger-scale system or a more conventional fuel source, it will increase the probability of a successful search. Alternatively, if the interested parties have technical expertise and are capable and willing to operate, maintain, and develop a pre-commercial unit, they may be able to find one that meets the needs of their operation.

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Appendix A: Project Timeline

CCHRC's investigation into small-scale biomass CHP technology spanned 3 years, beginning in 2007 and continuing through 2010. The phases and tasks of the project appear below.

February 2007	Beginning phases of CHP research: Background research and investigation. This first phase focused mostly on a search for a CHP using gasifier technology.
March 2007	Request for Proposals issued by CCHRC for a small-scale biomass gasification CHP.
December 2007	RFP cancelled by CCHRC because of the lack of viable proposals among the responses. At this time an independent contractor (T.R. Miles Technical Consultants, Inc.) was retained to search for a company to partner with to test a CHP.
May 2008	Contract with Crorey signed to manufacture a CHP unit viable for testing at the CCHRC facility in Fairbanks.
April 2009	Visit to Crorey by CCHRC wood specialist to check on progress. After this visit the contract with Crorey was terminated as it was determined that the CHP unit was still in its developmental phase.
Fall 2009 through Winter 2010	Continued search for a CHP to test or for a partner company to design a CHP that fit the project criteria. This search included all CHP technologies and also utilized a foreign consultant to identify potential companies located overseas.

Appendix B: Companies Contacted during CHP Investigation

The following companies were contacted during the CHP investigation. CCHRC sought to identify which companies manufactured CHPs that were within the parameters of the project. Companies were identified by literature reviews, internet searches, interviews, and by consultants with expertise in the biomass heating industry.

Company	Location
A.H.T. Pyrogas	Germany
Adoratec	Germany
Advanced Biorefinery Inc.	Canada
Alternative Energy Solutions	Kansas, USA
Aruna Electrical Works Ltd.	India
Associated Physics of America	Mississippi, USA
B9 Organic Energy Ltd.	Massachusetts, USA
Babcock and Wilcox Volund	Denmark
Battelle Columbus Laboratories, BCL	Ohio, USA
Bioenergy Technology Ltd.	United Kingdom
Bioflame Ltd.	United Kingdom
Biomass Combustion Systems, Inc.	Massachusetts, USA
Biomass Engineering Limited	United Kingdom
Biosphere Environmental Energy	California, USA
BioSynergi Process ApS	Denmark
BOREAS Energie	Germany
Brightstar Synfuels Co.	Louisiana, USA
Capstone Turbine Corporation	California, USA
Carbo Consult & Engineering (Pty) Ltd.	South Africa
Carbon Sequestration, LLC	California, USA
Chanderpur Works	India
Chiptec	Vermont, USA
Climate Energy LLC	Massachusetts, USA
Cogenco Ltd.	United Kingdom
Combustion Consultants Ltd.	New Zealand
Compact Power	United Kingdom
Condens Oy	Finland
Costich Company	Washington, USA
Community Power Corporation	Colorado, USA
Cratech	Texas, USA
Dectra Corporation	Minnesota, USA
DESI Power	India
Dynamotive USA, Inc.	Virginia, USA
EC Power UK Ltd.	United Kingdom
ECN – Energy Research Center	The Netherlands
Emery Energy Company	Utah, USA
ENER-G Combined Power Ltd.	United Kingdom
Energreen Power, Ltd.	India
Energy and Environmental Research Center, UND	North Dakota, USA
Energy Products of Idaho	Idaho, USA
Ensyn Technologies Inc.	Canada

Entimos Ltd.	Finland
Enviro-Access, Inc.	Canada
Enviropower CHP Ltd.	United Kingdom
Exus Energy Ltd.	United Kingdom
FERCO/SilvaGas	Georgia, USA
Fern Engineering, Inc.	Massachusetts, USA
Flexenergy	California, USA
Foster Wheeler Energia Oy	Finland
Gas Technology Institute	Illinois, USA
Heuristic Engineering, Inc.	Canada
HRL Limited	Australia
Hurst Boiler and Welding Co.	Georgia, USA
Infinia Corporation	Washington, USA
Ingersoll Rand Engineering and Technology Development	New Hampshire, USA
Innovation Technologies, Ltd.	Ireland
Julio Berkes SA	Uruguay
Kara Energy Systems B.V.	The Netherlands
Klean Industries Inc.	Canada
Kohlbach	Austria
KWB	Austria
LIN-KA Maskinfabrik A/S	Denmark
Marathon Engine Systems	Wisconsin, USA
MARCEGAGLIA USA	Pennsylvania, USA
Martezo	France
Mawera Canada, Ltd.	Canada
Messersmith Manufacturing, Inc.	Michigan, USA
METSO Corporation	Finland
Nexterra Energy Corp.	Canada
Ngen LLC	Colorado, USA
Peter Brotherhood Ltd.	United Kingdom
Phoenix Energy	California, USA
Power Reclamation, Inc.	Arkansas, USA
Primenergy, LLC	Oklahoma, USA
PRM Energy Systems, Inc.	Arkansas, USA
Puhdas Energia Oy	Finland
Pyroforce Energy Technology	Switzerland
Radhe – Renewable Energy	India
Renewable Oil International LLC	Alabama, USA
Repotec	Germany
MESH-RES/OP Technologies Inc.	Canada
Rural Generation Ltd.	United Kingdom
Spilling Energie Systeme	Germany
Stirling Denmark ApS	Denmark
Stirling Energy Systems, Inc.	Arizona, USA
SUNPOWER, INC.	Ohio, USA
SunTechnics Energy Systems Pvt. Ltd.	India

T.R. Miles Technical Consultants, Inc.	Oregon, USA
Talbott's Ltd.	United Kingdom
Taylor Biomass Energy, LLC	New York, USA
Tecogen	Massachusetts, USA
Thermochem Inc.	Maryland, USA
Thermogenics, Inc.	New Mexico, USA
THERMOSELECT, SA	Switzerland
TPS Termiska Processer AB	Sweden
Turboden	Italy
Umwelt-und Energietechnik	Germany
UTC Power	Connecticut, USA
Vidir Biomass Inc.	Canada
Waste to Energy Ltd.	United Kingdom
Wellman Robey, Ltd.	United Kingdom
WhisperGen DC	New Zealand
XYLOWATT (Menag Group)	Belgium