Feasibility Study of a Biomass Energy System for Boulder County Parks Department

Final Report

Prepared for:

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June 2003

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Executive Summary

This study evaluates the feasibility of heating several planned buildings in Longmont, Colorado, with wood fuel. This would displace use of a limited resource, natural gas, with a renewable resource, and make use of wood that currently has a negative value.

A large quantity of waste wood is generated each year from forest thinning projects and urban tree trimming. Wood residue from Boulder County Parks and Open Space projects is currently disposed of, incurring hauling and handling costs. The new facilities would be heated using wood from these Parks and Open Space thinning projects, though other sources of material are available if the Parks and Open Space material is insufficient.

Results

This study resulted in a system size estimate of 100-boiler horsepower (bhp) for a primary wood-fired boiler, with a natural gas-fired backup boiler of 1000-bhp. This backup boiler would be used if either the wood-fired boiler was unavailable, or if wood supplies on site were depleted. During times of extreme cold, if the primary boiler were not capable of reaching the desired temperature, the backup boiler would come on automatically to assist.

Quotes for wood-fired boiler systems were received from two manufacturers, Chiptec and Messersmith. The total cost for the wood-fired boiler, underground piping, wood storage shed, boiler room, and other associated equipment was estimated to be $834,500. The cost for an equivalent natural gas system was estimated to be $478,000. Items considered to be equal between the two systems are not included in these estimates.

Total thermal energy required to heat the facilities was estimated to be 67,166 therms[1] per year. Required wood quantities were estimated to be 648 tons per year. It was assumed that the wood available from thinning projects would have a moisture content of 40%, wet basis, and an energy content of 5184 Btu per pound, as delivered.

Natural gas prices in Colorado have recently experience large increases. In 2002, Boulder County was paying about $0.425 per therm. In 2003, this has already increased to $0.62 per therm. The price of natural gas is expected to continue to increase.

Boulder County Parks and Open Space can supply wood fuel for almost no increase in cost over the current handling, hauling, and disposal costs. The supply of wood fuel resulting from BCPOS projects will probably be sufficient to heat the facilities, but a resource assessment to quantify this has not been performed. It was estimated that wood would be available from other sources for 20 to 30 dollars per ton, delivered. Therefore, two economic analyses were performed, one with an initial fuel wood price of $30 per ton ($2.89 per million Btu), and one with a wood price of $5 per ton ($0.48 per million Btu). Both cases used an initial natural gas price of $6.20 per million Btu.

Findings

Over the 30-year expected system life, the wood-fired system has lower costs than the natural gas system, as long as the wood price is less than about $25 per ton. Above that price, the natural gas system has a slight economic advantage.

[1] 1 therm = 100,000 british thermal units (Btu)

1 Introduction

This study investigates the feasibility of heating a planned building with fuel derived from forest thinning.

Description: Boulder County Parks and Open Space and Boulder County Transportation Department have plans to build a new facility in Longmont and want to evaluate the feasibility of heating the new buildings with wood waste from local forest thinning operations. Construction on the new buildings is currently expected to begin during the summer of 2004. The buildings currently occupied by these two departments are heated by natural gas.

Due to advances in technology and changing economic conditions, wood fuels are emerging as preferred energy sources for many schools, particularly in New York and Vermont.[2] Concurrently, forest health issues in Boulder County, as well as the entire Front Range, are a cause for concern for area residents. The severely crowded forests in the area are increasing the likelihood for catastrophic fires, pest infestation, and decreased water run-off necessary for aquifer recharge. The US Forest Service, the state of Colorado, local agencies, including Boulder County, and private landowners are currently thinning small diameter. The parks department has requested a feasibility study for a local renewable resource to provide heat to the new facility.

1.1 Objective

The intent of this proposed work effort is to determine the engineering, economic, and regulatory feasibility of installing a biomass energy conversion system at the new Boulder County Parks and Open Space facility in Longmont, Colorado. The wood-fired heating system will be compared with a natural gas system since that is the alternative heating system for the facility.

1.2 Task Descriptions

The following tasks shall be performed for the study:

1) Initial meeting with BCPOS staff. The purpose of this meeting is to discuss the project scope and schedule, and for the consultant to elaborate the data and information that BCPOS needs to provide to the consultant.
2) Contact the Colorado Department of Health and/or relevant local authorities to determine the emission limits and criteria pollutants for the site where the new office will be built. Determine which, if any, permits will be needed for the facility. Contact wood chip heating system vendors with these regulations and determine which of their systems can meet these limits.
3) Determine the proper size of the wood chip heating system that will be needed to meet the heating requirements of the new building. The system will be sized based on historical natural gas usage data and heating degree-days. Also include an estimate of the amount of physical space needed for the system as well as the fuel storage requirements.
4) Estimate the amount of wood biomass that would need to be consumed per year to provide the facility with heat. Coordinate with BCPOS staff to determine whether sufficient biomass exists from BCPOS' on-going wildfire mitigation (thinning) efforts, or whether supplemental sources of biomass need to be located. Determine the delivered cost

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[2] Maker, Timothy, "Heating Schools with Biomass: Fifteen Years of Success in Vermont," paper presented at Bioenergy 2002, Boise, ID.

per ton of biomass, as well as the likely physical and chemical characteristics of the biomass.

5) Estimate system capital costs. The capital costs should include the wood chip heating system and water tube boiler, fuel handling and storage, controls, emissions controls, fans, ash removal systems, and engineering and installation. The capital costs will be developed for the wood chip heating system only and not include the balance of system components for the remainder of the building.
6) Provide estimates of annual operations and maintenance (O&M) costs. The evaluation should include estimates of the number of hours of labor per week/month/year that will need to be spent to maintain the system. The O&M costs should include items such as fuel costs, ash removal, ash disposal, cleaning of boiler tubes, and basic maintenance procedures for motors, augers and belts.
7) Compare the capital and annual O&M costs of the wood chip system with the most likely alternative to be used in the facility.
8) Develop a final report documenting the results of the study and outlining recommendations to move forward. Consultant shall present the results of the study at a meeting of BCPOS staff.

1.3 Project Information

Following are some details of the proposed building, past energy use data from an existing building that will be used as a proxy to estimate energy use at the proposed facility, and climate data.

Boulder County Parks and Open Space and Boulder County Transportation District planned facilities:

- Elevation 5050 **feet** above sea level (ASL)
- The planned floor area of the Parks and Open Space building consists of office space, shop area (machine and wood shop) and a heated storage area.
- The Road Maintenance Division facilities will (probably) consist of three buildings: The **Administration** building will consist of offices, storage areas, conference rooms, rest rooms, and a break room, etc. The **Fleet Maintenance** building will be a large, heated garage, and is planned to be about **45,000** ft^2. The third building is a **storage** building, which will have shops, tools, and vehicles.
- Total heated area for both facilities: approximately **27,535** ft^2 of office facilities, **45,151** ft^2 of garage facilities, and **53,724** ft^2 of "heated storage/parking", for a total of 126,410 ft^2.
- The office facilities and garage facilities will typically be occupied 8-10 hours per day during the heating season, (longer on snow days); the typical office temperature set-point will be 69-70 °F, with a turndown temperature of 62 °F outside of operating hours. The typical garage set point is 67 °F (currently 24 hours per day). The heated storage area will be kept above freezing, probably 45-50 °F.
- Ceiling heights: Offices – 8 feet, Garage – 14 feet (at walls) to 16 feet (at peak)

1.4 Climate: Boulder and Longmont

Table 1 shows typical heating degree-day data (base temperature 65°F), as well as heating degree data for 2002, for Boulder and for Longmont. Note that the heating requirements for Longmont are considerably higher than the requirements for Boulder.

Table 1. Boulder and Longmont Climatic Data

	2002		Typical HDD		2002 vs. typical	
Period	Boulder	Longmont	Boulder	Longmont	Boulder	Longmont
Jan	989	1125	1003	1182	0.99	0.95
Feb	813	983	818	941	0.99	1.05
Mar	852	1017	750	840	1.14	1.21
Apr	364	487	482	541	0.75	0.90
May	193	317	233	261	0.83	1.21
Jun	40	60	55	67	0.73	0.90
Jul	5	10	5	8	1.00	1.25
Aug	8	12	8	14	1.00	0.86
Sep	85	107	121	158	0.70	0.68
Oct	592	630	374	469	1.58	1.34
Nov	760	823	723	843	1.05	0.98
Dec	854	864	931	1106	0.92	0.78
12-month	5536	6353	5504	6430	1.01	0.99

The heating degree-day (HDD) value is calculated by subtracting the mean temperature for a day from the base temperature. If the mean temperature is greater than the base temperature, the heating degree value for that day is zero. The mean temperature for a day is calculated as the average between the high temperature for a day and the low temperature for the same day. All of the heating degree-days in a period are added together to arrive at a heating degree-day value for that period. Heating degree-days are reasonably good indices of the heating requirements of buildings. It is not a perfect system for predicting heating loads for any single day, but it works fairly well over a longer term.

1.5 Natural Gas Use

Future natural gas use estimates are based on data from similar existing Parks and Open Space buildings. It is estimated that heating energy use will be 67,000 therms[3] per year for the proposed facilities.

As an example of past natural gas use at one location, the data for the Walden facility for 2002 is shown in Figure 1. This figure shows, by month, the energy used by the heating system at the Walden Main Building during 2002. The Walden Main Building is 21,910 ft^2, and is one of the Road District's facilities. The total gas used at this building in 2002 was 15,316 therms. The total gas cost was $6,372. The average price of gas over this period was $0.43 per therm ($4.30/MBtu). Future natural gas prices are expected to increase significantly from those of previous years, with the price for 2003 already up to $0.62/therm.

[3] Natural gas quantities for Boulder County are charged based on energy content, not based on volume, and are measured in *therms*. One therm = 100,000 Btu.

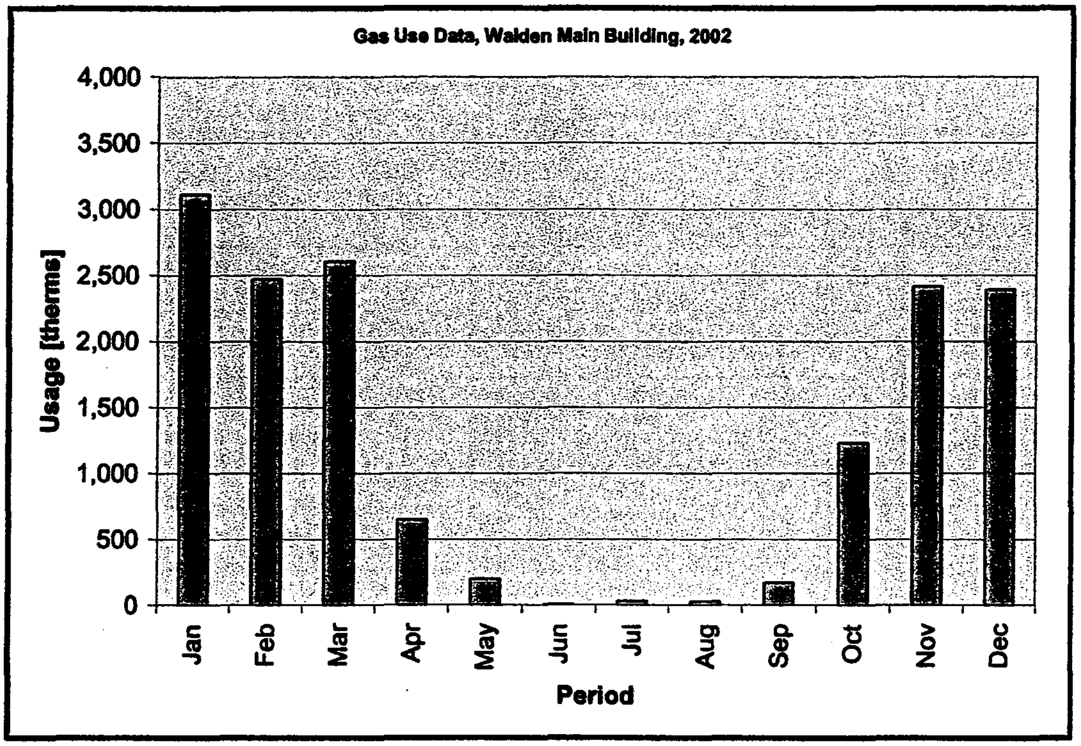


Figure 1. Natural Gas Use at Walden Main Building in 2002

Figure 2 is a graph of thermal energy use vs. heating degree-days (base 65 °F) at the Walden facility. A trend line and equation are included on the graph for reference. The trend line equation is useful for estimating thermal energy use under various heating degree-day conditions.

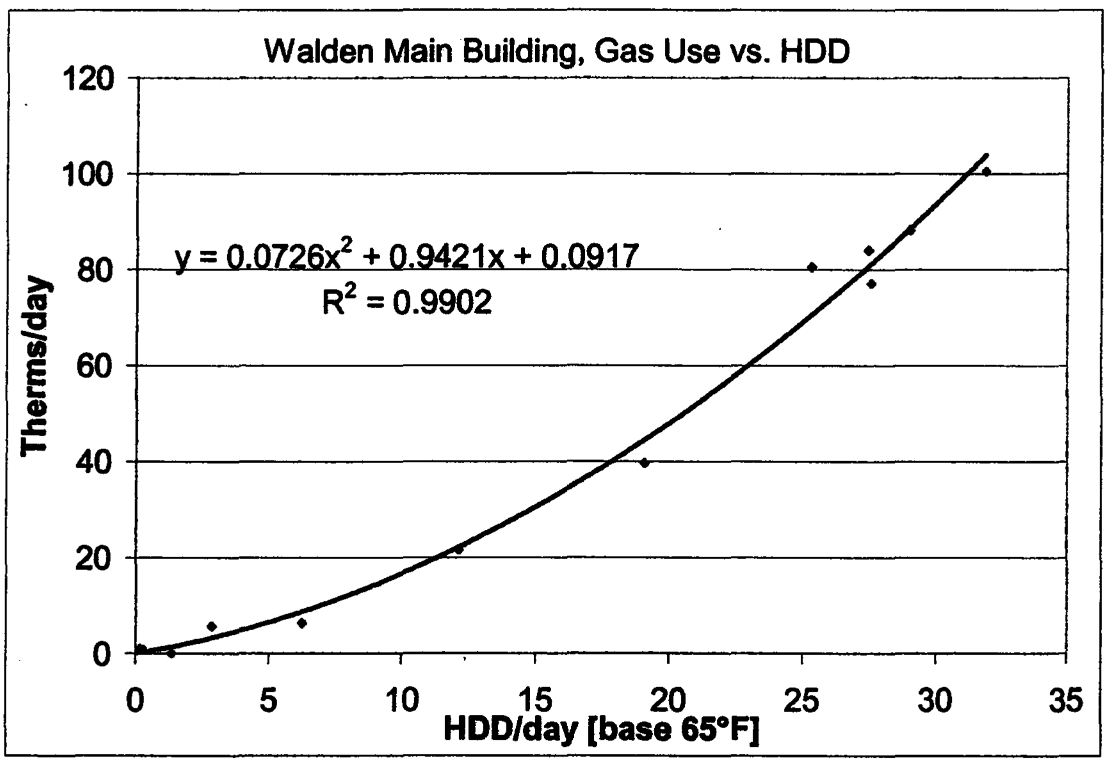
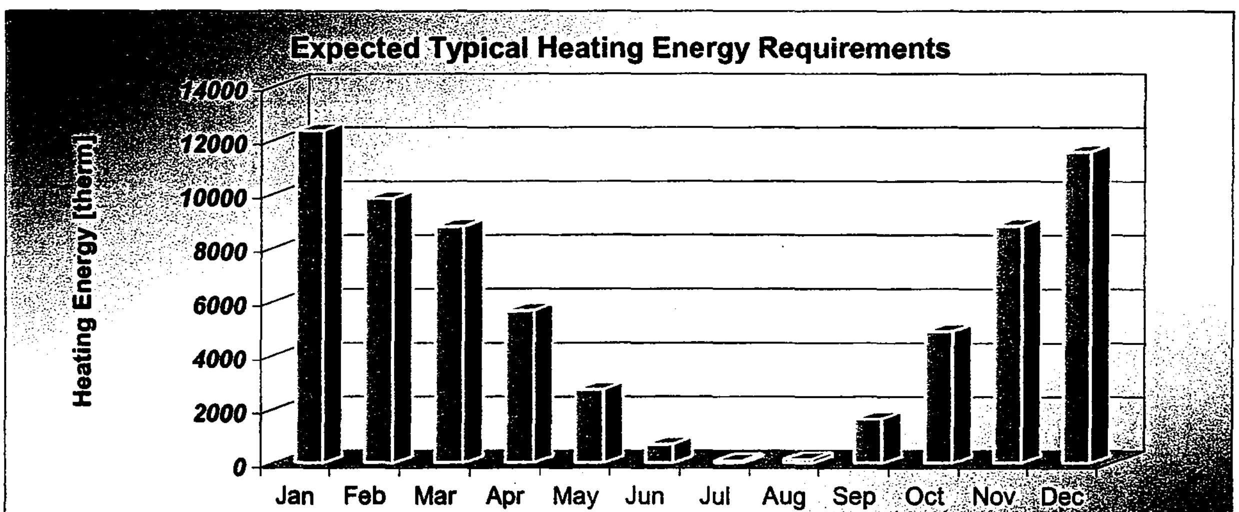


Figure 2. Walden Facility, Gas Use vs. Heating Degree Day

							Wood Properties	
		Btu/dd/ft2				ft2	40	% MC wb
Office (avg)		10.2		Office Space		27535	8640	Btu/lb dry
Garage (avg)		14.0		Garage Space		45151	5184	Btu/lb wet
Heated Storage (avg)		2.5		[illegible]		[illegible]	103.68	Therm/ton
					Total	126410	0.5	% ash
Expected Heating Energy Use at New Building								
Period	# days	Office Therms	Garage Therms	Heated Storage Therms	Total Therms		Wood Required Tons	Ash Production Tons
Jan	31	3311	7448	1588	12347		119	0.6
Feb	28	2636	5929	1264	9829		95	0.5
Mar	31	2353	5293	1128	8774		85	0.4
Apr	30	1516	3409	727	5651		55	0.3
May	31	731	1645	351	2726		26	0.1
Jun	30	188	422	90	700		7	0.0
Jul	31	22	50	11	84		1	0.0
Aug	31	39	88	19	146		1	0.0
Sep	30	443	996	212	1650		16	0.1
Oct	31	1314	2955	630	4899		47	0.2
Nov	30	2362	5312	1132	8806		85	0.4
Dec	31	3098	6969	1485	11553		111	0.6
12-mont	365	18014	40516	8636	67166		648	3.2

Table 2. Estimated Typical Heating Energy at new Longmont Site

Estimated heating energy use by month, for office space, garage space, and heated storage is shown in Table 2, above, and in Figure 3, below.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
▪ Therms	12347	9829	8774	5651	2726	700	84	146	1650	4899	8806	11553

Figure 3. Projected Heating Requirements at Proposed Facility

The price of natural gas through the end of 2002 was $0.425/therm. This has increased to $0.62/therm in 2003. This translates to a cost of heating the proposed facility, if using natural gas, of about $42,000 per year, based on 2002 data and 2003 costs. This works out to about $0.41 per square foot per year to heat the office area, $0.56 per square foot per year to heat the garage area, and $.10 per square foot per year to heat the "heated storage" area.

Several events are pushing natural gas prices up, and prices in 2003-2004 are already 44 percent higher than 2002 prices. These prices are not expected to go down. Figure 4 shows natural gas prices for two locations in California and three locations in Colorado. There is a general upward trend in these gas prices. Note that the Colorado prices are approaching the California prices. This is partly due to a new natural gas pipeline that recently opened between the Rocky Mountains and West Coast.

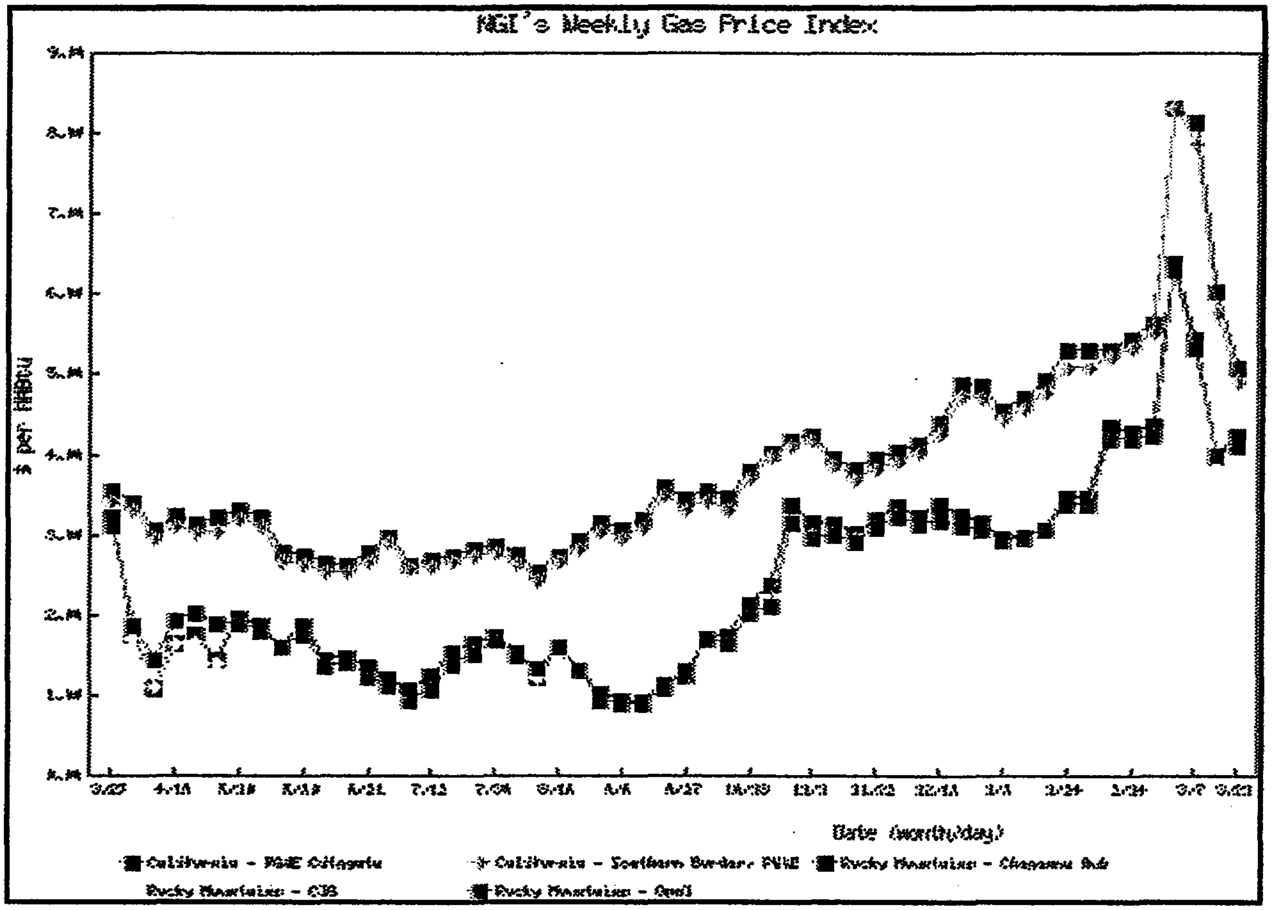


Figure 4. Weekly Natural Gas Prices, From Natural Gas Intelligence Web Site[4]

[4] From NGI Web site: http://intelligencepress.com, accessed March 26th, 2003

2 Equipment Emissions and Emission Regulations

The Colorado Department of Health and Environment (CDPHE) was contacted to determine the emission limits and criteria pollutants for the site where the new office will be built. Required permits for a wood-fired system are discussed. Wood-fired heating system vendors were contacted with these regulations to determine if their systems could meet these limits. Allowable methods of ash disposal are discussed.

2.1 Emission Limitations and Regulations

After discussions with health departments for both the City and the County of Boulder it was determined that the Colorado Department of Health and Environment (CDPHE) is the regulating agency for air emissions at the proposed site.

Emissions limits are set in stages[5]. The first stage is reached when the emission of any criteria pollutant[6] exceeds two tons per year. Below this stage, no paperwork need be filed with CDPHE. If the emission of any criteria pollutant is expected to exceed two tons per year, an Application for Construction Permit and Air Pollutant Emission Notice (APEN), must be submitted to CDPHE. Note that these emissions are the uncontrolled emissions, meaning that they are measured before the exhaust enters any emission control equipment.

Table 3. Colorado Emission Limits

Area	Uncontrolled Actual Emissions
Attainment	2 Tons Per Year
Nonattainment	1 Ton Per Year
All Areas	Lead Emissions: 100 pounds per year

The Longmont site is in an Attainment area, so the limit for criteria emissions at the site are two tons per year. If the annual (uncontrolled) emissions are estimated to exceed those shown in Table 4, a modified construction permit must be obtained.

Table 4. Emissions Limits for Permit

CRITERIA POLLUTANT	ATTAINMENT AREA uncontrolled actual emissions [tons/year]	NON-ATTAINMENT AREA (for any criteria pollutant) uncontrolled actual emissions in tons per year
Volatile Organic Compounds	5	2
PM10	5	1
Total Suspended Particulates	10	5
Carbon Monoxide	10	5
Sulfur Dioxide	10	5
Nitrogen Oxides	10	5
Lead	200 pounds per year	200 pounds per year
other Criteria Pollutants[7]	2	2

[5] Emission regulations and Construction Permit are available at http://www.cdphe.state.co.us/ap/conperm.asp

[6] Criteria Pollutants include PM_{10}, NO_x, SO_2, CO, VOCs, and lead

[7] Other criteria pollutants include: fluorides, sulfuric acid mist, hydrogen sulfide, total reduced sulfur, reduced sulfur compounds, and municipal waste combustor emissions.

2.2 Expected Emissions

Figure 5 shows the expected emissions from a wood-fired heating system for a typical year. The products with the highest emissions are Oxides of Nitrogen, at 1787 pounds per year and Particulates at 1343 pounds per year. Note that all of the emissions are considerably below the APEN limit of two tons (4,000 lb) per year.

Period	Emissions (Controlled) [lb/period] Total Particulates	Oxides of Nitrogen	Carbon Monoxide	Total Organic Compounds	Sulfur oxides
Jan	247	328	200	74	31
Feb	197	261	159	59	25
Mar	175	233	142	53	22
Apr	113	150	92	34	14
May	55	73	44	16	7
Jun	14	19	11	4	2
Jul	2	2	1	1	0
Aug	3	4	2	1	0
Sep	33	44	27	10	4
Oct	98	130	79	29	12
Nov	176	234	143	53	22
Dec	231	307	187	69	29
12-month	1343	1787	1088	403	168
Ton/yr	0.67	0.89	0.54	0.20	0.08

Figure 5. Expected Emissions from Wood-Gasifier

2.3 Emissions Reductions due to Gasification of Wood Waste

Much of the fuel for the wood-fired boiler would come from material that is currently being burned by Boulder County Parks and Open Space, and by other agencies. Table 5 compares the emissions due to burning wood waste in piles, in prescribed burns, in uncontrolled forest fires, and in a gasifier.

Table 5. Comparison of Different Wood-burning Alternatives

	PM10	NOx	SO2	VOC	CO
	(lbs/green ton)				
Pile Burning (1)	19 to 30	3.5	0.1	8 to 21	154 to 312
Prescribed Burning (2)	24	4.0	??	13	224
ForestFire (2)	15	4.0	??	21	140
Chiptec Gasifier	2.07	2.76	0.26	0.62	1.68

(1) Patrick Gaffney, California Air Resources Board, 916-332-7303. Available at www.gisc.berkeley.edu/~jscar/agburn/agburnefs.html

(2) Environment Australia. Emissions Estimation Technique Manual for Aggregated Emissions from Prescribed Burning and Wildfires, Version 1.0. September 1999.

Due to the carefully controlled conditions in the gasifier, and the emissions control equipment, the level of emissions of CO (carbon monoxide), PM10 (particulate matter smaller than 10 micrometers) and VOCs (volatile organic compounds) are greatly reduced when these materials are burned in the gasifier, compared to any of the other three methods. The level of NO_x (oxides of nitrogen) is also reduced, but not as significantly. Emissions of SO_2 (sulfur dioxide) are dependent on the amount of sulfur in the wood, and are probably the same for each of these burning methods.

2.4 Projected Ash Production

The ash production from the gasifier will be proportional to the fuel use and to the ash content of the fuel. Figure 6 shows the expected ash production for each month of a typical year, assuming that the fuel has 0.5% ash, by weight. This data is based on expected heating requirements at typical heating degree-day conditions and expected ash production rates from the typical wood available near the new Boulder County Parks and Transportation District site.

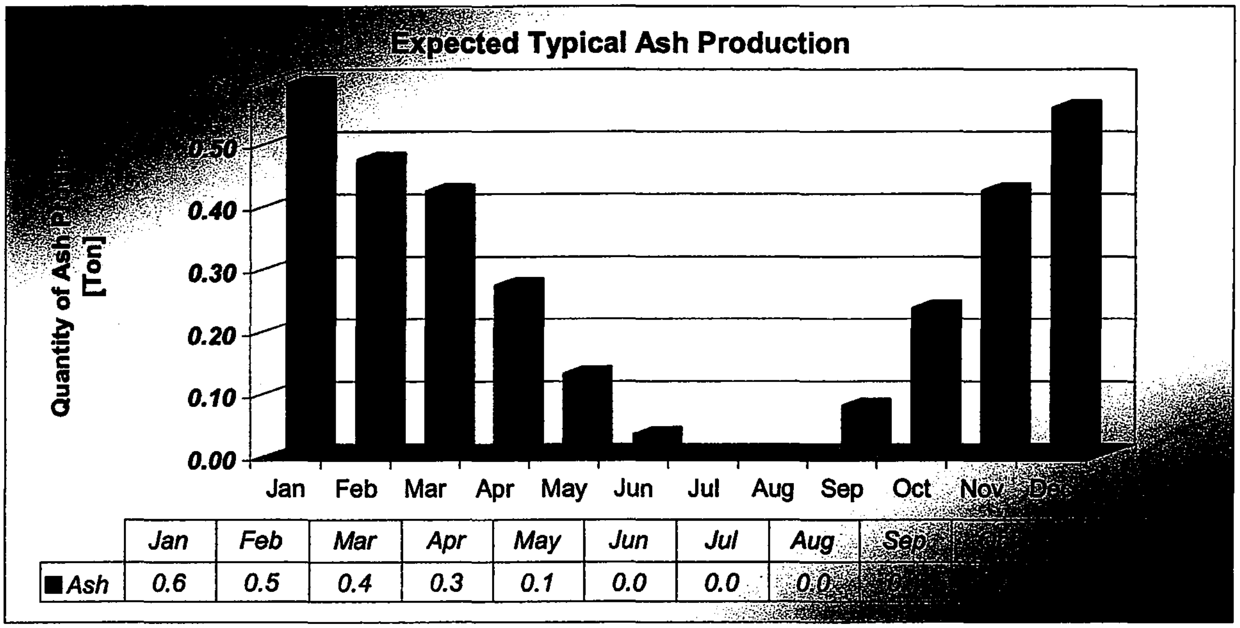


Figure 6. Projected Monthly Ash Production from Heating with Chiptec Wood-Gasifier

Total ash production is expected to be about 2.7 tons per year. This ash is not classified as harmful, and can be spread on sports fields, agricultural fields or disposed of at the local landfill.

3 Heating System Size

The appropriate size of the wood-fired heating system needed to meet the heating requirements of the new building is determined. Boulder County provided historical data for the current buildings that they occupy. The system size is based on historical natural gas usage data and heating degree-days.

3.1 Summary

Typically, for a facility of this type, a thermal loads analysis would be performed to estimate the building heating requirements on the design day, and this data would be used to determine the appropriate size of the system. Because this analysis was not available, more rudimentary methods had to be used to estimate system size.

Two different methods were used to estimate an appropriate heating system for the facilities. In the first method, the gas consumption, and local climate, for several existing facilities, was used to determine thermal energy use per square foot, per degree-day. This data was then scaled by the Longmont climate and the building types and sizes for the planned facility. This resulted in an estimated gasifier size of 3.3 MBtuh (98 boiler horsepower (bhp[8])). This calculation is for input energy. Boilers are generally sized in terms of maximum output capacity. At a system efficiency of 80%, this would result in 78.5-boiler horsepower output from the boiler.

The second method used a simple "rule of thumb" of multiplying the cubic feet of heated space by a factor to estimate peak load. The factor for office space is 7 Btu/ft^3 and for garage space is 10 Btu/ft^3. The resultant number is then divided by four to arrive at an estimated output size of 2.3 MBtuh (69 boiler horsepower output from boiler - this estimate includes the heated storage areas requirements).

An independent analysis by MKK Consulting Engineers for Boulder County estimated a total maximum heating load of 173 bhp. It was then decided to size a wood-fired boiler and natural gas-fired backup boiler each at 60% of this estimated maximum heating load, which works out to each system being 100 bhp.

3.2 Details

The wood-fired system should be sized to heat the building (or buildings) on a typical cold winter day (design day). Since the building designs are not complete, and no building load calculations or simulations have been performed, we can only approximate the amount of thermal energy required to heat the facility under any particular weather conditions.

The month with the coldest average minimum temperature in Boulder is January, with an average minimum temperature of +9.5°F. The month with the coldest average minimum temperature in Longmont is also January, with an average minimum temperature of –1°F. In Boulder, the minimum temperature drops below 0° an average of 5 times per year, and in Longmont this occurs 13 times per year. The ASHRAE 1% design condition for Boulder in winter is 2 °F. For sizing purposes, the average minimum temperature is here used to estimate peak heating loads at the Longmont facility.

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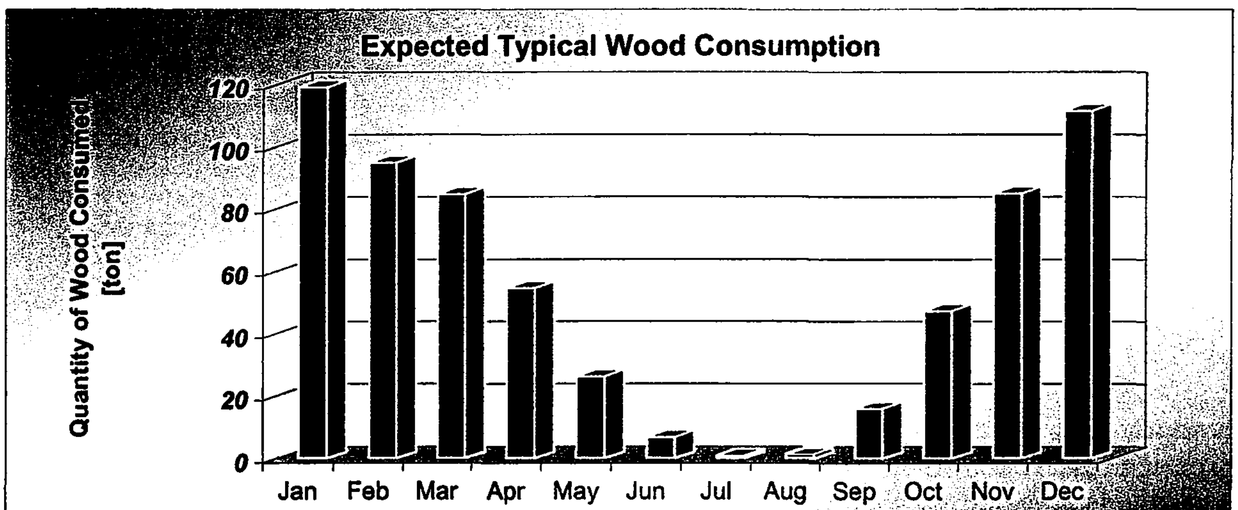
[8] BOILER HORSE POWER (bhp) - The equivalent evaporation of 34.5 pounds of water per hour at 212°F to steam at 212°F. This is equal to a heat output of 33,475 Btu per hour.

4 Annual Wood Biomass Quantity Required

This section discusses the amount of wood biomass required to provide the facility with heat. Part of the motivation for investigating wood-fired heating systems was to find an outlet for the materials resulting from thinning forests on Boulder County property. McNeil coordinated with BCPOS staff to estimate biomass quantities that could annually be supplied from BCPOS' on-going wildfire mitigation (thinning) efforts. Efforts were also made to determine supplemental sources of biomass in case BCPOS material was insufficient. Estimates of the delivered cost per ton of biomass, as well as the likely physical and chemical characteristics of the biomass (e.g. species, percentage of bark and needles, moisture content, ash content, Btu content), were also made enabling an economic comparison between heating with wood and heating with natural gas.

Figure 7 shows a chart and table of expected wood consumption at the proposed Longmont facility. The quantities given are in units of green tons of wood. It has been assumed that the wood is primarily Ponderosa Pine, with a moisture content of 40%. This material would have an energy content of approximately 5184 Btu per pound (dry material would have an energy content of about 8640 Btu/lb).

The total wood required for the year is projected to be 648 green tons, to supply 6717 MBtu.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Wood	119	95	85	55	26	7	1	1	16	47	85	[illegible]

Figure 7. Estimated Wood Consumption

4.1 Wood Biomass Physical and Chemical Characteristics

Wood fuel characteristics impact the combustion process and therefore the choice of conversion technologies. This section provides information on wood biomass.

Moisture content greatly affects the quality of biomass fuel. Moisture content can be measured on a wet or a dry basis. In engineering calculations moisture content is expressed as a percent of the total weight. This is the wet basis method. In the dry basis method the moisture content is expressed as a percent of the dry weight of the wood. This report uses the wet basis method.

Design engineers use heat content values to size a biomass conversion system. The heat content of wood and bark varies considerably due to differences in the chemical composition of the sample. As a general rule, softwoods contain a higher percentage of volatiles in the form of gums and resins. Softwoods, therefore, often, but not always, have a higher heat content per pound than hardwoods.

The most common problems associated with the direct combustion of wood are boiler slagging and fouling, erosion and corrosion, combustion instability, and particulate carryover. The amount of boiler slagging and fouling is dependent upon fuel ash fusion temperature. High alkalinity also causes fouling and slagging in stoker type boilers and agglomeration in fluidized bed combustion systems. Alkali content can be used as an indicator to estimate the potential for biomass fuels to cause boiler slagging and fouling. Research indicates that fuels with alkali contents below 0.4 lb. alkali/MBtu are not likely to cause slagging problems.[9] In general, whole-tree chips are higher than clean chips in alkali content due to the concentration of potassium, sodium salts and other organic compounds in the small branches, twigs and needles of the tree. Sodium and potassium compounds typically have low melting points resulting in increased slagging problems.

Ash content can be analyzed to assess combustion characteristics and determine the likely quantities of ash that will be left over and require disposal.

Physical fuel characteristics such as density and particle size affect combustion and material handling considerations. Changes in fuel density could cause combustion to occur in the wrong place in the boiler, upsetting the heat transfer scheme and therefore the boiler efficiency. Physical fuel characteristics are most often controlled through grinding and screening techniques.

9 Miles, T.R., T.R Miles Jr., Larry L Baxter, Bryan M. Jenkins, Laurence L. Oden. Alkali Slagging Problems With Biomass Fuels, In Proceedings of the First Biomass Conference of the Americas, Held August 30 - September 2, 1993. NREL/CP-200-5768 DE93010050. pp. 406.

5 System Capital Cost Estimate

Capital cost estimates from two vendors are presented for the wood chip heating system. The capital costs include the wood chip heating system and water tube boiler, fuel handling and storage, controls, emissions controls, fans, ash removal systems, and engineering and installation. The capital costs are developed for the wood-fired heating system only, and do not include the balance of system components for the remainder of the building.

Capital costs depend on the system size, which depends on the area to be heated, among other things. Due to the uncertainty in estimating building thermal loads, due to lack of definition of building type, size, layout, number, etc., the system size cannot at this time be certainly stated. We have estimated the system size at 50 to 100 bhp (this is the output from the boiler). Chiptec Wood Energy Systems has quoted two systems, one in each of these sizes, detailed in Table 1. Note that the costs listed do not include the back-up natural gas-fired boiler.

Table 6. Chiptec Budgetary Quotations for 50- and 100-bhp systems

50 bhp system	100 bhp system
Gasifier B-Series, **Model C-2**	Gasifier B-Series, **Model C-4**
Feed screw assembly	Feed screw assembly
Chiptec rotary air lock	Chiptec rotary air lock
Induce Draft Stack Fan Assembly	Induce Draft Stack Fan Assembly
Total Air Fan Assembly (primary/secondary fan)	Total Air Fan Assembly (primary/secondary fan)
Pre-wired control panel	Pre-wired control panel
Three-pass fire tube, hot water boiler capable of producing 50 bhp	Three-pass fire tube, hot water boiler capable of producing 100 bhp
Single-cyclone collector for particulates in the exit gas stream	Single-cyclone collector for particulates in the exit gas stream
Chiptec Sweep unloader	Chiptec Sweep unloader
Receiving Auger: 30'	Receiving Auger: 30'
Metering Auger: 20'	Metering Auger: 20'
Budgetary quote: $167,010	**Budgetary quote: $215,322**

As the system size will likely be close to 100 bhp, we asked Messersmith to quote a system of that size. Their rough estimate was $276,118 for a hot water system. This price includes engineering, augers, conveyers, control panel, electrical subcontract work, some spare parts, training, startup, set-up, and shipping.

Other costs in the analysis include a chip-storage shed, incremental boiler room cost, above-ground storage for about 1 week's fuel supply (about 25 tons), and an allowance of $10,000 for additional engineering. If a wood-fired boiler is used, it will serve several buildings, but if natural gas is used for heating, a separate boiler would be placed in each building. Therefore, a wood-fired boiler would require insulated, underground piping between the boiler-room and the other buildings. This piping has been estimated to cost $250 per foot, installed. About 625 feet would be required, for a total additional cost of $156,250 for the insulated piping.

6 Annual Operations and Maintenance Costs Estimate

System vendors and operators of currently installed systems were contacted to estimate the annual Operations and Maintenance (O&M) costs of the system. The evaluation includes estimates of the number of hours of labor per week/month/year that will need to be spent to maintain the system. The O&M costs include items such as ash removal, ash disposal, cleaning of boiler tubes, and basic maintenance procedures for motors, augers and belts. Estimated wood fuel costs are assessed in Task 4.

Table 7 summarizes maintenance hours for three companies that are using Chiptec boilers.

Table 7. Reported Maintenance Hours for Chiptec Systems

Company	Number gasifiers	Boiler Output per System	Hrs/wk for maintenance per gasifier
Columbia Forest Products	2	250 hp	4
Penley Corporation	1	135 hp	2
Patterson Lumber	1	225 hp	2

Table 8. Chiptec Customer Contact Information

Columbia Forest Products	Rick Nelson	802-334-6711
Penley Corp.	Dick Penley	207-674-2501
Patterson Lumber	Bob DeCamp	814-434-2210

Most of the Chiptec systems installed in schools are operated and maintained by the custodians. The routine maintenance is dependent on fuel type and operating load and hours.

The following is a conservative initial maintenance plan. As the operators become familiar with the equipment, they can modify this as necessary. (Many installations go far longer between maintenance routines then indicated here.)

Grate maintenance consists of cooling the box down slightly, and scraping the grate with the provided tool. When the box is closed, after scraping the grate, it will restart by itself (if it hasn't cooled down too much). The ash removal screw will push the material into the external ash box for disposal. The entire procedure takes about ten minutes. This should be done about twice a week initially. (Though some go as long as twice a month between cleanings).

Boiler tube cleaning is also dependent on degree-days and fuel. Most systems in schools clean tubes twice a year, during the summer, and during a mid season shut down (during the holiday period). The frequency of required boiler tube cleaning can be determined by monitoring the stack gas temperature.

Equipment maintenance consists of lubricating gear drives, replacing seals or bearings, or gaskets, occasionally. A $500 to $1,000 per year "sinking fund" will normally fully cover any equipment maintenance required.

Additional maintenance costs include the cost to move the wood around on-site, and to load the hopper from a larger storage area. This handling has been estimated to cost about $2,000 per year.

Based on heating energy use of 6,717 million Btu per year, the O&M costs for the wood-fired system are about $0.50 per million Btu. For a similarly sized natural gas system, the O&M costs are estimated to be $0.10 per million Btu.

7 Comparison of System Capital Costs

Relative cost differences between a wood-fired heating system with natural gas backup, and a complete natural gas-fired system are discussed.

A wood-fired system would consist of a 100-bhp wood-fired boiler, with a 100-bhp natural gas boiler for back-up and supplemental heating. These would both be located in a central boiler room, with insulated, underground pipes distributing hot water to all of the buildings. The boiler room would also have a bunker that would hold about 1.5 semi-loads of wood chips. The fuel would be fed from the bunker to the gasifier/boiler by mechanical systems controlled by the central control system. Additional fuel storage would be accommodated on-site by a covered storage area (which may share space with salt or sand storage). The additional storage should hold 50 tons of wood chips, which would be sufficient to supply about 2 weeks of fuel during the coldest months. The chips would need to be manually moved from the wood storage shed to the bunker once or twice per week.

The cost of a 100-bhp system (gasifier, boiler, controls, bunker, emissions systems, etc., see Appendix) is $215,322 from Chiptec. The underground pipe is estimated to cost $156,200, the chip storage shed $40,500, the boiler room $72,000. Other miscellaneous costs bring the estimated total to $834,500.

The cost of the natural-gas backup system and the piping and radiators, etc., in the individual buildings are not included, as they would be approximately the same for either system, and hence drop out of the calculations.

A traditional natural gas fired system would consist of smaller boilers located in each building, along with a back-up natural gas fired boiler in each building. This would require a small mechanical room in each building, but would not require a large, central boiler room. Underground pipes, which have been estimated to cost as much as $250 per foot, installed, would not be required, nor would the chip-storage shed.

MKK Consulting Engineers provided a rough cost estimate for a heating system fired with natural gas. The estimated cost for the natural gas-fired systems was $478,000

Table 9. System Costs

System component	Capital cost 100 Bhp Wood-fired primary, NG	Natural Gas System	
Wood-Fired Boiler, 100 Bhp	$ 215,322	N/A	
Other Mechanical	$ 396,678	$ 390,000	
Site Work	$ 20,000	$ 10,000	
Insulation	$ 27,000	$ 23,000	
Temp. Control	$ 45,000	$ 39,000	
Balancing	$ 18,000	$ 16,000	
Chip Storage Shed	$ 40,500	$ -	
Boiler Room (40'x40')	$ 72,000	$ -	Incremental Cost
Total capital costs	**$ 834,500**	**$ 478,000**	$ 356,500

Table 9 shows system costs included in the analysis. The items under "Natural Gas System" cover the system that would be installed instead of the wood-fired system. That cost is subtracted from the other costs to arrive at the incremental capital costs of the wood-fired system over the natural gas fired system.

8 Economic Analysis

A simple economic analysis of three cases is presented. One case is for a system using natural gas only, one using wood costing $30 per ton delivered, and one using wood from BCPOS thinning projects, costing $5 per ton delivered.

System economics are dependent on capital costs, operating expenses, and fuel costs, and other factors. Table 10 and Table 11 show the assumptions used for the economic analysis of the wood-fired system, using the 100-bhp system from Chiptec. Details of the items included in these quotes are shown in Table 6.

The only difference between Table 10 and Table 11 is in the cost of fuel wood. The cost of $2.89 per million Btu shown in Table 10 is based on a delivered cost of $30 per green ton, at 40 % moisture content (wet basis) and 8640 Btu per pound of dry wood (5184 Btu per pound of wet wood). This price is at the high end of cost estimates from outside suppliers. The wood coming from Boulder County Parks and Open Space thinning projects would have to be cut and hauled out even if it was not to be used for heating purposes. Therefore, the fuel price is the incremental cost to deliver the wood to the Longmont site. In Table 11, the fuel costs are reduced to $0.48 per million Btu ($5 per green ton) for wood from BCPOS thinning projects.

Table 10. Assumptions for the Economic Analysis – Full Fuel Costs

Wood vs. Natural Gas Boiler Data	**100 Bhp Wood-fired primary, NG backup**	**Natural Gas System**
Full wood purchase cost - year 1 ($/MBtu)	$ 2.89	$ -
Natural Gas purchase cost - year 1 ($/MBtu)	$ 6.20	$ 6.20
O&M costs - year 1 ($/MBtu)	0.50	0.10
O&M growth rate (%/year)	5%	5%
Thermal Energy Use (MBtu/year)	6,717	6,717
Percentage of Heating from Wood (%)	95%	0%
Annual energy cost (wood) - year 1 ($/year)	$ 18,463	$ -
Annual energy cost (gas) - year 1 ($/year)	$ 2,082	$ 41,643
Annual energy cost (total) - year 1 ($/year)	$ 20,545	$ 41,643
Estimated Annual Cost Inflation - Natural Gas	5%	5%
Estimated Annual Cost Inflation - Wood	2%	2%

Table 11. Assumptions for the Economic Analysis – Incremental Fuel Costs

Wood vs. Natural Gas Boiler Data	**100 Bhp Wood-fired primary, NG backup**	**Natural Gas System**
Incremental wood purchase cost - year 1 ($/MBtu)	$ 0.48	$ -
Natural Gas purchase cost - year 1 ($/MBtu)	$ 6.20	$ 6.20
O&M costs - year 1 ($/MBtu)	0.50	0.10
O&M growth rate (%/year)	5%	5%
Thermal Energy Use (MBtu/year)	6,717	6,717
Percentage of Heating from Wood (%)	95%	0%
Annual energy cost (wood) - year 1 ($/year)	$ 3,077	$ -
Annual energy cost (gas) - year 1 ($/year)	$ 2,082	$ 41,643
Annual energy cost (total) - year 1 ($/year)	$ 5,159	$ 41,643
Estimated Annual Cost Inflation - Natural Gas	5%	5%
Estimated Annual Cost Inflation - Wood	2%	2%

Table 12 shows details of the analysis of the 100 boiler horsepower system for the first ten years, using incremental fuel costs for wood from BCPOS projects.

Table 12. Details of the Economic Analysis for the 100-bhp System, First Ten Years

	Year									
	1	2	3	4	5	6	7	8	9	10
Estimated Fuel Costs										
Wood-Fired Primary System	$ (5,159)	$ (5,262)	$ (5,368)	$ (5,475)	$ (5,585)	$ (5,696)	$ (5,810)	$ (5,926)	$ (6,045)	$ (6,166)
Complete Natural Gas System	$ (41,643)	$ (43,725)	$(45,911)	$(48,207)	$(50,617)	$(53,148)	$(55,805)	$(58,595)	$(61,525)	$(64,601)
Difference	$ (36,483)	$ (38,462)	$(40,543)	$(42,731)	$(45,032)	$(47,451)	$(49,995)	$(52,669)	$(55,480)	$(58,436)
Expense ($)										
O&M - Wood + Natural Gas backup	$ (3,202)	$ (3,362)	$ (3,530)	$ (3,707)	$ (3,892)	$ (4,086)	$ (4,291)	$ (4,505)	$ (4,731)	$ (4,967)
O&M - Full Natural Gas System	$ (672)	$ (705)	$ (740)	$ (778)	$ (816)	$ (857)	$ (900)	$ (945)	$ (992)	$ (1,042)
O&M Difference	$ (2,530)	$ (2,657)	$ (2,790)	$ (2,929)	$ (3,075)	$ (3,229)	$ (3,391)	$ (3,560)	$ (3,738)	$ (3,925)
Total Annual Costs										
Wood-Fired Primary System	$ (8,361)	$ (8,624)	$ (8,898)	$ (9,182)	$ (9,476)	$ (9,783)	$(10,101)	$(10,432)	$(10,775)	$(11,133)
Complete Natural Gas System	$ (42,314)	$ (44,430)	$(46,651)	$(48,984)	$(51,433)	$(54,005)	$(56,705)	$(59,540)	$(62,517)	$(65,643)
Savings (Wood over Natural Gas System)	$ (33,953)	$ (35,806)	$(37,754)	$(39,802)	$(41,957)	$(44,222)	$(46,604)	$(49,109)	$(51,742)	$(54,510)

This analysis has been carried out for a 30-year period with results shown in Table 13. This table shows the simple payback period for the two fuel cost scenarios shown in Table 10 and Table 11. The row labeled "30-Year total of Savings" is the sum, over the 30-year analysis of the annual cost savings of using a wood-fired system instead of a natural gas-fired system. The 30-year savings are then divided by the initial incremental capital costs to derive the next row of data. If the incremental capital earned simple interest equal to the value listed as "The 30-year APR Equivalent", it would result in income equal to the "30-Year total of Savings".

Table 13. Economic Analyses for the 100-bhp System

	Full wood fuel costs	Incremental wood fuel costs
Simple Payback Period (Years)	19.2	10.5
30-Year total of Savings [$]	$ 1,765,119	$ 2,389,284
Total of savings/capital costs	5.0	6.7
30-year APR Equivalent	5.5%	6.5%
		Difference over Natural Gas System
NPV Natural Gas System ($)	$ (1,082,490)	
NPV Wood System - Full Fuel Costs ($)	$ (1,121,721)	$ (39,231)
NPV Wood System - Incremental Fuel Costs	$ (940,881)	$ 141,608

The last calculations in Table 13 are for a net present value (NPV) of three cases: one using natural gas only, one using wood costing $30 per ton delivered, and one using wood from BCPOS thinning projects, costing $5 per ton delivered. The use of the 100-bhp wood fired boiler, using BCPOS wood, results in the best NPV, and beats the natural gas system by $141,608. (At an average wood price of about $25 per green ton, the natural gas system and the wood-fired system would come out about even.)

Figure 8 is a chart of Simple Payback Period versus Wood Prices for four different natural gas prices: $3, 5, 7, and 9 per million Btu. Simple payback period is defined as the incremental capital cost (e.g. wood-fired system – natural gas fired system capital cost), divided by the first year savings. The annual costs include both O&M costs (which are considered fixed, in this analysis), and fuel costs. When gas costs are relatively low (i.e. $3 per MBtu), the wood cost strongly effects the payback period. As the fuel cost increases, the payback period graph begins to flatten out, and becomes less sensitive to wood cost.

When natural gas prices are low, it is very difficult for wood to compete, as the annual O&M costs are higher for the wood-fired system. As the price of gas increases, the wood-fired system becomes very inexpensive to operate, relatively, and the payback period becomes very short.

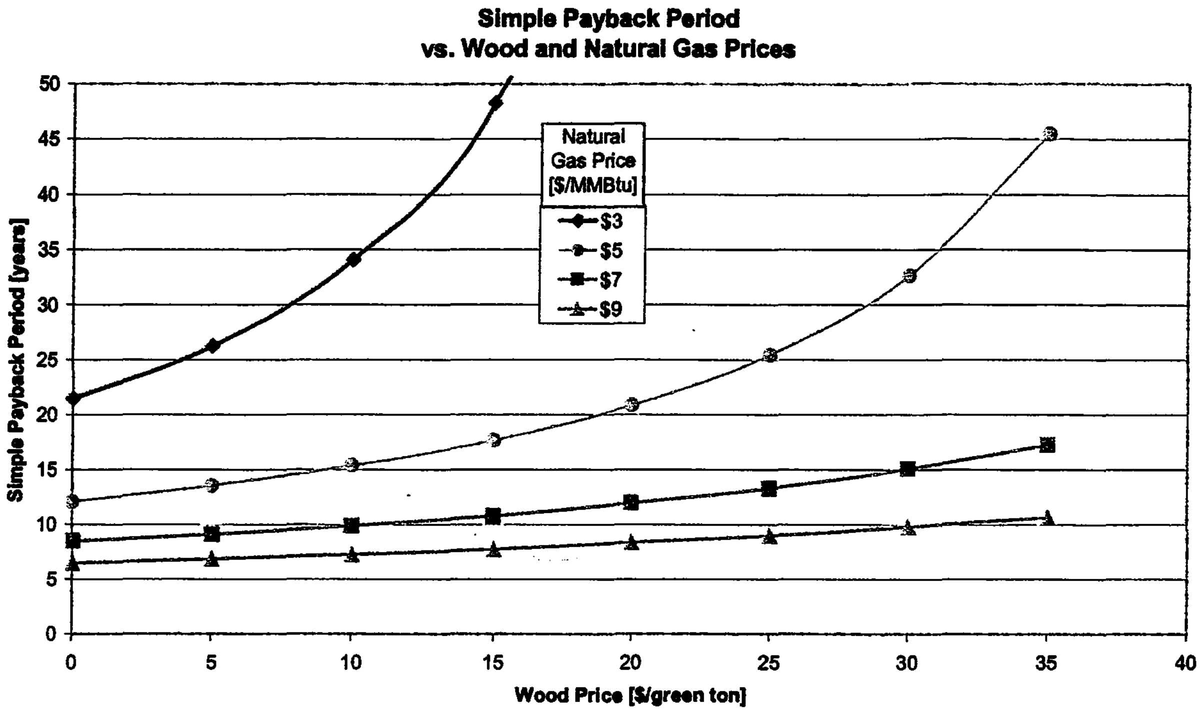


Figure 8. Simple Payback Period vs. Wood and Natural Gas Prices

9 Conclusions and Recommendations

The intent of this study was to evaluate the feasibility of heating planned Boulder County facilities in Longmont, Colorado, with wood fuel. There is a large quantity of waste wood annually available, resulting primarily from forest thinning projects and urban tree trimming. Wood residue from Boulder County Parks and Open Space projects is currently disposed of, incurring hauling and handling costs. Ideally, these materials would be used to heat the new facilities, though other sources of material are available if the Parks and Open Space material is insufficient.

9.1 Results of Study

Because the facilities are still early in the design stage, heating loads had to be estimated based on heating data for existing facilities, and on climate data for the cities of Boulder and Longmont, Colorado. This study resulted in a system size estimate of 100-boiler horsepower (bhp) for a primary wood-fired boiler, with a natural gas-fired backup boiler of 100 bhp. This backup boiler would be used if either the wood-fired boiler was unavailable, or if wood supplies on site were depleted. During times of extreme cold, if the primary boiler were not capable of reaching the desired temperature, the backup boiler would come on automatically to assist.

Quotes for wood-fired boiler systems were received from two manufacturers, Chiptec and Messersmith. The total cost for the wood-fired boiler, underground piping, wood storage shed, boiler room, and other associated equipment was estimated to be $834,500. The cost for an equivalent natural gas system was estimated to be $478,000. Items considered to be equal between the two systems are not included in these estimates.

Total thermal energy required to heat the facilities was estimated to be 67,166 therms per year. Required wood quantities were estimated to be 648 tons per year. It was assumed that the wood available from thinning projects would have a moisture content of 40%, wet basis, and an energy content of 5184 Btu per pound, as delivered.

Until recently, the price of natural gas in the Rocky Mountain region, including Colorado, typically has been lower than in other parts of the country. This was due partly to the fact that production in the region has exceeded demand, without an easy way to transport the gas to other parts of the country. In recent months, an expanded natural gas pipeline has opened, allowing producers to ship larger quantities of natural gas to the West Coast. This, among other things, has caused natural gas prices in Colorado to experience large increases. In 2002, Boulder County was paying about $0.425 per therm (100,000 Btu). In 2003, this has already increased to $0.62 per therm. The price of natural gas is expected to continue to increase.

Boulder County Parks and Open Space can supply wood fuel for almost no increase in cost over the current handling, hauling, and disposal costs. The supply of wood fuel resulting from BCPOS projects will probably be sufficient to heat the facilities, but a resource assessment to quantify this has not been performed. It was estimated that wood would be available from other sources for 20 to 30 dollars per ton, delivered. Therefore, two economic analyses were performed, one with an initial fuel wood price of $30 per ton ($2.89 per million Btu), and one with a wood price of $5 per ton ($0.48 per million Btu). These are referred to as the "Full Fuel Cost" and "Incremental Fuel Cost" cases. Both cases used an initial natural gas price of $6.20 per million Btu.

Table 14 summarizes the economic analyses.

Table 14. Summary of Analyses

	Full wood fuel costs	Incremental wood fuel costs
Simple Payback Period (Years)	19.2	10.5
30-Year total of Savings [$]	$ 1,765,119	$ 2,389,284
Total of savings/capital costs	5.0	6.7
30-year APR Equivalent	5.5%	6.5%

		Difference over Natural Gas System
NPV Natural Gas System ($)	$ (1,082,490)	
NPV Wood System - Full Fuel Costs ($)	$ (1,121,721)	$ (39,231)
NPV Wood System - Incremental Fuel Costs ($)	$ (940,881)	$ 141,608

Note that the net present values (NPV) in Table 14 appear as negative values because they are costs, not income. These reflect the total costs of the system over a 30-year period. Over the 30-year expected system life, the wood-fired system has lower costs than the natural gas system, as long as the wood price is less than about $25 per ton. Above that price, the natural gas system has a slight economic advantage.

9.2 Next Steps

The calculations in this report are based on very preliminary building data. If the decision is made to proceed with the wood-fired boiler, a more thorough analysis of heating loads should be performed, based on building types, dimensions, insulation, and orientation. The economics of the project will be most favorable if the system is accurately sized. The wood-fired heating system should be sized to be able to provide nearly all of the facility heating, but not so large as to be operating at very low capacity.

In addition, the latest emission regulations should be reviewed to ensure compliance.

There may be grants available from federal agencies to reduce the capital costs of the system. One potential source of funds is the U.S. Forest Service.

Two manufactures of wood-fired heating systems are Chiptec Wood Energy Systems (800-244-4146 www.chiptec.com) and Messersmith Manufacturing (906-466-9010 www.burnchips.com). Both of these companies have been contacted for information for this report, and are good sources of information for the next stage of this project.

Appendix A - Examples Of Facilities that Have Installed Wood-fired Heating Systems

Site	Application	Manufacturer	Size (MWth)
Marty Moore Greenhouse, Bennington, VT	Heat for a green house	Messersmith gasifier	0.4
Allard Lumber, Brattleboro, VT	Thermal heat for dry kilns	Chiptec C-6 gasifier	2
Cerossimo Lumber Mill, Brattleboro, VT	Thermal heat for lumber mill dry kilns	2 McBurney boilers, stoker system	5.9 (each)
Vermont Army Guard, Burlington, VT	Thermal heat for buildings	Chiptec C-series gasifier (C-3)	0.9
Camel's Hump Middle School	Thermal heat for school	Chiptec C-series gasifier (C-3)	0.9
Ethan Allan Furniture (small facility)	Thermal heat for kilns	Chiptec C-series gasifier (C-10)	2.9
A. Johnson Lumber Co	Thermal heat for kilns	Chiptec C-series gasifier (C-10)	2.9
Addison County Courthouse, Middlebury, VT	Thermal heat for office building	Chiptec C-series gasifier (C-2)	0.6
Ethan Allan Furniture, Orleans, VT (large facility)	Thermal heat for kilns and buildings; co-generation of electricity	McBurney stoker, fixed grate; Skinner turbine (500 kW)	17
Emory Hubbard State Office Building, Newport, VT	Thermal heat for offices	Messersmith combustor	1.2
North Country Union High School, Newport, VT	Thermal heat for school	Messersmith combustor	1.6

Appendix B – System Quotes

We received two system quotes from Chiptec, one for a 50-bhp system, and one for a 100-bhp system. The text of those quotes is included in this section.

Monday, March 31, 2003

Randy Hunsberger
McNeil Technologies, Inc
43 Union Blvd
Lakewood, CO 80228

Dear Mr. Hunsberger;

CHIPTEC WOOD ENERGY SYSTEMS is pleased to present the following budgetary quotation for your consideration. This budgetary quote reflects our understanding of your needs. Please contact us if anything is unclear or contrary to what you desire.

This budgetary quote is based upon the following "Scope of Work". The scope of work is the fundamental agreement between us about pricing, who is responsible for what, and the ultimate cost & success of the project. Chiptec must provide the gasifier & related control, operation and performance equipment. Chiptec or key strategic vendors or sub-contractors normally provide most of the ancillary equipment and services to insure specifications, compatibility & pricing. In most cases, Chiptec can provide a turnkey system if desired.

Scope of work:

The following boiler and gasifier system is designed to produce up to 50 boiler horsepower (boiler output) with fuel that has a moisture content of 40% (calculated on a wet basis). The fuel particle size shall be 2" or less in size with no more than 10% (of weight) less than 1/16 inch particle dimension (minimum overall size). The system is configured with a rotary air lock and ready to receive fuel from the storage and delivery system. (by others). Fuel quality, ash content and moisture content will effect the system output and ash production. The following are general equipment specifications for the system.

Chiptec Wood Energy Systems Equipment:

- One (1) Chiptec Gasifier B-Series, Model C-2
- One (1) feed screw assembly
- One (1) Chiptec rotary air lock
- One (1) Induce Draft Stack Fan Assembly
- One (1) Total Air Fan Assembly (primary/secondary fan)
- One (1) Pre-wired control panel
- One (1) three pass fire tube, hot water boiler capable of producing 50hp
- One (1) single-cyclone collector for particulates in the exit gas stream
- One (1) Chiptec Sweep unloader with: heavy-duty sweep auger assembly, steel front wall with required openings, heavy-duty gear drive. Sweep auger advance assembly with heavy-duty pillow block bearings. The unloader is 24'x12wide and can be filled to a height of 12'-0". Unit is complete and ready to install into a concrete bunker. The bin is sized to provide 3 days worth of storage with the gasifier operating at maximum output.
- Receiving Auger: Flare trough with: access covers, safety switches, drop box connection and a motor drive assembly. Overall length of 30'-0".
- Metering Auger: "U"- trough with: access covers, safety switches, and a motor drive assembly. Overall length of 20'-0".
- Operating & Maintenance manuals (2 sets)
- Operator orientation & Test firing equipment
- Technical support. (CAD layout drawings, installation drawings, wire diagrams etc.)
- Delivery of above mentioned equipment
- Rigging & setting of the above mentioned equipment into building
- Installation of above mentioned equipment

- All electrical wiring for above-mentioned equipment

Customers Responsibilities:

- Initial fill, clean out & boil out of the boiler
- Any & all mechanical system installation not specifically stated above
- Breeching connection between the boiler, multi-cyclone, induce draft fan & stack
- Steel stack for boiler
- Electrical connections from building main power supply to CHIPTEC Corporation master control panel.
- Hose bib for water safety equipment on the gasifier (as indicated on customer approved layout drawings)
- Any and all piping, breeching insulation (recommended)
- All associated building and site work. Including through wall/roof penetrations and repairs
- All associated concrete work
- Any and all structural, civil, architectural & mechanical engineering that is required
- State and local taxes
- Permits, fees and penalties not specifically stated in the includes section
- Fuel sample ultimate analysis

Budgetary quote: $167,010.00

The above pricing is for budget purposes only, and should not be construed as an offer to sell. An offer to sell is made by formal proposal only with terms and condition of sale.

This quote is valid for 30 days from above date. The CHIPTEC patented gasification systems are among the hottest, cleanest and most efficient gasifiers on the market today. CHIPTEC offers complete customer support before, during and after the sale. As a manufacturer of commercial gasifiers for 17 years, CHIPTEC has a proven track record of quality manufacturing and complete customer satisfaction. If you have any questions, please feel free to call. Thank you for considering CHIPTEC WOOD ENERGY SYSTEMS for you energy needs.

Sincerely

Bradley Noviski
Vice President

Monday, March 31, 2003

Randy Hunsberger
McNeil Technologies, Inc
143 Union Blvd
Lakewood, CO 80228

Dear Mr. Hunsberger;

CHIPTEC WOOD ENERGY SYSTEMS is pleased to present the following budgetary quotation for your consideration. This budgetary quote reflects our understanding of your needs. Please contact us if anything is unclear or contrary to what you desire.

This budgetary quote is based upon the following "Scope of Work". The scope of work is the fundamental agreement between us about pricing, who is responsible for what, and the ultimate cost & success of the project. Chiptec must provide the gasifier & related control, operation and performance equipment. Chiptec or key strategic vendors or sub-contractors normally provide most of the ancillary equipment and services to insure specifications, compatibility & pricing. In most cases, Chiptec can provide a turnkey system if desired.

Scope of work:

The following boiler and gasifier system is designed to produce up to 100 boiler horsepower (boiler output) with fuel that has a moisture content of 40% (calculated on a wet basis). The fuel particle size shall be 2" or less in size with no more than 10% (of weight) less than 1/16 inch particle dimension (minimum overall size). The system is configured with a rotary air lock and ready to receive fuel from the storage and delivery system (by others). Fuel quality, ash content and moisture content will effect the system output and ash production. The following are general equipment specifications for the system.

Chiptec Wood Energy Systems Equipment:

- One (1) Chiptec Gasifier B-Series, Model C-4
- One (1) feed screw assembly
- One (1) Chiptec rotary air lock
- One (1) Induce Draft Stack Fan Assembly
- One (1) Total Air Fan Assembly (primary/secondary fan)
- One (1) Pre-wired control panel
- One (1) three pass fire tube, hot water boiler capable of producing 100 hp
- One (1) single-cyclone collector for particulates in the exit gas stream
- One (1) Chiptec Sweep unloader with: heavy-duty sweep auger assembly, steel front wall with required openings, heavy-duty gear drive. Sweep auger advance assembly with heavy-duty pillow block bearings. The unloader is 24'x12wide and can be filled to a height of 12'-0". Unit is complete and ready to install into a concrete bunker. The bin is sized to provide 3 days worth of storage with the gasifier operating at maximum output.
- Receiving Auger: Flare trough with: access covers, safety switches, drop box connection and a motor drive assembly. Overall length of 30'-0".
- Metering Auger: "U"- trough with: access covers, safety switches, and a motor drive assembly. Overall length of 20'-0".
- Operating & Maintenance manuals (2 sets)
- Operator orientation & Test firing equipment
- Technical support. (CAD layout drawings, installation drawings, wire diagrams etc.)
- Delivery of above mentioned equipment
- Rigging & setting of the above mentioned equipment into building
- Installation of above mentioned equipment
- All electrical wiring for above-mentioned equipment

Customers Responsibilities:

- Initial fill, clean out & boil out of the boiler
- Any & all mechanical system installation not specifically stated above
- Breeching connection between the boiler, multi-cyclone, induce draft fan & stack
- Steel stack for boiler
- Electrical connections from building main power supply to CHIPTEC Corporation master control panel.
- Hose bib for water safety equipment on the gasifier (as indicated on customer approved layout drawings)
- Any and all piping, breeching insulation (recommended)
- All associated building and site work. Including through wall/roof penetrations and repairs
- All associated concrete work
- Any and all structural, civil, architectural & mechanical engineering that is required
- State and local taxes
- Permits, fees and penalties not specifically stated in the includes section
- Fuel sample ultimate analysis

Budgetary quote: $215,322.00

The above pricing is for budget purposes only, and should not be construed as an offer to sell. An offer to sell is made by formal proposal only with terms and condition of sale.

This quote is valid for 30 days from above date. The CHIPTEC patented gasification systems are among the hottest, cleanest and most efficient gasifiers on the market today. CHIPTEC offers complete customer support before, during and after the sale. As a manufacturer of commercial gasifiers for 17 years, CHIPTEC has a proven track record of quality manufacturing and complete customer satisfaction. If you have any questions, please feel free to call. Thank you for considering CHIPTEC WOOD ENERGY SYSTEMS for you energy needs.

Sincerely

Bradley Noviski
Vice President

Appendix C – Fuel Specification

Chiptec's fuel specification follows:

CHIPTEC®

WOOD ENERGY SYSTEMS

STANDARD "CLEAN FUEL"* SPECIFICATION

Particle size:

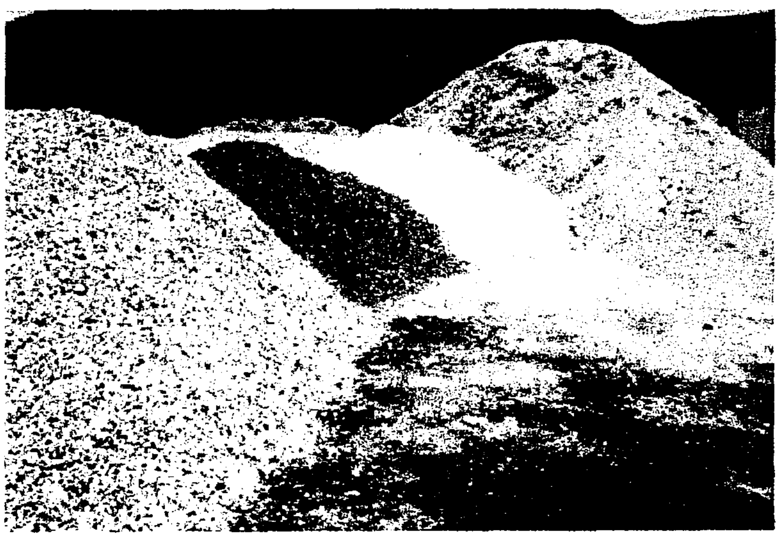
- **The fuel particle size shall be 2" or less in size with no more than 10% (of weight) less than 1/16 inch particle dimension (minimum overall size).**

Moisture content, wet basis:

- **C-Series Gasifiers: 6% to 45% M.C.**
- **B-Series Gasifiers: 6% to 50% M.C.**

Clean fuel sources outside of this specification may be utilized if fuel is analyzed, and specialized equipment is added to bring fuel into specification.

***"Clean Fuel": Free from matter that adulterates, contaminates, or pollutes. Contaminates found in the fuel will affect combustion quality and refractory life.**



Our recommendation is simple: *The better the fuel the better the performance!*

SYSTEM PERFORMANCE IS DIRECTLY RELATED TO FUEL QUALITY!

Appendix D – Utility Data

Boulder County
Summary of gas usage and cost during 2002 at selected sites.
February 7, 2003

Site	Square footage	Therms	Cost ($)	Therms/ (ft2*yr)	$/Therm	Btu/ dd/ft2
		1/01/02 – 12/31/02				
Office Buildings (Exisitng)						
Simpson Building	18,068	7,028	$3,054	0.389	**$0.43**	6.8
Old County Hosiptal	15,721	12,224	$5,269	0.778	**$0.43**	13.6
Health Social Services	18,212	14,080	$6,015	0.773	**$0.43**	13.0
Longmont Courts	29,381	15,705	$6,687	0.535	**$0.43**	8.1
Courthouse Annex	25,287	15,878	$6,733	0.628	**$0.42**	10.5
1750 33rd St	30,857	19,082	$8,088	0.618	**$0.42**	10.5
Office Building Totals	137,526	83,997	$35,845	0.611	**$0.43**	10.2
Road District shops (Existing)						
Walden Main Bldg	21,910	15,317	$6,372	0.699	**$0.42**	10.6
1288 Alaska Ave. - Road Dist. #2	16,600	18,600	$8,001	1.120	**$0.43**	16.8
Road Dist. 3 Main Bldg.	22,955	20,078	$8,586	0.875	**$0.43**	15.1
Road District Totals	61,465	53,995	$22,959	0.878	**$0.425**	14.0

Appendix E – Wood Ash

Description

(From: Recommended Practices for Using Wood Ash as an Agricultural Soil Amendment. The University of Georgia College of Agricultural and Environmental Sciences. http://www.ces.uga.edu/pubs/PDF/B1147.pdf)

Wood ash is the ash from the combustion of the following: bark, wood, sawdust, leaves, woody debris, pulp, sludge from pulp and paper waste water treatment systems, and unbleached wood fiber. Except for the auxiliary use of gas or oil to start the process or for routine maintenance, wood ash does not include ash from mixed fuels or other products. These procedures do not apply to any materials registered with the Georgia Department of Agriculture and do not replace or circumvent any state regulations.

Mixed ashes and other residuals from pulp and paper manufacturers also have value as a soil amendment and lime substitute, but they do not meet the definition of wood ash as defined in this publication. The University of Georgia, in cooperation with several other organizations, is studying many of these other by-products. If these studies indicate that land application of these materials is appropriate, procedures for their use will also be developed.

Testing

Any supplier wishing to make wood ash available to the public for land application should first test the product. Testing should include an analysis for nitrogen (N), phosphorus (P), potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), lime equivalency (CCE), and the nine metals outlined in EPA regulations for application of municipal sludge (40 CFE part 503.13) and listed in Table 1. All analysis should use EPA approved procedures and laboratories. If any of the metal concentrations exceed the pollutant concentrations outlined in Table 1, the wood ash should not be land applied using the recommendations in this publication.

Pollutant concentrations from 40 CFR part 503.13.

Pollutant	Pollutant Concentration (milligrams/kilogram)*
Arsenic	41
Cadmium	39
Copper	1500
Lead	300
Mercury	17
Molybdenum**	18
Nickel	420
Selenium	100
Zinc	2800

* Dry weight basis, 1 mg/kg = 1 ppm.

** The limit for molybdenum is no longer part of the 503.13 regulations.

Note: These are the pollutant concentrations from the EPA regulations for land application of municipal sludge. They are used as a guideline in this publication. The wood ash should have concentrations below these pollutant levels; however, they do not need to meet all of the conditions outlined in 40 CFR part 503.13. If the concentration of any metal exceeds these concentrations, then do not land apply the wood ash.

Test the ash using weekly composite samples -- two to three samples per day over five days -- twice per year. In addition, the supplier should retest the ash after any significant process modification or if changes in raw material inputs have occurred. The supplier should keep records of all test results for at least three years, and the records should be provided upon request to the county extension office, landowner or commercial applicator so application rates can be calculated.

Application

Base the amount of wood ash to be land applied to a particular area on the desired soil pH and nutrient requirements of the crop. Each landowner/farm operator who wishes to receive bulk wood ash should test the soil on each site before each wood ash application. Use the Georgia Extension Service's Soil Testing Handbook or laboratory recommendations to determine the proper liming rates.

While the application rates should primarily depend on the lime requirement to bring the soil to the optimum pH, the nutrient contribution of the ash may also be calculated so fertilizer inputs can be reduced where appropriate. Using the application rate, also estimate the total amount of wood ash required for each location based on the land available for application. It is the responsibility of the landowner or farm operator to adhere to these requirements for the application of this product. All soil testing and application rate calculations are available through the University of Georgia Cooperative Extension Service; however, any qualified laboratory can provide these services.

Before providing wood ash to any farmer/landowner, the wood ash supplier should ensure that the following requirements are met: (1) the wood ash has been tested and the test results did not exceed the allowable metal concentrations, (2) at each application site, soil testing has been performed and the optimum application rate has been calculated, (3) each landowner has received a copy of the University of Georgia Cooperative Extension Service bulletin Best Management Practices for Wood Ash Used as an Agricultural Soil Amendment; (4) each receiver of ash has completed and returned to the supplier an acceptance form agreeing to take ownership, control and responsibility for this material as provided. To ensure that these conditions are met, the supplier may wish to keep records of each transaction. Include the name and address of the person receiving the wood ash, the amount, and the date provided.

(From: Wood Ash--Can Be Useful In Yard If Used With Caution. Oregon State University Extension. http://eesc.orst.edu/AgComWebFile/Garden/Composting/woodash.html)

What can you do with all the ash from burning wood in your fireplace or wood stove? Wood ash can be useful in home gardens, in your compost pile or as a pest repellent, explained Dan Sullivan, soil scientist with the Oregon State University Extension Service.

Wood ash has long been recognized as a valuable substance, Sullivan said. Many centuries ago, ancient Roman scientists and scholars documented the value of returning ash to the land.

In the 18th century, the benefits of ash-derived potash, or potassium carbonate, became widely recognized. North American trees were felled, burned and the ash was exported to Great Britain as "potash fever" hit. In 1790, the newly-independent United States of America's first patented process was a method for making fertilizer from wood ash (U.S. patent number 1: "An improved method of making pot and pearl ash)."

Cheaper sources of lime and potassium eventually killed the commercial market for wood ash, said Sullivan.

For the home gardener, however, wood ash can be a valuable source of lime, potassium and trace elements.

"Since wood ash is derived from plant material, it contains most of the 13 essential nutrients the soil must supply for plant growth," said Sullivan. "When wood burns, nitrogen and sulfur are lost as gases, and calcium, potassium, magnesium and trace element compounds remain. The carbonates and oxides remaining after wood burning are valuable liming agents, raising pH, thereby helping to neutralize acid soils."

Where soils are acid and low in potassium, wood ash is beneficial to most garden plants except acid-loving plants such as blueberries, rhododendrons and azaleas. Use wood ash on flower beds, lawns and shrubs.

The fertilizer value of wood ash depends on the type of wood you burn. As a general rule, hardwoods such as oak weigh more per cord and yield more ash per pound of wood burned. Hardwood ash contains a higher percentage of nutrients than ash from softwoods such as Douglas-fir or pine.

"Hardwoods produce approximately three times as much ash per cord and five times as many nutrients per cord as softwoods," said Sullivan.

Ash from a cord of oak meets the potassium needs of a garden 60 by 70 feet, he said. A cord of Douglas-fir ash supplies enough potassium for a garden 30 by 30 feet. Both types of ash contain enough calcium and magnesium to reduce soil acidity (increase soil pH) slightly.

One-half to one pound of wood ash per year is recommended for each shrub and rose bush. Spread ash evenly on the soil around perennial plants. Rake the ash into the soil lightly, being careful not to damage the roots. Never leave ash in lumps or piles, because if it is concentrated in one place, excessive salt from the ash will leach into the soil, creating a harmful environment for plants.

Lawns needing some lime and potassium can also benefit from wood ash. Apply no more than 10-15 pounds of ash per 1,000-square feet of lawn; at high levels, ash can be toxic. Do not use if soil pH is more than 7.0 or if potassium levels are excessive.

"You may want to have your soil analyzed periodically to determine its need for lime and potassium," said Sullivan. "As a general rule, acid soils that would benefit from ash application are usually found in those places in Oregon that get more than 20 inches of rain per year. Alkaline soils (pH greater than 7) soils in portions of central and eastern Oregon generally won't benefit from ash application."

In compost piles, wood ash can be used to help maintain a neutral condition, the best environment to help microorganisms break down organic materials. Sprinkle ash on each layer of compost as the pile is built up. Ash also adds nutrients to compost.

If used judiciously, wood ash can be used to repel insects, slugs and snails, because it draws water from invertebrates' bodies. Sprinkle ash around the base of your plants to discourage surface feeding pests. But once ash gets wet, it loses its deterring properties. Continual use of ash in this way may increase the soil pH too much, or accumulate high salt levels harmful to plants.

Sullivan offered advice for using wood ashes as a soil or compost amendment:

- Protect yourself when applying wood ash. Use the same precautions you would use when handling household bleach, another strongly alkaline material. Wear eye protection and gloves. Depending on the fineness of the ash, you may want to wear a dust mask.
- Do not use ash from burning trash, cardboard, coal or pressure-treated, painted or stained wood. These substances contain trace elements, harmful to many plants when applied in excessive amounts. For example, the glue in cardboard boxes and paper bags contains boron, an element toxic to many plant species at levels slightly higher than that required for normal growth.
- Do not use ash on alkaline soils or on acid-loving plants.
- Do not apply wood ash to a potato patch as wood ashes may favor the development of potato scab.

- Do not apply ash to newly germinated seeds, as ash contains too many salts for seedlings.
- Do not add ash with nitrogen fertilizers such as ammonium sulfate (21-0-0-24S), urea (46-0-0) or ammonium nitrate (34-0-0). These fertilizers produce ammonia gas when placed in contact with high pH materials such as wood ash.

(Excerpt from: Mahendra K. Misra, Kenneth W. Ragland, And Andrew J. Baker. Wood Ash Composition As a Function of Furnace Temperature. Biomass and Bioenergy Vol. 4, No. 2, pp. 103-116, 1993. Pergamon Press Ltd. Great Britain. http://www.fpl.fs.fed.us/documnts/pdf1993/misra93a.pdf)

Chemical analysis

The concentration of different elements and the variation with temperature for different ash types was determined by ICPES, and the results are presented in Figs 4 to 11. Table 4 lists the measured concentrations of various elements in low temperature ash heated to 600OC. The major elements in the wood ash are calcium, potassium and magnesium. Sulfur, phosphorus and manganese are present at around 1%. Iron, aluminum, copper, zinc, sodium, silicon, and boron are present in relatively smaller amounts.

Oxygen and carbon are also present but are not determined by ICPES. The nitrogen content in wood ash is normally insignificant due to the conversion of most of the wood nitrogen to NH3, NOX and N2 during the combustion of wood. Pine and aspen ash have higher amounts of potassium compared to poplar or oak ash. The other alkali metal, sodium, is generally low in all ash types with the exception of the poplar which had 2.3% Na.

	Wood Ash Composition						
	Elemental Analysis of Ash at 600°C (wt% of ash)						
	Pine	Aspen	Poplar	R. Oak	W. Oak	W. Oak Bark	D.F. Bark
Calcium	29.05	21.17	25.67	36.58	31.35	36.14	34.26
Potassium	16.24	11.25	7.93	6.08	10.25	0.97	2.78
Magnesium	7.03	3.55	9.09	5.20	7.57	0.34	0.37
Sulfur	1.07	0.70	1.02	1.80	1.21	0.40	0.52
Phosphorus	0.84	1.18	0.95	1.56	0.56	0.08	0.51
Manganese	4.04	0.14	0.45	1.49	0.14	0.16	0.37
Zinc	0.36	0.34	0.04	0.22	0.08	0.05	0.07
Iron	0.58	0.26	0.32	n.d.	0.09	0.01	0.26
Aluminum	0.47	0.14	0.35	0.68	<0.03	<0.03	0.59
Sodium	0.06	0.06	2.30	0.08	<0.06	<0.06	<0.06
Silicon	n.d.	0.11	n.d.	n.d.	0.13	0.12	0.24
Boron	0.06	0.05	0.05	0.08	0.04	0.007	0.07
Copper	0.04	0.03	0.03	0.07	0.02	<0.002	0.02
n.d. - not determined							

(Excerpted from: Mark Risse and Glen Harris. Best Management Practices for Wood Ash Used as an Agricultural Soil Amendment. http://hubcap.clemson.edu/~blpprt/bestwoodash.html)

Field and greenhouse research have confirmed the safety and practicality of recycling wood ash on agricultural lands. It has shown that wood ash has a liming effect of between 8 and 90% of the total neutralizing power of lime and can increase plant growth up to 45% over traditional limestone. The major constraints to land application of wood ash are transportation costs, low fertilizer analysis, and handling constraints. With ever increasing disposal costs, land application of wood ash will probably be the disposal method of choice in the coming century resulting in savings for the industry, an opportunity for agriculture, and conservation of our resources.

During application of wood ash to the soil, special care should be taken to prevent the ash from entering any surface or ground water. A distance of at least 50 feet should separate the wood ash from any farm ditches, wells, or other bodies of water. This distance should be increased to 100 feet in highly erodible areas or areas without riparian stream side vegetation or buffer zones. Wood ash should not be applied to areas with water standing on the soil surface. Care should also be taken to avoid wood ash applications immediately preceding periods of prolonged rainfall or when large storms are expected.

Wood ash should be land applied as soon as possible to avoid the need for on-site storage. When conditions such as inclement weather do require on-site storage, wood ash should be stored in a manner that prevents runoff particulate from entering surface or ground water. Indoor storage is ideal; however, when it must be stored outdoors it should be placed on packed soil or pad surrounded by a small berm to prevent surface water from entering or leaving the storage area. The storage area should also be located away from wells, surface water, and animal watering areas and covered or shielded as much as possible to prevent nuisance conditions if it were moved or disturbed during dry or windy weather.

One of the major obstacles to land spreading of wood ash is the undesirable handling and spreading characteristics of ash. Most ash has a low density and small particle size and consequently creates dust problems during transport and application. Wood ash should always be covered during transport to prevent losses in route to the application sites. Studies indicate that the handling characteristics of ash generally improve with increasing relative humidity so attempts should be made to avoid spreading on extremely dry days. Moisture can be added to improve the handling characteristics of ash, however, if too much moisture is added the ash will cake and become difficult to spread uniformly. Ash can be spread with conventional manure spreading or lime application equipment and is either top dressed or incorporated. To get the maximum benefit, incorporate the wood ash throughout the root zone whenever possible as the benefits only occur where the ash and soil are in contact. It is also essential to calibrate the spreader to insure that the target application rate is met. Due to the physical characteristics of ash, it is often difficult to obtain uniform application, but calibration and knowledge of the application distribution of the spreader can help to minimize non-uniformity.

The fall is generally the best time for wood ash application. Soil pH is generally lower in the fall and applications at this time will allow the ash will have plenty of time to react with the soil before rapid spring growth. Soils are also usually drier and more accessible in the fall. Application at other times throughout the year is acceptable; however, ash should not be applied immediately preceding planting or during early emergence as it could cause short term concentrated alkaline conditions that could interfere with plant growth. Ash may also absorb pesticides if it not given time to neutralize in the soil, so chemical applications should be avoided for three to five days prior to or after wood ash application.

Health considerations must be taken into account when dealing with ash to prevent both particle inhalation and contact with the skin. Inhaling any small particle is dangerous so masks should be worn during application or when dusty conditions warrant them. Ash is an alkaline material with a pH ranging from 9-13. Therefore, this material could irritate the skin. To prevent this, skin should be covered during application and transport and skin areas exposed to ash should be washed and thoroughly rinsed with water immediately following application. It is also important to remember that fresh ash can still retain hot coals, which are both a health risk and a fire hazard.

In summary, wood ash application is similar to lime application. Both materials can benefit crop productivity but wood ash has an added advantage of supplying additional nutrients. Both materials are also alkaline and could cause crop damage if over applied or misused. It is imperative that the land owners follow the prescribed application rates and use common sense approaches to prevent accidents and avoid environmental contamination.

Table 1. Range in elemental composition of industrial wood ash samples and ground limestone.

Element	Wood Ash*	Limestone
Macroelements	Concentration in %	
Calcium	15 (2.5-33)	31
Potassium	2.6 (0.1-13)	0.13
Aluminum	1.6 (0.5-3.2)	0.25
Magnesium	1.0 (0.1-2.5)	5.1
Iron	0.84 (0.2-2.1)	0.29
Phosphorus	0.53 (0.1-1.4)	0.06
Manganese	0.41 (0-1.3)	0.05
Sodium	0.19 (0-0.54)	0.07
Nitrogen	0.15 (0.02-0.77)	0.01
Microelements	Concentration in mg/kg	
Arsenic	6 (3-10)	.
Boron	123 (14-290)	.
Cadmium	3 (0.2-26)	0.7
Chromium	57 (7-368)	6.0
Copper	70 (37-207)	10
Lead	65 (16-137)	55
Mercury	1.9 (0-5)	.
Molybdenum	19 (0-123)	.
Nickel	20 (0-63)	20
Selenium	0.9 (0-11)	.
Zinc	233 (35-1250)	113
Other Chemical Properties		
$CaCO_3$ Equivalent	43% (22-92%)	100%
pH	10.4 (9-13.5)	9.9
% Total solids	75 (31-100)	100
* Mean and (Range) taken from analysis of 37 ash samples		