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Converting Small Industrial Boilers to Burn Wood Fuels

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Abstract

Investigates the engineering and economic feasibility of retrofitting two small industrial boilers (32 hp and 52 hp, respectively) for firing green wood fuels. Subjects covered include fuel requirements and costs; availability, storage, and handling of wood fuels; and designs, specifications, stack emissions, cost estimates, and economic feasibility. The economics of boiler conversion projects are heavily dependent on annual savings in fuel costs. Analyses of variables affecting annual fuel savings determined that the boiler utilization rate (BUR) and the price of fuel oil had the greatest impact on the economic feasibility of this project.

Introduction

Interest in the use of wood fuels to replace ever more costly oil and gas continues to increase. More companies are installing new wood-burning boilers or converting old ones to burn wood. Conventional technology is available to serve these needs. Usually, the decision to convert to wood is an economic one, and the economics of switching to wood become more favorable as the price of fossil fuels continues to increase.

Today, nearly all wood-fired boiler installations serve forest-industry plants that generate their own wood wastes. However, we are beginning to see wood-fired boiler installations in other industries, e.g., textiles, power stations, brick plants, greenhouses, tanneries, and institutions such as the Waterbury (Vt.) State Hospital and the Northwest Regional Hospital, Rome, Georgia.

We attempted to convert two small industrial boilers at the Forestry Sciences Laboratory, Princeton, West Virginia. Both were designed and built to burn coal. Our objectives were to determine the engineering and economic feasibility of firing both boilers with green sawdust and wood chips.

Boiler Description and Evaluation

The smaller of the two boilers is a Spencer^{1,2} low-pressure, hot water steel boiler that provides space heating for laboratory offices. It was fired with stoker coal for several

years in the 1960's, but then was retrofitted with a propane burner.

The firebox was not large enough to install an underfeed, single-retort stoker and grate. Further, the insufficient clearance would not allow a good flow of the combustion gases and proper heat transfer to the boiler. The latter condition would result in a stress build-up in the boiler jacket, weakening it and shortening its life. For these reasons, we did not retrofit the Spencer boiler. However, should manufacturers build smaller stokers for firing wood fuels, conversion of the Spencer boiler could be reconsidered.

The second boiler is a sectional cast iron unit manufactured by American Standard.³ It provides both hot water and low-pressure steam for heating our pilot testing plant. This unit was designed to burn coal but was converted to oil when installed.

There was sufficient clearance (28 inches) between the built-up hearth and the top of the cast iron furnace arch. This height allows the installation of a standard stoker and grate and provides a good flow of hot gases to the boiler surfaces.

Since the firebox construction and size was adequate for installing a stoker and firing green wood, we decided to retrofit the American Standard boiler. However, the boiler's net rating had to be reduced. This derating resulted from firing green wood in a firebox sized and designed to burn coal. Elliott (1980) explained why firebox characteristics and the burning of green wood fuels result in derating of boiler capacity:

"Three unique characteristics of wood combustion must be accounted for in furnace design: First, the high moisture content of

green wood fuels causes large volumes of superheated steam to be evolved in the firebox and this depresses the combustion temperature; second, depending on fuel quality, large amounts of excess air are required for combustion; third, residence time in the firebox must be sufficient to allow combustion of volatiles and entrained particles. Therefore, the firebox must be large enough to maintain reasonable gas velocities and must contain significant refractory material to sustain the temperature of the fire when wet fuel is used."

Boiler derating can be a crucial factor when converting to green wood fuel. Where boiler capacity is critical to meeting current steam needs, newly retrofitted boilers should be equipped with an oil or gas burner to provide full steam capacity when needed. Wood then becomes the base-load fuel with occasional peak demands supplied by firing the auxiliary burner. In our case, the American Standard boiler is oversized for our needs and is equipped with an oil burner, so derating can be tolerated.

Fuel Requirements and Costs

In 1979 the American Standard boiler consumed 12,496 gallons of No. 2 fuel oil. Our oil bill, at an average price of \$0.62 per gallon, was \$7,747.

Using our oil consumption figure, we calculated our total energy needs and determined the equivalent quantity of wood fuel required. At an average heat value of 142,000 Btu per gallon, 12,496 gallons of fuel oil yield a total of 1.774×10^9 Btu. At a combustion efficiency of 80 percent, net energy input with oil was 1.419×10^9 Btu.

Bone-dry hardwood fuels yield an average of 17 million Btu per ton, but the moisture content in green fuels plus losses during combustion reduce heat yields substantially.

¹ The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

² Spencer type A (Series 3M-40, #6102-365), Spencer Heater Division, Avco Manufacturing Co., Williamsport, PA. Gross rating 1,440 pounds of steam per hour.

³ Model A-713-50(B) (Series 2B-J2 #97AH1LO 7658). Gross rating 2,304 pounds of steam per hour.

Green sawdust, which typically is half water, has a net energy yield of 5.525 million Btu per ton. Thus, the amount of sawdust required to meet our annual energy needs was 257 tons (1.419×10^9 Btu \div 5.525×10^6 Btu).

Considerable quantities of sawdust could be purchased from local sawmills in 1979 for \$7.50 per ton delivered. At this price, our estimated annual wood fuel cost totaled \$1,927, a reduction of \$5,820 from the \$7,747 paid for fuel oil; \$5,820 was our projected annual fuel savings.

Retrofit Design and Specifications

The underfeed stoker. Originally, the boiler was designed with open grates for the hand firing of lump coal. When installed it was modified by adding a second base to provide the proper setting and combustion space to burn fuel oil. For burning green sawdust and

wood chips, the engineer recommended installing an underfeed, single-retort stoker system. Small stokers of this type are available from two U.S. manufacturers and several overseas firms (Fig. 1).

To achieve maximum boiler output, green wood requires a larger firebox than is needed for coal or oil. However, enlarging the firebox was deemed impractical. Accordingly, the boiler's net output was reduced to approximately 30 hp, a 42 percent reduction from 52 hp obtainable when firing coal or oil.

With underfeed stokers, fuel is delivered to the grate from the fuel hopper by an auger powered by a motor-driven, variable-speed drive (Figs. 2-3). At its maximum speed (16 rpm), the auger will deliver 15.6 cubic feet of sawdust per hour to the grate. The Btu yield of this quantity of fuel (at 50 percent moisture content) produces 1,035 pounds of steam per hour (30 hp), the capacity of the derated boiler.

The grate, which is an assembly of perforated cast iron sections called tuyeres, is positioned on top of the wind box. Fuel on the grate is ignited by the oil burner maintained as a backup firing system. Automatic controls shut off the burner after the wood fire is hot enough to maintain combustion. Most of the combustion air is supplied to the grate as underfire air forced through the wind box and the tuyeres.

The forced air system. Because of the highly variable conditions associated with stoker-fed fuels, underfeed systems are less efficient than suspension or vortex combustion systems in achieving a good mixture of air and fuel in the firebox. To overcome this problem, our design features two forced-air systems: an underfire forced draft and an overfire swirling draft. The overfire draft is intended to create a turbulence over the grate for mixing air with the volatile gases and entrained fuel particles. In practice, not all of the oxygen combines with

Figure 1.—Industrial stoker of U.S. manufacture. (Photo by Will-Burt Co., Orrville, Ohio).

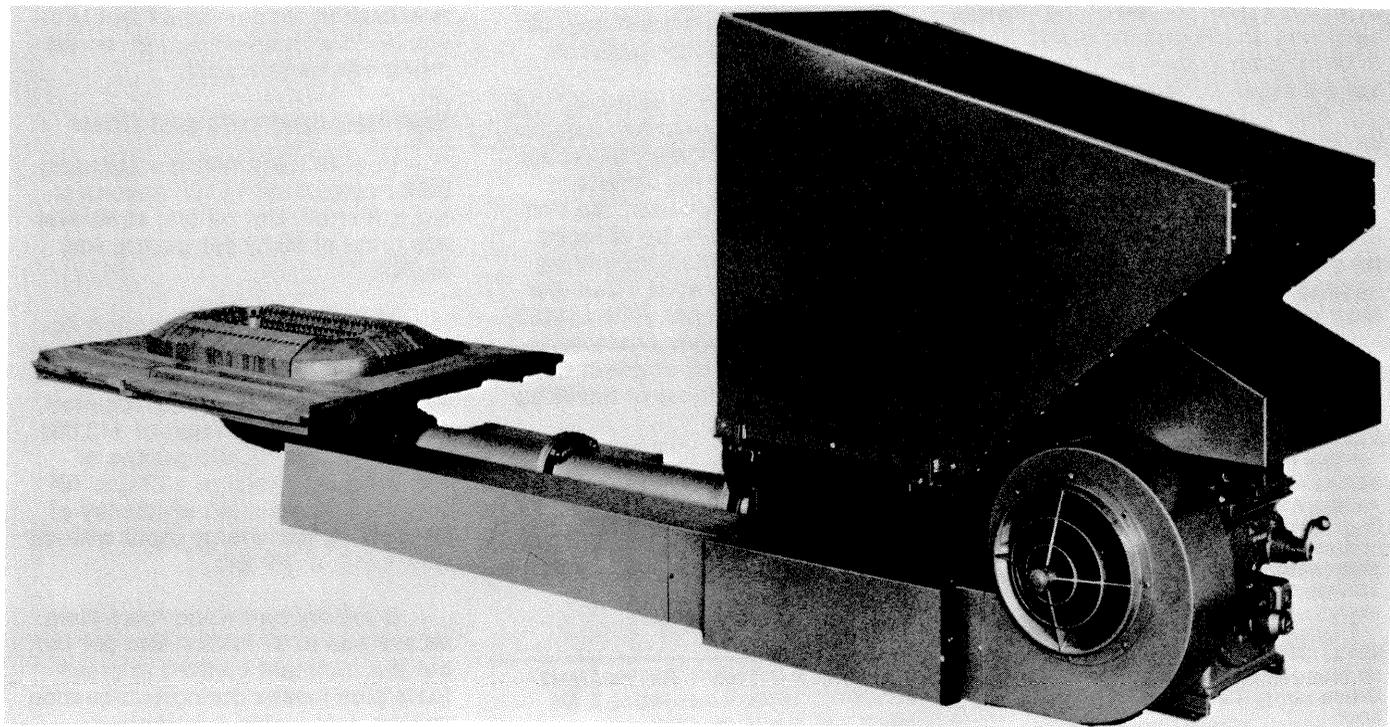


Figure 2.—Plan and sectional views of Will-Burt industrial stoker installed in American Standard A-7 boiler.

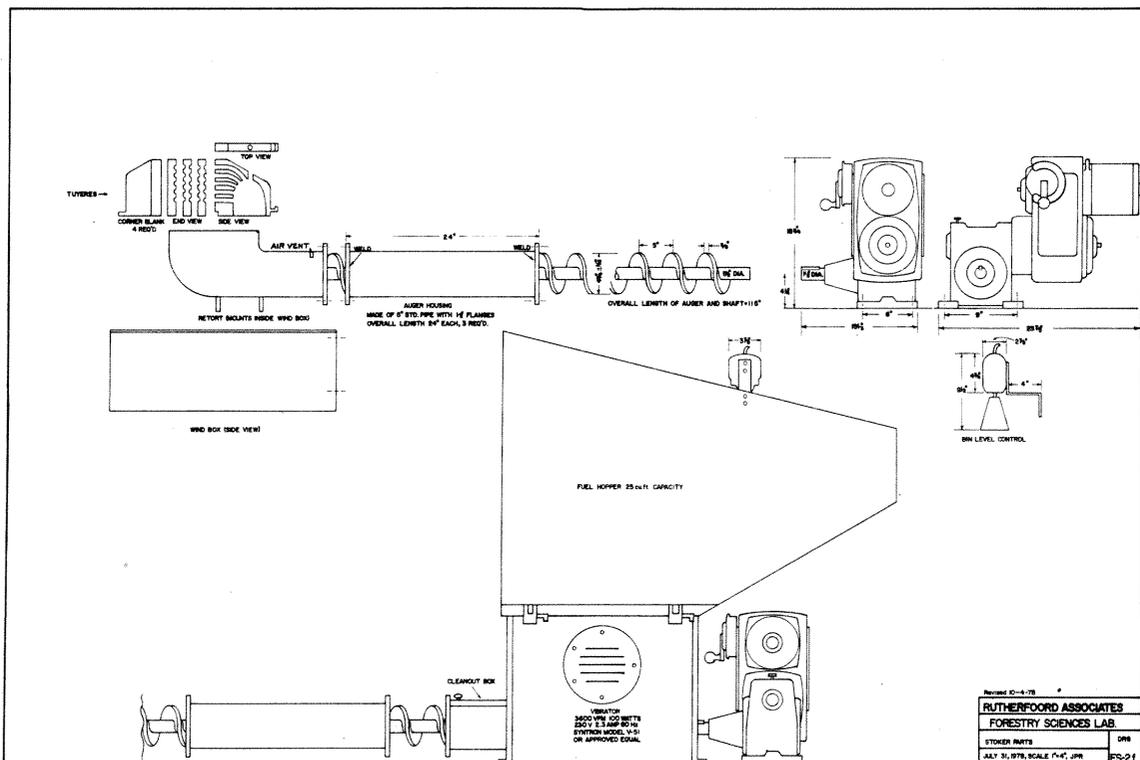
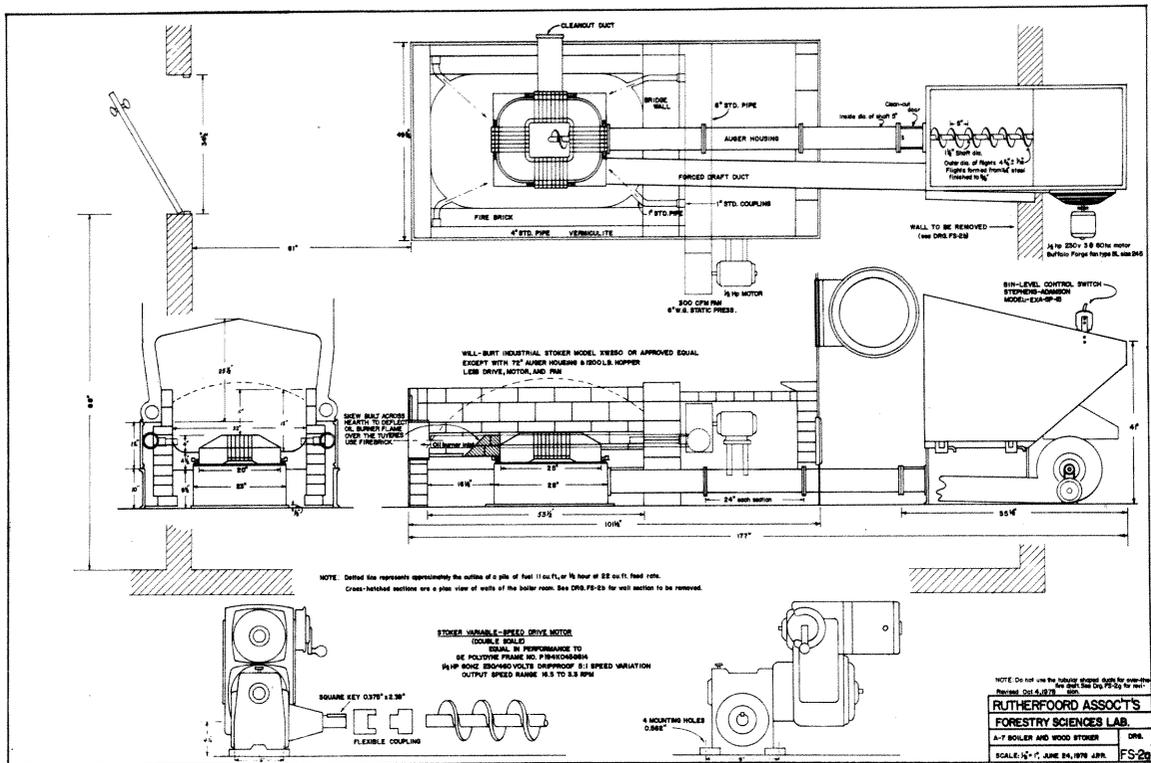


Figure 3.—Underfeed stoker fuel delivery parts: hopper, variable-speed drive, auger, auger housing, retort, and grate.

the carbon and hydrogen in the fuel during combustion. To obtain complete combustion, the air system was designed to supply excess air—in amounts of 150 percent or more of theoretical air—to allow for variability in fuel conditions, e.g., moisture content, particle sizes, and species of wood. Firing the boiler at full capacity with wet sawdust requires about 400 cubic feet of air per minute. Dampers in the air ducts allow adjustment of the quantity of air supplied to achieve optimum combustion. Proper adjustment of air reduces visible stack emissions to a minimum.

The underfire forced-draft system is part of the stoker and consists of wind box, air duct, fan, and drive motor. The overfire system consists of custom-fabricated ductwork fitted with four 1-inch air nozzles, and a direct-connected motor driving an industrial blower which supplies the air (Fig. 4).

Emissions control. Because the chemical makeup of wood is almost pure hydrocarbon, the stack pollutants of concern are mainly solid particulates. Sulfur is present only in very small amounts. The following shows the chemical makeup of coal and wood (on a dry-weight basis):

Item	Coal	Wood
	-- Percent --	
Carbon	75.5	52.0
Hydrogen	5.0	6.3
Oxygen	4.9	40.5
Nitrogen	1.2	0.1
Sulfur	3.1	0.01
Ash	10.3	1.0

Carbon monoxide may be emitted if there is insufficient air for complete combustion. However, this is unlikely unless the damper settings are tampered with as the air system is designed to supply extra excess air for complete combustion. Proper draft settings also will

control oxides of nitrogen well below toxic levels. Some of the excess nitrogen from draft air will be emitted from the stack as oxides of nitrogen, but most of it will leave the system uncombined.

Though it is commonly thought that the particulate in smoke is composed of fly ash, analysis shows that very little of the smoke from wood fires contains uncombustible ash. At least 50 percent of the ash residue remains in the combustion chamber or settles in the furnace flues. What we see in smoke is mostly unburned carbon which settles out as soot.

Environmental Protection Agency regulations allow a maximum of 0.6 pound of particulate matter per 1 million Btu of heat input when firing wood fuel. In our case, the maximum rate of heat input on the coldest of days could be 2.8 million Btu per hour for short intervals. At this

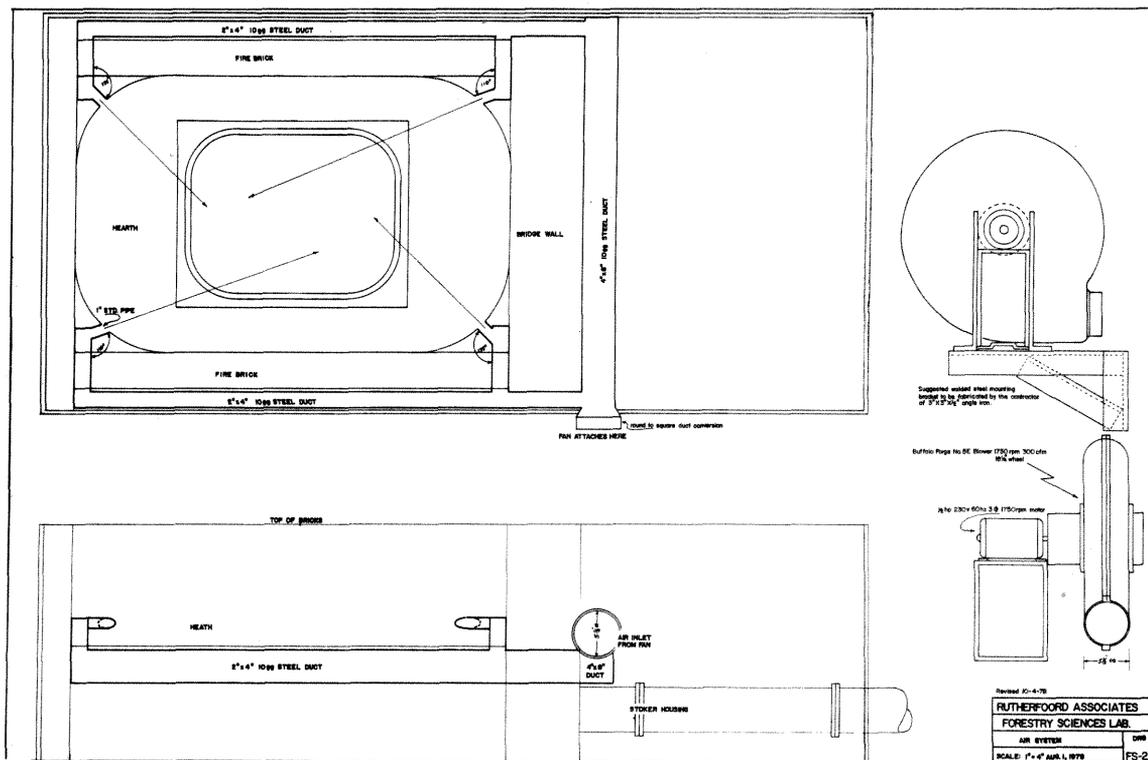


Figure 4.—Overfire forced-air system designed to produce a swirling draft for more complete combustion.

level of fuel consumption, the EPA allows 1.68 pounds of particulate matter per hour. Expressed as parts per million of emitted hot gases, EPA regulations allow particulate matter emissions of 560 parts by weight or 4.20 parts by volume. At this emission rate, a stationary wood-burning facility would not produce visible smoke.

These allowable limits are based on the boiler operating at 100 percent of rated capacity. But, as we determined, firing the boiler with wet sawdust reduces heat input from 2.8 to 1.6 million Btu per hour. At this level, we estimate that 0.96 pound of particulate matter will be emitted per hour, well below the allowable EPA maximum. However, it remains to be seen if emissions will be at this level under actual operating conditions. If fire conditions are less than optimum for complete combustion, and the boiler is in

noncompliance, a cyclone separator will be used to control emissions of solid matter.

Firing system controls. The electrically operated system controlling the boiler is fully automatic. It provides for two options: firing with stoker-fed wood fuels or fuel oil. The options are selected manually by operating a dipole switch. Firing with either fuel will produce enough Btu for sufficient steam and hot water to meet space heating needs of the plant during the coldest winter months.

Automatic controls for burning wood are more complex than the controls needed to burn fuel oil. When wood is burned, more operations must occur either simultaneously or, more critically, sequentially. For example, with a cold startup, ignition of wood fuel depends on the oil burner igniting, burning for a period of time, and then shutting off

when combustion of the wood is well advanced. Simultaneously, the draft system (underfire and overfire air) and the induced-draft stack fan must start up. As wood fuel is consumed, the stoker auger is activated to feed more fuel to the grate. It shuts off automatically when enough fuel is loaded on the grate. Should the stoker auger jam, or for any reason fail to deliver fuel to the grate, the oil burner ignites automatically and takes over as the back-up source of heat to operate the boiler.

Fuel storage and handling. A complete fuel-handling system was designed to handle sawdust and whole-tree chips. Fuels will arrive by truck and be dumped into a concrete pit fitted with a vibratory screen (Fig. 5). Screening separates oversized pieces and trash from particles passing through the 1-inch holes. The latter are sucked up and blown into the top of a 3,000-cubic-

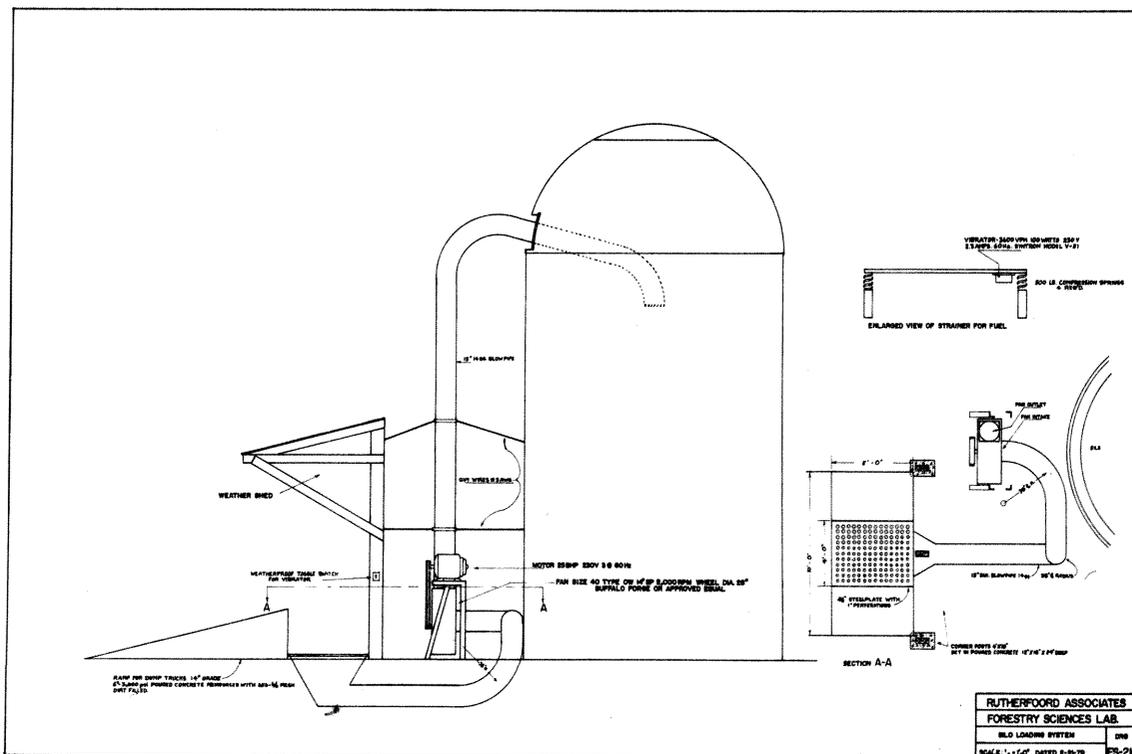


Figure 5.—Sawdust receiving dump pit, vibratory screen, and silo loading system.

foot silo calculated to hold sufficient fuel for 10 days during the coldest weather (Fig. 6). Collected trash will be disposed of; oversized pieces will be collected and fed manually into the boiler firebox as needed.

Movement of fuel from the silo to the stoker hopper is controlled by the bin-level switch mounted on the hopper. The hopper is equipped with an electric vibrator to break up compacted fuel in the hopper. As the fuel level in the hopper drops, the switch activates electric motors that drive augers in the silo and the screw conveyor. These, in turn, deliver fuel to the hopper. When the hopper is full, the control switch shuts off the auger motors. Barring equipment breakdowns, jamming of the augers, or power failure, fuel is conveyed automatically to the boiler house as needed.

Boiler Utilization Rate

An important variable in the operation and evaluation of a boiler is how much it is used and how hard it is used. Usage, expressed in percent, is termed the boiler utilization rate (BUR). It is a product of several factors: fuel consumption, fuel energy value, boiler efficiency, boiler rating, and hours of operation per year. Our American Standard boiler is started up in the fall and shut down about June 10; annual hours of scheduled operation total 6,072. In practice, office and working spaces are heated only 40 hours a week, and thermostats are set back at night and on weekends. As a result, our average annual BUR is only 10 percent. Our estimate of the average annual BUR for the wood-fired boiler, operating on the same schedule, is 15 percent. Compared with industrial plants, these are low rates;

however, they may be similar to rates for boilers in public institutions, for example, schools. The BUR has an important bearing on the economics of converting a boiler to wood fuels (Figs. 7-8).

Conversion Costs and Economic Feasibility

In 1979, our cost estimate for converting the boiler to wood fuels, in accordance with the engineer's design and specifications, was \$65,500.⁴ This estimate was developed from contractors' bids for equipment and services, plus estimates of equipment purchased by the USDA Forest Service and services provided by our own crew:

⁴ Rutherford Associates, Marion, VA.

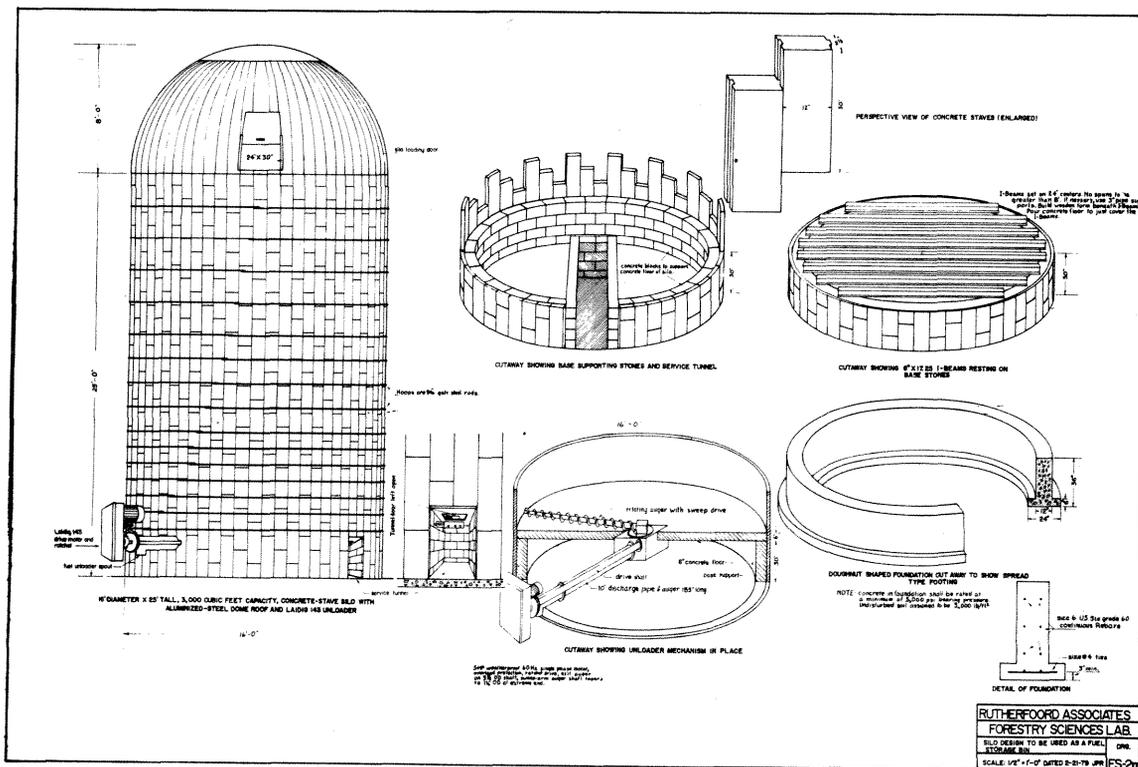


Figure 6.—Fuel storage silo with concrete foundation, unloading mechanism, and concrete stave construction.

Item	Cost (Dollars)
1. Rebuild boiler firebox; install underfeed stoker complete with hopper, auger feed, retort, grates, variable-speed drive, etc.; install new oil burner; fabricate new forced-air system; provide all controls and electric service for full automatic operation. Turnkey job by mechanical contractor.	33,500
2. Concrete stove silo (3,000 cubic feet) complete with unloading auger, delivered and erected in place on foundation built by owner.	23,500
3. Fuel receiving facility, boiler room addition, and 24-foot screw conveyor; construction by owner.	8,500
Total	65,500

To determine the economic feasibility of this investment, we used The New England Regional Commission's "Wood Conversion Economic Model, WOOD II" (Ewing and Cody 1980). The model provides: (1) annual fuel costs for oil and wood-fueled boiler systems, (2) annual net cash flows over the life of a proposed wood replacement system, and (3) economic indexes including net present value (NPV), internal rate of return (IRR), and years to pay back (YPB).

Figure 7.—Effect of the boiler utilization rate and year of investment on net present value of boiler conversions in 1979, 1981, and 1983.

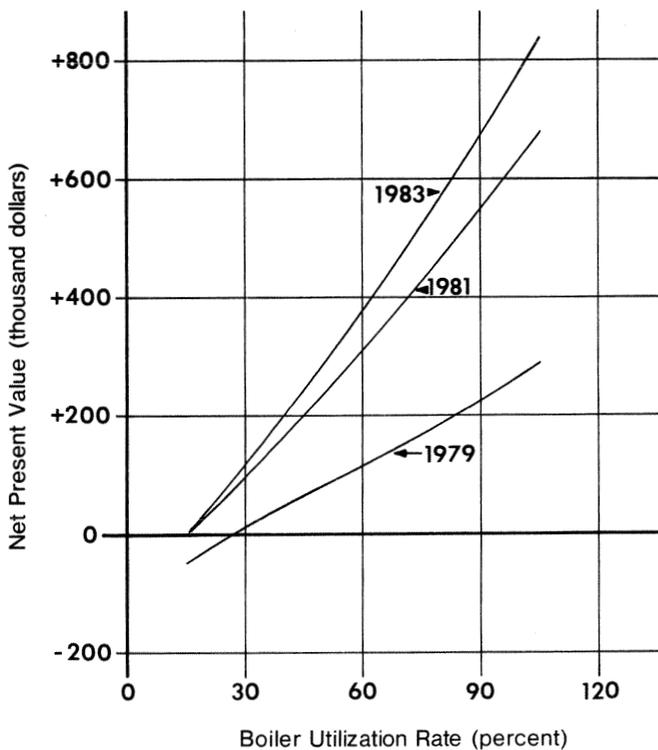
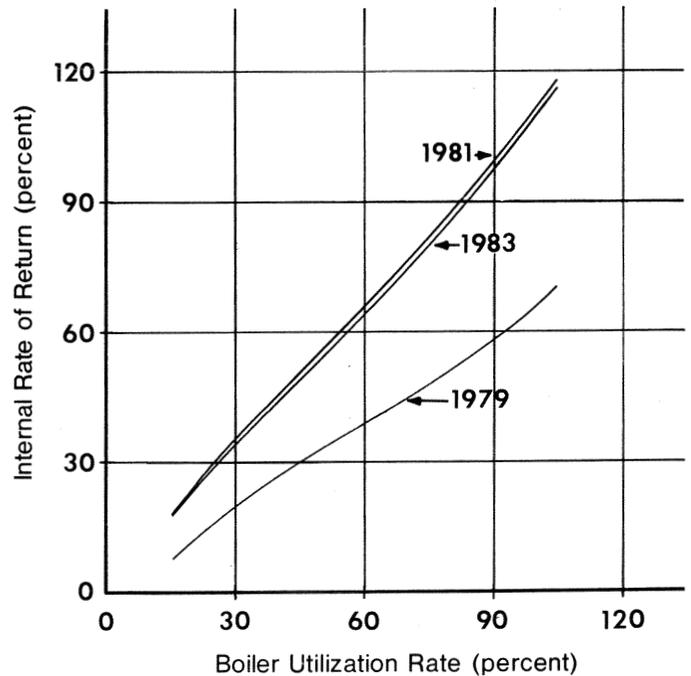


Figure 8.—Effect of boiler utilization rate and year of investment on internal rate of return of boiler conversions in 1979, 1981, and 1983.



The model uses 32 variables which describe the existing and proposed boiler systems, operation and maintenance costs, fuel characteristics and prices, inflation rates, taxes, tax credits, and financing terms. Federal and state tax rates and tax credits do not apply to our situation, or to other tax exempt institutions, hence zero values were assigned to these variables. Data for other variables were either known (e.g., boiler rating, fuel oil grade) or were calculated, estimated, or assumed:

A key feature of WOOD II is its ability to assess the impact of changes in any of the variables. Groups of variables can be changed, or individual variables can be varied systematically over a range of values. We found these characteristics of the model to be useful in exploring the range of economic feasibility for different years.

Applying the model to our basic data set (which includes a discount rate of 20 percent), we determined that the investment to con-

vert the boiler to wood was not economically viable. Actual annual savings in fuel costs were not sufficient to generate a positive net present value (NPV) over the project's 20-year life.

We then tested several of the variables to determine their effect on economic outcomes. The variables selected were those that either the boiler designer, user, or passing of time could change. For example, we ranged values for wood boiler efficiency from 50 to 75 percent and wood fuel moisture content from zero to 60 percent. In a similar manner, we tested a range of values for annual hours of boiler operation, average annual boiler utilization rate, price of oil, price of wood, amount of equity capital, and capital cost. In only three cases did the change of variables result in positive outcomes: Increasing the price of oil to \$1.00 per gallon resulted in an NPV of \$3,816 and an IRR of 19 percent; doubling the average boiler utilization rate to 30 percent gave an NPV of \$14,638 and an IRR of 21 percent; decreasing capital cost to \$18,000 resulted in an NPV of \$941 and an IRR of 21 percent.

Two of these three positive outcomes, that is, those due to increases in oil price and boiler utilization rate, represented realistic options. Since higher oil prices are almost a certainty, one could justify an investment in boiler conversion on the basis of anticipated increases to \$1.00 or more per gallon. Similarly, increasing the BUR through planning for use of more steam and hot water, for example, additional space heating, cooling, and drying, also could justify the investment. The third option, decreasing the capital cost to \$18,000, was not viable because the conversion job could not be done for that price.

<i>Variable</i>	<i>Oil</i>	<i>Wood</i>
Pounds of steam/hour	2,304	1,565 ^a
Annual operating hours	6,072	6,072
Average utilization (%)	10.15 ^a	14.94 ^a
Boiler efficiency (%)	80 ^b	65 ^b
Btu/pound of steam	1,000	1,000
Cost/gallon (dollars)	0.62 ^c	—
Cost/ton (dollars)	—	7.50
Dry wood energy (million Btu)	—	17
Moisture content, wet basis (%)	—	50
Annual operation and maintenance cost (dollars)	1,000 ^d	5,000 ^d
Operation and maintenance inflation rate (%)	10 ^b	10 ^b
Inflation rate (%)	10 ^b	5 ^b
Tax rate (%)		
Federal		0
State		0
Tax credit (%)		
Federal		0
State		0
Depreciation period (years)		NA
Depreciation method		NA
Loan period (years)		10 ^b
Loan interest rate (%)		12 ^b
Equity capital (dollars)		22,000 ^b
Capital cost (dollars)		65,500 ^d
Operating life (years)		20 ^b
Discount rate (%)		20 ^b

^a Calculated.

^b Assumed.

^c No. 2 oil.

^d Estimated.

Analyses for 1981 and 1983.
Knowing the effect of oil price increases, we analyzed the economic feasibility of boiler conversion for the years 1981 and 1983. To correct the data set for increased prices

Table 1.—Values for six cost items increased to reflect changing economic conditions in 1981 and 1983

Variable	1979 base case	1981 scenario	1983 scenario
	----- Dollars -----		
Cost of oil/gallon	0.62	1.20	1.46
Cost of wood/ton	7.50	8.25	9.10
Annual operation and maintenance cost			
Oil	1,000	1,210	1,464
Wood	5,000	6,050	7,321
Capital cost	65,500	82,000	103,000
Equity capital	22,000	28,000	34,000

and costs, we changed six variables: price of oil and wood, operation and maintenance costs, capital cost, and amount of equity (Table 1). The 1981 oil price was obtained from our purchase records. Other oil and wood prices and operation and maintenance costs were increased in accordance with stated inflation rates. Capital cost was increased by approximately 25 percent for each 2-year period, and equity capital was maintained at approximately one-third of capital cost.

Our analysis showed that an investment in boiler conversion in 1981 and 1983 would be economically feasible, given the changes in fuel prices and other costs as stated. Net present values for both years were \$2,510 and \$2,428, respectively. The IRR was 18 percent in both instances. The effect of BUR and year of investment on NPV and IRR of boiler conversions are shown in Figures 7 and 8.

A small tax paying business: To this point our analysis has examined conversion of a small boiler owned and operated by a public agency. We might ask what the results would be if the boiler were privately owned and operated by a small corporation. We examined this possibility for the same set of years: 1979, 1981, and 1983. However, to

correct the data for a tax paying business, we changed seven variables in the basic data set: taxes, tax credits, depreciation period and method, and interest rate.

Variable	Tax exempt institution	Tax paying corporation
Federal tax rate (%)	0	17.5
Federal tax credit (%)	0	20.0
West Virginia tax rate (%)	0	4.0
West Virginia tax credit (%)	0	0
Depreciation period (years)	NA	10
Depreciation method	NA	straight line
Loan interest rate (%)	12	18

Federal tax rate and loan interest were based on assumptions that the corporation's annual taxable income was \$30,000, and that the interest rate was higher.

Surprisingly, these changes did not change the outcome of the 1979 analysis as much as might be expected. For that year, the NPV was negative and IRR was only 8 percent. Thus, as in the case of the tax exempt institution, the boiler conversion was not economically feasible for 1979. However, the scenarios for 1981 and 1983 were economically feasible. In both cases, NPV's were positive—\$5,124 and \$5,848, respectively; IRR's were 19 percent.

The effects of BUR on NPV and IRR were similar to those for the tax exempt cases.

Conclusions

Equipment and technology are available to retrofit small industrial coal-fired boilers for automatic firing of wood fuels. However, limitations of firebox size and construction can affect wood combustion efficiency and heat release to the extent that derating of the boiler may be required.

Conversions of boilers to wood fuels are technically feasible, but

may not be economically feasible. Economic feasibility depends to an extent on savings achieved in annual fuel cost. Given the owner's expected rate of return for capital, these savings dictate how much capital can be prudently invested in a boiler conversion project.

Our analyses showed that the price of oil and the BUR had the greatest impact on the project's economic feasibility, and that the project's feasibility was approximately similar for tax exempt and tax paying organizations.

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Keywords: Wood residues; boiler retrofitting; emissions control; economic feasibility

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