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Wood Pellet-Fired Biomass Boiler Project at the Ketchikan Federal Building

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The Green Proving Ground program leverages GSA's real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

DISCLAIMER

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I. Executive Summary

BACKGROUND

Biomass boiler technology is an economical and renewable energy resource alternative for buildings with high fuel costs, consistent heating requirements, and close proximity to biomass sources. These buildings are typically located in areas where low-cost natural gas is unavailable and expensive fuels such as diesel, home heating oil, and propane are used. Biomass heating technology is potentially applicable to any building with an installed hot water heating distribution system; however, deployment potential will vary, depending on the operational efficiency of existing heating equipment and other factors. The cost effectiveness is also dependent upon the amount of time that the boiler is operational during the year. For example, buildings in colder climates are better candidates for this technology. Also, biomass can be expensive to transport, so the proximity of the biomass source is an important consideration. Therefore, the key economic factors are the current cost of fuel oil, the delivered cost of wood pellets, and the amount of heating required annually at the facility.

General Services Administration (GSA) is interested in biomass heating technologies for several reasons:

1. Fuel oil costs are high at more remote locations compared to biomass fuel prices
2. Biomass fuel is abundant in many areas due to pine beetle infestation and other local and regional factors
3. Regional interest in supporting the biomass fuel market in Alaska and the northwest

Recent advances in biomass pellet combustion have made systems available on a small-scale that are efficient, fully automated, produce low emissions and require little operation and maintenance support. This type of system offers an economic and reliable renewable energy resource for GSA buildings that fit the criteria outlined below:

1. Have a hot water heating system and not a steam system
2. Are located where natural gas is expensive or not available
3. Are located in a climate where the heating load is substantial and the heating season is extended relative to the average
4. Are located in close proximity to the biomass resource (within an approximately 50-mile radius is a good rule of thumb).[1]

As of July 2013, GSA had jurisdiction, custody, and control over 1,523 federally owned buildings. Based on the criteria above, there are approximately 150 buildings in the GSA portfolio that would be good candidates for further investigation for use of this technology. Likewise, biomass heating should also be considered in the design phase of any new facility that meets the criteria. This report describes a study at the federal building in Ketchikan, Alaska, to demonstrate that a biomass boiler system can be installed in an existing building in a turnkey fashion and perform reliably and cost effectively. Furthermore, the study aims to use the lessons learned from this installation in order to assess deployment potential at other GSA facilities.

[1] https://bioenergy.ornl.gov/faqs/index.html#pg2

OVERVIEW OF BIOMASS BOILER TECHNOLOGY

The use of biomass to heat buildings is not new, but recent technologies have improved the areas of controls, efficiency, air emissions and cost effectiveness. These systems use wood pellets or wood chips that are fed on an automated basis to satisfy the heat load demands of the building, providing a cost-effective, renewable energy option for heating. While building heating typically uses natural gas, some buildings must rely on more expensive fuels like diesel, home heating oil, and propane. If the biomass fuel supply is located close to the building, transportation costs are moderate, thereby realizing substantial savings over the use of costly fossil fuels. In such cases, a biomass heating system may offer a clean, reliable, and economical heat source for large heat loads of buildings, with diesel fuel systems used as a backup heating supply.

Many case studies and operating data are available to show the economic benefits of biomass heating systems. There are numerous vendors in the United States that can provide this technology, and biomass resources are increasing across the nation for both wood chip and pellet fuels. In recent years, the systems have become highly efficient and fully automated to increase the heat output and reduce the manpower required for operation. The technology used at Ketchikan exemplifies these improvements. The reduction in labor costs due to increased automation allows for economically feasible systems to be developed on a small scale. The technology chosen for this demonstration is discussed in further detail in this report.

STUDY DESIGN AND OBJECTIVES

This study had two distinct objectives. The first was to demonstrate that a biomass boiler system can be installed in an existing building in a turnkey fashion with reliable, cost-effective performance. GSA Region 10 installed the system at the federal building in Ketchikan, Alaska, and submitted the project to the Green Proving Ground program. GSA contracted with the National Renewable Energy Laboratory (NREL) to assess the installation and technology after it had experienced a full year of run time. Installation and operation issues were documented, and the boiler was tested to ensure that it could perform to the level that was defined by the vendor. The project team/researchers examined other issues, including fuel transportation costs, building energy savings, and overall economics.

The second aspect of the project was to understand the lessons learned from this single installation and use them to assess additional deployment potential at other GSA facilities. Information from this effort would help discern where this technology would be most appropriate, while illustrating the advantages and disadvantages of implementing it in other GSA buildings.

PROJECT RESULTS/FINDINGS

The results of the testing are shown in Table 1 below.

Table 1: Test Results

Description	Value	Units
Full load output	1,000,000	BTUs per hour
Test length	8.25	hours[2]
Heat to water	3,711,968	BTUs during test
Avg heat to water	449,935	BTUs per hour
Pellet feed	537	pounds during test
Pellet higher heating value (HHV)	8,147	BTU/pound
Pellet heat input	4,335,574	BTUs during test
Avg Pellet heat input	525,524	BTUs/hour
Average Boiler Load	45%	of Full Load
Efficiency	**85.6%**	

The vendor's claim for 85% to 90% efficiency is normally expected to be assessed at full load operation. Given the oversized capacity, the units tested were operating at an average of 45% load during the testing. However, the boiler operated within the stated efficiency range and would most likely have performed even better given the opportunity to test it at full load. This technology performed well and within the expected efficiency range.

The cost savings and return on investment are dependent upon several variables that are outlined and assessed herein. The installation at Ketchikan was unique as it was a demonstration project and the costs for other construction on the building were consolidated with the boiler installation costs, artificially raising the stated investment. Assuming an installation cost for the boiler system and appurtenances of $450,000, the simple payback estimate for this location is approximately 30 years, depending on the price of pellets, as explained in Section VI of this report. Shorter payback periods at other sites may be possible with optimal boiler sizing and lower pellet fuel prices.

[2] ASME Power Test Code PTC-4.1 requires 8 to 12 hours for boiler testing.

II. Introduction

A. PROBLEM STATEMENT

Biomass boiler systems have existed for many years, but the technology has advanced in recent decades and can now provide automated and efficient operation for a relatively modest investment. Key advances in system monitoring and control allow for lower operating costs, since the control systems run all aspects of the boiler, including feed, load reduction and even tube cleaning. These advances have made such systems economical on a small scale in situations where inexpensive fuels like natural gas are not available. This creates an opportunity for building operators in remote, cold-climate locations to reduce the use of expensive fuels for heating buildings.

General Services Administration (GSA) Region 10 installed the system at the federal building in Ketchikan, Alaska and submitted the project to the Green Proving Ground (GPG) program. GSA's GPG program contracted with the National Renewable Energy Laboratory (NREL) to assess the installation and the technology. The system serves as a demonstration to assess actual system efficiencies, as well as operating characteristics and financial benefits. In addition to installation and operational issues, the project team/researchers examined other issues, including fuel transportation costs, building energy savings, and overall economics.

B. OPPORTUNITY

At the biomass boiler system demonstration project, the project team evaluated the technology's cost effectiveness, operational issues, and potential usefulness at other facilities. The appropriateness for these types of systems on a broad scale is essential as the GSA has jurisdiction, custody and control over 1,500 federally owned properties across the United States. The $4.7 million contract for the GSA biomass heating system was awarded to a small business with operations in Anchorage. The project was commissioned in early 2012 and the final commissioning report was submitted on February 6, 2012. Researchers at NREL estimated that only $450,000 of the total $4.7 million was directly associated with the biomass heating system, with the balance of the costs applied to the modification to convert the building from steam heating to hot water heating and to install a new oil-fired boiler for backup.

This type of technology has been commercially available for many years; however, small biomass systems that require little operator attendance are relatively new. There are hundreds of these types of systems operating in the United States in small buildings, schools and other applications.[3] There are numerous vendors that could supply a similar technology to the one assessed in this study with comparable efficiencies. The availability of multiple sources is favorable for the government and should increase the opportunity for competitive pricing during acquisition of biomass systems. Biomass fuel pricing has remained stable compared to fossil fuel prices, which is an advantage and a hedge against potential oil price increases.

These types of biomass systems are typically well received by local communities. They are powered by renewable energy, have low emissions, and help to support local economies with additional job

[3] "Wood-Chip Heating Systems, A Guide for Institutional and Commercial Biomass Installations." Maker, Timothy M., 2004.

opportunities. Since this is not an “emerging” technology with many unknowns, the key issue and major barrier is the cost. If the system can help a facility save money on its heating bills without being a more labor-intensive or unreliable system, the focus of the decision-making process becomes economics. The other issue of concern is the availability of the biomass fuel.

Transportation comprises a large percentage of the cost of the fuel and the fuel provider is often a small operation. If the project is based on receiving all fuel from one vendor, the vendor’s solvency becomes a critical factor in evaluating whether to pursue the technology because the vendor could close operations at some point, leaving the plant with no fuel or with fuel coming from a much greater distance at a significantly increased cost.

In the past, operations and maintenance tasks such as feeding chips, removing ash, and cleaning boiler tubes were more cumbersome and labor intensive than using an oil-fired boiler. With the recent improvement in these biomass systems and the implementation of pellet fuel, the required maintenance and operational attendance has become minimal. Additionally, the older oil-fired boilers can often remain onsite and serve as backup systems providing an effective, redundant heating source. This backup approach can be a significant advantage in harsh, remote, cold-climate installations.

III. Methodology

A. TECHNOLOGY DESCRIPTION

Small biomass boilers—500,000 BTUs per hour to about 3 million BTUs per hour—that burn wood pellets, sawdust, and chips have existed for many years. Newer biomass boilers have improved system efficiency, air emissions and automated operation. Improved efficiency offers obvious advantages, and air emissions reductions have met changing environmental regulations, another benefit of a biomass boiler system (although emissions were not tested as a part of this evaluation). The key shift in these biomass boiler systems is that they now operate with automated controls systems that require little operator attendance. This development has reduced labor costs, which allows for economically feasible systems to be developed on a small scale.

These biomass boiler systems are typically designed for hot water heating applications. Heating water for distribution in buildings is not a new concept, although many older buildings have steam systems in place. Modifying steam heating systems to accommodate hot water boilers can be expensive. Small biomass steam boilers were not assessed as a part of this study. Steam systems may be available but are far less common at this size range. If a distribution system upgrade is independently planned, such a project could potentially fit well with the addition of a biomass-fired, hot water heating system. If the economics are assessed with the inclusion of the distribution modifications, it is unlikely that the payback for the investment would be favorable, due to the capital cost associated with those modifications.

The technology differs from other emerging technologies since it has been in commercial service in numerous installations. From a technology readiness standpoint, it would rank a Technology Readiness Level (TRL) 9 under the U.S. Department of Energy's Biomass Program system. This means that the technology is:

> System Proven and Ready for Full Commercial Deployment: Actual system proven through successful operations in operating environment, and ready for full commercial deployment. The technology is in its final form and operated under the full range of operating conditions. Examples include steady state 24/7 manufacturing meeting cost, yield, and output targets. Emphasis shifts toward statistical process control.[4]

An efficient biomass heating system can deliver energy savings over systems that use liquid fuels like diesel and heating oil. With the current low cost of natural gas, biomass systems are not likely to be competitive with systems that have access to cheap natural gas for their heating needs. Savings are realized where the cost of biomass energy is less expensive than the alternative fuels locally available. The newer biomass systems, like the one installed in Ketchikan, also offer high efficiencies resulting in additional energy savings.

[4] U.S. Department of Energy. Energy Efficiency & Renewable Energy. "Biomass Multi-Year Program Plan." April 2011

B. TECHNICAL OBJECTIVES

The project team for this biomass boiler installation project established the following objectives:

1. Demonstrate that a biomass boiler system can be installed in an existing building in a turnkey fashion with reliable performance.
2. Document installation and operation issues, including those associated with the larger size of the biomass boiler, and the need for wood pellet storage infrastructure.
3. Document fuel transportation costs and determine their effect on projected payback.
4. Analyze cost/benefit and deployment potential.

C. DEMONSTRATION PROJECT LOCATION

The Ketchikan Federal Building typically burns up to 9,000 gallons of oil each winter at a cost of $3.48 per gallon (2012) as reported by the staff. Backup mechanical systems in federal facilities are also required in case of an emergency.

This building was a good candidate for biomass heating due to its northern location, frigid temperatures, and high fuel costs. The biomass project was part of another much larger renovation/heating systems upgrade project that replaced the building's outdated, inefficient 1964 steam heating system with an energy efficient hot-water heating system. This project was the first to pilot and include a biomass heating technology project for GSA.

GSA had the opportunity to upgrade the heating system through the American Recovery and Reinvestment Act. It was decided to integrate the deployment of a biomass technology that would be relevant and sustainable for decades to come.

IV. Measurement and Verification Plan

A. FACILITY DESCRIPTION

The Ketchikan Federal Building is located in Ketchikan, Alaska, which is situated on the southwestern coast of Revillagigedo Island. It is 679 miles north of Seattle and 235 miles south of Juneau. This six -story reinforced cast-in-place concrete office building was built in 1938. It is configured as an "I" with one two-story addition forming an "L" shaped building. There are six floors above grade with one floor below grade. The building has been well maintained over the years. The Ketchikan Federal Building is located in the southeast quadrant of the central business district, and is surrounded by the Visitors' Center shops, art galleries, restaurants, and other tourist-related businesses.

Figure 1: Ketchikan Federal Building

B. TECHNOLOGY DESCRIPTION

The project team chose a pellet boiler system for this site. The boiler uses wood pellets as a fuel source, which are more standardized in size and shape than wood chips (this reduces the level of needed quality control). Wood pellets also have a higher density than wood chips, which reduces storage requirements and transportation costs, and are a more effective fuel source. The vendor claimed that the boiler system would achieve up to 90% efficiency, stating that they had previously measured 85%-92% efficiency for their systems. The vendor also claims to have emissions comparable to those of oil or gas burning systems. These types of systems could be suitable for approximately 150 federally owned properties under GSA's jurisdiction, custody and control across the United States. The Ketchikan Federal Building project was the first in GSA's inventory to pilot biomass heating technology.

Biomass pellet boilers that heat water for distribution typically come in standard sizes. Typical heat outputs range from 500,000 BTUs per hour to about 3 million BTUs per hour for the small packaged systems. Larger systems can be procured, although the complexity of operation will increase with size. The boiler installed at the Ketchikan Federal Building is rated at 1 million BTUs per hour, making it a relatively small system.

An elevation drawing of the system layout is shown below in Figure 2. The wood pellets are stored in a silo outside of the building and are augured into the building when the low-level signal is given from the fuel bin level sensor. The pellets automatically replenish the fuel bin and the conveyor stops when the upper level sensor is triggered. The fuel system, including the silo and transfer conveyor, was not part of the vendor's scope of supply for the project, but associated costs were included in the payback analysis.

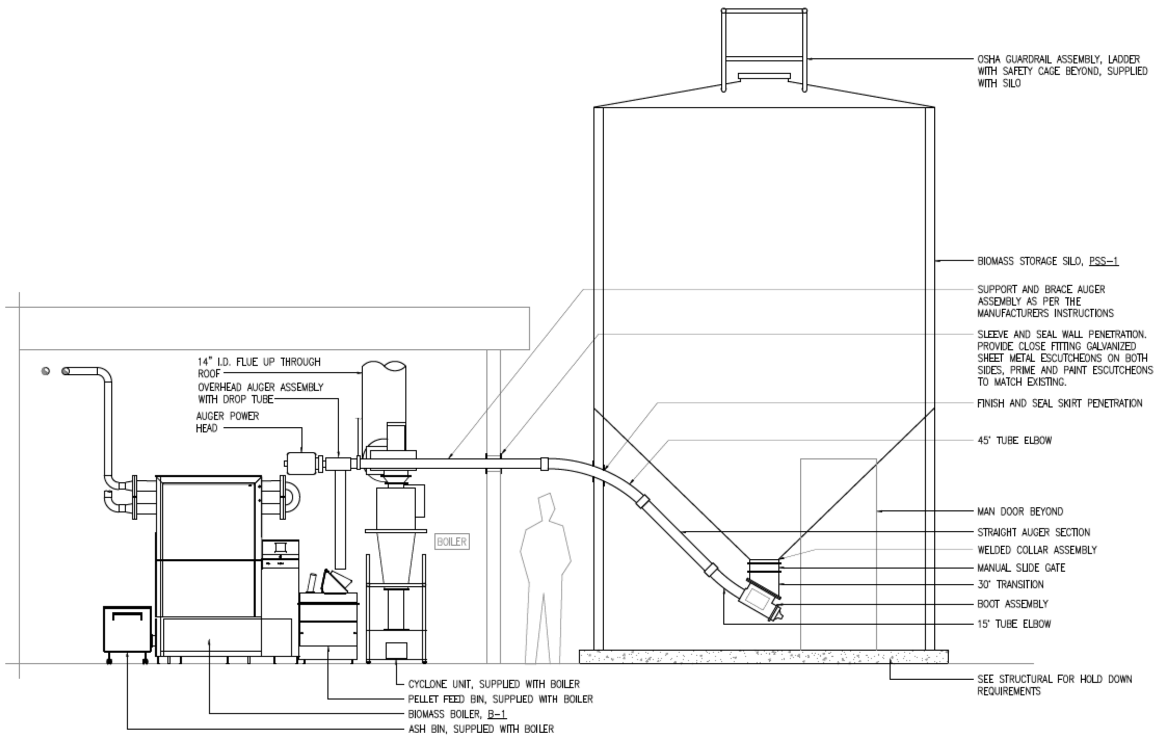


Figure 2: Boiler elevation graphic

A cut away graphic of the boiler system is shown below in Figure 3. The auger on the right of the drawing transfers pellets from the fuel bin to the burn ring as needed to satisfy the heat demand. The fuel is burned efficiently using staged combustion air injection. The hot flue gas travels through a bank of tubes where the heat is transferred to the water that surrounds the tube bundle. This is known as a "fire tube" design as opposed to water tube where the water is on the inside of the tubes and the gas is on the outside.

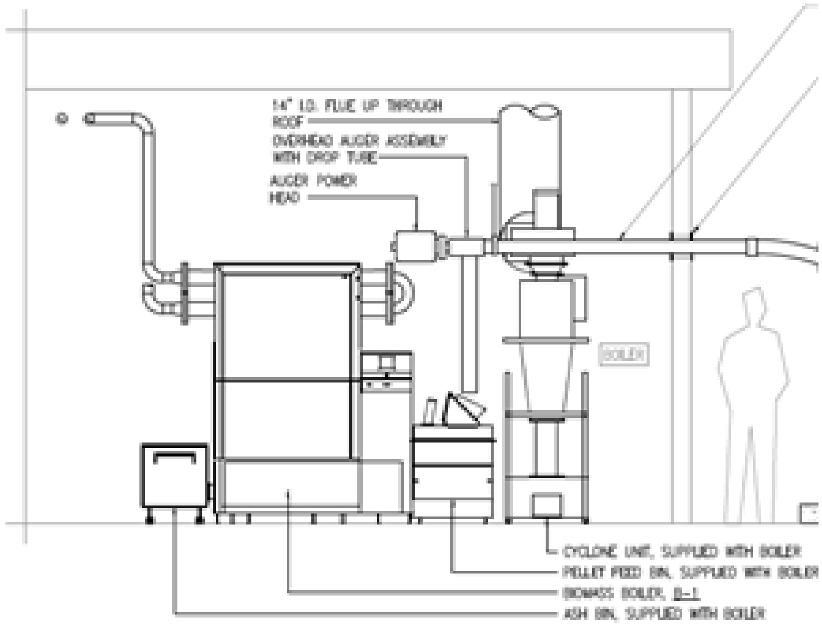


Figure 3: Boiler elevation

Keeping the tube heat transfer surface clean is key to maintaining long-term efficient operation. This boiler design is equipped with an automated mechanical cleaning system that periodically removes ash buildup from the tubes. This is done online to avoid interruptions in the heating process.

Emissions were not tested as a part of this project, because of the added expense of emissions testing. Typically, on a small scale, the emissions requirements are minimal due to the amount of fuel processed. Particulate is a primary concern because it releases dust into the atmosphere that can be inhaled. A cyclone is implemented in the flue duct with a rotating paddle system to aid in knocking out particulate matter where it is collected as part of the ash removal system. This is an effective system for small-scale pellet boilers and allows the equipment to meet environmental regulations relatively inexpensively.

C. TECHNOLOGY SPECIFICATION

The most common biomass used is “woody” biomass, that is, biomass comprised of trees and woody plants, including limbs, tops, needles, leaves and other woody parts, grown in a forest, woodland, or rangeland environment that are the byproducts of forest management.[5] In the United States, woody biomass is typically burned as chips on a large-scale and wood pellets for small-scale applications. Economics tend to favor large-scale applications, although newer technologies that burn wood pellets are automated and are low maintenance. Smaller technologies often burn wood pellets due to their energy density, which is higher than wood chips and reduces storage requirements and transportation costs. Wood pellets provide a more standardized product when compared with wood chips (reducing the level of quality control), and also provide ease of handling and storage and consistent heating. Many of these systems are also capable of

[5] U.S. Department of the Interior, Bureau of Land Management.

burning small wood chips, which can be an advantage depending on fuel availability and pricing in the region.

In addition to claiming boiler efficiency up to 90% efficiency, the vendor also claims to have emissions comparable to those of oil or gas burning systems.

Table 2 below illustrates key parameters regarding the boiler system and its fuel requirements.

Table 2: Boiler Feed Pipe and Bucket Test

Description	Value	Units
Full load output	1,000,000	BTUs per hour
Partial load output	256,000	BTUs per hour
Boiler efficiency at full load	85 - 90	percent
Boiler operating temperature	140 - 210	°F
Minimum return water temperature	135	°F
Furnace exhaust temperature (full load)	390	°F
Furnace exhaust temperature (partial load)	250	°F
Maximum wood chip size	1	inches
Maximum fuel moisture	30	percent

D. TECHNOLOGY DEPLOYMENT

Prior to this project, the building had an outdated and inefficient steam heating system implemented in 1964. This entire heating system was replaced as part of this project. The steam distribution system and all piping were removed and replaced with an energy efficient hot water heating system. The biomass boiler was installed as part of the demonstration project. An oil-fired boiler serves as a backup heating system. The schematic in Figure 4, below, shows the new boiler system (indicated by arrow) and the piping interconnection to the water distribution system.

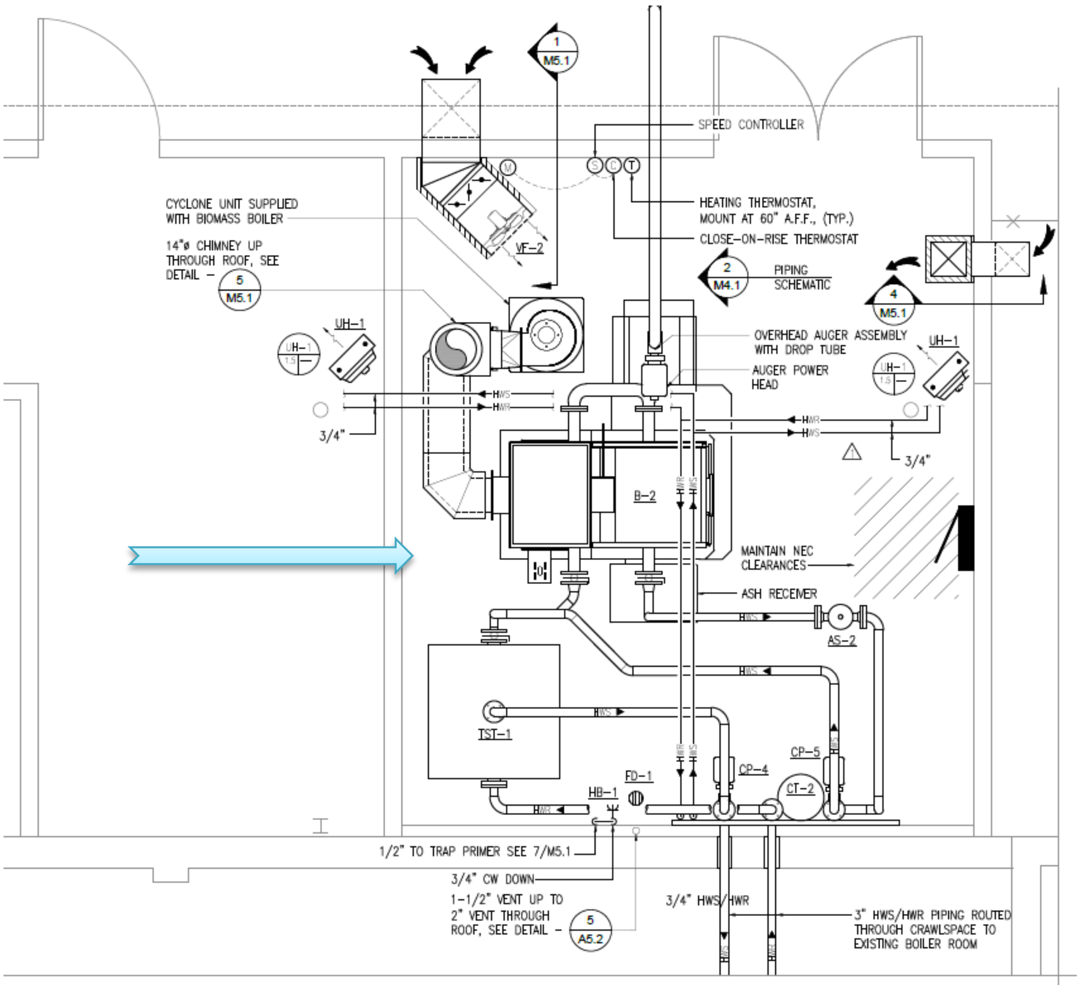


Figure 4: Ketchikan heating system schematic

E. TEST PLAN

The goal of the measurement and verification was to calculate the efficiency of the unit during operation to verify the vendor's claims and to help assess the technology's economic viability, effectiveness, and suitability for further deployment. It should be noted that typically boilers are designed for their best efficiency at or near full load conditions. It is not always practical to perform efficiency testing at full loads if the demand for thermal energy is lower at the time of testing. This was the case for the test performed and it is understood that lower efficiencies may be seen at these lower loads. The percent load at which the system was operating during the test was measured to be about 45%, due to a combination of mild weather and the fact that the boiler system was oversized.

Solid fuel systems present challenges for efficiency testing. Typical American Society of Mechanical Engineers (ASME) protocol—the standard protocol for this industry—allows for two methods of testing. One is to measure the useable heat output and all of the energy losses from the system. The total heat input to the system is summed and the efficiency is the useful heat output divided by the heat input. The other method also involves measuring the useful heat output but requires that the total heat input from the fuel be measured. The efficiency is still determined by dividing the useful heat output by the total heat input, which in this case, is the heat in the fuel. The latter is the method used for this analysis. Although it can be difficult to accurately measure solid fuel flow, it is more difficult and costly to measure all of the system heat losses and would require more instrumentation for the measurement of flue gas flow and its constituents.

The basic equations used for determining efficiency are shown below. The heat input is the heat that is extracted from the wood pellet fuel that is used.

$$\text{efficiency} = \frac{\text{useful energy out}}{\text{heat input}}$$

$$\text{efficiency} = \frac{\text{heat added to water}}{\text{heat in wood pellets}}$$

$$\text{efficiency} = \frac{(h_{\text{water out}} - h_{\text{water in}}) \times \text{water flow}}{\text{pellet flow} \times \text{pellet heating value}}$$

h = enthalpy at temperature (^{o}F)

Water flow in lb/hr – (gpm / 7.48 lb/ft3 x 60 x density at T_{avg})

Pellet flow – lb/hr – (minutes feeding x feed rate in lb/min) x 60

Pellet HHV – btu/lb from sample analysis

Figure 5: Efficiency equations

The key challenges are to test the heat that is transferred to the water and the amount of heat that is supplied to the boiler via the wood pellets. In both cases, it is necessary to know the heat of the medium in BTUs per pound and the flow rate in pounds per hour. Multiplying the two provides BTUs per hour. The BTUs per hour entering the water, divided by the BTUs per hour coming in as pellets, equals the overall system efficiency. The difference is primarily the heat that goes out the stack in the flue gas along with other minor heat losses.

The testing period lasted a total of 8 hours and 15 minutes. The testing data and results are summarized in Appendix A.

The boiler efficiency listed is 85% to 90%. Additionally, the maximum fuel moisture content allowed by the vendor fuel specification is listed at 30%. The moisture content in the wood pellets was much lower at 4.6%. The drier fuel aids performance and will result in a higher efficiency. Achieving the stated efficiencies with wetter fuel would have been more challenging, although dry pellets will be used in most or all applications, negating the need to perform further testing for this variance. If wood chips are to be considered at another site, however, performance testing should be conducted using the specific fuel size and parameters for the fuel under consideration; boilers perform differently when operated under different fuels.

As mentioned earlier, the efficiency calculation requires that two heat flows are established: the energy coming in as wood pellets and the flow of heat captured in the hot water. The heating value of the wood pellets was determined by sending a fuel sample to a laboratory for analysis. The results of the test show the heating value of the pellets in BTUs per pound. Although only a small sample of the total fuel stream is taken, the heating value of dry wood pellets is fairly consistent. The laboratory test results for the wood pellets are shown below in Table 3.

Table 3: Wood Pellet Lab Analysis Results

Reporting Basis	As Rec'd	Dry	Air Dry
Proximate (%)			
Moisture	4.59	0.00	4.59
Ash	0.25	0.26	0.25
Volatile	81.81	85.75	81.81
Fixed C	13.35	13.99	13.35
Total	100.00	100.00	100.00
Sulfur	0.014	0.015	0.014
BTU/lb (HHV)	8,147	8,539	8,147
Ultimate (%)			
Moisture	4.59	0.00	4.59
Carbon	53.93	56.52	53.93
Hydrogen	5.37	5.62	5.37
Nitrogen	0.04	0.04	0.04
Sulfur	0.01	0.01	0.01
Ash	0.25	0.26	0.25
Oxygen*	35.81	37.55	35.81
Total	100.00	100.00	100.00

* Oxygen by difference

Wood Pellet Flow Rate: To calculate the total amount of fuel consumed in the boiler during the test period, researchers needed to know the flow rate of the pellets during transfer of pellets from the silo to the fuel bin, as well as the amount of time that the conveyor was operating. To measure the operating flow rate, the white downspout shown in Figure 6, below, was detached and pellets were captured in a bucket (bucket test). A stopwatch was used to measure the seconds of operation and a scale was used to weight the pellets in the bucket (Figure 7).

Figure 6: Boiler feed pipe

Figure 7: Test bucket

The flow of fuel was 30.625 pounds in 30 seconds, yielding a flow rate of 61.25 pounds per minute. During the test, the amount of time that the conveyor was operational was measured in seconds and the total time of operation equaled 8.77 minutes. Therefore, the 61.25 pounds per minute feed rate times a total feed time of 8.77 minutes yields a total fuel input of 537 pounds of wood pellets during the testing period of 8 hours and 15 minutes.

Water Flow Rate: To calculate the amount of useful heat obtained from the boiler, the water flow rate was measured. A "bucket test" is not useful here, so an ultrasonic flow instrument was used to measure the volumetric flow in the piping and readings were recorded periodically throughout the test. Given that the pump was not variable speed and there was not automated valve modulation in the system, the water flow rate was fairly constant at about 98.5 gallons per minute.

F. INSTRUMENTATION PLAN

The instrument accuracy for the application involved was listed at plus or minus 1.0 %. The instrument and its location are shown below.

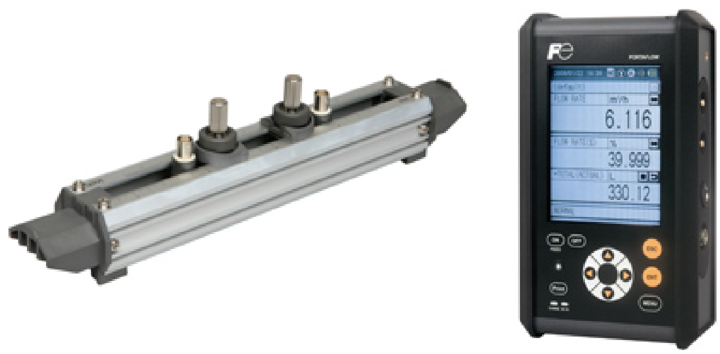


Figure 8: Water flow measurement instrument

Figure 9: Water flow measurement location

Existing temperature gauges were located at the point of water entry into the boiler and at the boiler water exit. Both of these temperatures were measured every 15 minutes during the test and recorded. The heat content of the water in and out was found by using data from steam tables that show the enthalpy for water at a specific temperature. The enthalpies for the cold and hot water were recorded for every 15-minute data point and used to calculate the amount of heat difference between the cold water and the hot water. Multiplying the flow rate in pounds per hour by the difference in enthalpies (BTUs per pound) provides the BTUs per hour that was transferred from the boiler to the water as it circulated through the system.

V. Results

A. TESTING CHALLENGES

The greatest challenge for this test was to get an accurate flow rate for the pellet fuel. It is not possible to measure the fuel as it goes into the combustion chamber, so it is necessary to measure the quantity of fuel going into the fuel bin. The methodology adopted was to measure the pellet flow rate while the transfer conveyor from the silo was operating. If the total time of operation is known during the test period, an estimate of the total wood flow from the silo can be made. However, the transfer conveyor, turns at a constant speed and the variance in the pellet flow rate was minimal during the fuel bin feeding cycle.

Potential error could be realized in the difference in the hopper level, if any, between the start of the test and the end of testing. In other words, if the test started with a full hopper and ended with an empty hopper, the amount of fuel between the high and low level sensors would need to be determined. To avoid this potential for error, the test was started with the hopper at its low point just as the feed cycle began. Then, it was ended just prior to another feed cycle beginning so that no fuel bin variation calculations needed to be done.

Another smaller challenge was to find a suitable location for the water flow measurement. It must be in a location where there is a reasonably straight run of pipe (for instrument accuracy), it must capture the full water flow without any prior tees that may bleed off or add flow, and it must be reasonably accessible. The researchers needed to remove a section of new insulation that was complete with labeling, causing some concern to the plant staff due to the potential adverse impact on operations. The team took care to leave the testing site in the same condition as prior to testing.

B. TECHNOLOGY PERFORMANCE

The technology implemented at this site is performing well both from an efficiency standpoint and an operational one. The boiler does not require a lot of tending, cleaning or repair. It runs on an automated basis and has sophisticated controls to maintain efficient operation under varying circumstances. The test results are shown below in Table 4.

Table 4: Test Results

Description	Value	Units
Test length	8.25	hours
Heat to water	3,711,968	BTUs during test
Avg heat to water	449,935	BTUs per hour
Pellet feed	537	pounds during test
Pellet HHV	8,147	BTUs per pound
Pellet heat input during test	4,335,574	BTUs
Avg Pellet heat input	525,524	BTUs/hour
Efficiency	85.6	%
Percentage of full load	45	%

As mentioned earlier, the vendor's claim for 85% to 90% efficiency is typically assessed at full load operation. As noted above, the units were run at an average of 45% load during the testing. However, the boiler operated within the stated range and would most likely have performed even better if the researchers had the opportunity to test it at full load, because full load is where the optimum design is targeted. Given these conditions, this technology performed well and within the expected efficiency range.

C. PAYBACK

The payback for this installation should not be calculated on the total $4.7 million cost of the project. The aging steam distribution system at this location was replaced at a substantial cost as part of this overall demonstration project. Replacement of the steam distribution system was independent to the work described herein. This evaluation was only concerned with the heat generation system and not the heat distribution system. A full breakdown of the project costs was not available for review, so the cost for the boiler system alone was estimated based on preliminary project budgeting that was available. The estimate total was $450,000, and it includes both the cost of materials and the installation of the boiler.

The payback for this project is extremely long due to the fact that the system capacity factor is only about 13%. The boiler is capable of generating 1 million BTUs per hour. Over the course of a year, that equates to 8,760 million BTUs. The boiler actually burned 83 tons of pellets in 2011. At a pellet heating value of 8,147 BTU/pound, 83 tons of pellets equals 1,352 million BTUs for the year. Using a boiler efficiency of 85%, the annual heat output from the boiler for 2011 is estimated at 1,150 million BTUs. This means that 1,150 million BTUs of useful heat were generated by a system that could theoretically generate 8,760 million BTUs in a year, or 13% of its full capacity. This is a rough estimate as assumptions had to be made regarding the starting and ending silo fuel level, but the capacity of the system utilized is still very low, regardless. Since there was a large amount of capital expended for a system that is often idle or at low load, the payback is high at approximately 30 years.[6] Additionally, the payback is calculated using the most current price for pellets in the area, which is approximately $250 per ton, according to plant personnel.

Sizing of the unit is important. The 13% capacity factor means that a smaller unit may have been implemented. The unit is often sized large enough to supply the peak amount of heat required if there is no other heat source. Because the Ketchikan site has oil-fired capabilities, the unit could have been sized smaller, using oil to assist in meeting peak demand periods. Appropriate sizing is a consideration that needs further analysis in future deployment efforts. A typical rule of thumb is to design the system output for 60% of the peak load. A higher percentage is probably warranted in areas that have a flatter heating load profile. A review of each building load profile should be done to optimize the system sizing for maximum savings in identifying potential candidate locations for biomass boiler system installations.

D. KEY CONSIDERATIONS

A couple of key considerations greatly affect the economics of this type of installation. The necessity for implementation at more remote locations affects the overall project costs and the costs for delivering fuel to the site.

Project Costs: For buildings that already have a hot water heating system, the costs will be much less than those at the Ketchikan Federal Building since they would not need to replace the steam distribution piping system at great expense. The key economic factors will be the current cost of fuel oil (assumes no natural gas available), the delivered cost of wood pellets, and the amount of heating required annually at the facility.

Table 5 below shows the estimated costs for a biomass heating system for future applications using cost data from the Ketchikan project. A transfer conveyor was included but no money is available for a new building that could be required to house the boiler. In many cases, this will not be necessary as there is room in existing buildings to house the new system. Where space is not available, another $40,000 to $50,000 may be required for this structure.

[6] Assuming a system cost of $450,000

Table 5: Estimated Costs for 1,000,000 BTU rated Biomass Boiler and Related Components

Mechanical	Equipment
Biomass Boiler	$130,000
Silo	$25,000
Pellet conveyor	$4,000
Mechanical/Electrical	$4,000
Piping, insulation, integration	$10,000
Permits	$5,000
Startup/commissioning	$15,000
Subtotal	**$193,000**
	Soft Costs
	Initial Estimate
General Contractor Overhead, Profit & Bonds	$9,700
GC Overhead, Profit & Bonds	$19,300
Design Fee	$12,600
Construction Contingency	$9,800
Construction Management / Meals & Incidentals Fees	$15,600
Total	**$260,000**

It is assumed that an existing building's designated utilities area can accommodate a small pellet boiler. For the Ketchikan installation, the footprint required for the system was very small. Given the size of the project, the costs associated with constructing a new addition to locate the boiler would be considerable.

The capital costs can be difficult to estimate since the best locations for these units are often in more remote areas. The construction costs for remote areas usually carry "multipliers" due to the complications associated with shipping, construction, and commissioning of equipment.

Each potential project will have a set of unique characteristics that must be examined. If the remote location contingencies shown above are removed, a cost estimate of approximately $450,000 is assumed for a system with a heat output of 1 million BTUs per hour.

To perform a preliminary screening for a large number of buildings, a simple payback model can be set up to determine, in rough terms, what project parameters are necessary to make the implementation of a biomass boiler cost effective. This tool can be used to prioritize potential projects for further analysis. For projects that show potential, further analysis is required using a more sophisticated economic model and better defined inputs.

In order to create the simple payback model, the following key factors should be known for the facility:

1. Total annual heat currently supplied by fuel oil
2. Cost of fuel oil

3. Estimated delivered cost of wood pellets
4. Logistics for installation of boiler equipment

Fuel Delivery Costs: In assessing numerous potential sites for biomass, the proximity to a pellet manufacturer is a key factor. A current rule of thumb is that transportation costs add about $0.15 per ton-mile. For example, if the pellet price was $150 per ton at the mill, and the mill was 100 miles away, the delivery would cost another $15 per ton, increasing the price to $165 per ton. For every 100 miles of travel distance, the fuel price would go up about 10%. This depends on the area and the local fuel prices. If the project is remote, bad roads and high fuel prices could double the transportation cost.

VI. Summary Findings and Conclusions

A. OVERALL TECHNOLOGY ASSESSMENT AT DEMONSTRATION FACILITY

The foremost goal of this demonstration was to show that a biomass boiler system can be installed in an existing building in a turnkey fashion with reliable performance. In this project, GSA installed the biomass boiler system at the Ketchikan Federal Building, and then NREL researchers assessed the installation and technology after it had ample running time. The biomass system works well, needs very little maintenance or attention of any kind, and performs well within the efficiencies put forth by the vendor. These biomass hot water heating systems are efficient, clean burning, and provide a reliable source of renewable energy.

The second aspect of the project was to take the lessons learned from this single installation and use them to assess additional deployment potential at other GSA facilities. Information from this effort will help discern where this technology would be most appropriate while illustrating the advantages and disadvantages of utilizing it in other GSA buildings.

B. BEST PRACTICE

This technology does not necessarily represent a best practice in all cases. It is a mature, efficient and appropriate technology for buildings that:

- Have a substantial heating load and an extended heating season relative to the average
- Are located where natural gas is expensive or not available
- Have a hot water heating system rather than a steam system
- Are located in close proximity to a biomass resource.

Where low cost natural gas is available, a biomass system would not make economic sense.

C. BARRIERS AND ENABLERS TO ADOPTION

The barriers to a larger scale deployment of this technology are economic. The technology is proven and reliable throughout industry and this testing verified efficiency and operation claims by the vendor. If biomass prices come down or the alternatives become more expensive, or both, this technology should be reconsidered in areas that might not have been deemed economical at one time. The ease of operation, low emissions, and high efficiency make this technology acceptable with regard to all technical aspects.

D. DEPLOYMENT

While this technology is potentially applicable to any building with hydronic heating, it does not offer a reasonable payback where steam systems must be replaced with hot water systems. Generating steam with biomass on a small scale is feasible, although hot water systems are more common and less expensive. Deployment economics vary from building to building depending primarily on the size of the biomass system, the hours of operation throughout the year, fuel costs, and the proximity of the biomass fuel source. Also, the energy savings due to the difference in efficiencies between the old and new technologies is an advantage.

To screen a large number of buildings in GSA's inventory for their potential applicability, a "threshold" payback should be chosen and the following key variables entered into the simple payback formula. Initial steps that could eliminate many of the facilities as unsuitable candidates would be to identify facilities that:

1. Currently use natural gas for heating (could be rare exceptions)
2. Have a steam heating system in lieu of hot water (very large facilities could entertain a steam system).

This information can be gleaned from the GSA Energy Usage and Analysis System and should reduce the list substantially. Secondly, the payback can be calculated for the remainder of the facilities. This information will help identify in a short list those facilities that have a reasonably good chance of benefitting from a biomass heating system. The following parameters should then be applied to analyze the list further:

1. Total annual heat currently supplied by fuel oil
2. Cost of fuel oil
3. Estimated delivered cost of wood pellets
4. Evaluation of space availability at facilities for installation of a biomass boiler system
5. Evaluation of additional construction activities required to add adequate space for the biomass boiler system, as well as projected costs.

The first two items can be extracted from the GSA Energy Usage and Analysis System. The third item is more difficult. Data exists showing locations of pellet mills in the United States and some simple mapping efforts could provide mileage estimates from each building to the closest pellet supplier. Regional pellet pricing could be used at this point or calls could be made to suppliers to ascertain more accurate fuel supply and delivery prices.

Additionally, the short list of facilities should be analyzed for more specific parameters unique to the site and the facility. One example would be the amount of space available to install a biomass system or whether there is a need to construct additional building space.

Biomass systems could then be implemented starting with facilities that offer the best economics. Each facility would need to be individually analyzed and assessments made with regard to the specifics of the building, the reliability of the fuel supplier, shipping logistics, and other factors.

It should be noted that the cost of wood pellet fuel was estimated to be half the cost of heating oil and wood chip fuel was one quarter the cost of heating oil. Although the cost of wood chips is less than wood pellets, the capital cost of the wood chip storage and handling system would be significantly more expensive than the pellet fuel option. The wood chip storage and handling system is more expensive because it requires a larger, more robust space to store the lower density, irregularly shaped wood chips, and it would have to be custom designed to accommodate a sufficient supply to fuel the biomass system. Pellet fuel systems are often selected because the pellets can be stored in a standard agricultural type silo and fed to the boiler in a 5 in.-diameter flexible auger at a much lower installed cost.

E. MARKET POTENTIAL WITHIN THE GSA PORTFOLIO

This type of technology is cost efficient in a finite number of applications. As previously discussed, it must be located where there is a hot water heating system already in place, in new facilities under development, where low-cost natural gas is not available, and in cold climate locations.

These sites can be identified using the GSA Energy Usage and Analysis System. Below are maps showing the locations of GSA buildings that use heating oil. The blue markers show buildings that use heating oil only and the orange markers indicate that heating oil is used in conjunction with some other fuel.

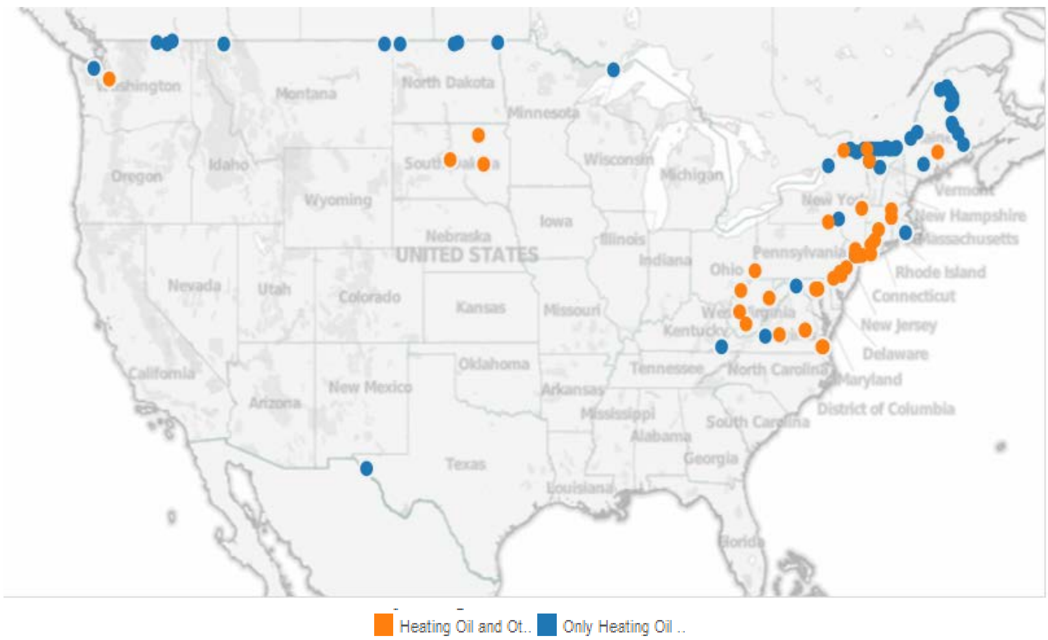


Figure 10: GSA buildings using heating oil

Source: Derek Przybylo, GSA

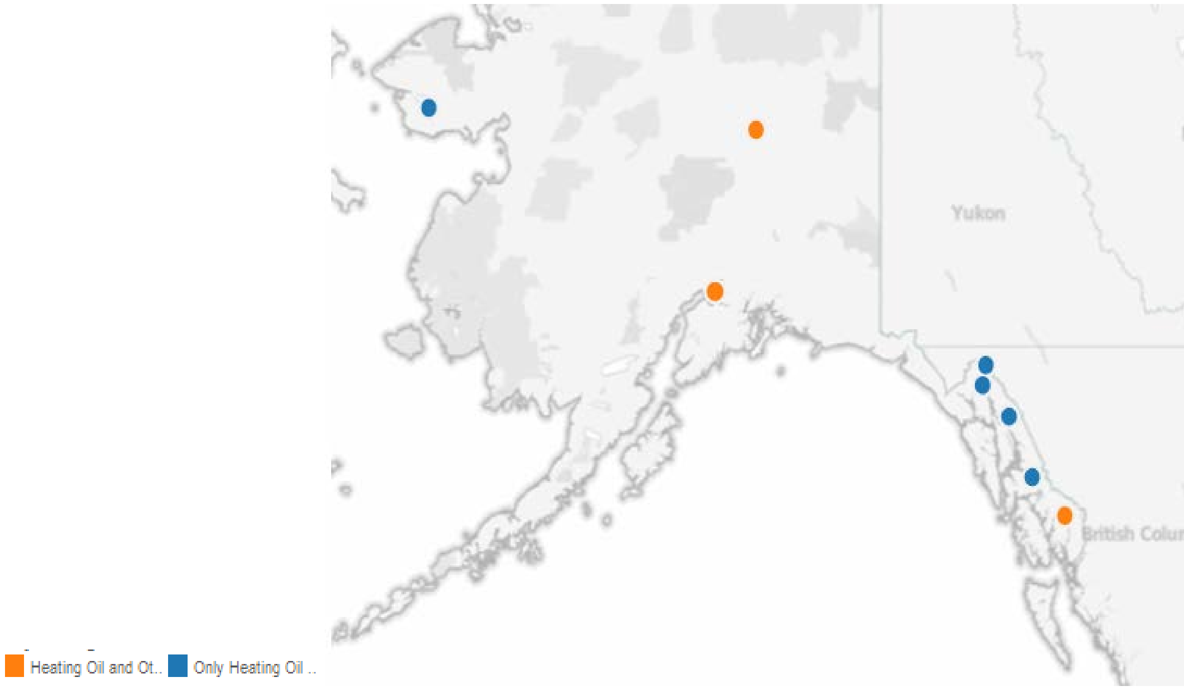
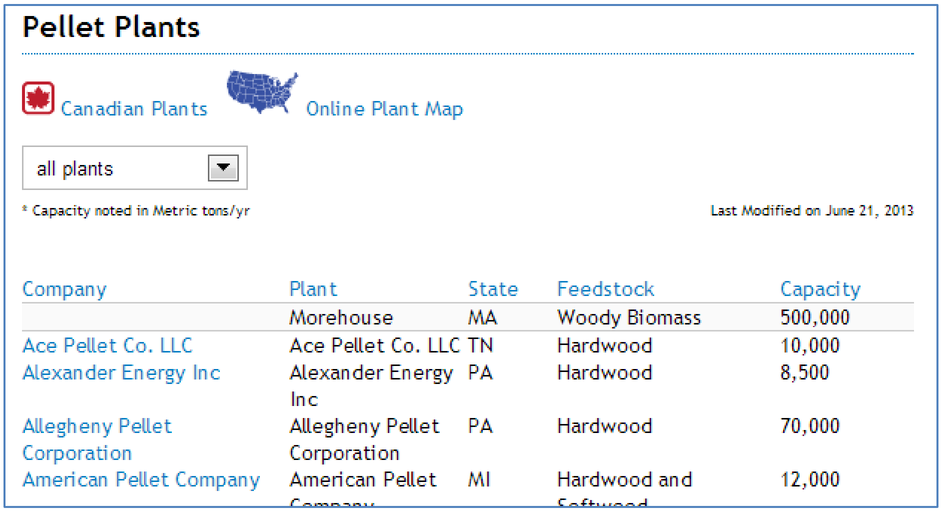


Figure 11: GSA buildings (Alaska) using heating oil

Source: Derek Przybylo, GSA

Replacing the heating oil used by these buildings could be economical depending on the heating oil price, the cost to get wood pellets to the site and the size of the heating load at the building. The GSA Energy Usage and Analysis System provides information on how much of each fuel is consumed for every month of the year. Additionally, the cost for the fuel in dollars per million BTU is listed for every month. Using this data, a simple payback analysis can be performed once the cost for biomass fuel is ascertained, as well as any ancillary required construction activity.

Data is available showing the location of sawmills in the United States and Canada that sell wood pellets, but pricing information must be obtained on a case-by-case basis since good cost data is not readily available. *Biomass Magazine* has an online resource for mill location and size that is available to the public. For a list of pellet producers, the URL is http://biomassmagazine.com/plants/listplants/pellet/US. The type of information included is shown in Figure 12 below:



Pellet Plants

Canadian Plants   Online Plant Map

all plants

* Capacity noted in Metric tons/yr   Last Modified on June 21, 2013

Company	Plant	State	Feedstock	Capacity
	Morehouse	MA	Woody Biomass	500,000
Ace Pellet Co. LLC	Ace Pellet Co. LLC	TN	Hardwood	10,000
Alexander Energy Inc	Alexander Energy Inc	PA	Hardwood	8,500
Allegheny Pellet Corporation	Allegheny Pellet Corporation	PA	Hardwood	70,000
American Pellet Company	American Pellet Company	MI	Hardwood and Softwood	12,000

Figure 12: Biomass Magazine Online pellet mill database sample

Source: Biomass Magazine (http://biomassmagazine.com/plants/listplants/pellet/US)

A graphical representation is located at http://biomassmagazine.com/plants/map/pellet. A sample image is shown below:

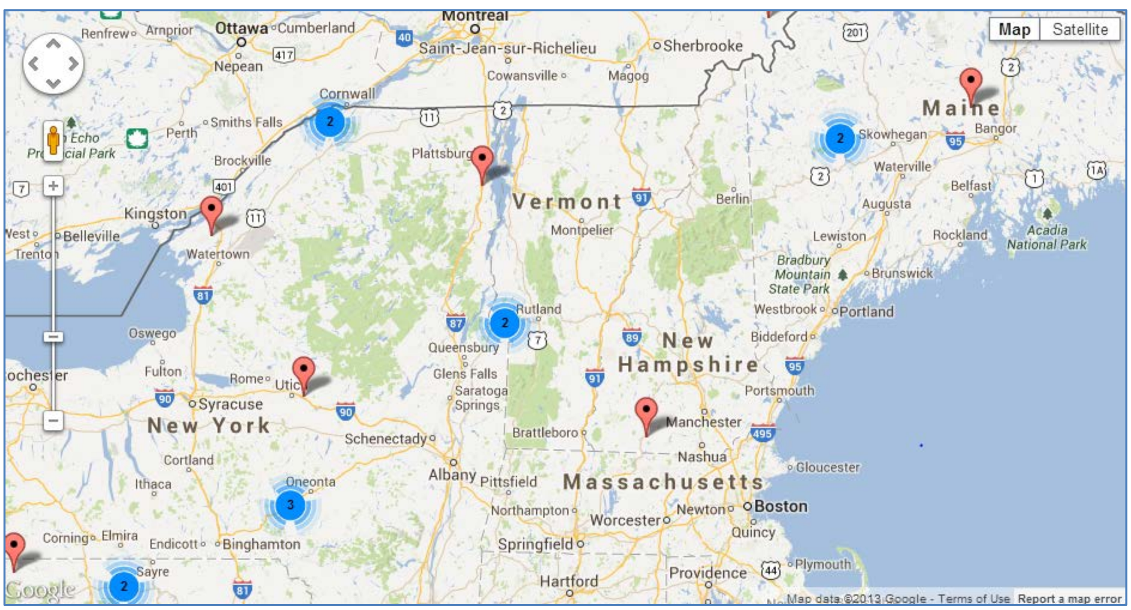


Figure 13: Biomass Magazine Online pellet mill location map

Source: Biomass Magazine (http://biomassmagazine.com/plants/map/pellet)

Matching the locations of the candidate GSA building with the locations of pellet mills would be a useful step for targeting facilities that could benefit from a biomass heating system. Contacting these mills for bulk pellet pricing would be required, although the chart below shows average “bag” pellet prices across the United States. The cost of transportation would need to be added to the prices shown below as they are for the price at the mill. Transportation costs vary, but a rule of thumb for this cost is typically between $0.08 and $0.15 per ton/mile.

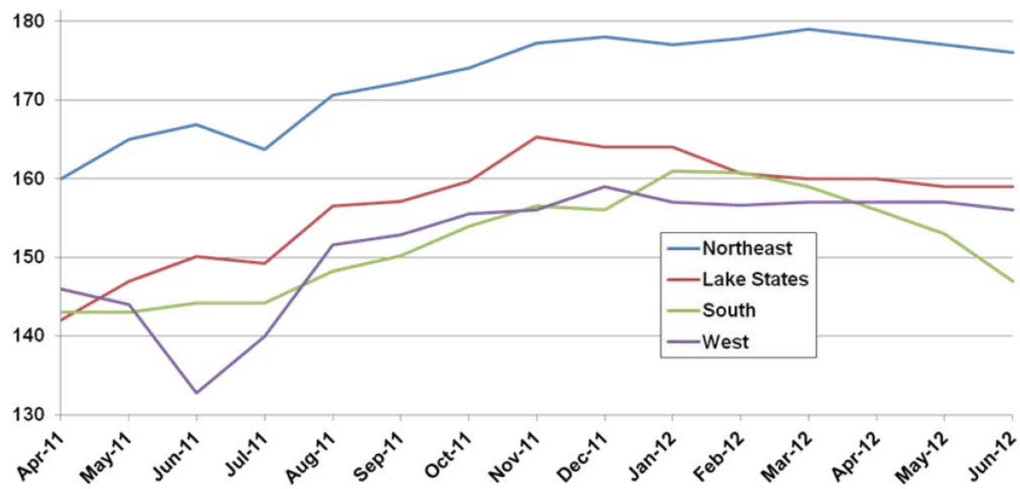


Figure 14: U.S. regional pellet cost[7]

The map/list of potential building candidates can be compared to the map of pellet manufacturers to understand where the most optimal locations are for further investigation. A "delivered" cost could be estimated quickly by using the regional cost estimates and rule of thumb transportation costs.

For illustration purposes, the tables below show the simple payback in years for the installation of biomass heating systems given various parameters. For the analysis, the estimated cost of the 1,000,000 BTU/hr system ($260,000) was used and the other systems sizes were estimated from this value.

When estimating costs for systems with different capacities, an algorithm is used to account for the nonlinear relationship between capacity and cost. In other words, a system with twice the capacity does not cost twice as much. The estimates for other sizes were approximated using the ratio of the system size to the base case, raised to the power of 0.65, multiplied times $260,000. This is commonly known as the "six tenths" rule although 0.65 is used for conservatism[8]. This is an industry accepted form of estimation, but is relatively rough and real cost quotes should be obtained when analyzing potential projects. For Table 6 below, $26.19 per MMBtu was used for the diesel fuel cost since this was the average cost at Ketchikan in 2011. For future projects, it was assumed that about 75% of the full capacity of the system was utilized during the life of the project. Table 6 shows the paybacks as they vary with the cost of pellets for a 4,000,000 BTU per hour system.

[7] Pellet Manufacturing Survey by RISI and PFI.

[8] "So You Think You're an Estimator." Dysert, Larry R. 2005 AACE International Transactions EST.01.

Table 6: Sample Payback Calculations[9]

Average Diesel Price	**$3.63**	per gallon
Average Diesel Price	**$26.19**	per MMBTU
Capacity Factor	**75%**	

Pellet Cost	**$400**	**$350**	**$300**	**$250**	**$200**	$/MMBtu
Pellet Fuel Price	$24.55	$21.48	$18.41	$15.34	$12.27	per MMBtu
Fuel Price Difference (pellets vs. diesel)	$1.64	$4.71	$7.78	$10.85	$13.92	per MMBtu
System Size	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	BTU/hr
Heat Used	26,280	26,280	26,280	26,280	26,280	MMBtu/yr
Biomass System Cost	$640,195	$640,195	$640,195	$640,195	$640,195	
Annual Savings	$43,127	$123,771	$204,414	$285,057	$365,700	
Simple Payback	**14.8**	**5.2**	**3.1**	**2.2**	**1.8**	

If a 50% capacity factor is used in lieu of a 75% capacity factor, the payback period increases by about 30%.

Table 7 shows the reduction in payback period with a diesel fuel price of $30 per MMBTU. This is an increase of almost 13% in diesel fuel costs and the payback period is reduced substantially.

Table 7: Sample Payback Calculations - $30/MMBTU Diesel Price[10]

Diesel Price	**$30.00**	per MMBTU
Capacity Factor	**75%**	

Pellet Cost	**$400**	**$350**	**$300**	**$250**	**$200**	$/mmBTU
Pellet Fuel Price	$24.55	$21.48	$18.41	$15.34	$12.27	
Fuel Price Difference	$5.45	$8.52	$11.59	$14.66	$17.73	
System Size	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	BTU/hr
Heat Used	26,280	26,280	26,280	26,280	26,280	mmBTU/yr
Biomass System Cost	$640,195	$640,195	$640,195	$640,195	$640,195	
Annual Savings	$143,255	$223,898	$304,541	$385,184	$465,827	
Simple Payback	**4.5**	**2.9**	**2.1**	**1.7**	**1.4**	

The payback period is also very sensitive to the size of the system. Larger systems fare better due to economies of scale.

[9] 1 gallon of diesel fuel = 138,690 Btu, per the Energy Information Administration (EIA).

[10] 1 gallon of diesel fuel = 138,690 Btu, per the Energy Information Administration (EIA).

Using the initial values from Table 7 above, Table 8 below shows the estimated payback periods for varying system sizes along with changes in pellet pricing.

Table 8: Payback Period Variance by System Size and Pellet Cost

		Pellet Cost ($/ton)				
		$400	**$350**	**$300**	**$250**	**$200**
System Size (BTU/hr)	**500,000**	30.7	10.7	6.5	4.7	3.6
	1,000,000	24.1	8.4	5.1	3.6	2.8
	1,500,000	20.9	7.3	4.4	3.2	2.5
	2,000,000	18.9	6.6	4.0	2.9	2.2
	2,500,000	17.5	6.1	3.7	2.6	2.1
	3,000,000	16.4	5.7	3.5	2.5	1.9
	3,500,000	15.6	5.4	3.3	2.4	1.8
	4,000,000	14.8	5.2	3.1	2.2	1.8

These tables illustrate why the Ketchikan project does not have an attractive payback period. The capacity factor for the Ketchikan system is about 13%, meaning the biomass system is oversized. It also is a relatively small system, which shows that biomass heating systems will work best at locations with substantial loads. Smaller systems can work, but they rely more heavily on lower biomass fuel pricing and higher competitive heating oil costs.

Wood chips, pellets, and firewood are not tracked on energy exchanges or by the Energy Information Agency like other commodities, such as gas, coal or oil. A European exchange (North American pellets going to Europe) and this New Hampshire government site (http://www.nh.gov/oep/programs/energy/fuelprices.htm) are two resources for published prices for pellets.

VII. Appendices

A. TEST DATA

This section provides the raw data taken during testing. Data was recorded every 15 minutes during the eight hour testing period. The columns titled, "Enthalpy (BTU/lb)", "Flow (lb/hr)" and "Heat Output (BTU/hr) are calculated values. The table is used to calculate the boiler heat output using the boiler water flow and temperatures.

Test Data

	Feedwater						
	Blr in °F	Enthalpy BTU/lb	Blr Out °F	Enthalpy BTU/lb	Flow gpm	Flow lb/hr	Heat Output BTU/hr
8:00 AM	160	127.98	168	135.99	99.1	48,422	387,831
8:15 AM	160	127.98	168	135.99	98.9	48,324	387,049
8:30 AM	160	127.98	168	135.99	97.9	47,836	383,135
8:45 AM	158	125.98	168	135.99	97.0	47,412	474,629
9:00 AM	157	124.97	166	133.98	97.3	47,582	428,639
9:15 AM	156.5	124.47	166	133.98	98.5	48,173	458,059
9:30 AM	156	123.97	165	132.98	97.9	47,891	431,384
9:45 AM	156	123.97	164	131.98	98.2	48,046	384,672
10:00 AM	157	124.97	166	133.98	98.7	48,267	434,806
10:15 AM	156	123.97	164	131.98	98.5	48,193	385,847
10:30 AM	156.5	124.47	162	129.98	99.0	48,449	266,663
10:45 AM	154.2	122.17	164	131.98	99.1	48,500	475,644
11:00 AM	158	125.98	168	135.99	99.1	48,438	484,905
11:15 AM	155.1	123.07	165	132.98	98.5	48,192	477,481
11:30 AM	155.8	123.77	164.5	132.48	98.4	48,141	419,168
11:45 AM	157.8	125.77	165	132.98	98.7	48,268	347,852
12:00 PM	155.8	123.77	165	132.98	99.8	48,807	449,400
12:15 PM	156.9	124.87	166	133.98	98.4	48,118	438,279
12:30 PM	156.7	124.67	165	132.98	96.9	47,396	393,735
12:45 PM	156.2	124.17	166	133.98	96.9	47,375	464,691
1:00 PM	156.0	123.97	165	132.98	99.5	48,656	438,276
1:15 PM	158.2	126.18	166	133.98	99.2	48,495	378,634
1:30 PM	156.4	124.37	164	131.98	97.2	47,544	361,632
1:45 PM	154.0	121.97	165	132.98	99.0	48,445	533,298
2:00 PM	154.8	122.77	165	132.98	99.6	48,718	497,319
2:15 PM	157.8	125.77	170	137.99	99.4	48,570	593,251
2:30 PM	158.4	126.38	166	133.98	99.1	48,451	368,596
2:45 PM	155.5	123.47	165	132.98	98.3	48,091	457,237
3:00 PM	159.8	127.78	169	136.99	98.7	48,220	444,164
3:15 PM	158.3	126.28	168	135.99	96.1	46,969	456,103
3:30 PM	157.2	125.17	168	135.99	96.3	47,076	508,949
3:45 PM	156.3	124.27	166	133.98	97.2	47,539	461,541
4:00 PM	156.1	124.07	166	133.98	98.2	48,029	475,915
4:15 PM	156.7	124.67	167	134.98	99.0	48,408	499,084

B. GLOSSARY

ASME	The American Society of Mechanical Engineers
BTU	British thermal unit
CM/M&I	Construction Management/Meals and Incidentals
EIA	Energy Information Agency
GC	General Contractor
GPG	Green Proving Ground
GSA	General Services Administration
HHV	Higher heating value. The gross heat of combustion expressed in British thermal units per pound.
hr	hour
lb	pound
MMBTU	1 million BTU
NREL	National Renewable Energy Laboratory
TRL	Technology Readiness Level