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Fuels for Schools: Case Study in Darby, Montana

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Abstract

To reduce the risk of catastrophic fires, the USDA Forest Service and its partners are developing practical, economic uses for forest thinnings from National Forests and state and private lands in western states. Because mechanical thinning is costly, developing markets for removed wood as fuel for community energy applications is one way to support the economics of forest management while saving money for communities. By installing a wood heating system in the public schools in Darby, Montana, the Fuels for Schools Program is demonstrating the potential of putting low-quality wood residues to practical use in a rural forest-based community. The wood-fired heating system installed in Darby Schools replaced three separate oil-fired systems and saved the school district $24,500 of total fuel costs for the 2003–2004 year. Because of higher fuel oil prices, total fuel cost savings increased to $61,500 in the 2004–2005 heating season. Heating fuel costs were reduced from $0.63 per ft^2 per year (last full oil heating season) to $0.36 and $0.35 per ft^2 per year for the 2003–04 and 2004–05 heating seasons. Adjusting for heating degree days (HDD) for the respective heating seasons, the corresponding seasonal fuel costs in $/thousand ft^2/HDD were reduced from 0.068 in 2002–2003 to 0.040, and to 0.040 in the 2003–2004 and 2004–2005 heating seasons, respectively. In an analysis to show actual costs for a school, we found a payback period of 9.8 years based on 2004–2005 heating fuel values. The project life was for 20 years, and a desired discount rate of 8.0% was specified for determining the before tax net present value.

Keywords: wood chips, Darby, Montana, forest residue, school campus wood heating system, FFS, Fuels for Schools

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Contents

Conversion Table

	Multiply by	To get
Mass		
lb	0.4536	kg
ton (U.S.)	0.9072	metric ton
Length		
ft	0.3048	m
mile	1.609	km
Area		
ft^2	0.0929	m^2
acre	4.046	m^2
Volume		
gal	3.7854	L
ft^3	0.0283	m^3
Power		
Btu/h	0.2931	W joules/s
Energy		
Btu	1,055	joules
Temperature		
Fahrenheit (°F)	$T_{°C} = [T_{°F} - 32]/1.8$	Celsius (°C)

Fuels for Schools: Case Study in Darby, Montana

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Background

Wildfire is a concern to the USDA Forest Service and surrounding communities. Beginning in 2000, wildfires brought to the public's attention a forest health problem that had its beginnings several decades ago.

The Forest Service estimates that 70 million acres of federal land need immediate hazardous fuel reduction, and 140 million acres nationwide will soon need treatment. At the rate of 2.5 million acres a year, it will take more than 80 years to treat all areas. Thinning forests for fuel reduction reduces wildfire hazards but is expensive. The total cost of treating all these acres could exceed $100 billion. Developing ways of using forest residues from these treatments is vital for rural communities. The Fuels for Schools program is one part of this effort.

The Fuels for Schools program began in 2001 after an unusually severe wildfire season (2000) in Montana's Bitterroot Valley. Increasing federal, state, and local interest in hazard-reduction logging led to a need for utilizing the resultant unmerchantable woody material. Using this woody material as fuel to fire boilers for heating systems provides a means of accomplishing this purpose. The Fuels for Schools program grew out of the recognition that using hazardous fuels for heating public facilities like schools was a win–win situation for local communities. At the same time, one goal of the Fuels for Schools program is to demonstrate that wood heating systems can reduce conventional heating fuel use by as much as 85% and cut fuel costs by 50% or more. The first Fuels for Schools project was instituted by the Forest Service and its local partners in Darby, Montana, one of the communities of the Bitterroot Valley most severely affected in the 2000 fire season.

Introduction

The goal of the Fuels for Schools program is demonstrating modern, automated, clean-burning, and efficient wood-chip heating technology in schools and similar public facilities. The intent of the Forest Service is to show that wood heating is a viable and sustainable technology for western states and to provide a site in the West where other schools and interested parties could visit and see the technology in use. The Fuels for Schools program aims to convert the mostly unmarketable byproducts of forest thinning and logging into low-cost heat for schools.

In modern biomass heating systems, wood chips are fed from a storage bin to a boiler automatically, where high combustion temperatures result in a high-efficiency, nearly smoke-free burn (a desirable attribute that can be obtained by using this highly automated system and modest operating labor).

The Project

The following partners helped originate the Fuels for Schools concept:

Bitterroot National Forest, Hamilton, Montana

Bitter Root Resource Conservation & Development (RC&D) Area, Inc., Hamilton, Montana

Technology Marketing Unit, Forest Service, Forest Products Laboratory, Madison, Wisconsin

Forest Service, Regions 1 and 4, Missoula, Montana

The Technology Marketing Unit (TMU) at the Forest Products Laboratory (FPL) in Madison, Wisconsin, enlisted the assistance of the Biomass Energy Resource Center (BERC), Montpelier, Vermont, a nonprofit organization with extensive experience in school wood heating, to conduct a preliminary economic and engineering feasibility study of a few school districts in the Bitterroot Valley. One of the school districts visited, Darby Schools in the southern part of Ravalli County, Montana, was identified as the initial demonstration project for the program. The school district owns three schools on a single campus in the town of Darby, which offered the potential to convert three schools to wood heating in a single project.

In this demonstration project, the Forest Service provided all the capital costs. These costs included all design and project management costs for installing the wood heating system. Additional schools and other facilities will compete for federal funding with a maximum federal share of 50% of total cost. The Darby School District assumed responsibility for operating the system, purchasing fuel, monitoring system performance, and hosting visitors to the demonstration project on the school property.

Table 1. Dimensions and heat demand of the three Darby schools

School	Size (ft^2)	Expected heat demand [a, b] (million ×10^6 Btu/h)
Elementary	18,180	0.667
Junior High	20,494	0.750
High School	43,327	1.59
Total	82,001	3.0

[a] To maintain 70°F at a design outdoor temperature of – 20°F.
[b] Assuming the same insulation factor for all three schools of 26.4 at a height of 10 ft.

Existing Conditions

The three schools comprise 82,000 ft^2 of heated space (Table 1). Expected heat demand was calculated for the three schools based on the size of each school while maintaining an indoor temperature of 70°F with an outside design temperature of – 20°F (Manczyk 2001). Prior to the installation of the new wood heating system, each of the three schools had its own oil-fired steam heating plant (fuel oil #2). Annual oil use of the three schools averaged 47,600 gal at a cost of about $44,000 for the 2002–2003 school year. In addition, the school used liquid petroleum (LP) gas water heaters for the kitchen, lavatories, and locker room showers.

The three Darby schools are fairly typical for western Montana in age and condition. Insulation levels are far below those of new school construction. The steam-heat distribution systems within the schools were functional but required refurbishment. The Darby Elementary school oil-fired boiler was almost 40 years old at the initiation of this project (Table 2), and the other two boilers had over 10 years of useful projected life left.

Project Development

The BERC acted as project managers for the design of the new wood heating system and the overall construction project. BERC, in turn, contracted with a Missoula, Montana, design firm, CTA Architects and Engineers, to provide engineering design for the new three-school heating system and to provide architectural design for the new central boiler house. CTA was responsible for the day-to-day project management during construction. BERC had primary responsibility for specifying the wood heating system and providing the bid documents for selecting the wood-chip system. BERC was also responsible for commissioning the wood heating system after it was first fired, to ensure that it was performing according to specifications.

The first task in system design was to determine the scope of the project. The BERC–CTA design team first recommended that the old steam heat distribution piping be replaced with modern hot water heating. However, this proved too costly, and the Forest Service partners decided to retain steam as the means for conveying heat from the new central boiler facility to each of the three schools. The other key design decision was how many of the three schools would be connected to the new wood heating plant at the start and how the project would be phased. The partners were able to provide funding so that all three schools would be connected to the wood plant from the start. The design team felt it made sense to connect all three schools because the most benefit from the capital investment in the central wood plant would then be realized.

Project Components

The Darby project has four components:

- Boiler house—Creation of a central building to house the new wood-chip boiler and a large-volume wood storage bin (Fig. 1)
- Wood heating system—Installation of the wood-chip boiler with automated wood-chip handling equipment (conveyors and augers) to carry the wood fuel from the storage bin to the combustion chamber of the boiler
- Campus heating—Creation of a central heat distribution system by connecting the three school buildings to the new boiler plant using new buried steam pipes
- Refurbishments and upgrades—Refurbishments to old steam heating equipment so that the heat distribution system would be brought up to the level of function of the new boiler plant

The Forest Service partners and the design team required that the new wood system consist of two components: the equipment for handling and combusting the wood and the building that houses these functions. The new buried pipe system (which connects the buildings into one system) is considered a modernization improvement to the Darby

Table 2. Description of the old oil-fired boilers at the Darby schools (fuel oil #2)

School	Type of boiler	Fuel consumption (gal/h)	Size (×10^6 Btu/h)	Steady-state efficiency (%)	Year installed
Elementary	Cleaver Brooks	16.5	2.0	76–80	1964
Junior High	Kewanee [a]	8,23.8	2.7	78–84	1990
High School	Kewanee	37.4	4.2	78–84	1992

[a] This boiler is a low-high firing rate boiler, thus the reason for two numbers listed. High number (high firing rate) was used for determining boiler replacement size.

Figure 1—New Darby School boiler plant. Photo courtesy of Tim Maker, Biomass Energy Resource Center, Montpelier, Vermont. Used by permission.

Schools campus, and the repairs and upgrades are improvements that are specific to the needs of the particular schools. The existing oil boilers were retained in their original locations to serve as backup to the new wood heating plant.

Project Implementation

While CTA was finalizing the engineering design of the mechanical equipment and the architectural design of the new boiler house (including the wood fuel storage bin), BERC provided technical assistance to the Darby School District as they selected the vendor of the wood heating system, using a performance specification approach. The equipment required included the wood boiler and combustion chamber; all wood fuel handling equipment; the wood system controls; and a pre-fabricated, insulated steel chimney. The School District selected by competitive bidding Messersmith Manufacturing, a Bark River, Michigan, firm with extensive wood-heating experience, to supply and install the wood heating systems.

The Darby School District used a competitive bidding process to select a local firm, Gordon Construction, to carry out the general construction project. Gordon was responsible for building the boiler house, coordinating the installation of the Messersmith wood heating system, installing buried steam pipes and new mechanical equipment, and carrying out the modernizations to the old heating equipment. Construction was carried out from the spring through fall 2003, with the new wood system coming on line November 1.

Project Costs

The capital costs of the Darby project fell into two categories: (1) the cost of the complete wood heating system and (2) the cost of basic modernization and upgrades to existing heating equipment, as detailed below.

Wood Heating System (Fig. 2)

Equipment supplied by manufacturer	$230,500
Boiler house and fuel storage bin construction	$285,500
Total	$516,000

The equipment cost recognizes that Messersmith Manufacturing reduced their bid price by $14,900 as a donation to the demonstration project. Other project costs not in this summary included $6,000 for testing.

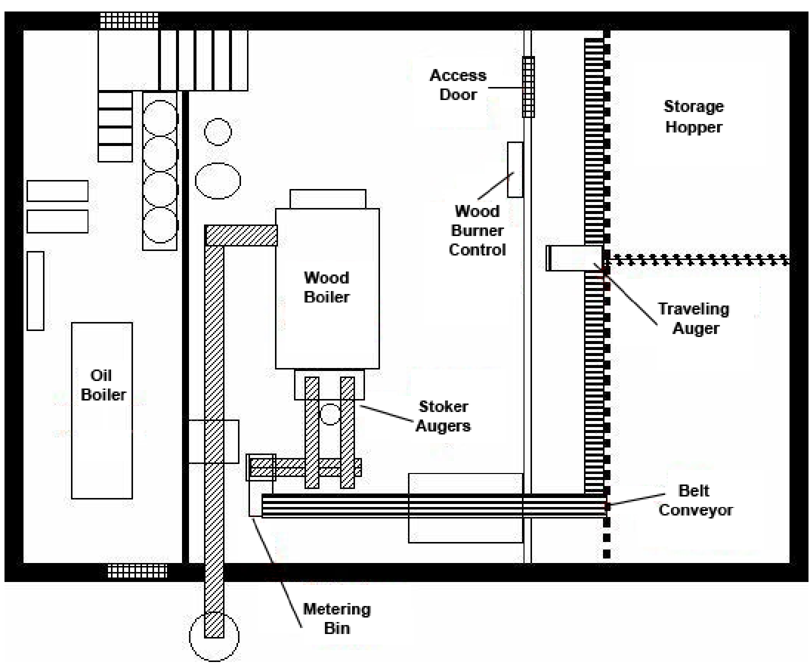

Figure 2—Schematic of boiler plant with new wood heating system. Courtesy of Messersmith Manufacturing, Inc., Bark River, Michigan. Used by permission.

Figure 3—Installation of wood boiler. Photo courtesy of Tim Maker, Biomass Energy Resource Center, Montpelier, Vermont. Used by permission.

Figure 4—Empty wood chip bin. Photo courtesy of Rick Scheele, Darby, Montana. Used by permission.

Modernization and upgrades

Buried steam pipes (to create campus system)	$ 95,000
Upgrades to existing mechanical equipment	$268,000
Total	$363,000

The total cost for the demonstration project was $885,000, excluding professional fees for design and project management. As part of the modernization and upgrades, steam to hot water heat exchangers (installed in each of the three buildings) allowed substitution of steam (from the wood-fired boiler) for propane to produce domestic hot water.

Wood System Description

General Description

Modern wood heating systems for use in schools are fully automated. No manual labor is associated with fuel deliveries, storing fuel, or transferring the boiler fuel from the storage bin to the point of combustion. These systems minimize maintenance staff time, keeping it to less than 1 h daily for one person. For the past 20 years, wood chip fuel has proven to be a cost-effective alternative to oil, gas, coal, and electricity in many institutional, commercial, and industrial settings (Maker 2004), particularly Vermont schools and other public facilities.

The system is designed so that backup boilers, which use conventional fuel (oil or gas), take over automatically in case of any problem with the wood heating system. The backup system is able to provide all the heat needed if the wood system is not in use. This wood boiler was sized for peak load so that it is able to provide all the required thermal energy needed by the school, except perhaps in the very coldest weather, at which time the backup system will make up the difference (Fig. 3).

An important feature of wood heating systems for institutional and commercial buildings is the turndown ratio between the maximum energy output rate by the minimum output rate at which efficient, smoke-free combustion can be sustained. The Darby wood heating system provides high, medium, low, and fire maintenance levels of load. It is vital for heating systems, such as schools that are operating with varying heating demands, to operate sufficiently at extremely low loads. For the Darby wood heating system, the maximum turndown ratio is 44:1 at the maintenance firing rate (personal communication, Carl Bielenberg, Better World Workshop, East Calais, Vermont, January 17, 2006).

The wood boiler system outputs 3 million Btu/h. Appropriate sizing of the wood boiler was found by calculating heat loss at design conditions outlined in Table 1. We anticipated that this size would be sufficient to heat the entire three-school campus, with no assistance from the backup oil boilers, except during the very coldest weather. The three backup oil burners have a combined peak heating capacity of almost 9 million Btu/h. The existing oil-fired boiler equipment was significantly oversized as there is a natural tendency to design oil heating plants that are oversized (Maker 2004). Grossly oversized wood systems will not operate efficiently, will consume too much fuel, and may produce smoke in low-load conditions.

Virtually no odor or visible smoke is produced by modern school wood heating systems. The ash, removed from the boiler on a regular basis, is nontoxic and can be either landfilled or used as a soil amendment on lawns or fields.

Wood Heating System

The following describes the components and functions of the wood heating system installed at the Darby Schools campus.

Fuel Storage

The wood fuel storage bin is a below-grade bin (with two overhead doors) located within the boiler house, designed to accept deliveries from a self-unloading truck that backs up to the doors. The Darby bin is approximately 34 ft long, 16 ft wide, and 9 ft deep, holding about 4,900 ft^3 of wood chips. A full-sized chip van load (using a 40- to 45-ft trailer) is about 2,560 ft^3 in volume. Therefore, the Darby bin holds approximately two full-sized van loads. Three sides of the below-grade bin are concrete and one side (supplied by the system manufacturer) is constructed of steel (Fig. 4).

Bin Unloading System

The Messersmith system uses a traveling auger that automatically removes fuel from the base of the wood fuel storage bin (Fig. 5). One feature of this system, also common to systems of other manufacturers, is that the first fuel into the bin is the first removed. In this way, no fuel has a chance to stay in the bin for long. Fuel is always moving through the bin according to the building's demand for heat.

Fuel Handling System

This subsystem consists of electric motor-driven belt conveyors, a metering bin, and covered troughs—all designed to move the chips automatically from the storage bin to the grates in the combustion chamber. Also included is a fire suppression system that prevents burnback from the combustion zone into the incoming fuel stream. The metering bin is a steel bin with a level sensor that operates to keep fuel in the bin at all times. The metering bin separates the relatively rapid removal of fuel out of the storage bin from the carefully metered flow of fuel to the fire. The metering bin is unloaded from the bottom by two augers. A variable speed motor drives the metering augers and regulates the flow of fuel onto the grates in the combustion chamber that depends on system demand (Fig. 6).

Combustion System and Boiler

The Messersmith Industrial Combustion System used in Darby is an automated solid-fuel combustion system designed to burn wood chips. The combustion system consists of a lined steel combustion chamber, cast iron grates designed especially for particle-wood fuels, and combustion air blowers. Fuel flows onto the grates, and the supply of both under-fire and over-fire combustion air is metered by programmable logic controllers (PLCs) in the manufacturer's control panel. The heat exchanger is a commercial boiler that sits on top of the combustion chamber (Fig. 7). Its function is to transfer heat from the hot combustion gases to heat water and produce (in the case of Darby) low-pressure steam.

Figure 5—Full wood chip bin. Photo courtesy of Nick Salmon, CTA Architects Engineers, Missoula, Montana. Used by permission.

Control System

The manufacturer's control panel houses PLCs, relays, a remote dial-in system, and a touch-screen for accessing information on the current status and history of the system operation. The panel controls all aspects of combustion using inputs from a variety of sensors. There are three stages or rates of combustion (low, medium, high), plus a pilot or flame-maintenance mode for periods when there is little demand for heat (1 min on, 10 min off). The system controls automatically cycle the combustion between the various firing rates, depending on the heat load of the schools at any time.

Prefabricated Chimney

The 50-ft, free-standing stack (measured from the boiler room floor) is insulated to provide good draft. The main job of a tall stack is to disperse the combustion gases into the prevailing wind stream so that there is no effect on ground-level air quality or on air quality within the school and

Figure 6—Wood system fuel handling and metering bin. Photo courtesy of Tim Maker, Biomass Energy Resource Center, Montpelier, Vermont. Used by permission.

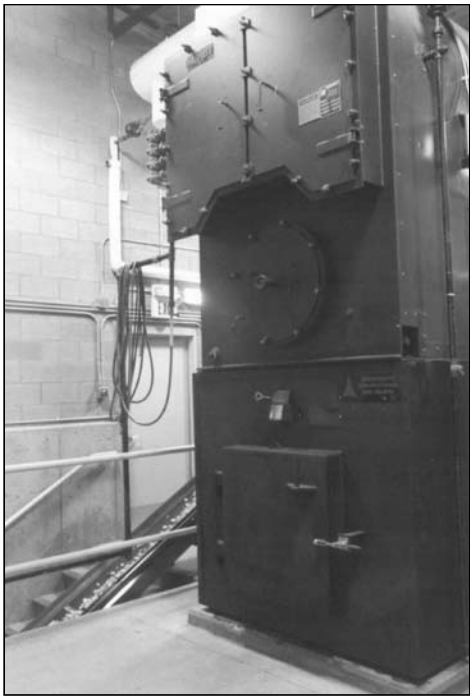

Figure 7—Messersmith wood boiler. Photo courtesy of Tim Maker, Biomass Energy Resource Center, Montpelier, Vermont. Used by permission.

surrounding areas. Although not technically part of the wood system, it was supplied by the wood system vendor. The $30,500 cost of the prefabricated chimney is included in the boiler house construction cost.

Air Emission Controls

The Darby system has no emission control devices installed between the boiler and the chimney. The boiler system is small enough that no state air permit is required. Although it would have been possible to include a cyclone or multi-cyclone particulate control device at additional cost, BERC recommended against this because wood-combustion systems of this type that have been previously tested showed particulate matter (PM) emissions of 0.12 lb/mm Btu (ERL 1996).

Also, a particulate-control device would have required the use of a draft fan, which would have increased the school's electric bills. The results of stack emission testing at Darby are presented later in this report showing PM emissions.

Wood Fuel

Prior to designing the wood system, the Bitter Root RC&D Area, Inc., worked with scientists from the University of Montana to characterize the likely wood fuels available to the Darby project. BERC synthesized these data and produced an expected fuel characterization:

Major species Ponderosa pine (*Pinus ponderosa*), Douglas Fir (*Pseudotsuga* spp. Lam.), Lodgepole Pine (*Pinus contorta*)

Energy content 9,000 Btu/lb of dry wood

Anticipated moisture content 40% (wet basis)

Actual energy content 5,400 Btu/pound of green wood

On BERC's recommendation, the school purchased uniform wood chips as the fuel at the beginning of the first year to ensure system performance without too many fuel variables. Then, assuming proper system function, the school could experiment with wood fuels of different characteristics and types. Working from these assumptions, BERC projected that annual fuel use would be 593 tons of wood chips, with 15% of the heat demand met by the backup oil system (6,434 gal).

First Year of Operation—System Commissioning and Operation

In the first 2 weeks of December 2003, the combustion of the new Darby wood system was tested on only the low and medium firing rates by the vendor's technical representative. Because of unusually warm weather during testing, the system could not be forced to operate at the high firing rate. Combustion testing measured the carbon monoxide level in the stack gas with wood fuel at 32.1% moisture content (MC, wet basis) with a sample stack temperature of 300°F to 335°F for all testing performed. BERC staff made a commissioning (operational verification) visit to verify the steady-state efficiency and functions of the system. Steady-state efficiency refers to the ratio of output energy (heat captured in the boiler fluid) to input energy (energy embodied in the wood fuel) when the combustion system is operating under design conditions (at the time of the test). Heating boilers operate at maximum efficiency when producing their rated heat output in Btu/h. Steady-state efficiency at lower firing rates is lower than the efficiency at rated capacity, and the efficiency at fire maintenance mode is even lower. In addition, steady-state efficiency determinations measure heat captured in the boiler fluid (steam) and do not account for heat losses in the steam distribution system (between boiler and buildings). These losses come into play when calculating seasonal efficiency.

Combustion efficiency is the efficiency of converting available chemical energy in the fuel to heat, typically in excess of 99% in wood combustors, as it measures only the completeness of fuel combustion that occurs in the combustion chamber (Bergman and Zerbe 2004). As noted earlier, efficiencies of conversion to usable heat are much lower. Both the vendor's testing and BERC's testing verified that the system's steady-state efficiency on the two lower firing rates (low and medium) was in the 70% to 80% range as required per contract specification (Table 3). The vendor measured the combustion rate temperature at the flame outlet of the combustion chamber at 1650°F and 1995°F for low and medium fires, respectively, and wood fuel measured at 32.1% MC_{wb} (BERC 2004). BERC found that all components of the system were operating properly.

Table 3. Steady-state efficiency test results

	Test 1	Test 2	Average
Low fire	71.7%	72.5%	72.1%
Medium fire	77.3%	75.0%	76.1%
High fire [a]	—	—	—

[a] Steady-state efficiency high firing rates were not measured because although it was early December, the boiler could not be forced from the medium firing to the higher firing rate.

Based on comments from school maintenance staff during commissioning and at the end of the school year, the 3 million Btu/h wood energy system was fully able to meet the heating requirements of the three schools in the coldest winter conditions, with no assistance from the backup oil boilers during both the 2003–2004 and 2004–2005 heating seasons (Coston 2005).

During the first year of operation, the school district incurred no operating expenses for the system other than the purchase of fuel and staff time for each school day (up to 1h daily) as well as each non-school day when temperatures were below freezing. Any start-up problems encountered during the first school year were handled under the terms of the warranty by the vendor, who visited the site monthly.

Operational Experience

Wood Fuel

The school district signed a 1-year contract with a local logger to provide the wood fuel during the first heating season. In the first months of operation, clean (no dirt) and uniform (matchbook-size) wood chips at less than 35% MC (wet basis) from a local thinning project were supplied. The small-diameter logs were delimbed using a flail-chain delimber prior to chipping, which probably removed some bark. A walking floor (self-unloading) trailer provided wood fuel delivery, with a capacity of about 14 tons of green fuel. This is significantly less capacity than the 25- to 30-ton chip van normally used; however, the smaller trailer was easier to use on narrow logging roads. The average delivery was 12 tons; chips were delivered 53 times over the course of the year.

Wood fuel for the Darby heating system was primarily chipped from small-diameter trees, limbs, tops, and other debris left over from logging. Air-dried peelings from a post and pole operation were also used. Attempts to use unscreened hog fuel from a logging operation were unsuccessful. This unscreened fuel had oversized wood pieces that were not handled well by the bin unloading and fuel-conveying equipment commonly bridging the metering bin and jamming the auger. Over the course of the year, 63% of the fuel supplied was chipped roundwood, 23% logging slash, and 14% post and pole residues.

Moisture content in the wood fuel was monitored to show the range that the wood heating system could use. During the 2003–2004 school year, staff and students measured the moisture content of wood fuel on an ongoing basis. Moisture content (wet basis) ranged from 16% to 46% for the 2003–2004 heating season. Three out of 19 loads tested (out of the 53 delivered) were less than 20% moisture and only one was greater than 40%. For the 2004–2005 heating seasons, the average MC_{wb} was 38%.

According to fuel delivery records, 75% of the wood fuel came from private lands, 21% from federal lands, and 4% from state lands. Bitter Root RC&D Area, Inc., concluded at least 50% of the wood fuel consumed in the project was from fire hazard-reduction operations.

Ash Removal

The combustion system does not allow for automatic removal of ash from the combustion chamber. Once a day, a maintenance staff person manually rakes the ash to the front of the combustion chamber (a 5-min task), and later in the day, shovels it out into metal trashcans to cool (10 min). Ash is saved and spread on the football field to adjust soil pH.

During the 2003–2004 heating season, approximately 1,200 lb of ash removed from the wood boiler was far less than the 8,000 lb based on expected 1% ash content for softwoods (Arola 1976). For every 12-ton truck loads of wood chips at 30% MC (wet basis); ash production appeared to be 25 lb. Although the means of measuring ash was crude and the results of this measurement did not yield reliable data, it is clear that ash production was quite low with a calculated value of 0.15%. Although this value, 0.15%, falls within the typical ranges of 0.1% to 0.5% stated for ash content of bark-free wood (Panshin and de Zeeow 1980), this wood fuel is not bark-free. Lehmann and Geimer (1974) measured ash content in Douglas-fir logging residues and found values for bark-free wood from 0.2% to 0.5%; in bark, roughly 1.3% to 2.5%; in twigs, 2.2%; and in needles, excess of 3%. With comminuted wood fuels, Arola reported ash contents of 1% and 2% for softwood wood and bark, respectively. However, for the Darby Schools' 2004–2005 heating season, 755 tons of wood fuel at 38% MC (wet basis) produced 1,080 gal of ash measured at 45 pounds/ft^3, an ash content value of 0.69%. Panshin/deZeeuw and Lehmann/Geimer values are from samples where effort was taken to prevent contamination, whereas Arola's values reflect an industrial environment where airborne dust may be prevalent, which fits the situation at Darby. This presents an open question requiring additional research on why the ash content values are low compared to industry values.

The Bitter Root RC&D Area, Inc., concluded the following from their data testing and experience in burning a variety of wood residues at Darby:

- Fuels were considerably dryer than initially thought.
- The fuel supplier, who has some flexibility in what fuels he chips and delivers, can exercise some control over

Table 4. Darby Schools' year one (2003–2004) fuel and cost savings for heat

	Historical usage		2003–04					
	Oil use (gal)	Oil cost ($)	Oil use (gal)	Oil cost ($)	Wood use (ton)	Wood cost ($)	Wood/oil total cost ($)	Total fuel cost savings ($)
	47,600	51,884	10,165	11,080	633	18,357	29,437	22,447
LP (estimate)								2,080
Total savings								24,527

Table 5. Darby Schools' year two (2004–2005) fuel and cost savings for heat

	Expected fuel usage (2004–2005)		2004–05					
	Oil use (gal)	Oil cost ($)	Oil use (gal)	Oil cost ($)	Wood use (ton)	Wood cost ($)	Wood/oil total cost ($)	Total fuel cost savings ($)
	47,600	88,060	1,900	2,451	755	26,660	29,051	59,009
LP (estimate)								2,500
Total savings								61,509

moisture content by checking with a probe-type handheld meter at the chipping site and by mixing fuel types in a single load.

- The computerized combustion controls automatically adjust for dry or green fuels.
- Higher moisture content (wet basis) values than 50% would be required to show moisture content variation tolerance in the wood combustor. As of January 2006, the highest moisture content found was 46%.

Fuel Use and Cost

Based on the oil consumption history of the three schools, BERC estimated that wood fuel consumption would be in 500 to 700 tons of green fuel each year with an approximate average of 600 tons. Part of the difficulty in providing a more accurate estimate came from uncertainty about the amount of LP gas previously used by the schools for domestic hot water. The new wood system was designed to provide almost all the schools' space heating as well as steam to the previously installed and refurbished domestic hot water system (primarily for kitchen use).

Actual wood consumption in the first school year of operation was 633 green tons (November 1, 2003, through June 1, 2004), with 10,165 gal backup oil use for the same time. For the same period, wood accounted for 73% of fuel costs and oil for 27%. In addition, it appears that LP use was reduced by 1,500–2,000 gal in the first year of the new system. During the 2003–2004 school year, the school paid delivered prices of $29 per ton for wood, $1.09 per gal for oil, and $1.04 per gal for LP gas. During the 2004–2005 school year (September 1, 2004, to May 31, 2005), wood consumption was 755 green tons, and the school paid delivered prices of $35 per ton for wood, $1.85 per gal for oil, and $1.29 per gal for LP gas. Total fuel costs for the heating seasons in 2003–2004 (Table 4) and 2004–2005 (Table 5) are shown. Wood consumption was higher than the 500 to 700 tons expected for a school of this size; a clear explanation for this is not known at this time.

The wood heating system did not start operation until November 1 because of administrative contractor delays. For this reason and because LP usage history is not confidently known, it is difficult to draw definite conclusions from the first-year fuel consumption. The second year of operation (which was the first full heating season year) was more definitive (Coston 2005).

In the 2003–2004 heating season, oil use was reduced by 79%. Of the 10,165 gal of oil used that heating season, 6,665 gal were used in the 2 months before the wood system started operation on November 1, and 3,500 gal were used in the following 7 months from November through May. As for 2004–2005, the first full heating season (September through May) of wood system use, total fuel cost savings of was over $60,000 because of higher fuel oil pieces.

A 15-year experience with school wood heating in New England has shown that over the course of a full year, the typical wood system provides 80% of the school's heat while the oil or other backup system provides 20% (Maker 2004). The oil consumption comes from four situations: (1) in summer months (also early fall and late spring), when the wood boiler is not in operation, (2) when the wood system has been shut down because of a problem, (3) in any situation when wood is not available and the bin is empty, and (4) in very cold weather when the wood boiler does not provide enough heat to keep the school warm.

Table 6. Darby emissions test results and comparisons

Darby testing	PM [a]	NOx [b]	CO [c]
Grains per dry standard cubic foot (gr/dscf)	0.061 ± 0.008 [d]	—	—
Parts per million (ppm)	—	57.18 ±1.42	127.73 ±12.12
lb/h	0.468 ± 0.118	0.365 ± 0.057	0.499 ± 0.111
lb/10^6 Btu	0.145 ± 0.037	0.113 ± 0.018	0.155 ± 0.034
Comparisons (lb/mm/Btu)			
Darby tests (total PM)	0.145 ± 0.037	0.113 ± 0.018	0.155 ± 0.034
PM10 – 1999 [e]	0.968	0.165	1.496
PM10 / Filterable PM -2003 (wet) [f]	0.29/0.33	0.22	0.60
PM10 / Filterable PM -2003 (dry) [g]	0.36/0.40	0.49	0.60
Messersmith water boiler [h]	0.12	0.211	0.902

[a] Particulate matter.
[b] Nitrogen oxides.
[c] Carbon monoxide.
[d] 95% confidence intervals.
[e] EPA 1999.
[f] EPA 2003.
[g] EPA 2003.
[h] ERL 1996.

At Darby, where the wood boiler is able to provide all the heat the school needs in the coldest weather, most of the annual oil consumption will be from warm months when the wood system is shut down. In the first heating season of operation, the Darby wood boiler was down for various periods while start-up debugging was taking place, but these problems were solved by the middle of the winter. Wood fuel consumption and square-foot-per-heating degree days heating costs were somewhat greater than anticipated.

Adjusting annual fuel costs using heating degree days (HDD) is an excellent method for determining accurate heating costs from year to year because HDD are independent of the previous year reading. Seasonal HDD is a seasonal cumulative total of daily values, with each daily value being the amount by which the mean daily temperature is below 65°F (Wikipedia 2006). The lower the temperature for a particular day, the higher the heating degree-day number is for that day. A series of seasonal HDD totals at a given location gives a relative indication of the total amount of energy needed for space heating at that location over a given series of heating seasons. Appendix A provides seasonal HDD totals for the 1999–2000 though 2005–2006 heating seasons, based on weather data from the nearest station maintained by the National Climatic Data Center (NCDC). Shorter-term HDD totals can be used to compare relative maximum heat load (system) demands over successive heating seasons. Appendix B shows HDD totals over the three coldest days in each winter of the 1996–1997 through 2005–2006 heating seasons (also based on weather data from the nearest station maintained by the NCDC). Appendix A indicates that total energy needed for space heating over each of the 2003–2004 and 2004–2005 heating seasons was slightly less than was needed over the 2002–2003 heating seasons. Appendix B indicates that maximum heat load demand was roughly similar over the three heating seasons.

Electrical Consumption and Cost

Electricity use in the building housing the wood-fired boiler turned out to be significant. Most of this electrical consumption was by the motors and other components of the wood heating system; the remainder of the consumption was by the heat distribution system's pump, lighting, and miscellaneous activities in the building. For November through May of the 2003–2004 heating season, metered electricity consumption in the boiler building was 13,040 kWh, at a unit cost of 6.84¢ per kWh for a total cost of $892. For the 2004–2005 heating season, (counting the full year from June 2004 through May 2005) metered electricity consumption in the boiler building was 25,400 kWh, at a unit cost of 8¢ per kWh for a total cost of $2,035 (Coston 2005).

Air Emissions and Testing

As stated previously, the Darby wood system, at 3.0 mmBtu/h peak output, was not large enough to require a permit under Montana air pollution control regulations.

Bitter Root RC&D hired a testing firm, Aspen Consulting Engineering (Helena, Montana), to measure emission levels from the stack of the wood boiler. The emission components tested were particulate matter (PM), nitrogen oxides (NOx), and carbon monoxide (CO) (Table 6). Aspen Consulting Engineering carried out their tests on April 12 and 13, 2004, and reported their findings in a report dated April 20, 2004 (ACEI 2004).

The Aspen report gave emissions in units of grains per dry standard cubic foot (gr/dscf) and pounds per hour (lb/h) for PM; and parts per million (ppm) and pounds per hour (lb/h) for NOx and CO. The boiler operated at 75% capacity

Table 7. Darby emissions test results and comparisons

	Comparisons (lb/green ton[d])		
	PM [a]	NOx [b]	CO [c]
Darby tests (total PM)	1.25 ± 0.32	1.22 ± 0.16	1.67 ± 0.29
Slash pile burn [e]	12.0 [b]	3.5 [c]	73.9 [b]
Wild fire [f]	17.0 [b]	4.0 [b]	140 [b]

[a] Particulate matter.
[b] Nitrogen oxides
[c] Carbon monoxide.
[d] Assumes wood fuel energy content of 10.8 million Btu/green ton (40% MC_{wb}) and a boiler efficiency of 80%.
[e] EC/R Incorporated 2002.
[f] McNeil Technologies 2003.

during all three test runs using wood fuel with a 11.0 ± 0.3% MC_{wb}, MC values substantially lower than was burned for either the 2003–2004 (30% MC_{wb}) or the 2004–2005 (38% MC_{wb}) heating seasons. Also included in the table are conversions from pounds per hour (lb/h) to pounds per million Btu input (lb/ mmBtu), a unit commonly used in comparing wood system stack emissions. This last calculation was carried out by the Resource Systems Group (White River Junction, Vermont) for BERC (RSG 2001). All emissions testing was performed in accordance with Environmental Protection Agency (EPA) methods as described in Title 40 of the Code of Federal Regulations Part 60, Appendix A (CFR 1989). The flue gas exhaust rate of 892 ± 119 dscfm was used in this analysis for calculating emissions per unit time in conjunction with a measure of concentration. For example, pounds per hour of particulate were found using this exhaust rate data. The Darby emissions results are summarized in Table 6.

Whether using woody biomass or fossil fuels, it is important for environmental concerns to know the cause of air emissions and how these emissions compare with U.S. Environmental Protection Agency (EPA) guidelines or with other heating systems that have been tested in the past. An example of poor heating system design was the previous green sawdust-fired heating systems installed during the 1970s at several schools in Salmon, Idaho. During a technology transfer visit in April 2001 to Salmon, Idaho, one of the schools was emitting smoke at ground level while school was in session. This type of emission problem plus wood fuel availability at that time resulted in the Salmon School District plan to replace all three of their school wood heating systems with propane. One wood heating system was already replaced with propane at that time. Therefore, it is critical that accurate air emission data from modern wood heating systems such as Darby's are available for comparison. Table 7 compares the Darby emissions test data to other indicators. For comparison purposes, Table 7 shows the EPA's AP-42 emission factors of the 1999 edition (note: AP-42 figures are for PM10). The EPA's AP-42 Section 1.6 is a standard reference document used by air quality regulators that gives typical emissions compiled, in the case of wood boilers. The emission factors of the 1999 edition were largely from compiled data on permitted large commercial and industrial boilers with no emissions control equipment and are based largely on the combustion of green wood with moisture contents greater than 20% on a wet basis (ERG 2001). From an air regulator's perspective, the Darby wood system is "uncontrolled," meaning it has no emissions control equipment. Data suggest that the Darby wood boiler, like other small, stage-firing institutional wood boilers of its class, performs much better than many of the older generation of much larger industrial wood boilers (BERC 2003). Also, the PM results were less than the average value of 0.22 lb/mmBtu found in a study completed by Conestoga-Rovers & Associates on 13 Ethan Allen industrial wood-fired boilers and several other wood-fired boilers (Kaminski 2002). Furthermore, PM emissions of 0.12 lb/mmBtu were found in an emission testing study on a Messersmith 2.2 million Btu per hour hot water boiler fired by wood chips (ERL 1996). The PM emissions of the Darby wood boiler are similar to those measured by ERL.

Revisions of the guidelines for AP-42 Wood Residue Combustion in Boilers proposed in July 2001 (ERG 2001) were officially adopted in September 2003. The main change in these revisions for wood-fired boilers with no emission control is a new filterable PM emission factor of 0.33 and 0.40 lb/mmBtu (less than the PM10 emission factors for the AP-42 1999 edition) that was established for both wet and dry woods, respectively. The stated filterable PM emission factors in the 2003 edition are more than twice the measured total PM emissions of 0.145 lb/mmBtu given off by the Darby wood-fired boiler. Also, new NOx and CO emission factors were determined and are listed as 0.22 lb/mmBtu and 0.60 lb/mmBtu, respectively, with a different CO emission factor of 0.17 lb/mmBtu listed just for fluidized bed combustors (NOx Emission Factor is the same regardless of wood combustor type). In Darby's case, NOx and CO emissions were 0.113 and 0.155 lb/mmBtu, respectively, which fell within the new specifications listed regardless of type of wood fuel or type of combustor. In conclusion, the newest AP-42 emission data regarding dry fuel (<20% MC_{wb}) fits better with the Darby case for analyzing emissions since the stack test for Darby wood heating system used wood fuel with a 11.0 ± 0.3% MC_{wb} The wood fuel tested was drier than any wood fuel used over the 2003–2004 and 2004–2005 heating seasons.

A wildfire or a slash pile burn is large-scale combustion process that consumes various ages, types, and quantity of trees. These processes are a significant source of pollutants that should be considered when showing the differences between what happens in a controlled environment versus an uncontrolled environment. Table 7 gives comparative figures to show how the Darby system emissions compare to emissions into the atmosphere from open burning of slash piled up with a bulldozer and to emissions from a wildfire. Sulfur oxide emissions were not measured in this case, although wood has substantially less sulfur than does fuel oil (Patterson 1990). Air emissions from wildfires are made up of tiny particles, gases, and water vapor. Water vapor makes up the majority of smoke, but the remainder includes carbon monoxide, carbon dioxide, nitrogen oxide, formaldehyde, benzene, and other irritant compounds, toxics, and small particles. Known health effects from smoke exposure can range from burning eyes, runny nose, and bronchitis to congestive heart failure and emphysema. It is not uncommon for western communities located within the "wildland urban interface" to experience extended periods of time where smoke from forest fires causes air quality to exceed the EPA National Ambient Air Quality Standards and pose health hazards. The main conclusion from Table 7 is that wood-fired boilers, although not devoid of emissions, produce far fewer emissions than do slash burning or wildfires, and not just because they consume less wood.

Economic Analysis

The Darby Schools project was intended by the Forest Service and its local partners to be a working demonstration of school wood heating technology for the western states.

The Darby wood energy system, as reported, cost $556,000, including $230,500 in vendor-supplied equipment and $285,500 in building construction. Wood heating systems for institutions cost typically two to three times the capital costs of oil heating systems mainly because they have complex fuel handling and fuel storage requirements and typically more operation and maintenance (O & M) costs. In this case, fuel costs are separate from O & M costs to illustrate the differences for oil heat and wood heat. What allows wood heating systems to compete in the marketplace is low-cost fuel ($ per million Btu). To support the demonstration project, the Forest Service also elected to invest an additional $363,000 in heating infrastructure improvements to the three schools. Based on the fuel costs between wood and fuel oil, Darby's heating system was expected to reduce fuel costs by $30,000 annually in the first few years after construction, but over twice that amount was determined for the 2004–2005 heating season. First year fuel savings were about $25,000, but the wood system did not start operation until part way through the heating season. For Darby Schools, the fuel cost savings represented a net budget reduction because there were no finance payments for the school district.

The simple payback of the $556,000 investment in the wood energy system (energy project cost divided by annual fuel cost savings) is 18.5 years, assuming that fuel oil prices remain steady at the 2003–2004 heating season value of $1.09 per gal. Fuel oil prices were on the average $1.85 per gal for the 2004–2005 heating season, which doubled the fuel cost savings. Thus, the adjusted simple payback is now 9.8 years. Simple payback estimates are sensitive to anticipated fuel oil prices.

One extremely important question is whether other schools in the western states can implement wood heating projects since other schools (unlike Darby) will have to shoulder much more of the capital cost. For other school wood heating projects, where the wood system will be financed by the local school district (perhaps with some form of state or federal aid), it is necessary to use a more realistic way of assessing each project's cost effectiveness. Life-cycle cost analysis is a more rigorous tool for doing this than the simple payback method.

All costs of operating the system are projected for 20 years using annual price inflation factors, for both the proposed project and for an alternative scenario. The complete operating cost over the life of the proposed system is considered and compared with the life-cycle cost of the alternative scenario in today's dollars. This analysis accounts for future changes in energy prices and inflation through a sensitivity analysis (Appendix C). This is particularly important for wood energy projects because wood residues are expected to maintain low, stable prices over time (EEA 2000). Long-term maintenance costs are well-known based on the empirical data gathered in the last 20 years for the Vermont Wood Heating Program (Maker 2004) where over 30 schools are heated by wood. We expect that operating and maintenance costs will significantly increase over time because of fuel handling and storage requirements and refractory replacements; these costs were summed and annualized over the life of the boiler. Although for the 2004–2005 heating season, maintenance costs were 50% of the old three-boiler oil system at Darby, Montana (Coston 2005), additional operating costs such as electricity and monitoring of boiler operation were added to the variable costs of operating the wood fuel system. The wood-fired boiler is checked twice daily during the school week and once daily on non-school days if the outside temperature is below 32°F. The (three) oil-fired boilers are available for backup operation if needed.

Net present value (NPV) is a valuation method based on discounted cash flows. The NPV is calculated by discounting a series of future cash flows, and summing the discounted amounts and the initial investment (a negative amount). It is a time-consuming process, but not difficult using spreadsheet programs. If the NPV method results in a

Table 8. Sensitivity analysis to show the potential net present values given a set of conditions

	Initial rates (%)	Max WFER (%)	Max FOER (%)	Max WSO & MER (%)	Max DDR (%)
General inflation	2.0	2.0	2.0	2.0	2.0
Wood fuel escalation rate (WFER)	2.0	**5.5**	2.0	2.0	2.0
Fuel oil escalation rate (FOER) [a]	1.3	1.3	**– 0.3**	1.3	1.3
Wood system O & M escalation rate (WSO & MER)	4.0	4.0	4.0	**12.8**	45.0
Net present value (NPV)	—	0	0	0	0
Desired discount rate (DDR)	8.0	8.0	8.0	8.0	**9.9**

[a] AEO 2006.

positive amount, this indicates that the project is more economically favorable than the alternative project with which it is being compared. Although this method is widely used for making investment decisions, a disadvantage of NPV is that it does not account for flexibility or uncertainty after the decision. A sensitivity analysis was done to show the potential NPVs given a set of conditions and shown in Table 8.

The following hypothetical calculations are based on the Darby Case except that the school district is assumed to receive no subsidy of any kind—the district is assumed to raise all capital needed for the project. The financial analysis is based on incorporating a wood heating system in a school without any outside financial assistance so school administrators can see the actual cost. It is vital to find the incremental costs of the new wood heating system and the alternative for completing a NPV analysis. The incremental cost is the difference in the initial cost between any two alternative projects. In this alternative, the oldest (1964) oil-fired boiler in the elementary schools was replaced by a new oil boiler, and the existing mechanical equipment was also upgraded. We compared this system to a new wood heating system similar to Darby's. The other campus heating system received no outside financial assistance; we found a before-tax NPV of $83,700. Incremental costs of $555,900 were calculated for this case with a desired discount rate of 8%. A positive cash flow occurred by Year 1 due mostly to large price increases in the backup fuel (fuel oil #2) used for the calculations over the life of project. Oil prices went from $0.92 per gal in 2002–2003 to $1.29 per gal in 2003–2004, $1.85 per gal in 2004–2005, to a December 2005 value of $2.20 per gal. Future fuel oil prices contain large amounts of uncertainty although the calculations allowed for 1% to 5% increases annually from the 2005–2006 heating season. The main assumptions were no grants, school paid for the wood energy system, and the one fuel oil boiler would be replaced with a boiler of the same capacity. Also, after 20 years, the salvage values of the two systems would be of equal value.

We performed one other analysis to show how different decisions produce different NPVs. In the second alternative (Appendix E), the oldest (1964) boiler was removed from service, the existing mechanical systems were upgraded, and the elementary school was connected to one of the other boilers. This system was compared to the new wood heating system just like in the first project. The NPV was found to be $115,000, which is higher than the first alternative. In conclusion, wood heat has an economic advantage over two different oil heat scenarios, which demonstrates the potential for other schools converting to wood heat given the right circumstances.

Conclusions

Wood system is a success from the perspective of Darby Schools. Heating fuels bills have been reduced by more than 50% in 2003–2004 and 75% in 2004–2005. The Darby Schools fully realized fuel savings, without incurring any capital costs, inasmuch as a $900,000 total subsidy was provided from three different sources ($879,000 by the Forest Service, $15,000 by the vendor, and $6,000 in waived commissioning costs). Primarily because of appreciable escalation in fossil fuel costs since 2004, NPV analysis indicates that the wood-fueled boiler project would have been financially viable over a forward-looking 20-year period without the subsidy provided. The school has experienced no problems with the fuel delivery truck traffic, smoke odor, or noise. The wood system is largely invisible to the casual observer.

Wood heating system saved money on fuel costs. Based on total square footage of the three schools on the Darby campus and heating degree days (HDD) for the three respective seasons, the corresponding $/thousand ft^2/HDD heating fuel costs were reduced from 0.068 in the 2002–2003 heating season, and to 0.040 in the 2003–2004 and the 2004–2005 heating seasons, respectively.

Wood heating system worked without problems on most forest fuel types. The system was able to easily handle and burn fuels of different types and different moisture content levels. With the exception of hog fuel (with a high percentage of oversized pieces), the wood system ran continuously on the available fuels with few problems. Steady-state efficiencies (fuel input to heat output efficiency) were generally 72% to 78% for this type of wood boiler, which includes both combustion and boiler efficiencies.

Installation cost of wood system was high. Overall project costs in the range of $500,000 can be supported for large schools (well over 100,000 ft^2), with high heating bills (> $75,000). Other schools, particularly small schools in rural areas, may find the capital cost to be too high to be supported by fuel savings. In Darby's case, installing a wood heating campus system compared with replacing the oldest oil-fired boiler, a before-tax NVP of $83,600 was found. The calculation did not include any outside funding.

Selection of schools that need costly upgrades to existing systems increases overall project costs; wood heating will be most cost effective in new school construction projects. Overall project costs will be reduced, compared with adding wood heat to existing facilities (e.g., Darby), because there would be no expensive retrofit costs and the overhead costs of the new building construction project would not be increased much. In either case, a fossil fuel back-up system is installed or left in place as part of the whole heating system. We recommend that the Fuels for Schools program undertakes a wood heating system as part of a new school construction project to document cost savings compared with retrofitting a wood system into an existing facility.

At Darby, wood fuel consumption and per-square-foot heating costs were somewhat greater than anticipated. For the second heating season (first full season), 755 tons were consumed, which is over 55 tons more than the 600–700 tons expected based on past fuel oil usage. It is not clear why this is so. The energy content of the wood fuel may have been less than was expected. Leaks in the steam system may have increased fuel consumption. The use of steam instead of hot water to distribute heat to the buildings may have resulted in more heat wasted to the boiler room and greater losses from the buried piping.

Next Steps

State foresters in the Forest Service five-state Northern and Intermountain Regions (Montana, Idaho, North Dakota, Nevada, and Utah) will administer the Fuels for Schools program, and the U.S. Congress has responded to the need by providing funding for grant assistance. Based on the success of the Darby project, three other sites in Montana are operating (Victor, Phillipsburg, and Thompson Falls). Outside of Montana, the first public school in the region to install a Fuels for Schools wood energy system was in Ely, Nevada (February 2005). Council Public Schools in Council, Idaho, installed their wood energy system in September 2005. Other sites in Forest Service Northern and Intermountain Regions under construction or in design include five other sites in Montana (Troy, Kalispell, Dillon, Townsend, and Lewistown), one in Bismarck, North Dakota, one in Carson City, Nevada, and one in Kellog, Idaho.

Although assisting public schools is the primary focus of the Fuels for Schools program, other public buildings are also eligible for assistance and are expected to play an expanded role in the future. Recently the partners in this effort—Forest Service in Montana, Idaho, Nevada, North Dakota, Utah, and the Bitter Root Resource RC&D—have completed over 20 studies on the feasibility of installing forest biomass-fired heating systems. About half the sites studied have the qualities desired for demonstration purposes.

In general terms, the Fuels for Schools grant program is based on a 50/50 cost-share between the program and the institution. Based on an initial financial analysis, each facility should be able to repay the indebtedness for its share of the capital cost out of fuel cost savings over a period no longer than 10 years. An institution with a completed feasibility study showing favorable economics can submit a project proposal for grant assistance to their state forester.

Besides Montana, Idaho, and Nevada, North Dakota plans on establishing at least one Fuels for Schools wood energy project by the end of 2005. The applicant schools and other facilities will compete for federal funding with a maximum federal share of 50% of total cost. In Utah, the state forester has a memorandum of understanding with the Utah Division of Energy to complete a statewide assessment of potential school conversions. When the assessment is completed, the State of Utah will look at developing a Fuels for Schools program.

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Appendix A—Seasonal Heating Degree Day Totals to 2006

Table A1. Seasonal heating degree day totals for the 1999–2000 through 2005–2006 heating seasons, based on weather data from the nearest station maintained by the National Climatic Data Center

	Monthly heating degree days for Butte, Montana, heating seasons [a]							
Month	1999–2000	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	Average for 1971–2000
June	314	177	319	252	304	312	353	278
July	134	66	106	62	45	103	78	129
August	63	30	52	217	55	164	147	165
September	445	414	275	387	380	458	412	410
October	664	726	735	947	655	732	644	748
November	803	1460	972	1130	1288	1058	1124	1137
December	1328	1570	1428	1295	1372	1200	1517	1464
January	1328	1558	1396	1297	1472	1338	1082	1471
February	809	1420	1235	1349	1256	1076	1300	1199
March	—	1054	1314	1022	862	1015	1060	1077
April	—	859	865	785	715	814	712	781
May	483	499	586	560	582	556	496	540
Total	~~6371~~[b]	9833	9283	9303	8986	8826	8429	9399

[a] Located 130 miles from Darby, Montana—nearest location
[b] Incomplete data for year.

Adapted from the Weather Underground, History for Butte, Montana http://www.wunderground.com/history/airport/KBTM/2000/1/1/MonthlyHistory.html

Appendix B—Total Heating Degree Days to 2006

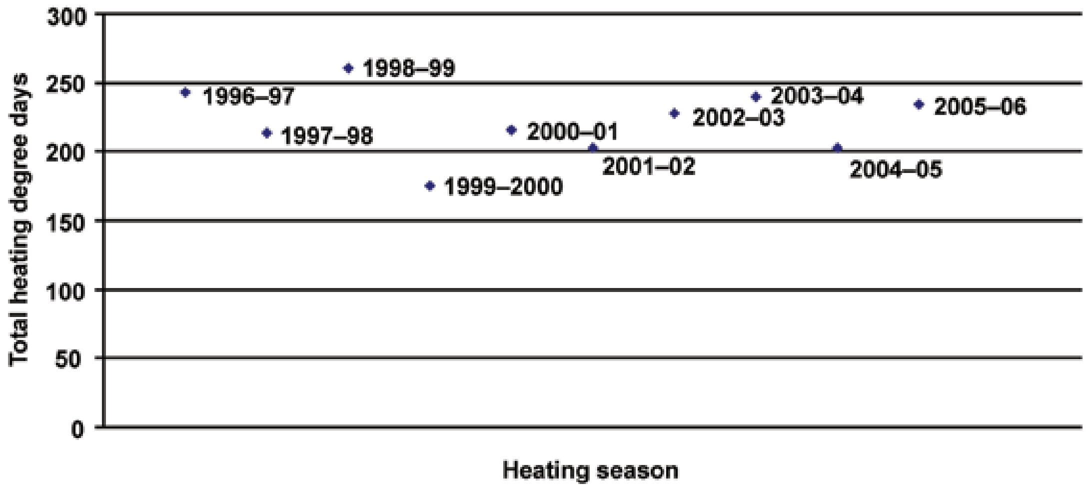

Figure B1. Total heating degree days for the three coldest days in each winter of the 1996–1997 through 2005–2006 heating seasons.

Reference: Weather Underground. History for Butte, Montana. http://www.wunderground.com/history/airport/KBTM/2005/12/19/DailyHistory.html

Appendix C—Energy Prices, Supply, and Disposition to 2030

The complete operating cost over the life of the proposed system is considered and compared with the life-cycle cost of the alternative scenario in today's dollars (Table 1). This analysis accounts for future changes in energy prices and inflation through a sensitivity analysis.

Annual Energy Outlook 2006 (Early Release)
Release Date: December 12, 2005
Next Release Date: December 2006

Table C1. Energy Prices, 1980–2030 (2004 dollars per million Btu)

	Crude oil (Imported)	Natural gas	Coal	Electricity	Crude oil (Imported) (Baseline—2003)	Natural gas (Baseline—2003)
1995	3.600	1.774	1.038	23.73	67%	37%
1996	4.245	2.438	1.001	23.19	79%	50%
1997	3.938	2.564	0.966	22.78	73%	53%
1998	2.705	2.132	0.926	22.17	50%	44%
1999	3.402	2.360	0.873	21.52	63%	49%
2000	5.351	3.886	0.862	21.60	100%	80%
2001	4.685	4.107	0.882	22.68	87%	85%
2002	4.563	2.985	0.904	21.98	85%	62%
2003	5.366	4.831	0.889	22.21	100%	100%
2004	6.766	5.329	0.973	22.18	126%	110%
2005	9.353	7.394	1.037	24.44	174%	153%
2006	9.883	6.650	1.050	24.07	184%	138%
2007	9.301	5.956	1.066	22.92	173%	123%
2008	8.746	5.607	1.071	22.14	163%	116%
2009	8.385	5.188	1.069	21.76	156%	107%
2010	7.908	4.880	1.088	21.43	147%	101%
2011	7.917	4.642	1.054	21.06	148%	96%
2012	7.968	4.584	1.043	20.92	148%	95%
2013	7.922	4.659	1.029	21.14	148%	96%
2014	7.843	4.569	1.012	21.07	146%	95%
2015	7.992	4.389	1.008	20.87	149%	91%
2016	8.060	4.332	1.004	20.89	150%	90%
2017	8.078	4.397	1.002	20.93	151%	91%
2018	8.234	4.569	1.001	21.05	153%	95%
2019	8.089	4.709	1.000	21.25	151%	97%
2020	8.478	4.756	1.003	21.23	158%	98%
2021	8.450	4.887	1.001	21.38	157%	101%
2022	8.780	4.967	1.005	21.43	164%	103%
2023	8.886	5.037	1.013	21.39	166%	104%
2024	8.706	5.150	1.021	21.52	162%	107%
2025	9.044	5.275	1.032	21.69	169%	109%
2026	9.165	5.353	1.043	21.70	171%	111%
2027	9.316	5.449	1.051	21.76	174%	113%
2028	9.422	5.506	1.067	21.75	176%	114%
2029	9.487	5.584	1.077	21.79	177%	116%
2030	9.526	5.747	1.085	22.00	178%	119%

Release date: December 2005
Next release date: December 2006
(full report available February 2006)

Table C2. Total energy supply and disposition in the Annual Energy Outlook 2006 (*AEO 2006*) reference case: summary, 2003–2030 released by the Department of Energy's Energy Information Agency

Energy and economic factors	2003	2004	2010	2015	2020	2025	2030	Average annual change, 2004–2030
Primary energy production (quadrillion Btu)								
Petroleum	14.40	13.93	14.83	14.94	14.41	13.17	12.25	– 0.5%
Dry natural gas	19.63	19.02	19.13	20.97	22.09	21.80	21.45	0.5%
Coal	22.12	22.86	25.78	25.73	27.30	30.61	34.10	1.6%
Nuclear power	7.96	8.23	8.44	8.66	9.09	9.09	9.09	0.4%
Renewable energy	5.69	5.74	7.08	7.43	8.00	8.61	9.02	1.8%
Other	0.72	0.64	2.16	2.85	3.16	3.32	3.44	6.7%
Total	70.52	70.42	77.42	80.58	84.05	86.59	89.36	0.9%
Net imports (quadrillion Btu)								
Petroleum	24.19	25.88	26.22	28.02	30.39	33.11	36.49	1.3%
Natural gas	3.39	3.49	4.45	5.23	5.15	5.50	5.72	1.9%
Coal/other (– indicates export)	– 0.45	– 0.42	– 0.58	0.20	0.90	1.54	2.02	NA
Total	27.13	28.95	30.09	33.44	36.44	40.15	44.23	1.6%
Consumption (quadrillion Btu)								
Petroleum products	38.96	40.08	43.14	45.69	48.14	50.57	53.58	1.1%
Natural gas	23.04	23.07	24.04	26.67	27.70	27.78	27.66	0.7%
Coal	22.38	22.53	25.09	25.66	27.65	30.89	34.49	1.7%
Nuclear power	7.96	8.23	8.44	8.66	9.09	9.09	9.09	0.4%
Renewable energy	5.70	5.74	7.08	7.43	8.00	8.61	9.02	1.8%
Other	0.02	0.04	0.07	0.08	0.05	0.05	0.05	0.9%
Total	98.05	99.68	107.87	114.18	120.63	126.99	133.88	1.1%
Petroleum (million barrels per day)								
Domestic crude production	5.69	5.42	5.88	5.84	5.55	4.99	4.57	– 0.7%
Other domestic production	3.10	3.21	3.99	4.50	4.90	5.45	5.84	2.3%
Net imports	11.25	12.11	12.33	13.23	14.42	15.68	17.24	1.4%
Consumption	20.05	20.76	22.17	23.53	24.81	26.05	27.57	1.1%
Natural gas (trillion cubic feet)								
Production	19.11	18.52	18.65	20.44	21.52	21.24	20.90	0.5%
Net imports	3.29	3.40	4.35	5.10	5.02	5.37	5.57	1.9%
Consumption	22.34	22.41	23.35	25.91	26.92	26.99	26.86	0.7%
Coal (million short tons)								
Production	1,083	1,125	1,261	1,272	1,355	1,530	1,703	1.6%
Net imports	– 18	– 21	– 26	5	36	63	83	NA
Consumption	1,095	1,104	1,233	1,276	1,390	1,592	1,784	1.9%
Prices (2004 dollars)								
Imported low-sulfur light crude oil (dollars per barrel)	31.72	40.49	47.29	47.79	50.70	54.08	56.97	1.3%
Imported crude oil (dollars per barrel)	28.46	35.99	43.99	43.00	44.99	47.99	49.99	1.3%
Domestic natural gas at wellhead (dollars per thousand cubic feet)	5.08	5.49	5.03	4.52	4.90	5.43	5.92	0.3%
Domestic coal at minemouth (dollars per short ton)	18.40	20.07	22.23	20.39	20.20	20.63	21.73	0.3%

Energy and economic factors	2003	2004	2010	2015	2020	2025	2030	Average annual change, 2004–2030
Average electricity price (cents per kilowatt hour)	7.6	7.6	7.3	7.1	7.2	7.4	7.5	0.0%
Economic indicators								
Real gross domestic product (billion 2000 U.S. dollars)	10,321	10,756	13,043	15,082	17,541	20,123	23,112	3.0%
GDP chain-type price index (index, 2000 = 1.000)	1.063	1.091	1.235	1.398	1.597	1.818	2.048	2.5%
Real disposable personal income (billion 2000 U.S. dollars)	7,742	8,004	9,622	11,058	13,057	15,182	17,562	3.1%
Value of manufacturing shipments (billion 2000 U.S. dollars)	5,378	5,643	6,355	7,036	7,778	8,589	9,578	2.1%
Energy intensity (thousand Btu per 2000 dollar of GDP)	9.51	9.27	8.28	7.58	6.88	6.32	5.80	– 1.8%
Carbon dioxide emissions (million metric tons)	5,815	5,919	6,365	6,718	7,119	7,587	8,115	1.2%

Reference: Energy Information Administration, Official Energy Statistics from the U.S. Government
http://www.eia.doe.gov/oiaf/aeo/table1.html

Appendix D–Alternative Project #1

In this alternative, the oldest (1964) oil-fired boiler in the elementary schools was replaced by a new oil boiler, and the existing mechanical equipment was also upgraded. We compared this system to a new wood heating system similar to Darby's. The main assumptions were no grants, school paid for the wood energy system, and the one fuel oil boiler would be replaced with a boiler of the same capacity.

Before-tax net present value: $83,600

Table D1—Fuel oil and wood heat systems compared

Year	Fuel oil system costs	Wood fuel cost	Annual fuel cost savings	Fuel oil O & M costs	Wood fuel O & M costs	Wood fuel fixed costs	Annual O & M cost savings	Before-tax U.S. dollars
0	$344,000	$900,000	—	—	—	—	—	$(556,000)
1	$51,440	$29,437	$22,003	$1,684	$4,892	$400	$(3,608)	$18,395
2	$87,306	$29,051	$58,255	$1,718	$5,998	$408	$(4,689)	$53,566
3	$103,823	$29,632	$74,191	$1,752	$6,238	$416	$(4,902)	$69,289
4	$105,173	$30,225	$74,948	$1,787	$6,488	$424	$(5,125)	$69,823
5	$106,540	$30,829	$75,711	$1,823	$6,747	$433	$(5,358)	$70,353
6	$107,925	$31,446	$76,479	$1,859	$7,017	$442	$(5,600)	$70,880
7	$109,328	$32,075	$77,253	$1,896	$7,298	$450	$(5,852)	$71,401
8	$110,749	$32,716	$78,033	$1,934	$7,590	$459	$(6,115)	$71,918
9	$112,189	$33,370	$78,819	$1,973	$7,893	$469	$(6,389)	$72,430
10	$113,647	$34,038	$79,610	$2,013	$8,209	$478	$(6,675)	$72,935
11	$115,125	$34,719	$80,406	$2,053	$8,538	$488	$(6,972)	$73,434
12	$116,622	$35,413	$81,209	$2,094	$8,879	$497	$(7,283)	$73,926
13	$118,138	$36,121	$82,016	$2,136	$9,234	$507	$(7,606)	$74,411
14	$119,673	$36,844	$82,830	$2,178	$9,604	$517	$(7,943)	$74,887
15	$121,229	$37,581	$83,649	$2,222	$9,988	$528	$(8,294)	$75,355
16	$122,805	$38,332	$84,473	$2,266	$10,387	$538	$(8,659)	$75,814
17	$124,402	$39,099	$85,303	$2,312	$10,803	$549	$(9,040)	$76,263
18	$126,019	$39,881	$86,138	$2,358	$11,235	$560	$(9,437)	$76,701
19	$127,657	$40,678	$86,979	$2,405	$11,684	$571	$(9,850)	$77,128
20	$129,317	$41,492	$87,825	$2,453	$12,152	$583	$(10,281)	$77,544

Years 1, 2, and 3 are known.
After year 3, estimates are shown based on the values shown in Table 2.

Table D2—Positive cash flow

Year	Heating season	General inflation	Fossil fuel cost escalation	Wood boiler O & M cost escalation	Wood fuel cost escalation	Fuel oil consumption reduction	Real discount rate
1	2003–04	2.0%	—	4.0%	—	—	—
2	2004–05	—	1.3%	—	2.0%	—	—
3	2005–06	—	—	—	—	99%	8.0%

Appendix E–Alternative Project #2

In this alternative, the oldest (1964) boiler was removed from service, the existing mechanical systems were upgraded, and the elementary school was connected to one of the other boilers. This system was compared to the new wood heating system.

Before-tax net present value: $115,000

Table E1—Fuel oil and wood heat systems compared

Year	Fuel oil system costs	Wood fuel cost	Annual fuel cost savings	Fuel oil O & M costs	Wood fuel O & M costs	Wood fuel fixed costs	Annual O & M cost savings	Before-tax U.S. dollars
0	$ 369,000	$ 900,000	—	—	—	—	—	$ (531,000)
1	$51,884	$ 29,437	$ 22,447	$ 1,684	$ 4,892	$400	$(3,608)	$ 18,839
2	$88,060	$ 29,051	$ 59,009	$ 1,718	$ 5,998	$408	$(4,689)	$ 54,320
3	$ 104,720	$ 29,632	$ 75,088	$ 1,752	$ 6,238	$416	$(4,902)	$ 70,186
4	$ 106,081	$ 30,225	$ 75,857	$ 1,787	$ 6,488	$424	$(5,125)	$ 70,731
5	$ 107,460	$ 30,829	$ 76,631	$ 1,823	$ 6,747	$433	$(5,358)	$ 71,274
6	$ 108,857	$ 31,446	$ 77,412	$ 1,859	$ 7,017	$442	$(5,600)	$ 71,812
7	$ 110,273	$ 32,075	$ 78,198	$ 1,896	$ 7,298	$450	$(5,852)	$ 72,346
8	$ 111,706	$ 32,716	$ 78,990	$ 1,934	$ 7,590	$459	$(6,115)	$ 72,875
9	$ 113,158	$ 33,370	$ 79,788	$ 1,973	$ 7,893	$469	$(6,389)	$ 73,399
10	$ 114,629	$ 34,038	$ 80,591	$ 2,013	$ 8,209	$478	$(6,675)	$ 73,917
11	$ 116,120	$ 34,719	$ 81,401	$ 2,053	$ 8,538	$488	$(6,972)	$ 74,428
12	$ 117,629	$ 35,413	$ 82,216	$ 2,094	$ 8,879	$497	$(7,283)	$ 74,933
13	$ 119,158	$ 36,121	$ 83,037	$ 2,136	$ 9,234	$507	$(7,606)	$ 75,431
14	$ 120,707	$ 36,844	$ 83,864	$ 2,178	$ 9,604	$517	$(7,943)	$ 75,921
15	$ 122,276	$ 37,581	$ 84,696	$ 2,222	$ 9,988	$528	$(8,294)	$ 76,402
16	$ 123,866	$ 38,332	$ 85,534	$ 2,266	$ 10,387	$538	$(8,659)	$ 76,875
17	$ 125,476	$ 39,099	$ 86,378	$ 2,312	$ 10,803	$549	$(9,040)	$ 77,337
18	$ 127,108	$ 39,881	$ 87,227	$ 2,358	$ 11,235	$560	$(9,437)	$ 77,790
19	$ 128,760	$ 40,678	$ 88,082	$ 2,405	$ 11,684	$571	$(9,850)	$ 78,231
20	$ 130,434	$ 41,492	$ 88,942	$ 2,453	$ 12,152	$583	$(10,281)	$ 78,661

Years 1, 2, and 3 are known.
After year 3, estimates are shown based on the values shown in Table 2.

Table E2—Positive cash flow

Year	Heating season	General inflation	Fossil fuel cost escalation	Wood boiler O & M cost escalation	Wood fuel cost escalation	Fuel oil consumption reduction	Real discount rate
1	2003–04	2.0%	—	4.0%	—	—	—
2	2004–05	—	1.3%	—	2.0%	—	—
3	2005–06	—	—	—	—	99%	8.0%