

# Chalkyitsik Village Council

## Level Two Biomass Feasibility Study

**Alaska Wood Energy Associates**



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## SECTION 1

### 1.1 Goals and Objectives

The objective of this Level 2 Cost and Feasibility Study report is to document the progress and findings at this stage of the project. The scope of the project is to provide enough analysis to allow the village to determine if the project or projects included should proceed to investment grade studies, design, and eventual implementation. The Level 2 Study looks at both small district heating “mini” plants as well as individual building-level biomass boiler applications.

A mini plant for the purposes of this report is simply one or more boilers in a single building serving two or more buildings, by piping the heat from the plant to the buildings. The term “District Heating Plant” (DH Plant) denotes a larger plant, using chip-fired boilers, and generally serving five or more buildings. The location and size of the buildings in Chalkyitsik are such that no DH plant is feasible here; there is not enough economy of scale to support the high first costs associated with DH plants.

The study is complete based on current knowledge; the author of the study has been to Chalkyitsik twice for the purpose of doing site work for this study. Should the project progress to an investment grade audit, further site visits may be required. The study is based on data from the village, from the site visits, from the State, and other professionals with experience in bush Alaska. As additional information comes to light in the design phase, this is expected to result in changes to the savings and/or cost projections.

Some of the examples herein are taken from a similar analysis performed for Fort Yukon, which is currently 90 percent done with an investment grade study and more than 35 percent complete with design.

The work on this project is being done by Alaska Wood Energy Associates. This team consists of professionals from a number of different companies, representing various skill and knowledge sets. Greg Koontz of efour, PLLC, Seattle, WA, is performing the feasibility modeling and will also provide design services specific to the boilers and any DH plant.

Obviously, a primary concern for any biomass-fired plant is availability of the wood resources. This issue is the responsibility of Bill Wall, PhD of Sustainability, Inc. The means and methods of procuring the wood and processing it will be documented in detail elsewhere; they are summarized briefly in Section 2.4 below. For that reason, this report does not address biomass supply in the same level of detail as the heating systems.

The objective for the team and the village at this point is to use the study to choose a path forward into final design and construction; or, failing that, to determine under what conditions the projects would be moved forward. This final report documents the L2 feasibility study that has been completed.

## 1.2 Project Scale

In order to be successful, a DH plant must achieve a certain economy of scale. The capital costs involved are quite large, and so the savings to the village must be on the same scale in order to make economic sense. One of the reasons why a DH plant must be large to be feasible is that they are projected to run on wood chips, not stick-wood. This is primarily a function of boiler capacity, and the need for manual labor to feed stick fired boilers.

As shown below in several of the Figures, the largest stick-fired boiler being considered has a firing rate of 925 kBTU/h (thousands of BTU per hour). The largest chip-fired boiler AWEA recommends has a firing rate of 4,265 kBTU/h - over four and half times larger. Chip-fired boilers are automatically fed; stick-fired boilers are manually fed. One consideration is the manual labor required to fire five stick-fired boilers four times a day each in cold weather.

At the same time, the equipment needed to harvest wood and chip it to feed a chip-fired DH plant represents a significant capital cost. Experience has shown that unless a village has about six to eight large buildings (minimum) in a fairly tight cluster, a chip-fired DH plant is not economically feasible. It follows that if there is no DH Plant to use chips, then it is not feasible to make chips at all – so in villages with no feasible opportunity for a DH Plant, the study focuses solely on stick-fired boilers, as in Chalkyitsik.

***One new building has been added*** since the preliminary report (the new clinic, which is expected to be in place at the same time, or earlier than the boiler plant is built).

Chalkyitsik has at least seven larger buildings, and these have all been included in the study. These buildings exist in two clusters, of three and four buildings; the two clusters are separated by about one third of a mile – too far apart to economically connect with piping. The associated first cost, heat loss and pumping energy would be very detrimental to the economics of the project.

As a result, the study looks at each of the seven buildings separately, and then at three “mini-plants”. The seven buildings are 1) the school, 2) teacher housing, 3) the upper water treatment plant, 4) the washeteria/old clinic, 5) the tribal offices, 6) the store, and 7) the new clinic (planned, but not yet constructed).

The upper water treatment plant is included twice – once with recovered heat and once without. This building currently gets almost 100 percent of its heat from heat recovered off of the village engine generators.

In addition to the individual building analyses, three mini-plants are included: 1) School + teacher Housing + Upper Water Treatment, 2) Washeteria/Clinic + Tribal Offices + new clinic, and 3) Washeteria/Clinic + Tribal Offices + Store + new clinic.

It is assumed that the space that currently serves as a clinic will continue to be used, and thus must be heated to the same temperatures as is the case now.

### 1.3 Resource Assumptions

In order to compare all the mini plants and individual boilers on an equal basis, some base level assumptions about these costs had to be made and used in the performance / financial model. The assumptions shown in Figures 1.1 and 1.2 below are based on current estimates of recent fuel costs in the villages, plus projections of the cost of obtaining stick wood.

Oil Data / Elec Data		
heating oil heat content	134.0	kBTU/gal
heating oil density	7.1	lb/gal
sulfur content	500.0	ppm
sulfur emissions	0.0010	lb/gal
CO2 emissions	22.013	lb/gal
low cost (school, etc)	\$7.000	per gal
unit cost to power plant	\$7.000	per gal
high cost (to village)	\$7.000	per gal
oil to H plant	\$7.000	per gal
unit cost of recovered heat		per kBTU
cost of elec to village	\$0.960	per kWh
cost of elec to DH plant	\$0.960	per kWh

NOx and CO emissions are a function of the boiler

Figure 1.1. Base Level Oil / Electrical Assumptions

**The unit cost of oil** has been increased to \$7.00/gal since the preliminary report. The table lists four oil prices; this model is used in a number of villages, so it needs to be flexible. The “low cost” is used when some buildings in the village get a better price than others (such as schools in some villages). The “high cost” is what everyone else pays. The other two are the cost of oil to the DH plant (in case it is different still), and the cost to the power plant (in case they also get a different price). In this case, only one value was used, \$7.00 per gallon.

Biomass Unit Costs	
wood chips, per green ton	\$175
pellets, per ton	\$300
stick wood, per cord	\$300

Biomass Properties	
chips, useable BTU per lb	5,890
yield per acre, tons	20.00
useable kBTU per cord	16,632
yield per acre, tons	20.00

Figure 1.2. Base Level Wood Assumptions (chip/pellet data grayed out)

*The unit cost of cordwood* has been increased to \$300/cord since the preliminary report

The primary resources of concern in this study are the various energy sources, current and proposed. Because the systems involved are closed piping loops, water and sewer use is almost zero on an annual basis. Aside from filling and/or flushing the system, there is no water use and thus no sewer use.

The fuels of concern, then, are No. 1 oil and electrical energy (current costs), and stick wood (proposed costs), as seen in Figures 1.1 and 1.2. As will be seen in the following sections, even if this project is implemented, oil and electrical energy will still be required in the village.

It was noted that the upper water treatment plant benefited from “free” recovered heat from the village generators. In this study, that heat has been treated as free; that is, the power plant does not charge for the use of this recovered heat. If this is not the case, the charge for the recovered heat can be included in a revision to this study. This would obviously negatively affect the economics of any boiler plant serving the treatment plant.

Finally, figure 1.3 shows the properties of the stick wood that were used in the model. These tables show the mix of species expected to be harvested in the area and the expected moisture contents; this input is used to calculate the composite stick-wood properties.

INPUTS, stick wood	moisture content at:			% by weight
	burn	store	cut	
5 : W Spruce, logs	0.25	0.35	0.50	0.400
4 : B Spruce, logs	0.25	0.35	0.50	0.300
3 : Aspen, logs	0.25	0.35	0.50	0.300
:				
:				
checksum				1.000
<b>other variables</b>				
avg fuel storage temp	46.0	deg F		
avg absolute humidity	36.0	gr/lb		
avg excess O2	0.20			
avg air specific volume	12.9	cf/lb		
avg stack temp	375	deg F		

Composite Stick Wood Properties	
net useable heat	5,738 BTU/lb at burn MC
net useable heat	16,632 kBtu/cord
weight at storage MC	1.154 lb/lb at burn MC
weight at cut MC	1.500 lb/lb at burn MC
density as stacked logs	22.396 lb/cf at storage MC
density as cord wood	26.129 lb/cf at storage MC
combustion air req	5.778 lb/wet lb at burn MC
combustion air req	74.537 cf/wet lb at burn MC
CO2 formed	1.430 lb/wet lb at burn MC
SOx formed	0.001 lb/wet lb at burn MC
ash	0.022 lb/wet lb at burn MC
ash specific volume	0.004 cf/wet lb at burn MC
available harvest rate	20.000 tons/acre wet

note: NOx, CO, VOC, and PM emissions are a function of the boiler

Figure 1.3. Stick-wood Properties

#### 1.4 Financial Metrics

There are any number of financial metrics that can be employed to evaluate a project. Many of these require that the source and means of financing the project be known. Many require knowing the expected interest rate that money could be borrowed at, and even the rate of return the client would expect to achieve if they invested the capital elsewhere (not in the project).

In the case of potential projects in Chalkyitsik, much of this information is not known at this time. The exact funding mechanisms are not known. The in-kind participation of the village, if any, is not defined, and therefore the value of it cannot yet be determined. Finally, forward-looking interest rates are not very predictable at this point in time.

Since this study is not an investment grade study assumptions about all of the relevant financial variables do not seem justified. For all these reasons, this study has used a single financial metric to evaluate each potential heating plant – both as a stand-alone investment and as a way to compare different technologies and combinations of buildings.

Net simple payback (NSP) as used herein is defined simply as the implementation cost of the project divided by the value in dollars of the annual year-one energy savings. Year one savings are specified; it is assumed that resource rates will change year to year (or faster).

All financial summaries used in this study use NSP as the sole financial metric for evaluating each option. There are a number of variables, which do not factor into the NSP as defined herein; perhaps the two most relevant here are the labor cost and the maintenance cost.

It is not known how the plants would be manned. Stick-fired boilers require up to 12 loads of wood per day, manually fed, at peak load. However, in such cold weather, the operator(s) may choose to simply feed the boiler during the day, and let the oil-fired boilers take over at night.

The levels of unknowns regarding the amount of labor that would actually be applied to each plant makes estimating labor costs difficult at best. Similarly, judging the maintenance costs of the boiler plants in the harsh climate of the interior of Alaska presents an issue. The Garn boilers are very simple, with not much to break. Nevertheless, they have moving parts to maintain, and possibly fail.

Labor and maintenance costs are annual, and thus deduct directly from the energy savings (lengthening the NSP). The point being made above is simply that the range of possible values for annual labor and maintenance costs is so wide that they should not be used to make financial decisions as a part of this study. Instead, as the project is developed in each village, the decisions on boiler technology and plant size should go hand-in-hand with discussions of how the boilers will be operated and maintained so that the true cost can be determined prior to making the investment.

## 1.5 Level 2 Summary

A mathematical model was constructed to model the performance of the various mini plants and individual boilers in the village, and to compare their financial performance. The model is discussed in more detail in Section 4, and a sample of the calculations involved is shown in Appendix A. To date, it is not known for sure how this project would be financed, so the financial model does not include the cost of money.

At this point, as noted above, the key financial metric is net simple payback (NSP) at current costs. Figure 1.4 shows a summary of the results of the model using the Base Level resource assumptions.

Building Load and Oil Consumption		(1) area sf	stick wood payback	stick wood boilers (1)	est project cost	est annual savings	oil displaced gal/yr	annual harvest cords/yr acres		Oil L2 study gal
1	school	11,450	5.0 yrs	3	\$348,975	\$69,934	16,322	145.6	10.6	18,000
2	teacher housing	1,624	12.1 yrs	1	\$248,338	\$20,556	4,973	45.4	3.3	5,000
3	upper water treat	1,458	9.1 yrs	1	\$248,338	\$27,355	6,500	58.4	4.2	6,500
4	washeteria/old clinic	2,880	8.6 yrs	2	\$471,113	\$54,802	12,742	112.5	8.2	14,000
5	tribal offices	2,040	16.6 yrs	1	\$248,338	\$14,962	3,800	36.7	2.7	3,800
6	store	1,600	22.8 yrs	1	\$248,338	\$10,875	2,800	27.0	2.0	2,800
7	upper WT, with HR	1,458	160.7 yrs	1	\$248,338	\$1,545	501	4.4	0.3	600
8	new clinic	2,100	24.9 yrs	1	\$248,338	\$9,984	2,600	25.3	1.8	2,600
9	Sch, TH, WT (no HR)		5.2 yrs	3.3	\$639,721	\$124,124	28,875	255.8	18.5	29,500
10	Sch, TH, WT (w/ HR)		4.8 yrs	2.2	\$593,507	\$124,124	20,399	180.0	13.0	23,600
11	wash. Off, n clinic		5.1 yrs	3	\$410,172	\$80,524	18,699	165.8	12.0	20,400
12	wash, Off, store, n clinic		6.0 yrs	2.2	\$562,909	\$93,268	21,697	191.2	13.9	23,200

(1) stick wood boilers, 1 = Garn WHS 1500, 2 = Gran WHS 2000, 3 = Garn WHS 3200. If more than boiler is req., it is noted as "X.X" (2 boilers at X size)

Figure 1.4. Project Summary

Some of the paybacks are very long, and it can be seen that in all these cases, the boiler proposed is the smallest available; the Garn WHS 1500. These long paybacks indicate that the associated building is small, and does not consume much oil on an annual basis. Even with the smallest available boiler, the cost of a biomass boiler installation is significant. Unless there are substantial potential annual dollar savings in the form of oil displaced, a given building may not be able to support a biomass boiler installation.

The primary reason we group buildings into mini plants it is to improve the economics of the projects. In the table above, items 1 through 6 and item 8 are the seven individual buildings, modeled with the assumption that the water treatment plant is not getting recovered heat. Item 7 is the water treatment plant again, this time assuming it does get recovered heat. In item 7, the payback gets very long – with the recovered heat in place, the building uses almost no oil, so there are almost no dollar savings to offset the first cost.

Items 9 and 10 are the upper village mini-plant (item 9 assumes no heat recovery, item 10 includes heat recovery). Item 11 is a lower village mini plant with just the washeteria, new clinic and the tribal offices. Item 12 adds the store to the plant in item 11. Normally, adding the store would likely lower the payback – it is relatively large, and not far away. However, because the store does not have a boiler, hooking the building into the mini plant is more expensive than it would be otherwise.

One conclusion that is drawn from the study to date is that the projects are extremely sensitive to the cost of oil, and less so to the cost of wood and electrical energy. Another is that economy of scale is important to make these projects feasible.

All of the mini-plants are financially feasible. The two that make the most financial sense are in line 10 for the upper plant and line 12 for the lower plant. Each of these plants will displace the most amount of fuel oil and will payback in six years or under for the capital cots. The real issue is developing an for profit business structure that is sustainable and can get, 191 cords for the lower plant and 180 cords for the upper plant, of wood harvested, seasoned and fed into the boilers on an annual basis. These two

plants will displace 23,200 gallons of fuel in the lower plant and 23,600 gallons in the upper plant.

*Since the preliminary version of this report was submitted*, Garn, the recommended stick-fired boiler manufacturer, has begun to develop a new product. Informally, it is known as the “Garn in a box”. As the name implies, it is a Garn boiler that comes as a complete package. Currently, a Garn boiler requires a primary pump, a heat exchanger, and some piping and controls in order to operate, as well as separate electrical connections for each piece of equipment (the additional required piping and equipment beyond the heat exchanger is considered part of the distribution system, not part of the “boiler plant”). In the new configuration, Garn will pre-pipe and pre-wire all the parts and pieces that make up the “boiler plant”. In addition, the boiler and remainder of the plant will be enclosed in a container that is meant to act not only as the shipping container but the as the boiler “building” as well.

On site, the end-user need only construct a concrete slab, and bring the power and distribution piping to the slab. Once the Garn is placed on the slab by a lift truck or similar, the piping and power can be connected in a day or two at the most. They are also meant to be able to sit side-by-side with no clearance between. The only site-erected “building” required is an enclosed storage or lean-to for wood, and perhaps an enclosed walkway from the storage to the “boiler room” doors (for multiple-boiler applications).

Currently, Garn is planning to offer this package only in the WHS 2000 size. However, this could work very well for Chalkyitsik – that is the recommended boiler size for the two most likely mini-plants, items 10 and 12; each consists of two WHS 2000s.

The units are scheduled to go into construction in 2012. The estimated cost of the units is relatively high, compared to just buying the boiler. As more are made, the cost may come down. In the preliminary report, the cost estimate assumed that all Garn WHS 2000s were bought separately (as were the other sizes), and piped and wired on site. And, for now, this appears to be perhaps slightly less expensive. However, there are advantages to having much of the work done off-site. For this final report, therefore, all of the Garn WHS 2000s are assumed to be the pre-packaged models. The prices are higher; but the net simple paybacks are still short. Pricing the models this way allows the village the flexibility to purchase either variety of the boiler. By the time an investment grade study / concept design is done, more will be known about the “Garn in a box”, and this new information will help inform any future equipment decisions.

Section 3 below includes a discussion about Garn boilers, and the design considerations that apply to stick-fired boilers. All of that information is valid regardless of how the Garn boiler is configured or packaged.

## SECTION 2

### 2.1 Existing Field Conditions

At this time, there are seven buildings included in the study, in clusters of three and four buildings each. Each of these seven buildings has been evaluated for the installation of a dedicated biomass boiler, and each cluster of buildings has been evaluated for a “mini district heating plant”, where one or two biomass boilers located in a single building would serve two to four buildings. Heat from the boiler “plant” would be piped to each building served. Economy of scale is important in biomass boilers, so these mini-plants generally have a better payback than the dedicated building boilers, as the summary in Section 1 indicated.

The seven buildings included in the study at this time are: 1) the school, 2) teacher housing, 3) the upper water treatment plant, 4) the washeteria/clinic, 5) the tribal offices, 6) the store, and 7) the new clinic.

All of these buildings are currently served by boilers (the new clinic will be as well), except the store, which has a direct-vented Toyotomi, ductless forced air heater. An important consideration is that connecting a new external boiler to an existing one in a building is generally very simple (and thus relatively inexpensive). Even connecting to a building with an oil furnace can be easily done, by adding a heating coil in the furnace ductwork.

However, because the Toyotomi heater has no ductwork, converting the store to biomass heat would require a different method. It would require adding a fan coil unit (FCU) to the space. The coil in the FCU would be fed hot water by the biomass boiler, and the Toyotomi would remain in place as back-up heat. The FCU could be a floor-mounted vertical unit (would look like a furnace, but has only a fan and a coil), or a horizontal unit that is ceiling mounted.

A potential complication in hooking up the buildings to a biomass-fired boiler or boilers exists in the washeteria, and is explained in detail in Section 3.7.2. The complication relates to the clothes dryers in the building and their specific requirements.

The table in Figure 2.1 below lists the existing heating equipment in the subject buildings, with some comments on condition.

Existing Village Boilers					capacity		notes
bldg	make	series	model	No.	output kBTU/h	oil gph	
school	Burnham	PF	505	2	786.0	6.90	medium condition
teacher housing	Weil McLain	Gold	P-WGO-4	1	145.0	1.20	good condition, but 1 only
upper water treat	<i>see note (1)</i>						
vasheteria/old clinic	Weil McLain		78	2	521.0	4.45	good condition
tribal offices	Weil McLain	Gold	P-WGO-3	2	115.0	0.95	good condition
store	<i>this building is heated by a direct-vented Toyotomi heater</i>						good condition
clinic	Weil McLain	Gold	P-WGO-3	2	115.0	0.95	(2)

(1) this building currently receives recovered heat from the generators; the operator reports that this holds the building until the ambient temperature drops below about -35 deg F

(2) Based on the proposed clinic for Venetie, which is under design and assumed to be the same size

Figure 2.1. Existing Village Boilers

The Teacher Housing is the only building on the list that has no back-up heat. The mechanical room in which the boiler is housed is not large enough to add another boiler. The one boiler appears to be in good condition, however, as are the remaining boilers on the list with the slight exception of the school boiler system.

The school boiler system was in generally good shape, but it could use some “touch-ups”. There is a lot of insulation missing, which not only represents a heat loss to the system, it also results in a lot of surface rust on the pipes that are continually wet. This is shown in Figure 2.2 below:



Figure 2.2. School Boiler Piping/Header

The upper village water treatment plant, which basically serves the school and school housing, is adjacent to the village power plant. Like many villages, a system has been installed to recover heat from the engines. In many villages, this system is turned off, or does not work, but in Chalkyitsik, the system is operating and appears to be in good shape.

Normally, the heat from the engines would be released to the atmosphere by running the cooling water through radiators. The heat recovery system is installed in series with, and upstream of the radiators; it has the ability to extract any amount of heat from zero to 100 percent of the heat in the cooling system. A 3-way control valve controls the flow of the cooling water through a flat plate heat exchanger. One the “other side” of the heat exchanger is the water treatment plant heating water. The heat exchanger transfers heat from one loop to the other, cooling the engine cooling water while heating the building heat loop. If the heating loop does not extract all the engine heat, the remaining heat in the engine-cooling loop is routed to the radiators for final cooling. Figure 2.3 below shows the key elements of this system.

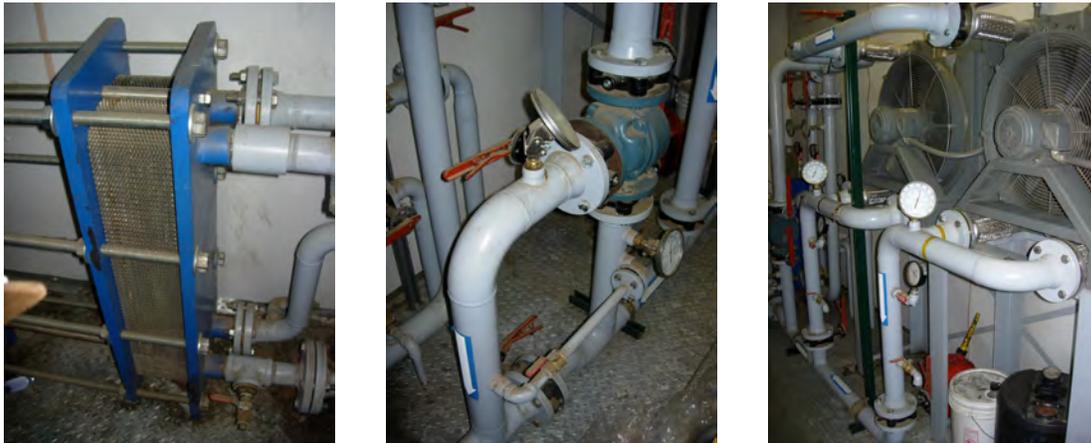


Figure 2.3. Flat Plate Heat Exchanger / 3 – Way Valve / Radiators

## 2.2 Preliminary System Integration Plan

Hot water will be piped from the external biomass boiler into the existing building mechanical room. Once in the building mechanical room, the new hot water distribution piping will be tied into the existing hot water supply and return lines that feed the existing boilers. Typically, four 2-position, 2-way automatic isolation valves will be installed in the piping, as shown in Figures 2.5 and 2.6 below. The position of these valves will determine whether the heat comes from the building oil-fired boiler, the biomass boiler, or both. The existing building pumps will continue to serve the building-heating load.

The valves that control the origin of the heat will be controlled by the existing building controls, where they exist, or by a small-dedicated control panel if needed. If this proves too costly for very small installations, the switchover can always be done with manual valves, but this relies on an operator.

Figure 2.4 below shows a schematic drawing of a typical installation for two oil-fired boilers. In this scenario, each boiler is sized for 100 percent of the load; the boilers are manually alternated so that they get roughly equal run time. In all cases (figures 2.4, 2.5, and 2.6), light solid lines indicate existing equipment and piping, dark solid lines depict new equipment and piping, and light dashed lines show the water flow through the system. For convenience, it is assumed in all cases that Oil Fired Boiler – 1 is the active

boiler, and boiler 2 has been isolated using the associated manual isolation valve. HWS is hot water supply to the building; HWR is hot water return from the building.

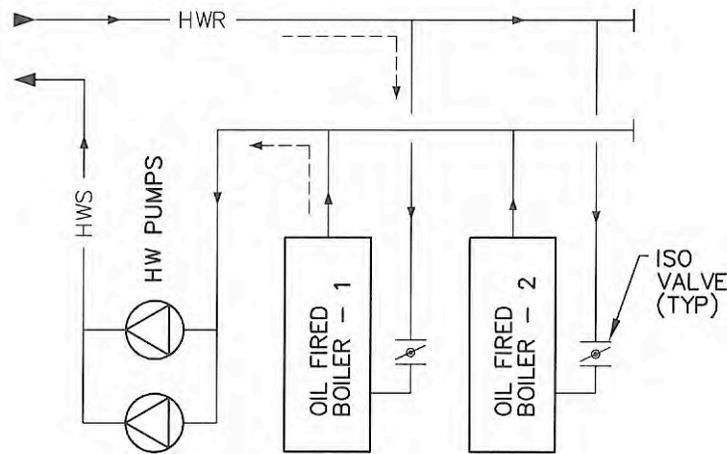


Figure 2.4. Typical Oil-fired Heating Plant

Figure 2.5 shows the initial configuration of the combined oil and biomass heat, with the biomass boiler providing all the heat. Closed “auto” (automatic) valves are solid, open valves are not “blacked in”.

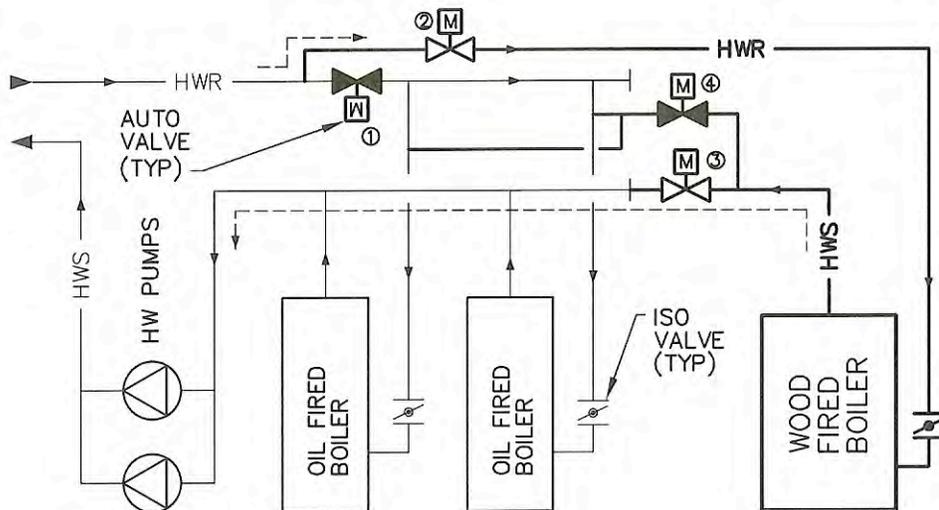


Figure 2.5, Combined Oil and Biomass Heat, all heat from Biomass

In the event that the biomass heat cannot meet the building setpoint for any reason, the two systems can operate in series. The lack of adequate heat output from the biomass boiler could range from small (an extremely cold day) to total (a boiler failure or someone forgot to fire the boiler in time), but the operation would remain the same – the oil-fired boiler would simply add enough heat to maintain setpoint, whether this is 1 percent or 100 percent of Load. This is shown in Figure 2.6.

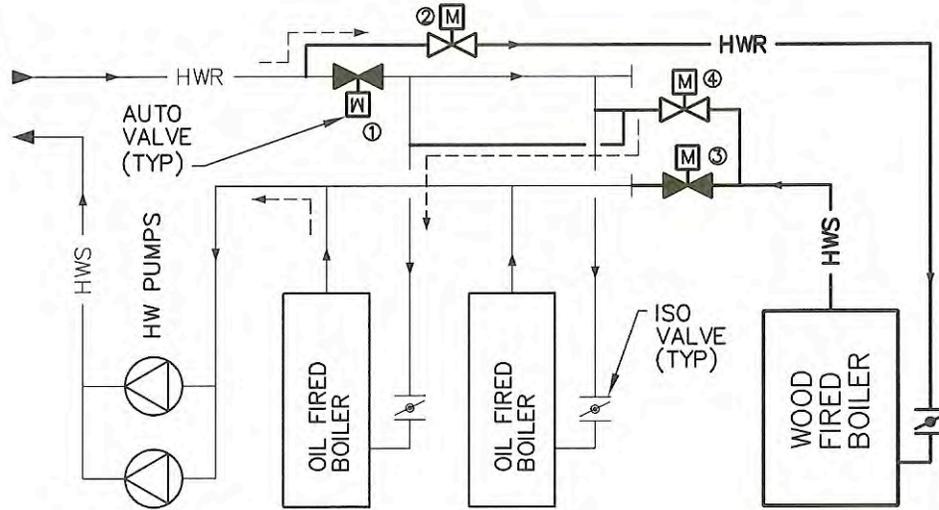


Figure 2.6, Combined Oil and Biomass Heat, Boiler Heat in series with Biomass Heat

The scenario gets only slightly more complex if recovered heat is to be used as well. In this case, the existing heat exchanger (HX) remains in place, and the piping on the “hot side” remains as is (the engine cooling loop is rejecting heat to the heating loop, so the engine cooling loop is the “hot side” of the HX, and the building heating loop is the “cold side”). On the cold side, the piping is re-arranged as shown in Figure 2.7 below:

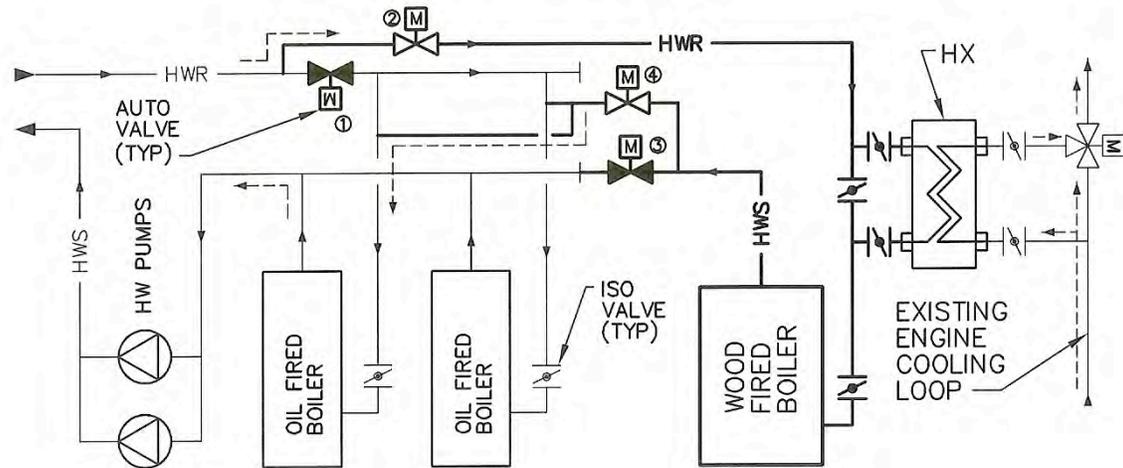


Figure 2.7 Combined Oil and Biomass Heat, Boiler Heat with Recovered Heat

The stick-fired boilers proposed for use on this project incorporate a hot water storage tank (see 2.3 below, and Section 3 for more detail). The water in this tank is normally kept between 120 and 200 deg F. The existing 3-way control valve (upper right of Figure) would be used to modulate the flow of heat through the heat exchanger, and thus

keep the boiler storage tank as close as possible to 200 deg F (its maximum charged temperature).

However, as it gets colder outside and the building heating load increases, tank temperature will begin to drop as more heat is extracted from the tank. When the temperature drops below 120 deg F, the recovered heat can no longer maintain the building heat. At that point, the boiler operator will have to begin to fire the biomass boiler. The recovered heat will continue to be used, however.

The HX is in series with, and upstream of, the biomass boiler, which in turn is in series with and upstream of the oil-fired boilers. This determines the order in which the heat sources are used: recovered heat first, then biomass heat, and then only when both of these sources are fully loaded will the oil boilers be used. A failure of either the HX or biomass systems is fully backed up by the existing oil boiler(s).

The exception to the proposed connections above is the Store, where no boiler exists. In this case, a new fan coil (see 2.3 below) would be installed to utilize the hot boiler water. The easiest means of “interconnecting” the fan coil unit (FCU) with the Toyotomi heater is to simply set the Toyotomi thermostat three or more degrees below that of the FCU. If the FCU can maintain the higher setpoint, the Toyotomi will not come on. If for some reason, the FCU does not maintain setpoint, the Toyotomi will automatically come on when the space temperature drops down to the lower setpoint.

## 2.3 Schematic Design Data

The subsection above shows how a proposed biomass boiler would be interconnected with the existing boilers in each building. Note that a single boiler (or two or three in combination) can serve multiple buildings. The piping from the boilers simply branches out to each building – all the connections would still look like those in 2.2 above. The subsections below contain preliminary design information on equipment proposed for this project. More detail about all these elements can be found in Section 3.

### 2.3.1 Piping

If the proposed biomass boiler installations and plants proposed herein had to rely on traditional rigid “arctic” piping, the payback would be significantly extended. Instead, the basis of design is a flexible, pre-insulated system that uses a plastic carrier pipe (carrier pipe is the pipe that “carries” the water, or the inner pipe). The carrier piping is constructed of cross-linked polyester, or PEX. The outer pipe (or casing), which protects the insulation, is made of corrugated plastic to make it flexible.

The piping comes on rolls that are dozens or hundreds of feet long. It is much lighter than steel or copper pipe, and thus cheaper to ship into the villages. Standard easy-to-install fittings are used anywhere in the piping to connect end-to-end, tee, or elbow as required. The piping can be obtained as a single pipe within a casing, or in the smaller sizes, supply and return can be combined into a single common casing. Figure 2.8 shows an example of a PEX system.



Figure 2.8, PEX Piping, Two Carrier Pipes in a Single Casing

Figure 2.9 shows the sizes of PEX piping available from Rehau, the manufacturer that the preliminary performance modeling is based on.

Piping Schedule					
nominal carrier size	carriers per casing	weight lb/ft	min bend radius in	temperature & pressure rating	
1.00 in	1	0.80	2.5	160 PSI @ 74 deg F	
1.25 in	1	0.88	2.5	100 PSI @ 180 deg F	
1.50 in	1	1.26	3.0	80 PSI @ 200 deg F	
2.00 in	1	1.45	3.0		
63 mm	1	1.75	3.3	132 PSI @ 74 deg F	
75 mm	1	2.28	3.5	66 PSI @ 180 deg F	
90 mm	1	3.06	4.0	58 PSI @ 200 deg F	
110 mm	1	3.82	4.0		
1.00 in	2	1.47	3.3	in all cases, the rating	
1.25 in	2	1.65	3.3	for each carrier pipe	
1.50 in	2	2.57	4.0	size is the same as	
2.00 in	2	3.38	4.5	listed for that same	
63 mm	2	3.56	4.5	size above	

Figure 2.9 Preliminary Piping Schedule.

The insulation rating, or R value, of the piping depends on the depth of bury, and the soil conditions. The performance model has all these factors built in. The standard installation detail is quite simple. A shallow trench is dug, between three and five feet deep. A minimal amount of bedding is put down, and the piping is unrolled into the trench. The trench is back-filled to about 6 inches above the top of the casing pipe. Then a 4' x 8' sheet of "blueboard" (rigid insulation) is placed lengthwise in the trench above the piping to increase the R value of the total assembly (blueboard not shown in Figure 2.10). Then the rest of the trench is back-filled as shown in Figure 2.10; the final assembly can support road traffic, if need be.

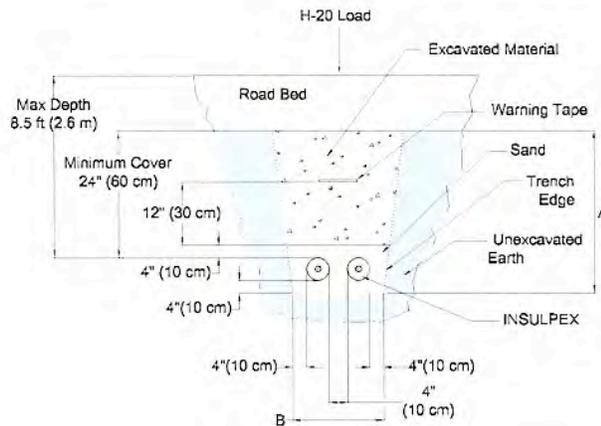


Figure 2.10 Preliminary Piping Installation Detail.

Within the buildings, piping will be steel or copper, with standard fiberglass insulation.

### 2.3.2 Boilers

Garn manufactures the proposed boilers; Dectra Corporation, located in St Anthony, Minnesota owns Garn. A number of Garn Boilers are already installed in Alaska. Some Design Considerations specific to stick-fired boilers are presented in detail in Section 3. Figure 2.11 is a schedule of capacity and physical characteristics of the Garn boilers.

Stick-Fired Boilers		capacity		Physical Data			
		burn	storage	H	L	W	weight
make	model	kBTU/h	kBTU	in	in	in	lb
Garn	1500	350.0	920.0	77	117	72	15,400
Garn	2000	425.0	1,272.0	77	141	72	19,000
Garn	3200	925.0	2,064.0	93	187	86	34,500

Figure 2.11 Garn Boiler Characteristics.

The model 3200 is quite a bit larger than the other two models, in every way. It is expensive to ship to Alaska, and therefore has not been widely used in bush Alaska. However, it is almost always less expensive to install one boiler with X capacity than two boilers with ½ X capacity each, so the model 3200 has been included in the study.

### 2.3.3 Fan Coil Unit

Fan coil units (FCUs) are exactly what they sound like. A single housing contains a fan, controls, and a heating and/or cooling coil (or both). In this case, only a heating coil would be selected. This unit would pull in inlet air from the room, blow it across a hot water coil (fed by the biomass boiler), and blow the heated air into the room. This discharge air can be ducted, if desired, although the existing Toyotomi unit has no ductwork. The picture in Figure 2.12 below is from the Trane Company; however, there are many manufacturers of FCUs. Final selection would be made during design. The FCU in the picture has both a cooling and heating coil (note the four piping connections).

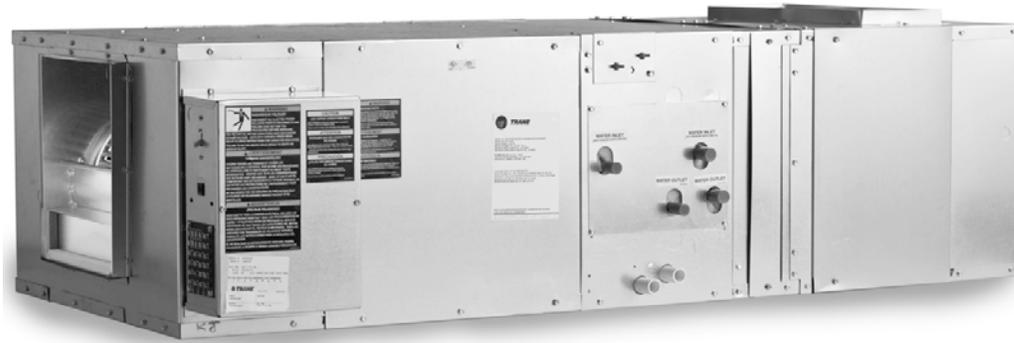


Figure 2.12 Trane Fan Coil Unit.

## 2.4 Resource Assessment

A significant amount of the forests around Chalkyitsik have burned in the past 60 years as part of a natural fire disturbed ecosystem (Appendix A). Burned areas typically regenerate to hardwoods first and then as succession moves through time the stands are taken over by spruce either white or black depending on the quality of the site and the return fire interval. Fires create a mosaic pattern of forests in all successional stages. There are burned and mature stands within five miles of Chalkyitsik. Since there have been recent fires (last 10 years), there is a lot of standing dead that is being utilized as fire wood and could also be used as fuel for a district heating system. Residents in Chalkyitsik have a lot of experience in gathering firewood and one fire wood supplier gets up to 50 cords of wood annually for sale into the village using hand felling with chain saws and transporting with a snow machine and sled.

There are two DH scenarios selected in this report as most feasible. Since the goal of the project is to displace as much fuel oil as is financially feasible and ecologically sustainable, the largest system appears to be the preferred. The plant of two Garn boilers with heat recovery from the generators will require approximately 180 cords of wood annually on the upper site at the school. The plant of two Garn boilers in the lower site will require 190 cords with no heat recovery available. We estimate ranges of dry standing burnt spruce to be approximately 12-14 cords per acre in many stands. The community is interested in using these stands first whenever possible. Approximately 26-30 acres annually will be needed to fully support the two largest DH system proposed.

This resource assessment is based on several trips to Chalkyitsik and field inspections of stands in all conditions from burned to early successional hardwoods to mature stands. No formal inventory has been developed nor has systematic forest stand cruises been conducted. However, two different experienced foresters have been on the ground observing the forest and all agree that the level of harvest for a DH heat system is fully sustainable within 5-10 miles of the village. If the project moves forward a harvest plan will need to be developed and followed. Training on the proper cutting methods for regeneration will need to be held with contracted woodcutters.

## 2.5 Harvest Systems

A full analysis of harvest systems is beyond the scope of this report. A harvest system can be developed as part of the final design and will depend on the final size and whether both boiler plants are installed. The following describes the general approach to a harvest system.

The key to a successful biomass program includes the integration of getting enough quality wood on an annual basis securely stored and then fed to the boilers. There are three different general harvesting systems that could work in Chalkyitsik: A. Hand cutting and loading with snow machine transport; however if both boiler sites are installed a total of 327 cords will be required and snow machines are inefficient for this level of harvesting; B. Hand cutting and mechanized loading and hauling; C. Mechanized cutting, loading, and transport. Of course, there are multiple scenarios for equipment for systems B and C.

Photos of different types of equipment that could be utilized are in Appendix B. Deciding which system to utilize will be an important decision for the community to make in the development of a final business model. It is the recommendation of this report to develop and use system B described below. Although system A yields more hand labor for potentially more people, this may not be the most effective way to assure an adequate supply of wood annually and may not be the most cost effective. System C could be too expensive in capital costs and maybe overkill for the amount of wood required for the Chalkyitsik DH system.

Hand felling and limbing will take a significant amount of labor in itself for producing 327 cords annually. Adding a tractor with a loading arm and a trailer for hauling (Appendix B) will make the harvesting-transport system both affordable and more reliable. The issue with the tractor for winter hauling will be maintaining the trail to the wood stock piled in the forest. The tractor will have attachments for snow removal, both a plow and a blower. Although not a versatile a track vehicle could be used instead of the tractor as the primary transport vehicle.

## SECTION 3

### 3.1 General

There are often two general configurations of boiler plants examined in studies such as this; single building applications (or very small groups of adjacent buildings) and district heating (DH) plants. Likewise, two wood burning technologies are usually included; stick fired and chip fired. An individual building boiler could be either a chip or stick-fired boiler, but only chip boilers are large enough (in terms of heat output) to power a DH plant.

However, chip-fired systems are very expensive to install, and require a great deal of support equipment (chippers, etc). Experience has shown that in order to get the required economy of scale to make a DH plant financially practical, a minimum of about six to eight or more buildings (depending on size) must be connected to the plant. Chalkyitsik, as noted in Section 2, has seven fairly large buildings included in the study, however, they are widely scattered into two clusters. The distance between the two clusters of buildings is too great to pipe between (for first cost, heat loss and piping energy reasons), so no DH plant has been proposed or evaluated for Chalkyitsik. In the absence of a chip-fired DH plant, there is no economical way to make wood chips, so by process of elimination, this study includes only stick-fired boilers.

In general, stick fired boiler systems are smaller, less automated, require less associated equipment, and their lower heat output range makes them appropriate for smaller scale installations (single building or small group applications), such as Chalkyitsik. They are simple and robust; but their simplicity means that they are more labor-intensive to operate than chip fired boilers.

Overall, the study considers three sources of heat: 1) heat recovered from power generator engines, 2) heat from wood, and 3) heat from oil.

### 3.2 Recovered Heat

Heat recovered from an engine generator and used in a boiler system or DH Plant is “free” in the sense that there is no marginal cost increase to reject that heat to a heating loop compared to the rejecting it to the atmosphere. The heat comes primarily from the cooling jacket of the engine, and must be carried away from the unit to prevent it overheating. In the absence of a co-located building or heating plant, the heat is normally carried to a radiator, which cools the jacket water by releasing the heat to the atmosphere (a fan blows air over a radiator coil).

Engine generators producing prime power are an ideal source of heat for any heating plant. They run continuously, and the quality (temperature) of the heat rejected is almost identical to the heat required by the boiler or plant. Generally, recovered heat is the lowest cost form of input energy to the heating system, thus it is normally selected first and used to the fullest.

However, in some villages the owner of the power plant chooses to charge for the recovered heat; in such cases the “waste” heat is “free” for them to provide, but not free to the end-user. In this model, the recovered heat has been assumed to be free to the end user. This will need to be confirmed in further studies, and, in the event that a cost for the recovered heat is to be charged to the user, this charge will be incorporated into the financial and performance models. Sections 3.6 below and 2.2 above describe how the recovered heat will be integrated into the proposed biomass fired systems.

### 3.3 Wood Heat

As noted above, recovered heat (when available) is considered the primary heat source, because it is generally the least expensive heat source. Wood heat is thus considered the secondary heat source. As with recovered heat, wood heat will always be used to the extent possible before using the tertiary heat source (oil, in this case). The villages own significant amounts of this wood resource in the surrounding lands, and AWEA believes it can be produced in a usable form (cord wood) at a price significantly below that of oil, on a BTU basis.

Solid fuel boilers require more infrastructure than oil-fired boilers. They require space for wood storage and processing. Stick fired boilers require space to cut to length and split wood to meet the boiler specifications.

Given the remoteness of the Yukon Flats, any equipment installed must be reliable and well tested. It is also desirable that any boilers used be standard units, “off the shelf” so to speak. The use of proprietary or customized equipment increases the chance that if equipment failure occurs, it will be expensive and/or time consuming to get it fixed.

For stick-fired boilers, the team proposes to use Garn boilers. A number of Garn Boilers are already installed in Alaska. Figure 3.1 is a picture of a Garn boiler.



Figure 3.1 Garn Boiler

Note that aside from cordwood, a Garn boiler can also burn clean construction waste, slab wood, and densified wood products (briquettes, etc). However, neither construction waste nor slab wood was considered to be a reliable resource at the sites considered. Densified wood products are not available in the interior; in fact, one of the primary reasons to consider a stick-fired boiler was minimize the processing required for the fuel.

As Figure 3.1 shows, the Garn boiler consists of a burn chamber (the chamber hatch-style door can be seen in 3.1) surrounded by a hot water storage tank. Because of the water tank, the Garn boilers are much larger than chip-fired boilers for a given output. It also means that Garn boilers have two output ratings: 1) burn rate, and 2) storage capacity. The burn rate is the rate at which heat is released when the chamber is loaded with stick wood per directions and fired. The storage capacity is how much heat the tank can hold.

In order for the storage capacity to have any meaning, the maximum and minimum storage temperatures must be specified. For the Garn, the tank is fully charged when the tank water is 200 deg F. It is depleted when the tank temperature is 120 deg F.

Heating a building is a continuous process; heat is continually withdrawn from the tank by a pump and heat is transferred to a building. Heating the boiler tank is a batch process. A discrete amount of wood is burned in each “batch”. No more fuel is added until the previous burn is complete.

Fuel is not added continuously, thus the burns are a batch process. The storage tank allows the Garn to bridge the gap between the batch process of burning a load of wood and the continuous process of heating a building. Section 3.7 below offers a detailed description of the implications of using stick-fired boilers.

Figure 3.2 below is reproduced from Section 2, and shows the characteristics of the Garn boilers included in the study.

Stick-Fired Boilers		capacity		Physical Data			weight lb
		burn kBTU/h	storage kBTU	H in	L in	W in	
make	model						
Garn	1500	350.0	920.0	77	117	72	15,400
Garn	2000	425.0	1,272.0	77	141	72	19,000
Garn	3200	925.0	2,064.0	93	187	86	34,500

Figure 3.2. Garn Boiler Characteristics

The material handling associated with stick-fired boilers is much simpler than that associated with chip fired boilers. In essence, the wood should be cut to length, and should fall within an acceptable range of diameters. Larger diameter lengths may have to be split. Ash must be removed from the burn chamber manually, and tube cleaning is manual as well.

The boilers must be fed manually regardless of how the wood is processed, but the actual processing is a trade-off between simplicity and availability of equipment and more manual labor versus more expensive, specialized equipment with correspondingly less manual labor. If chainsaws and splitters are the primary material handling equipment, then a great deal of manual labor is required to process the wood and feed the boilers. The benefit is that this equipment is cheap, easy to fix (and quick to ship, if new is needed), and abundant in the villages. If specialized harvesters and/or cutters are used, much of the manual labor is removed. However, this equipment is expensive, cannot easily be replaced and there is likely only one of each per village – so a failure means the operation is down until it is repaired. Each village in which a Garn is installed will need to consider the associated material handling carefully in cooperation with AWEA to determine the best solution for the village.

### 3.4 Supplemental Heat

There are conditions under which biomass alone or the combination of recovered heat and wood heat may not be able to meet the heating load. It is possible to supply enough boiler capacity to nearly eliminate the need for oil (except in the case of biomass boiler failure, which is always possible). However, it is not always the best answer financially.

In theory, one could pay someone to stand next to a Garn boiler and feed it continuously, which would maximize its output. In reality, this is not practical; the study assumed a maximum of four boiler “burns” a day. A burn is not necessarily a single loading and firing of the Garn; in this study a burn means burning enough wood to raise the storage tank temperature from 120 deg F (min) to 200 deg F (max) – in practice this might take two or more successive loads of wood in a row on very cold days. Remember that heat is being extracted from the tank even as the heat from the wood is charging it.

If the number of burns per day is limited, then it is possible (in fact common) that the expected peak load of a building on the coldest days is slightly greater than the capacity of a given boiler, or combination of boilers. In such a case, one could always either use the next larger boiler, or add another to cover the peak loads. However, the economics of this are generally bad – installing a very expensive boiler to run ten or so days a year makes no financial sense. It is easier and less expensive to simply use the building’s existing oil boilers on such days to supplement the biomass heat.

In the results summaries there is a value labeled “fraction of oil displaced”. A value of 1.000 means the biomass boiler has the potential to provide 100 percent of the building heat, with no need for supplemental oil heat (in reality, there is maintenance downtime, so coverage will probably never be 100 percent on an annual basis). In these cases, the peak load of the building matched up well with the capacity of one or more of the stick-fired boilers. Often, however, values such as 0.900 (90 percent) appear. In this case, the peak load is predicted to exceed the capacity of the boilers for a very small number of hours each year – and thus supplemental heat from the building oil boilers will be required.

### 3.5 Distribution

The heat generated by the external biomass boilers must be distributed to the various end-users. Unless the biomass boiler is very, very close to the building (in which case the piping could be above-ground), this is done by pumping hot water through buried distribution pipes to each building. Traditionally, the piping used in this part of Alaska is a rigid system of pre-insulated piping. A carrier pipe carries the fluid; this is standard steel piping. Rigid foam insulation surrounds the carrier, and insulation is protected by an outer spiral-wound metal jacket (or casing). See Figure 3.3 below.



Figure 3.3 Traditional “arctic pipe”

This system provides superior heat loss characteristics (i.e. very low losses), but it is expensive, and installation must be very well planned. It is expensive primarily because the whole piping system is rigid. It must therefore be installed below the permafrost or frost heave will snap the pipe – in many areas of interior Alaska this means 18 to 20 feet deep. The required trenching is expensive, requires large equipment, and takes time.

Installation must be well planned out because the pipe is difficult to modify in the field. Cutting a piece to length means cutting through all three layers; it is difficult to get a clean cut and subsequent clean connection to the next piece. For that reason, the system is typically laid out in great detail in the plans, and each piece and each fitting made for a specific spot in the system. Thus any mistakes in fabrication or any damage to a pipe in the field can take a long time to repair.

As noted in Section 2, therefore, AWEA proposes to use a flexible plastic piping system, manufactured by Rehau, which uses PEX carrier pipes. Figure 3.4 is reproduced from Section 2.3:



Figure 3.4 PEX piping

Because the system is flexible, it can be installed in the active layer of the soil – in the Plant proposed for Fort Yukon, the proposed depth is 48 to 60 inches deep. Further investigation will be needed to determine the appropriate depth in Chalkyitsik. Connections are simple, so the layout does not need to be planned in great detail. Because it comes in rolls, hundreds of feet of piping can be laid out in very little time. Trenches are shallow and simpler to construct, generally using equipment that may already exist in the villages.

The most significant negative aspect of the PEX system as opposed to the traditional system is that the insulation is not as effective. Piping losses are greater with the PEX system, and piping losses can have a significant effect on ongoing operating costs. In applications with free or low cost recovered heat, these operational savings can be leveraged on an ongoing basis to counteract the increased piping losses, allowing Chalkyitsik to realize the first cost savings associated with the PEX system without the additional piping losses excessively damaging the project financials.

This would not be the first installation of the PEX system in rural Alaska; thousands of feet of this type of piping were recently installed in McGrath in less than one week.

### 3.6 Integration of Recovered Heat

Diagrammatically, the integration of recovered heat into a DH Plant is shown in Section 2.2. The concept is very simple. Water in the cooling loop from the operating engine(s) producing power in the power plant is routed first to the biomass boiler plant.

In the Plant, the hot cooling water flows through a heat exchanger. A three-way control valve on the cooling loop side of the exchanger controls how much heat is rejected to the boiler loop. If the valve is wide open, all the flow goes through the heat exchanger.

A temperature sensor in the boiler storage tank is used to modulate the heat exchanger 3-way valve, extracting as much heat as possible from the engine-cooling loop. If this is not enough heat to meet the load, additional wood or oil heat will be added to primary loop, as required. If the load is less than the available recovered heat, the three-way valve will modulate, as required, to maintain the heating loop at setpoint.

On the generator cooling loop side, the water leaving the Plant, having flowed either through the heat exchanger or through the valve bypass, will return to the power plant cooler than it left. It will then flow to the engine radiators. If it is already cooler than the radiator setpoint temperature, the radiator fans will not come on – the water continues back to the engine jacket to start the cycle over. If the water from the DH Plant is warmer than the radiator setpoint, the fans will come on as needed to cool the water, and send it back to the jacket.

### **3.7 Design Considerations for the use of Stick Fired Boilers**

Some of the material below has also been presented above. The intent is for this section to be a stand-alone description of some of the implications of using stick-fired boilers without reference to the remainder of the report.

As the name implies, stick-fired boilers burn round or split wood in relatively straight pieces. The wood is minimally processed, being selected for a range of diameters and trimmed only for length. If the diameter of the wood is too large, the wood may be split. Although the processing is minimal (compared to chipping), it is generally all done manually (some splitting may be done with a machine). Nevertheless, at the assumed unit costs, stick-wood is the cheapest energy source available to the villages for generating thermal energy.

However, utilizing stick-wood means that much of the available biomass cannot be used. Wood that is too large or too small, smaller tops and limbs that are bent and/or tangled, or tops, which contain leaves, cones, or needles, are generally too difficult to handle in a stick-fired boiler. The burn chamber of the boilers (see figure 3.5 below) is designed for straight stick-wood of a given length. The wood used is generally air-dried, not mechanically dried; mechanical drying would be very expensive on such small scales.

The Garn stick-fired boilers used as the basis of evaluation for this study are scheduled above in this section and in Section 2.3.

#### **3.7.1 Sizing, Boiler Control, and Utilization Rate.**

A primary feature of the Garn boiler is the built-in thermal storage. Physically, this is a large hot water tank that surrounds the combustion chamber. Functionally, the tank “decouples” the burn rate of the boiler from the actual heat load requirements. In essence, the process of combustion heats the tank and the tank serves the load (through pumps and a piping system), but not at the same rate. This is illustrated in figure 3.2 above. In the WHS 3200, for instance, the process of combustion generates up to 925 KBTU/h. The storage tank can hold 2,064 KBTU. So, if the “burn” lasts a little over two hours, it will completely charge the tank. If at the same time the building-heating load is 500 KBTU/h, it will take a little over four hours to deplete the tank – thus the rate of charging the tank is decoupled from the rate of extraction (serving the heating load) by the storage tank.

Heating a building is a continuous process, heating the tank in a Garn is a “batch” process. The thermal storage tank bridges the gap between the continuous process of

heating and the batch process of burning. A batch process is one in which an event takes place at intervals – for instance, every eight hours, one fills the Garn with a “batch” of wood, and burns it.

This decoupling effect eliminates the need for sophisticated combustion controls that would allow the boiler to track the load; that is, to match the burn rate to the heating load. The boiler is manually fed, and manual started. This results in a very simple boiler, which holds down first cost. The primary control function of the Garn is combustion control – simply ensuring that the combustion air is controlled such that the wood burns hot and clean.

The decoupling effect also means that sizing is less of an issue than it would be with a chip-fired boiler. If more capacity is needed to meet load, the operator can simply conduct more “burns” per day (within the limits described above). When less capacity is needed, fewer burns are performed.

There are limits to this, of course. An operator would not want to have to feed the boiler once every three hours round the clock, especially in the -50 deg F temperatures that can occur in the interior of Alaska. In this study, the assumption was that if more than four burns per day were required to meet peak heating load, a larger boiler would be used, or another boiler would be added to the installation. Four burns per day implies a minimum of six hours between burns. Adding another boiler increases the time between burns, but it adds significant cost as well.

In addition, the number of stick-fired boilers per installation is generally limited to three. Beyond this limit, the installations would get too large and too expensive. (None of the combinations of boilers in Chalkyitsik would require three boilers.) Because of the thermal storage, the boilers are quite large, and they require at a minimum a covered roof and flat slab floor; ideally they would be completely enclosed. Equally important, the utilization rate of the equipment drops as the number of boilers increases. If one boiler is adequate in “warm” weather, two required for “cool” weather, and all three for “cold” weather, then the overall utilization rate of the plant is probably no more than about one half (50 percent). Installing equipment in the interior of Alaska is expensive; the higher the utilization rate, the more cost-effective the installation.

In the summer, heat loss from the tank may become a significant factor. The seasonal range of heating loads in the interior of Alaska is the highest in the country. The heat load at -60 deg F is 20 times higher (or more) than the load at 80 deg F (when the load is probably only domestic hot water). So a burn that only lasts six hours at peak theoretically lasts 120 hours in the summer. Obviously, in 120 hours, more heat is going to be lost through the tank insulation than is going to be actually used. It might therefore be more practical to run the existing oil-fired boilers when the load drops too low. However, for the purposes of this study, although insulation losses were accounted for, it was assumed that the Garn boilers were not turned off in summer.

### 3.7.2 End-user Issues.

All of the facilities included in this study already exist, thus any installation of a wood-fired boiler would by necessity be a retrofit to an existing heating system. The intent is that the boilers be installed in such a way as to be transparent to the end-user. That is, the occupants cannot tell whether the heat is coming from the existing oil-fired equipment or from the proposed wood-fired equipment. Moreover, the mechanical heating system must operate the same way regardless of heat source; switching from one source to the other must be as simple as opening and closing valves. Finally, the intent is that the systems will be installed in such a way that a failure of a wood-fired boiler automatically starts the oil-fired back-up, and ideally, notifies the operator of the failure.

The Garn boilers do have one major limitation in terms of end-user transparency; they cannot control the hot water supply throughout the burn cycle. When a burn finishes, the storage tank is at design temperature (200 deg F is the design temperature for Garn). However, as the hot water is pumped through the heating system, it gives up heat to the space. As a result, when it gets back to the tank it is colder than when it left – the difference between supply and return temperature, called the delta T (or change in T) depends on the type of heating equipment (air handling unit, baseboard heat, radiator, etc) and the heating load.

The cooler return water immediately begins to dilute the 200 deg F water, cooling it. Once the burn is done, no more heat is being added to the tank, but heat is continuously being removed to heat the space – thus the tank temperature falls throughout the tank's "draw-down" cycle. Garn considers the tank to be "depleted" when it reaches 120 deg F. The basis of the heat storage capacities listed in figure 3.2 is the assumption that the tank is heated to 200 deg F, and then heat is extracted until it reaches 120 deg F, at which time, another burn is initiated.

However, in a retrofit situation, 120 deg F hot water may not be suitable. Many hot water heating systems are designed to use hot water at 180 deg F or more when at peak load. For instance, the heating coil in an air handling unit may have been sized to provide the required peak heating output using 180 deg F supply water (180 deg F is a very common coil temperature). In such a case, with the heating load at or near peak, the Garn boiler will be able to meet load as long as the storage tank temperature equals or exceeds 180 deg F, but as it falls below that value, the air handling unit may no longer be able to meet the load. By the time the supply temperature falls to 120 deg F, the air-handling unit will be operating significantly below design capacity.

As a specific example, assume an air handling unit that requires 180 deg F supply water at peak load (i.e., there was no spare capacity in the coil at peak load), then in effect the storage capacity of the Garn boiler would be reduced by 3/4:  $1 - [(200 - 180) / (200 - 120)] = 0.75$ . The WHS 3200 that has been used as an example above would have a storage capacity of only 516 kBTU, rather than 2,064 kBTU. At the same time, the time between burns would also be cut to 1/4 of the calculated time, although each "burn" would be much shorter, since the burn only had to raise the temperature of the tank by 20 deg F.

Practically speaking, most heating systems use hot water in the 140 deg F – 200 deg F range. Only radiant floor systems typically use hot water as low as 120 deg F. Thus, in almost all cases, it would appear that the storage capacity of the Garn units would have to be de-rated. This study did not de-rate capacity of the Garn for three reasons: 1) there was not sufficient time to survey all the existing equipment, and related drawings and specs, to determine the design supply temperatures, and 2) In all cases, at load conditions not at or close to peak, 120 deg F water may suffice – thus the number of hours per year when the de-rate would be applied may be quite small (however, this is when the weather is coldest, and the most labor is required to maintain the fuel supply and burn rate), and 3) direct observations of systems in Alaska have shown that many are so over-sized that they operate even with low hot water supply temperatures. It was therefore assumed that the specified storage capacity could be used in full; *before any installation design is finalized, however, this assumption should be confirmed.*

In Chalkyitsik, there is one system of specific concern – the clothes dryers in the washeteria. Hot water coils served by the existing oil-fired boilers heat the inlet air for these dryers. Drying clothes is a function of not just BTUs, but also of air temperature. The boiler in the washeteria was set to maintain 210 deg F during our last site visit (in the summer). It is believed this supply water temperature was set this high to accommodate the dryers. If this is in fact the case, a Garn boiler would not be a good application to serve the dryers. It is likely that a small dedicated boiler would be required to serve very hot water to the dryers as needed. This would alter the economics of serving this building with heat from wood, but the effect is not likely to be large enough to make it infeasible – the dryers are not large and do not run continuously.

### **3.7.3 Material Handling.**

As noted above, the Garn boilers are manually fed. For each burn, the operator must clean out any ash as needed, load the combustion chamber with new stick-wood, and manually start the fire. Once the fire is lit, the chamber door is shut, and the fire burns until all the fuel is consumed.

However, as noted above, it would take a little over two hours of burn to fully heat the storage tank (using the WS 3200 as an example again). A single load of wood will not burn for two hours, meaning that each burn must consist of more than one load of wood. In addition, during that time that the burn is taking place, heat is being extracted from tank to meet the heating load. So although a “burn” is treated as a single event in this study, it is important to note that at or near peak load, a burn could take as long as three hours to complete, and require two to three “reloads” of the combustion chamber. (A complete burn is defined herein as burning enough fuel to raise the storage tank from 120 deg F to 200 deg F, even as heat is being extracted from the tank for ongoing heating.) Thus although the number of burns is limited (in this study) to no more than four a day, this could still imply roughly 9 - 10 hours a day of loading and cleaning the combustion chamber in cold weather.

As with any stick-fired appliance, the fuel should be kept dry, and should be located close to the point of use. Therefore, any building or structure constructed to house the boiler should have sufficient space to stack cordwood. The amount of wood to be stored within the building (as opposed to in a wood yard) depends on the site conditions. In harsh conditions, it may be desirable to store several days' worth of cordwood (at peak load consumption rate) in the boiler building, in case weather keeps the operator from being able to re-stock the building from the wood yard. On the other hand, in all cases the existing oil-fired system is assumed to be left in place as back-up, so this may limit how much wood the operator chooses to store in the boiler building.

Regardless of how much wood is stored in the boiler building, considerable manual labor would be required to get the sticks from the wood yard to the building; labor to load, unload, and stack the wood. Because no equipment is required once the stick-wood reaches the yard, the material handling, though labor intensive, is not subject to equipment breakdowns.

There are a number of options for discarding the ash. It is likely the ash would be collected in a small bin or dumpster, and emptied only as this gets full.

#### **2.7.4 Emissions Controls/Efficiency.**

Garn boilers have no active emissions controls. The boiler uses an induced draft (ID) fan to ensure that enough air is present to provide complete combustion. This alone helps eliminate or mitigate many emissions. It helps prevent the formation of carbon monoxide (CO), which forms as a result of incomplete combustion. It minimizes smoke and particulates (but cannot extract any particulate formed and emitted) by burning clean and hot and leaving very little behind but incombustible ash.

Using more air than is strictly necessary simplifies the control, and makes for a clean burn, but it also reduces efficiency. Excess air cools the boiler down as it enters and brings additional moisture with it, both of which require excess heat to bring them up to combustion temperature.

The Garn does provide good transfer from the stack gas to the hot water storage tank. The stack gas essentially passes through the tank five times (a five-pass heat exchanger); see Figure 3.5 below. There are four horizontal passes and one vertical pass. Overall, the efficiency of the Garn is good – the study assumed 75 percent of the net useable heat content of the wood was transferred into the tank.

#### **3.7.5 Maintenance.**

There is very little maintenance required on a Garn boiler, and in fact, there is not much that an operator could do. Figure 3.5 below shows a cross section of a Garn boiler. The wood is burned in the primary combustion chamber, "E". In the secondary combustion chamber, "F", only hot gases are burned. As long as the ash is removed from "E" before each burn, there is not much to maintain. The ID fan ("H") must be repaired or replaced if it fails.

Figure 3.5 also shows the “tubes” that transfer heat to the storage tank. The tubes (from the end of “F” through the end of “I”) must be cleaned; if not, then any scaling or fouling of the tubes is not removed, and these will gradually erode the efficiency of the boiler (or even cause the tubes to fail). Running a wire brush through them can generally clean the tubes. The frequency of cleaning depends in part on how clean the wood is; clean forest wood should have no inclusions, while scrap and construction debris often do. If these inclusions (adhesives, preservatives, etc) do not burn completely, they often plate out on the tubes, degrading performance.

Between cleanings, efficiency will slowly degrade as deposits accumulate, until the next cleaning. Figure 3.5 also shows that the boiler has two vertical tubes sections – these are more difficult to clean. All feeding, de-ashing, and cleaning are manual. The timing of the feeding is manual, although that could be partly automated (i.e., a control system could alert the operator when the tank is nearly depleted).

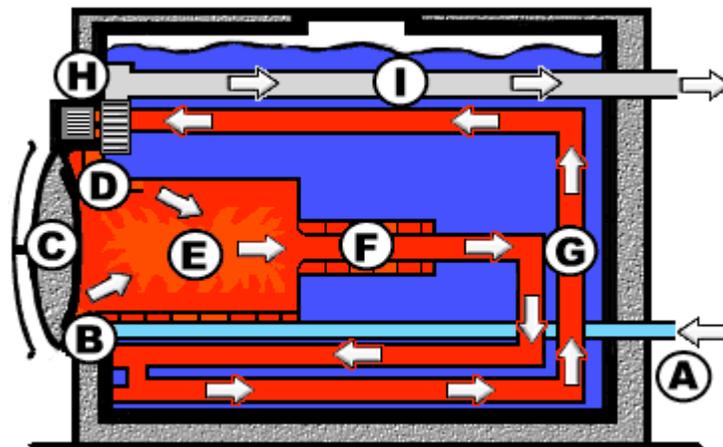


Figure 3.5 Cross Section through a Garn Boiler

### 3.8 Siting Issues.

As noted above, the Garn boilers are quite large as a consequence of the storage tank. The WHS 3200, the largest Garn boiler considered in this study, is 14' – 3" long, 7' – 2" wide, and 7' – 9" high. Each unit (full of water) weighs 34,500 lb. The largest Garn plant “allowed” in this study would include three WHS 3200 units (we arbitrarily limited the number of boilers per Plant to three, but no Plant at Chalkyitsik required three boilers). Not including interior wood storage (but including clearance around each unit), this would require a minimum of 678 square feet (20' – 3" long by 33' – 6" wide) with an average floor loading of 153 lb/sf. This floor loading will likely require a relatively thick reinforced concrete slab to prevent differential settlement.

The recommended sites are shown in Appendix C & D with all of the buildings to be heated labeled. The Chalkyitsik Village Council who also operates the power plant owns the area behind the Tribal Office for the lower boiler site. This area is a large enough site

to house both the dual Garn boiler plant and a small wood yard large enough to store over 25% of the annual wood supply needed to operate the plant. This site makes piping distances minimal for the lower plant. The plant and wood yard will be secured with a chain link security fence with a gate large enough to allow access to wood hauling equipment.

The upper plant will benefit the school mostly and will potentially be located on the school property. It will be associated with the current powerhouse in order to capture the heat from the generators. This site will need to be negotiated with the school in the final design phase of the project. There is room for wood storage for about 25% of the annual wood needed.

## SECTION 4

### 4.1 Limits

As with any performance evaluations, the quality and validity of the outputs and subsequent conclusions depends on the quality of the inputs and the methodology. Methodology is discussed in Section 4.2 below. The input data gathered for use in the analyses performed as a part of this study include:

- Building specific data
- Historical village PCE (electrical consumption) data
- Proposed equipment data
- Annual oil consumption, by building
- Annualized weather data (bin data) from the Fort Yukon airport
- Village maps and plans
- Interviews with Civil Engineers, contractors, and consultants with significant experience in the interior of Alaska
- Pricing data from boiler manufacturers, piping suppliers and other AK vendors
- Performance data from Garn
- Input from other Alaska Wood Energy Associate team members

Detailed measurements of building heat loads and existing equipment performance were not part of this analysis. A building heating load profile is central to predicting annual fuel consumption. Ideally, this would be generated by directly measuring heating load throughout the year. At the same time, the actual operating efficiency of the existing boilers and distribution system would be measured. This would provide a highly detailed profile of heating load and the energy required to meet that load, for any condition throughout the year.

In practical terms, however, the required measurements are difficult to perform, and not cost-effective. The equipment needed to make these measurements is not present at any of the installations in the village, and would have to be flown in and installed. The measurements would need to continue from winter to summer, to generate a complete

load profile. The resulting incremental increase in the accuracy of the load profile cannot justify that level of cost. As Section 4.2 explains, even without the measurements, the data that were collected limit the load profiles to within a narrow range of values.

Also missing from this analysis is a detailed analysis of electrical load profiles (and thus available recovered heat). The only data available was monthly. Ideally, at least some hourly or daily data would be included in any Level 3 analysis.

## 4.2 Methodology

### 4.2.1 Energy Savings.

The performance of the existing and proposed heating systems was modeled using spreadsheets; the type of model used is known as a “bin model”. In this case, the bins are ranges of outside air temperatures (OATs). Temperature bins are used because heating load is very closely correlated to OAT. Each “bin” of OAT is 2 deg F wide – for instance, 40 – 42 deg F is a bin, with the midpoint temperature of 41 deg F. For each OAT bin, the heating load profile assigns a heating load to that temperature bin. The actual “bin data” is the number of hours per year that the outside air temperature falls into each specific bin.

Bin weather data is published for numerous sites, including many in Alaska. However, no such data are published for Chalkyitsik. Therefore, actual hourly temperature data from the Fort Yukon airport was used to construct a bin table for this site. The weather data came from calendar years 2007, 2008, 2009 and 2010. The data were combined to come up the average number of hours per year that the OAT in the Yukon Flats area falls into each bin. This was done on a monthly basis – for instance, the data in Figure 4.1 shows the spread of temperatures in the first thirteen bins; from the 85 deg F bin to the 61 deg F bin (each 2 deg F bin is labeled by the midpoint temperature).

OAT	OAT Bin Data, Fort Yukon Airport, average of CY 2007, 08, 09, and 10												8,760
mid													annual
pt	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	hrs
85					0.5	0.8	3.1	0.3					4.7
83					0.3	2.1	5.5						7.9
81					1.0	8.0	10.0	1.7					20.8
79					2.8	16.1	24.4	3.3					46.6
77					2.2	9.1	17.1	5.0					33.3
75					4.4	19.7	33.4	3.1					60.5
73					12.7	24.8	37.1	9.0					83.6
71				0.2	11.1	30.8	40.6	13.3	0.5				96.5
69				1.1	24.1	72.3	74.8	33.4	3.8				209.6
67				1.2	18.1	58.4	59.4	26.4	5.5				169.0
65				1.9	15.1	56.4	50.0	39.6	17.2				180.2
63				2.8	16.3	56.4	61.2	33.9	19.2				189.8
61				3.3	21.3	61.9	60.5	50.0	25.2				222.2

Figure 4.1. Fort Yukon Airport Bin Data

In the calculations performed within the model, individual calculations are completed in a series of tables that have the same format as the original bin temperature data (see

Appendix A for sample calculations). Figure 4.2 below shows a portion of a calculation used in this study (in this case, the calculations involved with the School in Chalkyitsik).

	0.1 min	oil, act	18,000	<b>1</b>	boiler	B1 / B2 / B3	<b>3</b>	
	<b>5.3</b> max	oil, pred	18,000	307	max cap	storage	2,064	
	(0.043) a	oil boiler	<b>2</b>	102	min cap	eff	0.750	
	2.7 b	eff	0.790	0.850		losses	0.005	
OAT :	<b>school</b>							
mid :	<b>oil, gph</b>	<b>1</b>	load :	<b>chips / oil</b>	152	3,609	<b>stick</b>	
pt :	heat	DHW	total	kBTU/h	lb/hr	gph	tons	gal
85 :		0.3	0.3	27.9		0.3		1
83 :		0.3	0.3	27.9		0.3		2
81 :		0.3	0.3	27.9		0.3		5
79 :		0.3	0.3	27.9		0.3		12
77 :		0.3	0.3	27.9		0.3		9
75 :		0.3	0.3	27.9		0.3		16
73 :		0.3	0.3	27.9		0.3		22
71 :		0.3	0.3	27.9		0.3		25
69 :		0.3	0.3	27.9		0.3		55
67 :		0.3	0.3	27.9		0.3		44
65 :		0.3	0.3	27.9		0.3		47
63 :		0.3	0.3	27.9		0.3		50
61 :	0.1	0.3	0.4	39.0		0.4		82
59 :	0.2	0.3	0.5	48.1		0.5		61
57 :	0.3	0.3	0.5	57.2		0.5		124
55 :	0.4	0.3	0.6	66.3		0.6		174
53 :	0.4	0.3	0.7	75.4		0.7		150
51 :	0.5	0.3	0.8	84.5		0.8		244
49 :	0.6	0.3	0.9	93.6		0.9		159
47 :	0.7	0.3	1.0	102.7	21		2	
45 :	0.8	0.3	1.1	111.8	22		2	

Figure 4.2. Partial Bin Model, Chalkyitsik School

The basis of all calculations is the heating load profiles for each building included in the study. These load profiles reflect all the information available about the building, such as heating equipment capacity, operating data, historical oil consumption data, size and type of building, etc. As noted above, it is difficult to measure heat load directly, but simple to measure oil consumption. So the first profiles generated are oil consumption profiles. These profiles assign a specific oil consumption rate to each OAT bin. Using the calculation format above, the model calculates the amount of oil required to heat each building, and then compares that to known consumption – obviously, the model must be able to back-predict known consumption if it is to be used to predict future consumption.

Subsequent calculations are done to determine how much oil/wood/recovered heat is required to meet the predicted heating load – one table for each energy source (complex rules determine which source is the primary, secondary, or tertiary source in each load condition). Once the required oil (for instance) is calculated for each spot in the table, the SUMPRODUCT function sums up all the oil required for each month. This is the basic format of the calculations.

Once the oil consumption profiles are verified, the oil consumption profile is converted to a space heating load profile, by multiplying BTU of input heat (oil) times the efficiency of the boiler/furnace to arrive at the actual heat to the space. Once these space load profiles are generated, they are fixed. A visual example of oil consumption versus OAT load profile is shown in Figure 4.3 below.

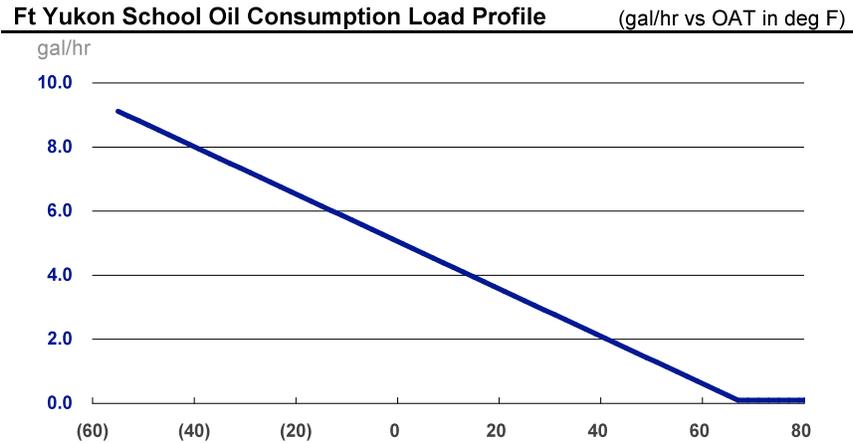


Figure 4.3. Oil Consumption versus OAT for Fort Yukon School

No matter what heat source is used, or how great any parasitic or piping losses are, any proposed mini plant or biomass boiler must deliver that same amount of BTUs to the space as the current oil-fired appliance does. Once the space load profiles are established, the spreadsheet models the various mini plants and boilers to determine how much energy they would consume to provide this required space heat.

As noted above, in addition to producing a set amount of BTUs for space heat, a mini plant must produce enough additional BTUs to heat the plant itself (parasitic loss) and to overcome the heat lost from the distribution piping into the ground (piping losses). Finally, the model must calculate how much pumping (electrical) energy must be used to get the heat to the buildings. Once inside the buildings, the electrical energy used for pumping is the same for the existing systems as it would be with a mini Plant in place, so this energy is not calculated or accounted for in the model.

Additional key load profile assumptions:

Space heating load varies linearly with OAT (a 10 deg F drop in OAT results in twice the increase in load that a 5 deg F drop causes). There is an OAT at which space heating stops – the OAT combined with the internal loads in the building (people, lights, equipment) are such that no additional heat is required; above this temperature, the only load is DHW. This value can be set individually for each building. However, in many buildings, there is heating required above this point, for heating domestic hot water. This DHW heating value can also be set individually for each building.

Figure 4.4 below shows the table where the user inputs their values.

Annual Oil Consumption & Load Data		annual oil	min as a % of max	% of peak to DHW	heat at OAT
bldg No.	Building	gal/yr			
1	1 school	18,000	0.020	0.050	61
2	1 teacher housing	5,000	0.020	0.020	61
3	1 upper water treat	6,500	0.020	0.650	55
4	1 washeteria/old clinic	14,000	0.020	0.300	61
5	1 tribal offices	3,800	0.020	0.010	61
6	1 store	2,800	0.020	0.010	61
7	1 upper WT, with HR	600	0.020		(31)
8	1 new clinic	2,600	0.020	0.050	61
9	3 Sch, TH, WT (no HR)	29,500	0.020	0.177	61
10	5 Sch, TH, WT (w/ HR)	23,600	0.020	0.177	61
11	3 wash, Off, n clinic	20,400	0.020	0.238	61
12	4 sh, Off, store, n clinic	23,200	0.020	0.207	61
13					

Figure 4.4. Building Characteristics

The column “min as a % of max” has to do with the space-heating load. A value of 0.020 for instance, means that at the temperature at which space heat begins (the last column), the space-heating load at that temperature is 2.0 percent of the maximum space-heating load. If the heat goes to a process (such as heating village water to keep it from freezing), this value can be set to 1.000 – in other words, the load is the same at all temperatures. The column “% of peak to DHW” is the percent of peak heating load assigned to heating domestic hot water. Some buildings use their boilers to heat DHW, and some have separate heaters. If the boiler heats the DHW, this column is an attempt to estimate how much of the boiler heat goes to DHW.

#### 4.2.2 Recovered Heat.

Just as with heating loads, a “recovered heat” profile is generated. This profile assigns a specific village power requirement to each temperature bin. This is less straightforward than assigning heat loads versus OAT, because the correlation between village power and OAT is not as strong – there is also a time-of-day component to power output. However, bin models predict long-term average performance, not hour-by-hour performance. A bin model that predicts consumption accurately on a monthly basis is generally as specific as is required – most utilities bill and/or report consumption on a monthly basis

A preliminary temperature versus power curve was developed for Chalkyitsik that accurately predicts monthly consumption. However, in a Level 3 analysis, this relationship would need to be better understood and defined.

#### 4.2.3 Cost Estimates.

The other component required to calculate the payback of any given scenario is the project cost. One estimate was prepared for each proposed mini plant and individual boiler installation. The current cost estimates contain the best knowledge of the team members regarding construction in bush Alaska. As the study level proceeds, these costs estimates will be constantly updated to reflect the current design.

Ultimately, actual vendor quotes and contractor's estimates or bids will be used for the final cost estimates.

### 4.3 Business Structure

A sustainable business structure is critical for a successful project. This report recommends that the business structure be based on a for-profit model. That is the District Heating Utility takes in more funds than it expends and it sets up a fund that will cover the costs of annual wood harvest, delivery, boiler operations, administration, equipment maintenance and an infrastructure and equipment replacement fund. Cost of BTUs should be calculated based on enough funds to make the business viable.

The NSP calculation in the feasibility model demonstrates the potential amount of savings \$124,124 annually for the upper installation and \$93,268 for the lower installation. This model includes a cost of \$300 per cord fed into the boiler displacing \$7.00 per gallon diesel fuel. We estimate approximately \$50 per cord of labor to cut the wood into appropriate sized sticks and to feed the boilers. So that leaves a potential to pay \$250 for a delivered cord of wood. The model also assumes that the boilers are fed up to four times per day on extremely cold days and they are fed seven days a week when needed. That is the only way the maximum amount of fuel oil can be displaced. Any time the optimum amount of wood based on the demand of the system is not fed into the boiler, then a less than optimum amount of fuel is displaced and the business revenues are less than optimum. However, a realistic expectation would be to capture 90% of the optimum values as there will be times when each buildings current oil heat systems will be used.

The feasibility analysis demonstrates that a for-profit heat utility is fully feasible. The basic benefits include almost doubling the efficiency in the use of diesel generators for making electricity and heating buildings, keeping a total of \$217,392 in the community for jobs, infrastructure maintenance and stabilizing the cost of heating fuel for primary public buildings if both heating systems are operated at an optimum level.

The most practical business structure, since the CVC owns the power plant and the heat recovered from that facility is a key part of the of the Upper District Heating System, is for the CVC to own the heat system as well. There are some business synergies that make a lot of sense. The powerhouse operator could easily pick up the responsibility of managing the upper and lower boiler plants. This does not mean that person will be the one to feed the boiler; but that the person is responsible to make sure that the boiler is fed. Feeding the boiler could be part of a wood gathering contract or be contracted separately. Another way of operating the plant itself would be to contract that aspect as well.

Billing of customers will be based on BTU meters in each connected building just as the electric meters are used. This can be done in a prepay manner or as you go. Both ways the meters must be read and billing must occur. The same office that does the electric billing could accomplish the heat billing and bookkeeping.

Wood delivery can be accomplished in several ways. Probably the most effective would be for the CVC to contract for wood delivery with key wood gathers as well as be willing to buy wood from independent wood haulers on an as needed basis. A prime contractor would lease any procured harvest equipment from the CVC at a minimal cost, but with key issues of insurance and maintenance spelled out in the contract and lease.

The discussion above is meant to start the process of creating a business structure. Once a decision is made to move forward with a biomass project and the CVC has worked out a general business structure a full-blown business plan will need to be developed with the final design process, costs and structures.

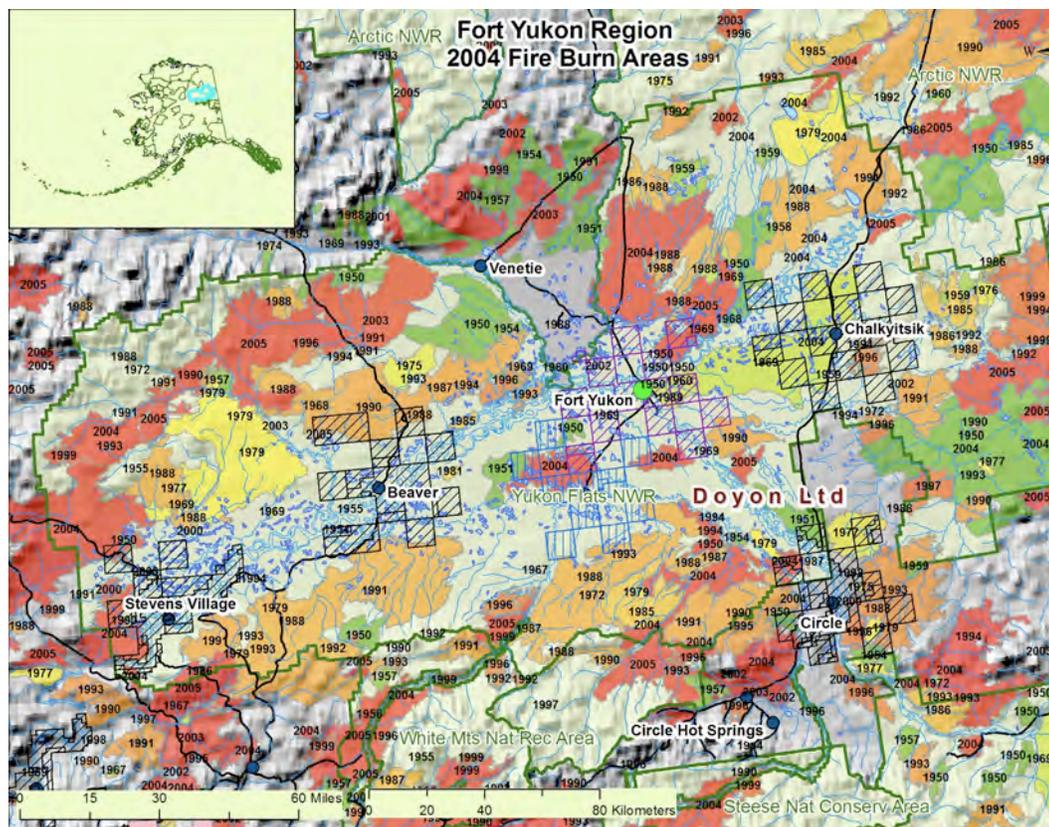
#### **4.4 Project Permits**

The project is small enough that no permit is needed operations of the boilers. Garn boilers are extremely efficient and have been used as the model for developing emissions specifications for boilers of this size by EPA.

The amount of effected acres for harvest is minimal annually for the 327 cords of wood required operating both of the boiler plants. However, it is not known whether the Alaska State Forest Practices Act for wood harvest on private lands will be enforced at this scale of harvest or whether this will be considered subsistence wood gathering. A discussion between AEA and DNR Forestry Department is currently underway to determine how and when Best Management Practices (BMP) will be enforced. If AFPA notification and BMP implementation is required then a Fish Habitat permit will be required for all crossings of anadromous fish streams when hauling wood during the winter.

If federal funds are used for the construction of the project or for purchase of harvest equipment an Environmental Assessment will be required under NEPA.

## Appendix A. Wildland fires in the vicinity of Chalkyitsik.



## Appendix B. Harvest Equipment Examples.



Tractor pulling log trailer with grapple arm loader.



Self-loading log trailer.



Tractor with a harvesting head for cutting, limbing and cut to length  
Forecat with self-loading trailer for transporting wood to the village



Example of an armored articulated tractor

### Appendix C. Lower boiler site.



### Appendix D. Upper boiler site.

