Support for Developing a Sustainable Fire Load Reduction Program by Creating and Expanding Wood-Energy Enterprises

RR 2008-01: Final Report for FNSB Grant UDAFF5 on Wood Energy

Dave Misiuk, P.E.
CCHRC Wood Energy Specialist

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Submitted to:
Fairbanks North Star Borough
809 Pioneer Road
Fairbanks AK 99701

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Abstract

The Cold Climate Housing Research Center (CCHRC) has researched the topic of residential scale wood energy including fuel sources, available technology and its proper use, regulations, particulate emissions, efficiency and economics. A description of the projects, a technology review and results of CCHRC lab tests of wood-fired devices are described in this report.

Figures and Tables

Figures

Tables

Research Objectives

The following is a summary of the objectives of this project:

1. Assess the feasibility of using woody-biomass harvested from wildland fire mitigation efforts such as fire breaks;
2. Assess the available technology for using this woody-biomass and other locally available wood species, and
3. Perform emissions testing of the woody-biomass and locally available wood species in the following heating devices:
    a. pellet stove,
    b. wood stove,
    c. masonry heater, and
    d. combined heat and power (CHP) unit.

Additional related wood-energy projects were not specifically identified in the original grant proposal but were subsequently added as the program progressed. These related projects were added based on their merit, public benefit and the demonstrated need for additional research. They include:

1. public education on available wood-fired heating technology and how to operate them cleanly and efficiently,
2. wood-fired hydronic heater research, and
3. masonry heater retrofit research.

These additional projects and the results are also described in this report.

Woody Biomass Harvested from Wildland Fire Mitigation Efforts

Wildland fires present a risk to life and property within the Fairbanks North Star Borough (FNSB) and are a perennial concern during the summer fire season due to vast forest acreage, frequent interface between forested and populated areas, prevailing climatic conditions, and the existence of large continuous stands of black spruce.

Black spruce is a particular concern due to its combustibility, growth pattern in continuous stands, and existence on hillsides and valleys near populated areas.
The 2004 fire season brought into sharp focus the risk wildland fires present in the FNSB as prevailing winds drove the Boundary Fire toward densely populated areas of the borough. The Boundary Fire was in large part fueled by continuous black spruce stands near town.

In 2006, in an effort to mitigate risk due to wildfires, the FNSB and the State of Alaska Division of Forestry developed the *Community Wildfire Protection Plan* (CWPP), which outlined a mitigation strategy including creating breaks in continuous black spruce stands and mapping the FNSB to identify zones of concern to better prevent and respond to wildland fires.

Phase I of the CWPP resulted in the removal of approximately 1,300 acres of black spruce in strategic areas throughout the FNSB. The method for creating the fire breaks was to shear, windrow, and burn the felled black spruce. This activity raises the question of whether the wood from the fire break could be used in local markets such as residential space heating or feedstock in a pellet plant.

The Cold Climate Housing Research Center (CCHRC) explored this question by examining the key considerations of harvesting, processing, and transporting wood from fire breaks.

Harvesting Black Spruce from Fire Breaks

The 1,300 acres of fire break that was created by Phase I of the CWPP can be categorized as continuous black spruce, as is likely to be the case at additional fire break sites. Therefore CCHRC focused its review of harvesting issues to those associated with black spruce.

Staff at CCHRC had several conversations with staff at the Alaska Division of Forestry relating to different methods of treating designated fire break acreage, including treatment methods that involved the harvest and removal of in situ black spruce.

Key Conclusions

- At the time of the original contract to establish the fire breaks, the shear blade, windrow, and burn method was determined to be the least expensive, and therefore enabled the maximum amount of fire break acreage. The report *An Evaluation of Fuel Conversion Treatments in Interior Alaska* (Barton St. Clair, 2006) evaluated methods of treating several forest test plots using a shear blade, masticating head, drum chopper, and chainsaw thinning. The report further evaluated treating the resulting wood by either burning or chunking and removing. The report supports the conclusion that shear-blading, windrowing, and burning is a cost effective method of establishing fire breaks.

- A review of the available wood harvesting equipment indicates that there are technical concerns regarding the ability of existing off-the-shelf equipment to harvest black spruce in Fairbanks due mainly to the small pole diameter and abundance of branches and needles. Much of the mechanical wood harvesting equipment on the market is designed for larger-diameter poles or denser growth.

- Overcoming the technical challenges of harvesting black spruce can create economic challenges. It may be possible to modify equipment, lengthen the operating time to take care of equipment malfunctions, or incorporate greater amounts of manual labor. Each of these techniques will add cost to the harvesting process.

- Fire break creation is infrequent and therefore it is difficult to amortize equipment specialized for handling small-diameter black spruce.

- It is plausible to open the acreage to clearing by a private entity that has a use for the in situ wood, and thereby transfer the risk and reward consideration while still benefiting from the result of the fire break.

In addition to discussions with the Division of Forestry, CCHRC staff conducted a cursory exploration of methods of harvesting black spruce including a review of available technology, consideration of technology modifications, and a site visit to a fire break site to examine the characteristics of the felled black spruce and fire break area.

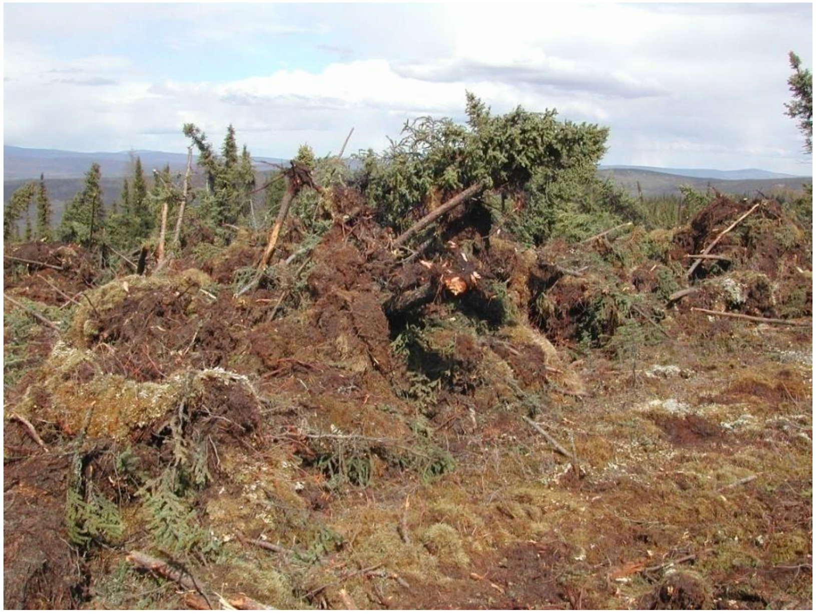

Figure 1. Felled Black Spruce, windrowed and ready for burning.

Processing Black Spruce from a Fire Break

The key considerations of processing black spruce in part relate to the issues of harvesting because to the extent practical, it is desirable to harvest in a way that enables efficient transfer to the processing step. Black spruce can be processed into cordwood, wood chips or chunks, or wood pellet feedstock.

Black spruce is usable in cordwood form, and it is best to trim the branches and needles. The small pole diameter of black spruce makes it difficult to process mechanically.

Processing black spruce into wood chips requires consideration of two key factors: black spruce pole size can be too small for feed systems to operate properly, and the branches and needles are often undesirable in the final processed product. Black spruce is usable as a feedstock in wood pellets.

Transporting Black Spruce from the Fire Break Site

The key considerations of transporting black spruce from fire breaks are: the condition of the access to the fire break site; the distance to the delivery point; the volume per vehicle trip; and the cost of fuel. Many of the fire break sites in the FNSB are reasonably accessible and range in distance from central Fairbanks up to 20 miles. Depending on the intended use of the wood, material can be chipped on site to increase the volume per vehicle trip, assuming appropriate technology can be identified.

Key Conclusions

- Black spruce can be used in cordwood, chip, or as feedstock for wood pellets.
- Based on a cursory review of available equipment it is either difficult or costly to *harvest* black spruce.
- Based on a cursory review of available equipment it is either difficult or costly to *process* black spruce.
- Equipment specialized for handling black spruce can be difficult to amortize given the infrequent need to create fire breaks.
- Repopulation of fire breaks with species other than black spruce can improve technological and economic feasibility.

Combined Heat and Power from Woody Biomass

Biomass-fueled combined heat and power (CHP) units use biomass to provide heat and shaft power. The usual configuration uses the shaft power to produce electricity through a shaft-driven generator. At the time the original grant proposal was prepared by CCHRC, it was known that some small, residential-scale CHP units existed; further research revealed that most of these systems are still in development and generally exist only in a pre-market prototype phase. It was also revealed that units are available for pre-market testing and demonstration of this new technology but they are larger than the residential scale sought and prohibitively costly usually in the range of $10,000 per kWe (kilowatt-electric) or more.

CCHRC attempted to identify appropriate units and manufacturers by issuing an RFP for the supply of a CHP unit to be installed at its Research and Testing Facility in Fairbanks. The RFP was solicited to more than 80 potential manufacturers located all over the world. Approximately 10% of manufacturers responded with a proposal and a price for supply of a unit. All of the proposals were for larger units than anticipated and the prices ranged from $350,000 to over $13 million.

A new CHP manufacturer was identified who could provide a unit for approximately $2,800 per kWe in March 2008 and CCHRC successfully negotiated a performance-based mutually-beneficial contract for supply of a 25 kWe unit. As of April 2009 during a site visit, the unit remained in development phase at the manufacturer’s facility in Portland, OR. The period established and agreed to for testing and demonstration expired in June 2009. If the manufacturer is able to complete and successfully demonstrate the unit at their facility in the immediate future, CCHRC will pursue negotiation of a new contract for supply of the unit to be tested and demonstrated in Fairbanks.

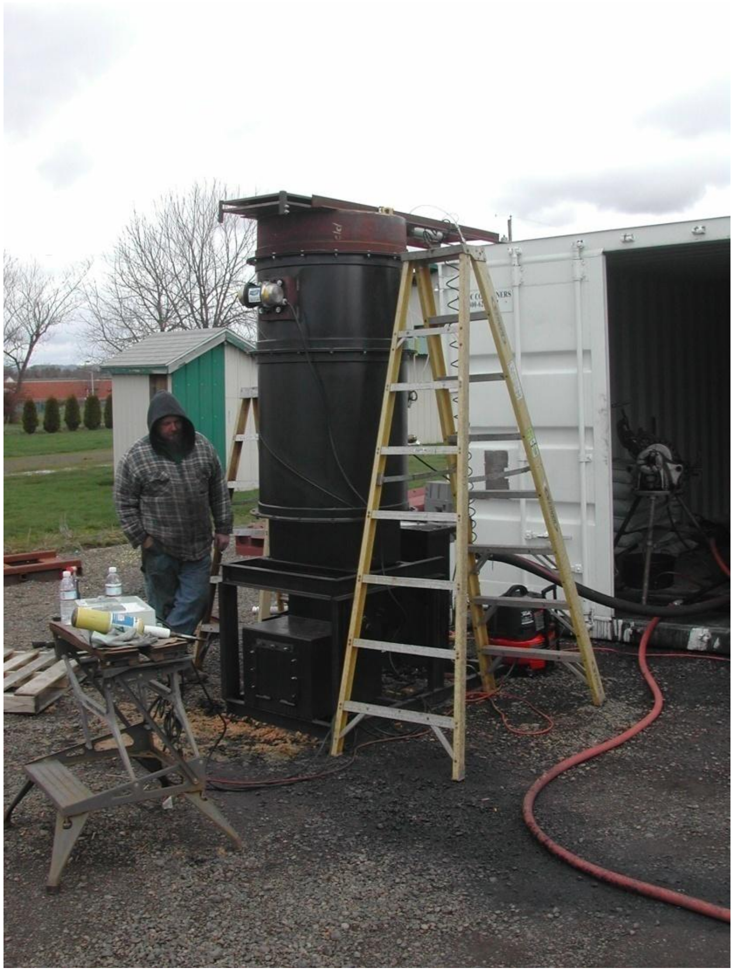

Figure 2. Wood gasifier testing in Portland, OR.

Public Education

The United States Environmental Protection Agency (EPA) suggests that residential emissions from wood burning could be curbed up to 10% by public education on proper wood burning practices. This suggestion—and the overwhelming interest and questions about wood-fired heating options—led to the creation of a one-hour class titled "Residential Heating Technology—Burning Cleanly and Efficiently" which was offered to local residents for free during the course of the 2008-2009 fall and winter heating season. The class was presented by the author at the AHFC/FNSB PORTAL in downtown Fairbanks.

Similar, more formal, presentations were given in many other forums including the Alaska Wood Energy Conference, Alaska Center for Energy and Power's (ACEP) Energy Lecture Series, UAF Museum of the North, UAF Life-long Learning Program, and the Delta Symposium on Biomass, all during 2008 and 2009.

As fuel prices rise, more people are turning to wood heat to save on heating costs, which also creates a demand for this educational component. The lack of comprehensive wood-burning technology, regulatory issues, and tax credit information also has residents seeking sound advice before making major purchases. Additionally, any change or implementation of new regulations related to wood heat would also create a need for expanded public education. CCHRC remains interested in seeking further funding to expand the current education program to suit the needs of the FNSB and local residents.

Wood-Fired Hydronic Heater Research

Due to the increasing popularity of indoor and outdoor wood boilers, "wood-fired hydronic heaters," CCHRC has procured two of these residential-sized units, both readily available from local suppliers. It's our intent to perform emissions and efficiency testing for these units, as delivered, with our local wood species and common operating practices.

CCHRC has designed and constructed a 1,400 gallon thermal storage water tank in the Research and Testing Facility to facilitate boiler testing. The thermal storage tank has been designed to be able to be built by local residents with locally available construction materials for a reasonable cost; construction plans will be made available for those who wish to pursue this project.

Use of a thermal storage tank in conjunction with a wood-fired hydronic heater has the likely potential to reduce emissions and increase efficiency of these units by allowing the boilers to be operated at a high-temperature and high burn-rate while in use.

Most of these boilers are typically installed to run "on demand" with the boiler "dampering" down to a smoldering condition when the heat demand of the house has been temporarily satisfied. CCHRC research would quantify actual emissions; efficiency of these units as operated in normal practice; and quantify the benefits of installing and operating them with proper thermal storage.

The installation of this testing platform is currently ongoing. CCHRC seeks additional funding to complete the installation, the testing and present the results.

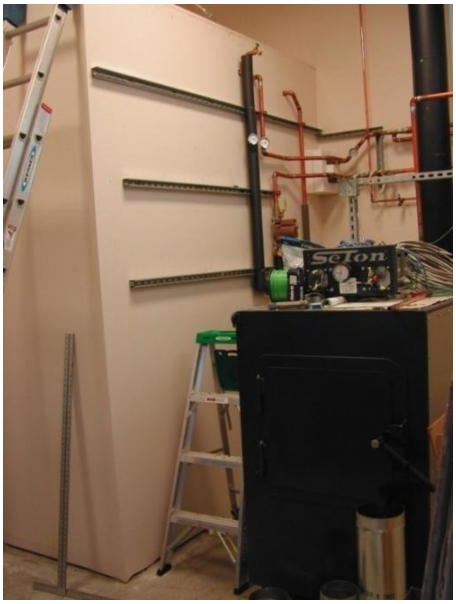

Figure 3.CCHRC wood-fired hydronic heater with 1,400 gallon thermal storage tank.

Masonry Heater Retrofit Research

CCHRC was approached by a Fairbanks family with questions about what could be done to improve the heating performance and efficiency of their existing traditional masonry fireplace in a home constructed in the 1950s. The inclusion of a traditional fireplace in homes was common for homes built during this period. The homeowners are retired and wanted to save money on heating oil. They agreed to allow us to convert their fireplace to a masonry heater to assess the feasibility and determine emissions and efficiency performance.

The project was successfully completed in December 2008. Emissions and efficiency testing was conducted on site and the results are reported in a subsequent section of this report. The homeowners have historically kept detailed records including oil consumption and heating costs. They have reported a savings of approximately 25% in fuel costs during a period that included an unseasonably cold portion of early winter 2009.

Construction plans for this retrofit will be made available to other homeowners wishing to pursue a similar retrofit to a high-performance masonry heater.

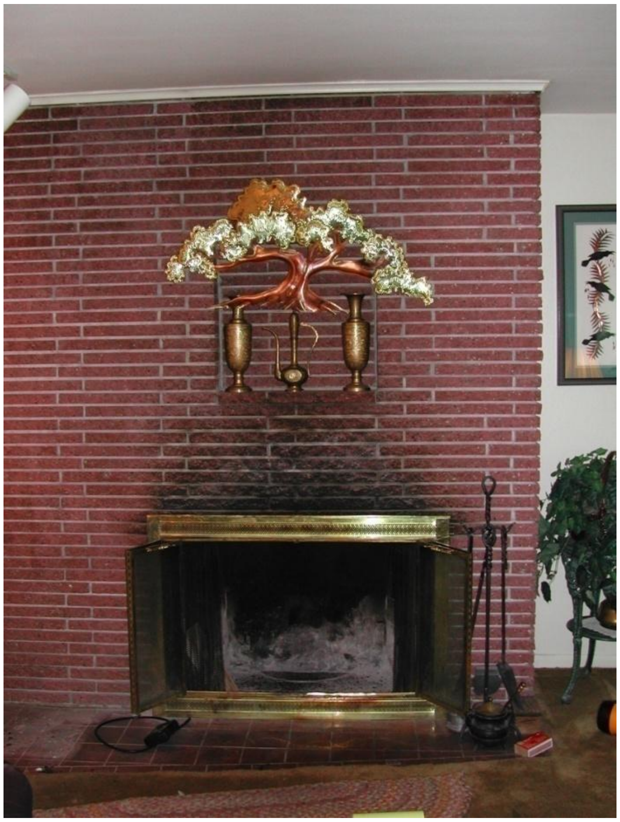

Figure 4. *Masonry heater retrofit:* before.

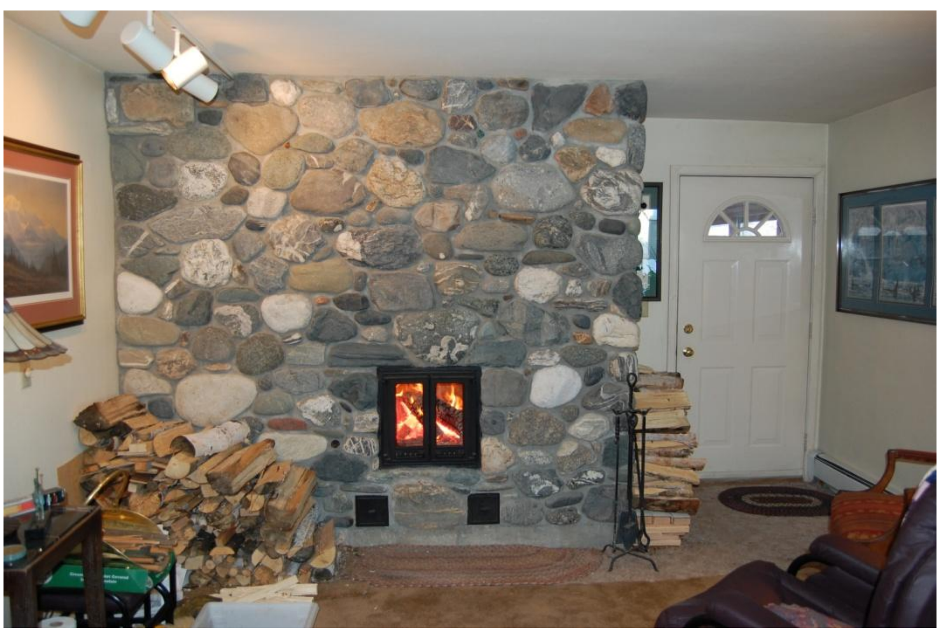

Figure 5. *Masonry heater retrofit:* after.

Current Wood-Fired Heating Technology

Wood Stoves

The EPA maintains a published list of more than 800 wood stoves currently certified by its federal certification program. This certification limits wood stove particulate emissions to 7.5 grams per hour. The technology of these wood stoves has evolved to a high level over the last approximately 20 years and currently includes stove models with either secondary burn technology or catalysts to improve combustion efficiency and reduce emissions. Although popular in the past, fewer catalytic wood stoves are now being manufactured. The most common explanation is that units with secondary burn technology approach the same low emission levels; and that catalysts have a limited lifespan and can cost $150 to $300 to replace. Because there catalysts do not always get replaced by homeowners when they should, the EPA certification program has set the emissions limit for these stoves at 4.1 grams per hour.

Wood stoves are the most reasonably priced wood-burning device and can be economical to operate.

Pellet and Grain Stoves

Pellet and grain stoves are currently exempt from EPA certification however, many manufacturers choose to have their products tested and certified under the EPA Wood Stoves Certification Program. This allows their products to be sold in regulated state or municipal markets that require a wood-burning device to be certified. Pellet stoves generally have the lowest emissions of all devices, usually in the 0.9 to 3 grams per hour range. By using a compressed, energy-dense wood pellet, the combustion is nearly steady-state, hence the low emissions.

Pellet stoves can be slightly more expensive than wood stoves to purchase but have the added benefit of operating unattended and automatically. The cost to operate is generally higher than wood stoves because pellets must be purchased. Pellet production and transportation costs factor heavily and it is predicted that the price of pellets will follow increases in home heating oil.

Masonry Heaters

Masonry heaters are a form of high-mass fireplace that have low emissions and high efficiency. They are batch-fired space heating devices and typically only operate for a few hours per day. Masonry heaters are exempt from EPA certification requirements. The emissions rate can be on par with that of pellet stoves. Masonry heaters are site-built or site-assembled with masonry materials, have efficient firebox design, and include very long flue passages to transfer heat energy to the large thermal mass, resulting in low stack temperatures. The stored heat from the short firing period can radiate to the home for up to 24 hours or longer, depending on the home heat demand.

The specialized materials and labor to construct masonry heaters make them fairly expensive to purchase but resultant fuel cost savings from their high efficiency make them an option that is increasing in popularity. Masonry heaters have a useful lifespan that matches the house and the payback can be fairly short.

Hydronic Heaters

Wood-fired hydronic heaters are units that are intended for installation outdoors or indoors. Hydronic heaters are not federally regulated but the EPA has formed a voluntary qualification program to encourage manufacturers to produce cleaner burning units. The EPA maintains the, "List of Cleaner Burning Hydronic Heaters" on their website. The heaters that qualify for the highest "Phase 2" level are required to meet a maximum emission limit of 0.32 lbs per 1M Btu. Comparing this to wood stove limits; it converts to 14.54 grams per 100,000 Btu of heat output. Emissions results for CCHRC emissions testing are presented in the same grams per 100,000 Btu of heat output format below for comparison. The hydronic heaters on the EPA Phase 2 list are in the same emissions range as other heating devices tested by CCHRC.

The initial price of hydronic heaters can be very expensive when including both the purchase price of the unit and complex plumbing installation. The overall cost may be comparable to the construction of a masonry heater however, when using a hydronic system, heat can more easily be sent to remote parts of a home. Operational costs of EPA-qualified units should be reasonable and comparable to other high efficiency devices. Operation costs of older "legacy" designs which are not qualified can be very high with excessively large wood usage and high emissions.

Pellet and grain boilers are also available adding convenience to their use; automatic fuel feeding systems make them almost as convenient as oil-fired boilers.

Key Conclusions

- Clean wood-burning technology currently exists and will continue to improve.
- Many device options currently available to consumers allowing purchasing decisions to be based on capital expense, operational costs, lifestyle and they way they plan to burn wood.

Emissions Testing of Black Spruce and Other Interior Alaska Firewood Species

Overview

CCHRC tested a locally available EPA Phase 2 wood stove to determine actual emissions and efficiency performance using black spruce and other local firewood species with a moisture content that is typically encountered in our environment. These tests offer two sets of results to consider: the emission and efficiency results of the local species can be compared and their average can also be compared to the certified emissions level published by the EPA for this particular stove model.

Methodology Summary

A Condar Emissions Sampler was used to collect particulate samples. The Condar was chosen because it is portable and can be used to test wood stoves or other devices in situ at a home or other site. The results using this sampler correlate very closely with results produced in a certified EPA test lab using EPA Method 5, Determination of Particulate Matter Emissions from Stationary Sources.

The Condar sampler shows closer correlation than some proprietary portable samplers which are EPA-approved. The Condar sampler was used in Oregon's Method 41 (OM-41), the first emissions testing program created in the US, and is the one on which the current EPA program is based.

Flue gas data was collected using a Testo 330 portable gas analyzer. The particulate catches on the glass-fiber filters and flue gas data were used to calculate emissions results in accordance with "Determination of Condensable Particulate Wood Stove Emission Factors Using Condar's Emission Sampler" (Barnett, 1983). Efficiency results were calculated from the standard American Society of Mechanical Engineers (ASME) stack loss method. The details of the formulas and calculations are beyond the scope of this report.

The unit tested was an England's Stove Works NC-13 non-catalytic woodstove. The fire was kindled from below with white birch kindling. The fuel charge was then added, firebox door shut, air supply adjusted accordingly and the test sampling started. All tests were performed in the same manner using the same testing technician. The test was ended at 95% of the oxygen depletion recovery, as it is considered a standard point at which the fire is considered "out" in other testing standards. Remaining coals and ash were recovered and weighed.

Each firewood species was tested while operating the stove set with the air-supply damper in the full-open position to produce the highest burn-rate and the maximum amount of heat possible. A minimum of three test runs were performed for each species and the result of the individual runs averaged. These results were then averaged to give an average efficiency, emissions factor and emissions rate that includes all interior Alaska wood species.

The wood stove was then operated with a single species, white spruce, with the stove's air-supply damper set to the lowest setting to achieve the lowest burn rate and simulate "banking" the stove for the night, as is common practice. This is considered to produce the highest emissions factor. Efficiency data was calculated from the fuel's actual calorific value produced by testing; this information is included in Appendix 1.

Results were calculated from data and individual test runs presented in the format shown in Figure 6.

CCHRC Emissions Data Form

General Info

Run Number	WS1
Date	2/17/2009
Location	CCHRC Lab
Model	13-NC
Manufacturer	England's Stove Works
Device Type	EPA-certified Phase II Wood stove
Configuration	Air damper set to highest burn-rate, cold start

Fuel Info

Cordwood/cribwood	Cordwood
Kindling Species	Alaska White Birch
Firewood Species	Alaska White Spruce w/bark
Comments	Test simulates normal burn

Heat Content (Btu/kg)	17,559	Kindling Weight (kg)	0.85
Average MC (dry basis)	7.3	Fuel Weight (kg)	4.83
Number of pieces	8	Total Weight (kg)	5.68
Weight of unburned fuel (kg)	0.07	Start Time (hr:min)	14:41
Length of burn (hr)	1.48	Stop Time (hr:min)	16:10

Particulate Filter Data

Filter Number	Clean Filter Wt	Dirty Filter Wt	Wt of Particulates
1	0.9914	1.0631	0.0717
2	0.9965	1.0028	0.0063
3			0.0000
4			0.0000
5			0.0000
6			0.0000
		Total:	0.0780

Gas Analysis Data

Average Ambient Temp (deg F)	70.5
Average Stack Temp (deg F)	392.2
O2 (%)	10.9
CO (ppm)	2511
CO2 (%)	9.66

Efficiency Results

Combustion Eff (%)	96.1
Heat Transfer Eff (%)	76.1
Overall Eff (%)	73.1

Emissions Results

Stack Temp Factor	0.79	Dry Gas Loss (%)	11.73
Stack Dilution Factor	2.09	CO Emissions (g/kg)	31.12
Burn Rate (kg/hr)	3.78	Emissions Factor (g/kg)	1.06
Boiling of H2O Loss	12.20	Emissions Rate (g/hr)	4.01
CO Loss (%)	3.53	Emissions per 100,000 Btu Output (g)	8.27
HC Loss (%)	0.41		

Data Input | Calculated Results

Figure 6. CCHRC Emissions Data Form

Results

The results of the firewood species comparison and average for all species are shown in Table 1. The average emissions and emissions rates are within a fairly small range for the different species, however the average emissions per 100,000 Btu ranges from 6.4 grams for white spruce to 10.3 grams for white birch, with black spruce falling at a median value of 7.9 grams. Total emissions for a 24 hour operation were calculated assuming that the stove was fired continuously at the corresponding burn rate.

Table 2 shows the EPA-certified emissions rate as 2.6 grams per hour for this stove, which can be directly compared with the average of 2.3 grams per hour for the Alaska species, as tested. The EPA-reported value is calculated by averaging test runs with dimensional lumber cribs from different burn rates. It was expected that the as-tested, high burn-rate result would have been lower but it is fairly close to the EPA rating even when the stove is assumed to be operating its potential cleanest.

Table 3 shows emissions results for the low burn-rate test. The average emissions are shown to be 14 times higher than the low burn-rate tests; the average emissions-per-100,000 Btu are 15 times higher; and the average emissions rate is six times higher. This suggests that the published EPA-certified emissions rate may underestimate emissions from these stoves in actual use with local firewood species.

13-NC Wood stove Highest Burn-rate, as Tested						
Fuel	**Average Efficiency (%)**	**Average Emissions (g/kg)**	**Average Emissions per 100,000 Btu (g)**	**Average Emissions Rate (g/hr)**	**Average Burn Rate (kg/hr)**	**Total Emissions for 24 hr operation (g)**
White Spruce	69.4	0.8	6.4	2.2	2.7	62.0
Black Spruce	68.6	1.0	7.9	2.1	2.0	49.7
Aspen	64.9	0.9	8.5	2.0	2.3	49.1
White Birch	67.6	1.2	10.3	2.7	2.3	65.4
Average	67.6	1.0	8.3	2.3	2.3	56.6

Table 1. Wood stove Highest Burn-rate, as Tested

13-NC Wood stove EPA-Published Certified Emission Rate						
Fuel	Assigned Efficiency (%)	Emissions (g/kg)	Emissions per 100,000 Btu (g)	Reported Emissions Rate (g/hr)	Average Burn Rate (kg/hr)	Total Emissions for 24 hr operation (g)
Doug Fir Cribs	63.0	Unknown	Unknown	2.6	Unknown	62.4

Table 2. Wood stove EPA Published Certified Emission Rate

13-NC Wood stove Lowest Burn-rate, as Tested						
Fuel	Average Efficiency (%)	Average Emissions (g/kg)	Average Emissions per 100,000 Btu (g)	Average Emissions Rate (g/hr)	Average Burn Rate (kg/hr)	Total Emissions for 24 hr operation (g)
White Spruce	63.4	13.8	123.8	14.5	1.1	348.6

Table 3. Wood stove Lowest Burn-rate, as Tested

Emissions Testing of Pellet Stove with Locally Available Wood Pellets and Alaska-Grown Barley

Overview

CCHRC tested a commonly available, reasonably priced pellet stove for emissions performance and efficiency, United States Stove Company model 6039HF multi-fuel stove. Testing included locally available wood pellets from a Fairbanks home supply store; the pellets were a western red fir blend manufactured in Idaho. Testing also included barley grown in Delta, Alaska.

Methodology Summary

Particulate and gas sampling were performed as described for the wood stove testing section above.

Before conducting any particulate sampling, the stove was operated with gas sampling only, which allowed the stove to be tuned so it was operating at the highest efficiency and heat output for individual test runs of both pellets and barley. After the optimum stove settings were determined, the particulate and efficiency tests were conducted with the same stove settings.

After conducting these tests, the stove was operated again at the same settings as the previous tests in order to determine the burn rate. In this test, a fixed weight of fuel was burned in the stove and the length to burn it was noted.

Samples of the barley and pellets used were sent to an independent test lab for calorific content and chemical analysis; the results were used to calculate efficiency and are included in Appendix 2.

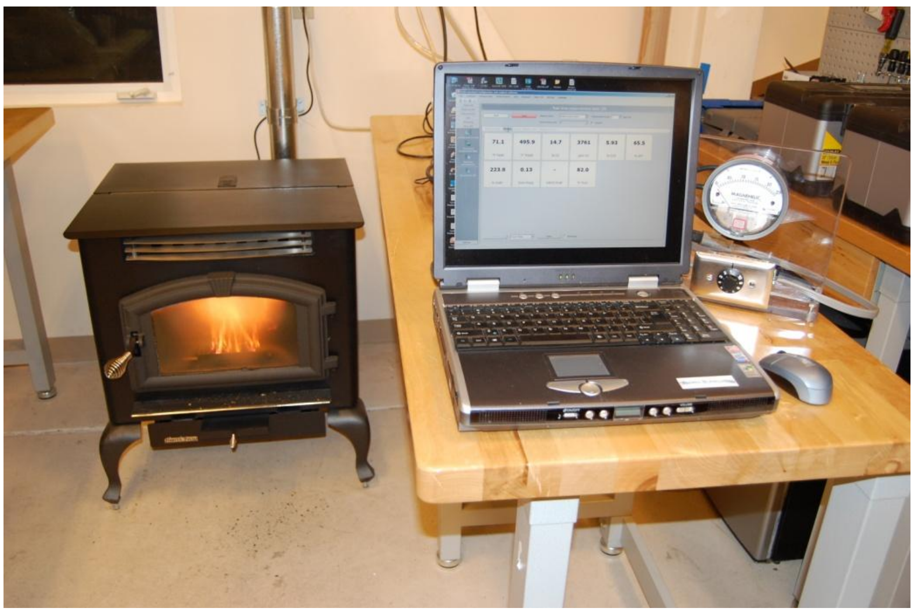

Figure 5.Testing pellet stove at CCHRC lab.

Results

The testing results for both pellets and barley are as shown in Table 4. A higher burn-rate was able to be established for the wood pellets as compared to the barley, which appeared to require a lower burn-rate to burn completely because of inadequate combustion air supply even when the air damper was set to full-open. While the average emissions rates were closer for pellets and barley, the average emissions and average emissions per 100,000 Btu show a larger difference. While both barley and pellet tested emissions rates are lower than the maximum EPA allowable 7.5 grams-per-hour level, the tested pellet emissions rate is nearly four times the EPA published certified value, as shown in Table 5.

Additionally, it is not known whether this stove model design was optimized for burning barley. It would be prudent to evaluate a stove model that was designed specifically for barley before formulating conclusions on this fuel source.

6039HF Pellet/Multi-fuel Stove, as Tested						
Fuel	Average Efficiency (%)	Average Emissions (g/kg)	Average Emissions per 100,000 Btu (g)	Average Emissions Rate (g/hr)	Average Burn Rate (kg/hr)	Total Emissions for 24 hr operation (g)
Delta, Alaska Barley	59.6	3.9	40.6	3.5	0.9	85.2
Idaho Wood Pellets	65.3	1.4	12.7	5.6	3.9	133.6

Table 4. 6039HF Pellet/Multi-fuel Stove, as Tested

6039HF Pellet/Multi-fuel Stove EPA-Published Certified Emission Rate						
Fuel	Assigned Efficiency (%)	Emissions (g/kg)	Emissions per 100,000 Btu (g)	Reported Emissions Rate (g/hr)	Average Burn Rate (kg/hr)	Total Emissions for 24 hr operation (g)
Wood Pellets	78.0	Unknown	Unknown	1.5	Unknown	36.0

Table 5. Pellet/Multi-fuel Stove EPA-Published Certified Emission Rate

Emissions Testing of Conventional Fireplace Converted to Masonry Heater

Overview

CCHRC converted a conventional masonry fireplace to a high-performance masonry heater as described in the "Masonry Heater Retrofit Research" section above. After completion, it was tested for particulate emissions and efficiency.

Methodology Summary

Particulate and gas sampling were performed as described for the wood stove testing section.

The masonry heater was tested during two test runs with white birch firewood; the firewood had the bark removed for one test run and still on in the second. The burns were ignited with a top-down ignition method, which is a common way to start masonry heaters. This ignition method places the firewood at the bottom, smaller pieces near the top and the smallest kindling and newspaper at the top. The emissions sampling was started before ignition so it includes all of the actual emissions from start-up through the end of the burn.

Comparing the test run with no bark to the run with bark would have been a useful comparison but the moisture contents were not similar for the two test runs because finding properly dried firewood was difficult. Therefore, no conclusions on this topic are included in this report.

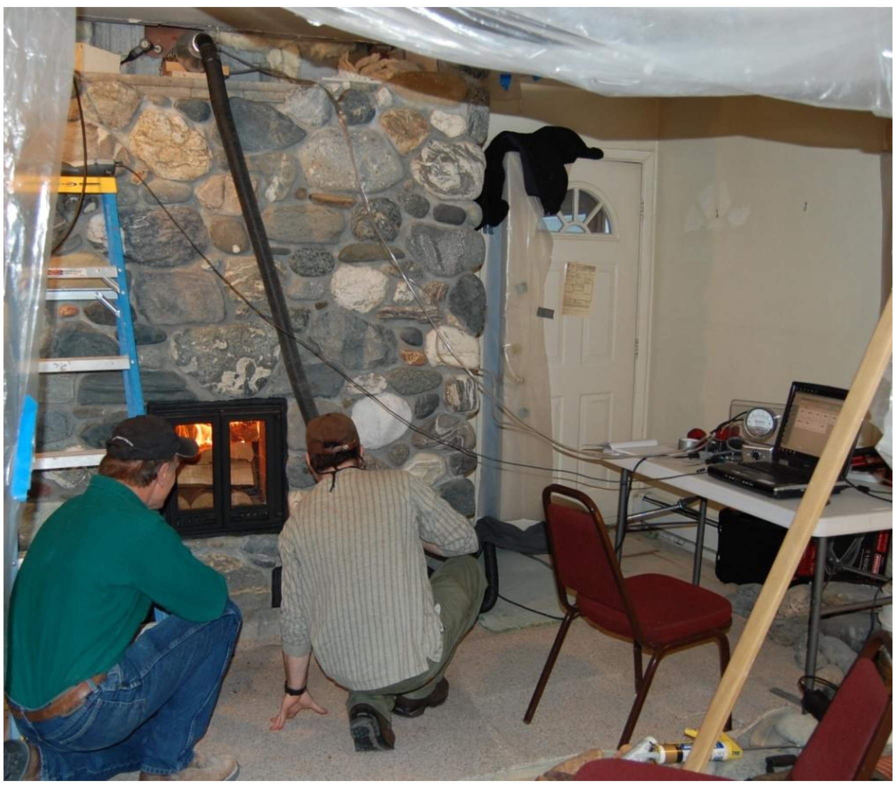

Figure 7.Testing the fireplace retrofit.

Results

The results presented in Table 6 represent an average of the two test runs. The average emissions are shown to be in the same range as pellet stoves. The average emissions rate which is higher than most other wood stoves or pellet stoves because of the very high burn-rate. Because the masonry heater is only burned for a few hours per day, but is releasing heat for 24 hours or longer, it is more useful to look at the emissions per 100,000 Btu of heat output when comparing devices.

Fireplace Converted to Masonry Heater, as Tested						
Fuel	Average Efficiency (%)	Average Emissions (g/kg)	Average Emissions per 100,000 Btu (g)	Average Emissions Rate (g/hr)	Average Burn Rate (kg/hr)	Total Emissions for Daily Operation (g)
White Birch	72.2	2.1	17.6	20.5	10.3	43.7

Table 6. Fireplace Converted to a Masonry Heater, as Tested.

Summary and Comparison of Biomass Heating Options, as Tested

Emissions and Efficiency

Table 7 shows a comparison of results for all wood-burning devices tested during an assumed daily device use pattern. The average Btu content for all four Alaska wood species was used in the calculations and the wood moisture content was assumed to be 10 percent.

Summary of Projected Emissions for Assumed Daily Device Use Pattern, as Tested							
Device	Use Period	Length of Burn Low Burn-rate (hr)	Length of Burn High Burn-rate (hr)	Weight of Fuel Burned (kg)	Total Heat Delivered (Btu)	Total Emissions for Daily Operation (g)	Emissions per Heat Output (g/100,000 Btu)
EPA Wood stove	Weekend	5	10	28.5	274,747	95.4	34.7
EPA Wood stove	Weekday	5	4	14.6	168,395	81.7	48.5
Masonry Heater	Every Day	NA	4	41.3	521,610	85.7	16.4
Multi-fuel Stove/Barley	Every Day	NA	24	21.8	209,957	85.2	40.6
Multi-fuel Stove/Pellets	Every Day	NA	24	93.2	1,054,322	133.6	12.7

Table 7. Summary of Projected Emissions for Assumed Daily Device Use Pattern, as Tested.

Table 8 shows a comparison of results for all wood-burning devices tested during an assumed weekly device use pattern extrapolated from the daily use results. Since these devices have significant differences in burn rates, total heat delivered, and daily emissions, it is most useful to compare the emissions per 100,000 Btu of heat output.

Table 9 shows the projected weekly emissions using the corresponding EPA-published emissions rate in grams per hour. Comparing the results from EPA-published data with the results from testing shows actual emissions from devices as used in the field may be higher than those predicted by EPA data.

Summary of Projected Emissions for Assumed Weekly Device Use Pattern, as Tested					
Device	**Use Period**	**Weight of Fuel Burned (kg)**	**Total Heat Delivered (Btu)**	**Total Emissions for Weekly Operation (g)**	**Emissions per Heat Output (g/100,000 Btu)**
EPA Woodstove	Week	129.8	1,391,469	599.3	43.1
Masonry Heater	Week	289.0	3,651,273	599.9	16.4
Multi-fuel Stove/Barley	Week	152.5	1,469,697	596.1	40.6
Multi-fuel Stove/Pellets	Week	652.3	7,380,253	935.4	12.7

Table 8. Summary of Projected Emissions for Assumed Weekly Device Use Pattern, as Tested.

Projected Emissions for Assumed Weekly Device Use Pattern using EPA published Emission Rate					
Device	**Use Period**	**Weight of Fuel Burned (kg)**	**Total Heat Delivered (Btu)**	**Total Emissions For Weekly Operation (g)**	**Emissions per Heat Output (g/100,000 Btu)**
EPA Woodstove	Week	Unknown	Unknown	436.8	Unknown
Multi-fuel Stove/Pellets	Week	Unknown	Unknown	252.0	Unknown

Table 9. Projected Emissions for Assumed Weekly Device Use Pattern using EPA published Emission Rate.

Economics

Residents of the FNSB continue to use wood for space heating and domestic hot water due in part to potential economic savings and shelter from fluctuating crude oil prices. Recently the price of crude oil has fluctuated from highs in excess of $130 a barrel during the summer of 2008 to below $40 in the spring of 2009.

Over the same period of time, the Alaska Division of Forestry realized a sharp increase in the number of personal use wood permits. In calendar year 2008, the Division of Forestry noted an increase of over 300% in personal use permits, and estimated that the price of a cord of wood increased by up to 40%.

This is likely a combination of those with wood burning devices using more wood, and more wood burning devices entering the market. Conservative estimates place the number of wood burning devices in the FNSB in excess of ten thousand.

The economics of wood burning are fundamentally the same as other fuels – the price-per-Btu multiplied by the number of Btus used. As with other fuels, the more efficiently the fuel is used, the less fuel is required. In wood burning devices, the efficiency of the device will determine how much wood is required to produce a given amount of heat, and therefore there is substantial economic incentive to using efficient wood-burning heating devices and operating them efficiently.

Table 10 shows a comparison of the economics of all of the tested devices assuming that firewood is purchased for the price shown.

Summary of Projected Cost for Assumed Weekly Device Use Pattern, as Tested, if Firewood is Purchased							
Device	**Use Period**	**Fuel Source**	**Weight of Fuel Burned (kg)**	**Weight of Fuel Burned (lb)**	**Assumed Fuel Cost**	**Total Cost**	**Cost per Heat Output (g/100,000 Btu)**
EPA Wood stove	Week	Purchase	129.8	285.6	$200 per cord	$17.39	$1.25
Masonry Heater	Week	Purchase	289.0	635.8	$200 per cord	$38.71	$1.06
Multi-fuel Stove/Barley	Week	Purchase	152.5	335.5	$8 per 40 lbs	$67.10	$4.57
Multi-fuel Stove/Pellets	Week	Purchase	652.3	1,435.1	$6 per 40 lbs	$215.26	$2.92

Table 10. Summary of Projected Cost for Assumed Weekly Device Use Pattern, as Tested, if Firewood is Purchased.

Table 11 shows a comparison of the economics of all of the tested devices assuming that firewood is cut by the homeowner on state lands with the proper firewood cutting permit.

Summary of Projected Cost for Assumed Weekly Device Use Pattern, as Tested, if Firewood cut by Homeowner							
Device	**Use Period**	**Fuel Source**	**Weight of Fuel Burned (kg)**	**Weight of Fuel Burned (lb)**	**Assumed Fuel Cost**	**Total Cost**	**Cost per Heat Output (g/100,000 Btu)**
EPA Wood stove	Week	Cut your own	129.8	285.6	$5 per cord w/permit	$0.43	$0.0312
Masonry Heater	Week	Cut your own	289.0	635.8	$5 per cord w/permit	$0.97	$0.0265
Multi-fuel Stove/Barley	Week	Purchase	152.5	335.5	$8 per 40 lbs	$67.10	$4.5653
Multi-fuel Stove/Pellets	Week	Purchase	652.3	1,435.1	$6 per 40 lbs	$215.26	$2.9167

Table 11.Summary of Projected Cost for Assumed Weekly Device Use Pattern, as Tested, if Firewood cut by Homeowner.

Conclusion

- Harvesting and use of black spruce biomass material from wildland fire mitigation efforts is currently limited by lack of efficient collection methods and transportation costs from distant sites.
- Black spruce used as cordwood fuel for wood stoves is comparable to other species in emissions and efficiency.
- Combined Heat and Power is quickly developing technology but has not been successfully commercialized. Current units are in the testing and prototype stage and the cost-per-unit energy output is high due to the fact that economies of scale from mass-production have not yet been realized.
- Published EPA emissions data for wood stoves may under-predict actual emissions compared with the way they may be used in the field.
- Published EPA emissions data for pellet stoves may under-predict actual emissions from the way they may be used in the field.
- It is feasible to convert a conventional masonry fireplace to a low-emissions and efficient masonry heater; the installation can be expensive but the pay-back period can be short.
- Clean wood-burning technology currently exists and will continue to improve.

Many device options are currently available to consumers which allow them to base purchase decisions on capital expense, operational costs, lifestyle and they way they plan to burn wood. The FNSB and local residents would benefit from an expanded educational program on wood burning and continued research on this topic.

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Appendix 1. Calorific Value and Chemical Analysis of Alaska Wood Species

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MATERIAL FUEL

MARKED WHITE SPRUCE, ALASKA INTERIOR CHIP PLANTS FROM BIOMASS, 01/19/2009, PURCHASE ORDER NO. 3017AK

LABORATORY NO. 499,034

	AS ANALYZED	DRY BASIS	ASH & MOISTURE FREE	AS RECEIVED
Moisture	3.26 %	0.00 %	0.00 %	51.26 %
Volatile	73.33	75.80	78.66	36.94
Fixed Carbon	19.90	20.57	21.34	10.03
Ash	3.51	3.63	0.00	1.77
Sulfur	0.07	0.07	0.07	0.03
Btu	9,075	9,381	9,734	4,572

Chlorine, dry basis 0.012 %

FUSIBILITY OF ASH (Reducing Atmosphere)

Initial Deformation Temperature	2600 'F
Softening Temperature	2640 'F
Hemispherical Temperature	2680 'F
Fluid Temperature	2700 'F

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LABORATORY NO. 499,034-1

ULTIMATE ANALYSIS (Dry Basis)

Ash %	3.78
Carbon %	54.46
Hydrogen %	5.65
Nitrogen %	0.86
Sulfur %	0.06
Oxygen %	35.19

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LABORATORY NO. 499,035

	AS ANALYZED	DRY BASIS	ASH & MOISTURE FREE	AS RECEIVED
Moisture	3.87 %	0.00 %	0.00 %	9.65 %
Volatile	81.35	84.62	84.85	76.45
Fixed Carbon	14.52	15.11	15.15	13.66
Ash	0.26	0.27	0.00	0.24
Sulfur	0.01	0.01	0.01	0.01
Btu	8,277	8,610	8,633	7,779

Chlorine, dry coal basis 0.004 %

FUSIBILITY OF ASH (Reducing Atmosphere)

Initial Deformation Temperature	2320 'F
Softening Temperature	2340 'F
Hemispherical Temperature	2370 'F
Fluid Temperature	2420 'F

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LABORATORY NO. 499,035-1

ULTIMATE ANALYSIS (Dry Basis)

Ash %	0.27
Carbon %	52.25
Hydrogen %	5.82
Nitrogen %	0.09
Sulfur %	0.02
Oxygen %	41.55

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MARKED WHITE SPRUCE GREEN, CONES AND NEEDLES, ALASKA INTERIOR CHIP PLANTS FROM BIOMASS, PUCHASE ORDER NO. 3017AK

LABORATORY NO. 499,036

	AS ANALYZED	DRY BASIS	ASH & MOISTURE FREE	AS RECEIVED
Moisture	3.66 %	0.00 %	0.00 %	40.71 %
Volatile	78.05	81.01	82.23	48.03
Fixed Carbon	16.86	17.51	17.77	10.38
Ash	1.43	1.48	0.00	0.88
Sulfur	0.01	0.01	0.01	0.01
Btu	8,676	9,006	9,141	5,340

Chlorine, dry basis 0.006 %

FUSIBILITY OF ASH (Reducing Atmosphere)

Initial Deformation Temperature	2620 'F
Softening Temperature	2660 'F
Hemispherical Temperature	2700 'F
Fluid Temperature	2740 'F

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LABORATORY NO. 499,036-1

ULTIMATE ANALYSIS (Dry Basis)

Ash %	1.85
Carbon %	53.05
Hydrogen %	6.31
Nitrogen %	0.37
Sulfur %	0.05
Oxygen %	38.37

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LABORATORY NO. 499,037

	AS ANALYZED	DRY BASIS	ASH & MOISTURE FREE	AS RECEIVED
Moisture	3.72 %	0.00 %	0.00 %	28.08 %
Volatile	82.84	86.04	86.85	61.88
Fixed Carbon	12.54	13.03	13.15	9.37
Ash	0.90	0.93	0.00	0.67
Sulfur	0.01	0.01	0.01	0.01
Btu	8,233	8,551	8,631	6,150

Chlorine, dry basis 0.006 %

FUSIBILITY OF ASH (Reducing Atmosphere)

Initial Deformation Temperature	2600 'F
Softening Temperature	2620 'F
Hemispherical Temperature	2660 'F
Fluid Temperature	2720 'F

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Lewis E. Cain

LEWIS E. CAIN
President

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LABORATORY NO. 499,037-1

<u>ULTIMATE ANALYSIS (Dry Basis)</u>

Ash %	1.37
Carbon %	51.11
Hydrogen %	5.91
Nitrogen %	0.28
Sulfur %	0.03
Oxygen %	41.30

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MARKED BIRCH, ALASKA INTERIOR CHIP PLANTS FROM BIOMASS, PURCHASE ORDER NO. 3017AK

LABORATORY NO. 499,038

	AS ANALYZED	DRY BASIS	ASH & MOISTURE FREE	AS RECEIVED
Moisture	2.99 %	0.00 %	0.00 %	24.98 %
Volatile	83.95	86.54	86.77	64.92
Fixed Carbon	12.80	13.19	13.23	9.90
Ash	0.26	0.27	0.00	0.20
Sulfur	0.02	0.02	0.02	0.02
Btu	8,357	8,615	8,638	6,463

Chlorine, dry basis 0.002 %

FUSIBILITY OF ASH (Reducing Atmosphere)

Initial Deformation Temperature	2600 'F
Softening Temperature	2640 'F
Hemispherical Temperature	2660 'F
Fluid Temperature	2720 'F

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12:23
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LABORATORY NO. 499,038-1

ULTIMATE ANALYSIS (Dry Basis)

Ash %	0.46
Carbon %	51.20
Hydrogen %	5.79
Nitrogen %	0.14
Sulfur %	0.01
Oxygen %	42.40

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MARKED BLACK SPRUCE WITH CONES AND NEEDLES, ALASKA INTERIOR CHIP PLANTS FROM BIOMASS, PURCHASE ORDER NO. 3017AK

LABORATORY NO. 499,039

	AS ANALYZED	DRY BASIS	ASH & MOISTURE FREE	AS RECEIVED
Moisture	2.59 %	0.00 %	0.00 %	35.87 %
Volatile	78.44	80.53	82.02	51.64
Fixed Carbon	17.20	17.65	17.98	11.32
Ash	1.77	1.82	0.00	1.17
Sulfur	0.01	0.01	0.01	0.01
Btu	8,526	8,753	8,915	5,613

Chlorine, dry basis 0.008 %

FUSIBILITY OF ASH (Reducing Atmosphere)

Initial Deformation Temperature	2450 'F
Softening Temperature	2520 'F
Hemispherical Temperature	2600 'F
Fluid Temperature	2620 'F

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President

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President
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LABORATORY NO. 499,039-1

<u>ULTIMATE ANALYSIS (Dry Basis)</u>

Ash %	1.35
Carbon %	52.91
Hydrogen %	5.81
Nitrogen %	0.21
Sulfur %	0.02
Oxygen %	39.70

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MARKED BLACK SPRUCE, ALASKA INTERIOR CHIP PLANTS FROM BIOMASS, PURCHASE ORDER NO. 3017AK

LABORATORY NO. 499,040

	AS ANALYZED	DRY BASIS	ASH & MOISTURE FREE	AS RECEIVED
Moisture	2.70 %	0.00 %	0.00 %	51.56 %
Volatile	74.74	76.81	79.70	37.21
Fixed Carbon	19.03	19.56	20.30	9.47
Ash	3.53	3.63	0.00	1.76
Sulfur	0.04	0.04	0.04	0.02
Btu	9,298	9,556	9,916	4,629

Chlorine, dry basis 0.034 %

FUSIBILITY OF ASH (Reducing Atmosphere)

Initial Deformation Temperature	2240 'F
Softening Temperature	2300 'F
Hemispherical Temperature	2340 'F
Fluid Temperature	2400 'F

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Lewis E. Cain
LEWIS E. CAIN
President

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515 CHEROKEE BLVD.

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President

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MARKED BLACK SPRUCE, ALASKA INTERIOR CHIP PLANTS FROM BIOMASS, PURCHASE ORDER NO. 017AK

LABORATORY NO. 499,040-1

ULTIMATE ANALYSIS (Dry Basis)

Ash %	3.48
Carbon %	55.09
Hydrogen %	6.34
Nitrogen %	0.62
Sulfur %	0.02
Oxygen %	34.45

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President

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CHATTANOOGA, TENNESSEE 37405
423/265-4533

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MATERIAL FUEL

MARKED COTTONWOOD, ALASKA INTERIOR CHIP PLANTS FROM BIOMASS, PURCHASE ORDER NO. 3017AK

LABORATORY NO. 499,041

	AS ANALYZED	DRY BASIS	ASH & MOISTURE FREE	AS RECEIVED
Moisture	3.00 %	0.00 %	0.00 %	34.28 %
Volatile	81.49	84.01	85.05	55.21
Fixed Carbon	14.33	14.77	14.95	9.71
Ash	1.18	1.22	0.00	0.80
Sulfur	0.01	0.01	0.01	0.01
Btu	8,511	8,774	8,882	5,766

Chlorine, dry basis 0.008 %

FUSIBILITY OF ASH (Reducing Atmosphere)

Initial Deformation Temperature	2600 °F
Softening Temperature	2620 °F
Hemispherical Temperature	2660 °F
Fluid Temperature	2720 °F

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President

TECHNICAL LABORATORIES, INC.

515 CHEROKEE BLVD.
LEWIS E. CAIN
President
CHATTANOOGA, TENNESSEE 37405
423/265-4533

ACCOUNT NO. 5790-001 **DATE** FEBRUARY 16, 2009

RECEIVED FROM GLOBAL ENERGY SOLUTIONS, INC., 100 WEST ROOSEVELT ROAD, SUITE B5-201, WHEATON, ILLINOIS 60187-5298
MR. GREG SMITH

RECEIVED DATE 01/21/09

MATERIAL FUEL

MARKED COTTONWOOD, ALASKA INTERIOR CHIP PLANTS FROM BIOMASS, PURCHASE ORDER NO. 3017AK

LABORATORY NO. 499,041-1

ULTIMATE ANALYSIS (Dry Basis)

Ash %	0.90
Carbon %	51.92
Hydrogen %	6.12
Nitrogen %	0.13
Sulfur %	0.05
Oxygen %	40.88

TECHNICAL LABORATORIES, INC.

LEWIS E. CAIN
President

ibc

Post-it® Fax Note 7671	Date 2/16/09 # of pages ▶ 8
To GREG SMITH	From
Co./Dept. GLOBAL ENERGY	Co.
Phone #	Phone #
Fax # 1-630-653-0658	Fax #

Appendix 2. Calorific Value and Chemical Analysis of Delta, AK Barley and Locally Available Wood Pellets

Twin Ports Testing Inc.

1301 N. 3rd Street • Superior, WI 54880 • 715-392-7114 • Fax 715-392-7163
218-722-1911 • 800-373-2562 • www.twinportstesting.com

Cold Climate Housing Research Center
PO Box 82489
Fairbanks, AK 99708

Date Received: Apr 13, 2009
Date Tested: Apr 22, 2009

Attn: Dave

Sample Log No: 09C1017
Sample Designation: CCHRC Wood Pellets

	METHOD	UNITS	MOISTURE & ASH FREE	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM D3173	wt. %			5.74
Ash	ASTM D3174	wt. %		0.25	0.24
Volatile Matter	ASTM D3175	wt. %		86.77	81.79
Fixed Carbon By Difference	ASTM D3175	wt. %		12.98	12.23
Sulfur	ASTM D4239	wt. %		0.005	0.005
Gross Heating Value	ASTM D5865	BTU/lb	8372	8351	7872
Carbon	ASTM D5373	wt. %		50.79	47.87
Hydrogen	ASTM D5373	wt. %		6.07	5.72
Nitrogen	ASTM D5373	wt. %		0.01	0.01
Oxygen	ASTM D3176	wt. %		42.88	40.42
Chlorine	ASTM D6721	ug/g			
Fluorine	ASTM D3761	ug/g			
Mercury	ASTM D6722	ug/g			
Sodium Oxide in Ash	ASTM D3682	wt. %			
Hardgrove Grindability Index	ASTM D409	wt. /index			

Additional:

Prepared By: Kevin Arnl **Date:** 4/22/09

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Cold Climate Housing Research Center
PO Box 82489
Fairbanks, AK 99708

Date Received: Apr 13, 2009
Date Tested: Apr 22, 2009

Attn: Dave

Sample Log No: 09C1018
Sample Designation: CCHRC Barley

	METHOD	UNITS	MOISTURE & ASH FREE	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM D3173	wt. %			7.73
Ash	ASTM D3174	wt. %		2.74	2.53
Volatile Matter	ASTM D3175	wt. %		85.86	79.22
Fixed Carbon By Difference	ASTM D3175	wt. %		11.40	10.52
Sulfur	ASTM D4239	wt. %		0.131	0.121
Gross Heating Value	ASTM D5865	BTU/lb	8188	7963	7348
Carbon	ASTM D5373	wt. %		44.65	41.20
Hydrogen	ASTM D5373	wt. %		6.08	5.61
Nitrogen	ASTM D5373	wt. %		1.83	1.69
Oxygen	ASTM D3176	wt. %		44.56	41.11
Chlorine	ASTM D6721	ug/g			
Fluorine	ASTM D3761	ug/g			
Mercury	ASTM D6722	ug/g			
Sodium Oxide in Ash	ASTM D3682	wt. %			
Hardgrove Grindability Index	ASTM D409	wt. /index			

Additional:

Prepared By: Kevin Arden

Date: 4/22/09