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Near Term Potential of Wood as a Fuel

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SUMMARY

The nation could save a significant quantity of oil and natural gas by increasing the industrial use of wood fuel. The forest products industry is considered a principal candidate for such expansion because it

- has a large annual energy requirement;
- has access to wood-fuel; and
- possesses the expertise and technology required to use wood-fuel.

The forest products industry purchased 1.3 quads of oil and natural gas during 1974. About 80 percent of this was used in the pulp and paper sector. The industry is approximately 40 percent energy self-sufficient and uses 1.1 quads of wood-fuel annually.

Sufficient additional wood-fuel is potentially available in the near-term to replace all of the oil and natural gas used annually by the forest products industry at a cost of $0.75 to $1.50/MMBtu ($4.50-$9.00/bbl crude oil, 1976 dollars). This wood is available from several sources which include:

- 17 quads of "non-commercial timber" growing on commercial forest land;
- 2.0 quads of forestry residues, annually;
- 1.7 quads of surplus annual growth; and
- 0.5 quad of mill residue, annually.

Technologies which are available to expand the near-term use of wood-fuel include direct combustion, low-Btu gasification, pyrolysis

and densification. Life-cycle costs were estimated for all of these technologies except densification and results are summarized in Table S-1. These costs can be compared with recent representative industrial fuel oil prices of $2.20/MMBtu and natural gas prices of $2.00/MMBtu.*

The direct combustion of wood-fuel is probably the best overall option for the forest products industry. Different opinions exist regarding certain technical and financial considerations associated with the production of low-Btu gas (LBG). However, a detailed engineering analysis of low-Btu gasification was beyond the scope of this study. A thorough assessment of LBG, therefore, should be performed to determine the potential of low-Btu gasification for large-scale industrial applications such as pulp mills.

Incentives for users could accelerate penetration of existing markets. Several possible incentives which could be used to expand the use of wood-fuels in the near-term are described in this report. The concept of an early retirement tax credit for existing oil and gas fired boilers is discussed. The impacts of a retirement tax credit and an investment tax credit were estimated.

The 1985 use of wood as a fuel might be expanded by about 0.4 quad above anticipated growth with a retirement tax credit of less than 1 billion dollars. This is equivalent to a replacement cost of

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*Intrastate gas. A representative industrial price for interstate gas is $1.40.

TABLE S-I

ESTIMATED "PLANT-GATE" SELLING PRICES FOR ENERGY PRODUCTS AVAILABLE FROM WOOD IN THE NEAR-TERM[1]

PRODUCT (TECHNOLOGY)	PLANT SIZE (ODT/D)[2]	PRODUCT COST ($/MMBTU)[3]
Process Steam	170	4.00
(Combustion)	850	2.70
Low-Btu Gas (LBG)	170	3.80
(Gasification)	850	2.70
Charcoal	850	4.90
Charcoal/Steam Credit	850	2.10
(Pyrolysis)		
Char, LBG, Fuel Oil	140	2.50
(Pyrolysis)	580	2.00
Fuel Pellets		
(Densification)	300	2.00

[1] See text for assumptions, important considerations and data sources.

[2] Oven dry tons of wood-fuel per day.

[3] Assumes feedstock cost of $1.00/MMBtu.

about $14.50/bbl or $2.50/MMBtu for imported crude oil. A similar expansion would cost about 2 billion dollars ($29.00/bbl oil) using an investment tax credit.

INTRODUCTION

Many of the advanced coal, solar and other technologies which could reduce the nation's reliance on petroleum-based energy sources are still in various stages of technological development. Others are not yet sufficiently cost-competitive with conventional energy systems to encourage their use. Systems such as those which produce alcohol fuels, substitute natural gas, fuel oil and nitrogen fertilizers from biomass and coal will probably gain rapid acceptance as they are improved and demonstrated. Unpredictable, diminishing petroleum supplies and increasing petroleum costs will also encourage acceptance of these alternative technologies. In the meantime, the nation could decrease its reliance on petroleum by increasing the use of available alternative fuels and conversion technologies in appropriate demand sectors. Suitable demand sectors should meet the following three criteria: They should

- have a significant energy need which could be jeopardized by increasing oil/gas prices and unreliable oil/gas supplies;
- have access to an alternative supply of fuel large enough to meet their demand; and
- possess the technological expertise and equipment required to convert the fuel to a usable energy form.

The forest products industry is illustrative of a suitable demand sector. Pulp/paper and wood products (lumber, plywood/veneer and building board) installations purchased 1.8 quads of energy in 1974. A total of 1.3 quads were in the form of oil and natural gas (Table I).

TABLE I

FUEL AND ELECTRICITY PURCHASED BY THE FOREST PRODUCTS INDUSTRY IN 1974

	PULP/PAPER	WOOD PRODUCTS (10^{15} Btu-Quads)	TOTAL
Fuel Oil	0.54	0.18	0.72
Natural Gas	0.51	0.08	0.59
Coal	0.29	0.01	0.30
Electricity	0.12	0.05	0.17
TOTAL	1.46	0.32	1.78

SOURCE: D. C. Junge, "Energy Alternatives for the Forest Products Industry," In: Wood Residue as an Energy Source, Forest Products Research Society, Madison, Wisconsin, 1976.

This was more than 2 percent of the nation's total use of coal, petroleum, natural gas, and hydro and nuclear power.

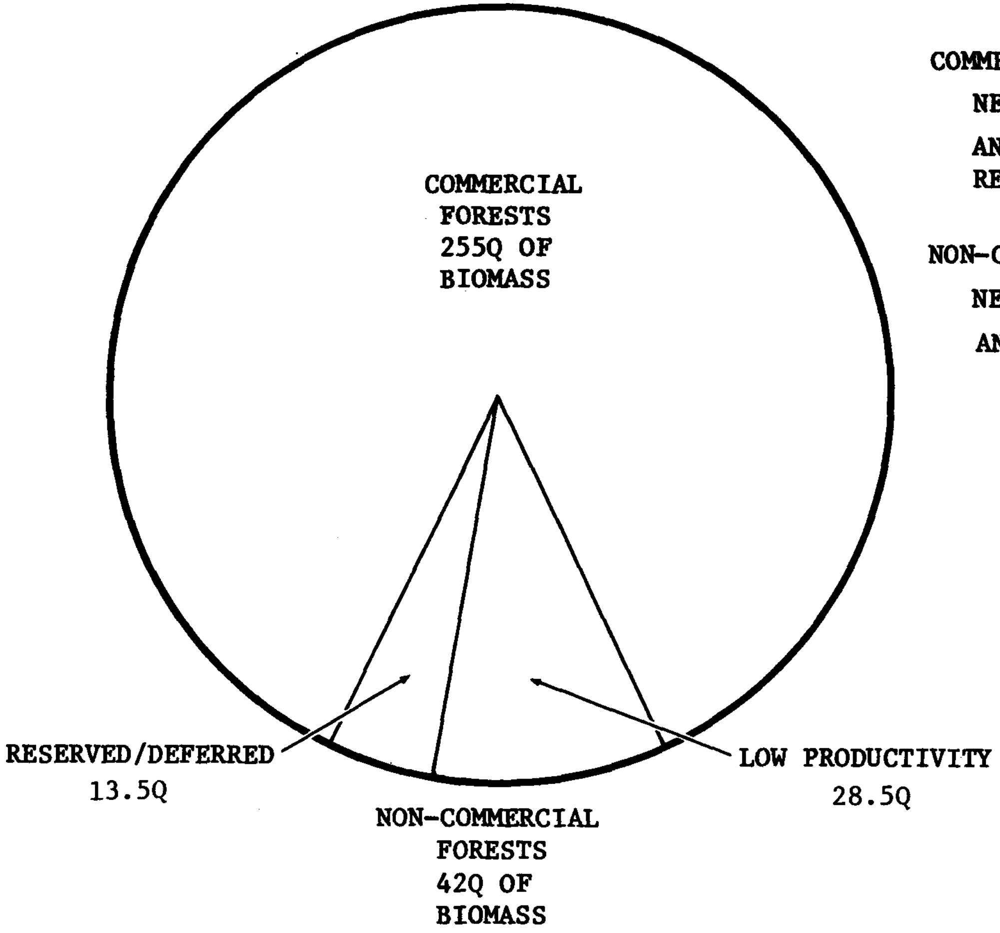
Nearly three-fourths of the forest products industry's fuel purchases are fuel oil and natural gas, one-sixth are coal and 10 percent are electricity. In addition to these purchases, the industry produces a considerable amount of its own energy from mill residues and process wastes. It has been estimated that energy self-sufficiency within the forest products industry is about 40 percent for pulp/paper mills, 20 to 40 percent for sawmills and 50 percent for plywood/veneer mills. The industry, therefore, uses about 3 quads of fuel annually and has been purchasing about 50 percent of this total in recent years. Nearly three-fourths of the self-generated fuel is produced from process wastes, principally pulping liquor. The remainder is wood and bark. Most of the fuel is burned to produce process heat and steam.

POTENTIAL WOOD-FUEL AVAILABILITY IN THE NEAR-TERM

Wood is available from existing near-term sources to increase energy self-sufficiency in the forest products industry. The energy equivalent of the nation's standing forest resources is approximately 300 quads (Figure 1). Commercial forests constitute 85 percent of this total. The distribution and ownership pattern of the forest resource is presented in Figure 2. Most of the noncommercial forests and national forests are located in the west. The forest products industry has relatively large holdings in the west, but most of the privately owned resource is controlled by individuals and miscellaneous private concerns.

The net annual growth of wood on commercial forest land is approximately 7 quads. The disposition of annual growth and salvaged wood is summarized in Figure 3. Approximately one-fourth of this wood is converted into primary forest products. The remainder is used as fuel or not used at all. The unutilized wood, which includes unused forestry/mill residues and surplus growth, together with the large inventory of "noncommercial timber" consisting of small or defective living trees and salvable dead trees, are potential sources of fuel-fiber.

The largest of these resources is the nation's inventory of "noncommercial timber." The U.S. Forest Service has estimated that this reservoir includes the equivalent of about 1-billion dry tons or at least 17 quads of wood-fuel. About one-fifth of this total

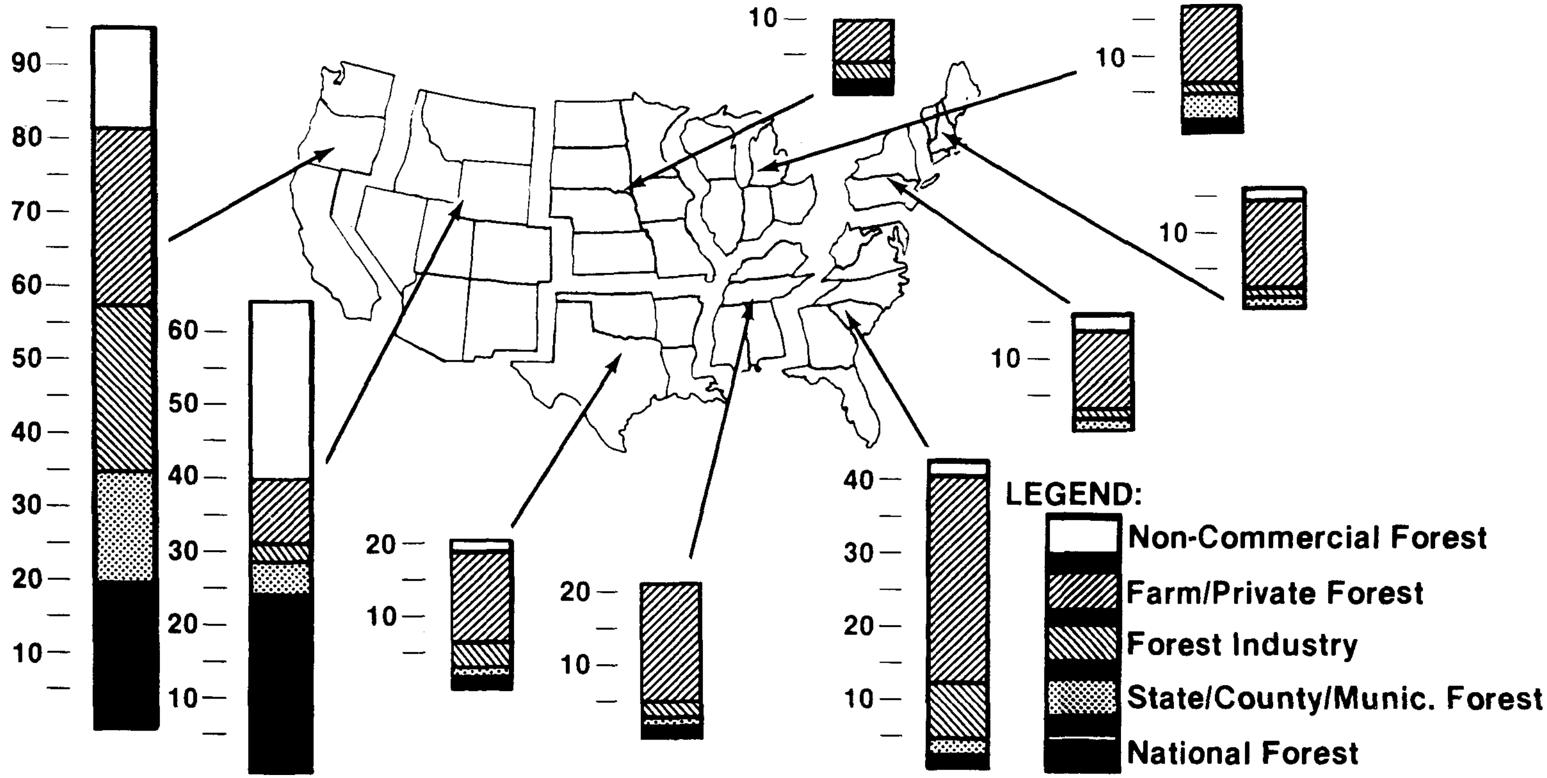


COMMERCIAL FORESTS
NET ANNUAL GROWTH 7Q
ANNUAL MERCHANTABLE REMOVALS 4Q

NON-COMMERCIAL FORESTS
NET ANNUAL GROWTH 0.7Q
ANNUAL REMOVALS 0.1Q

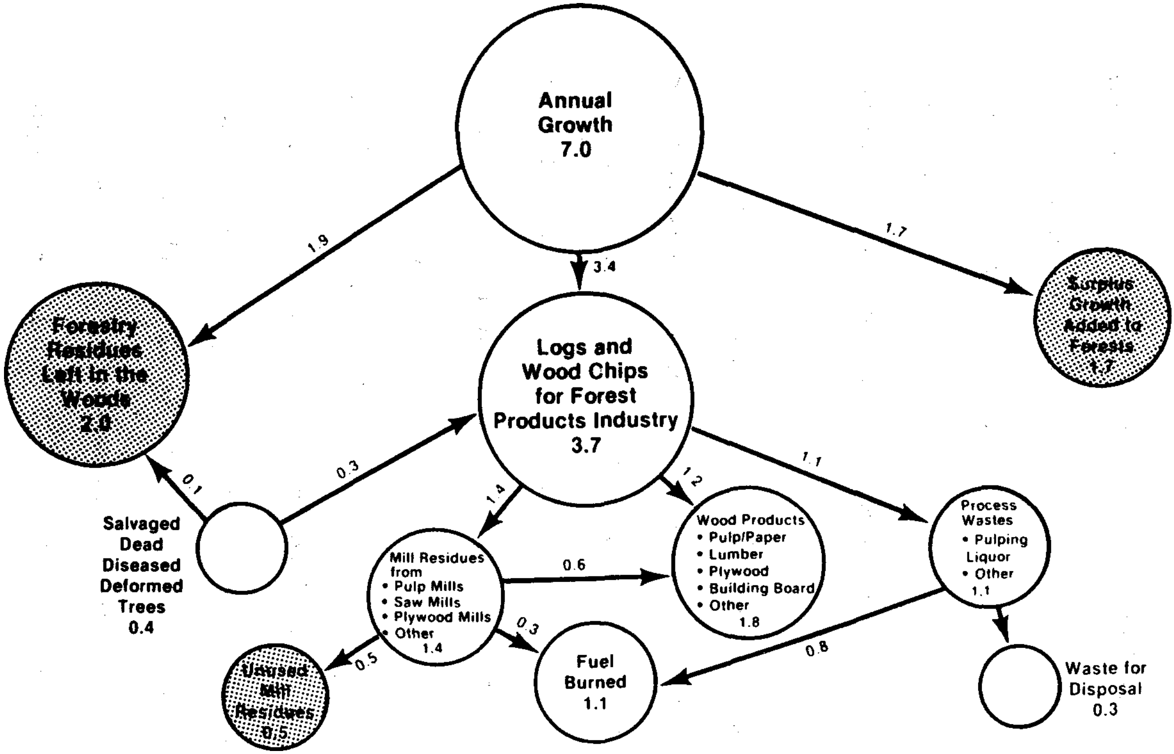
CALCULATED FROM: Outlook for Timber in the United States, USDA/USFS, 1974.

FIGURE 1
STATUS OF STANDING FORESTS IN THE UNITED STATES,1970



Source: Calculated from "Outlook for Timber in the United States," USDA/USFS, 1974.

FIGURE 2
DISTRIBUTION OF THE STANDING FOREST RESOURCE – QUADS BY REGION



- Total Annual Above-Ground Production on Commercial Timberland is 7.0 Quads
- Total Annual Salvage from Commercial Timberland is 0.4 Quad
- Total Annual Above-Ground Production of Noncommercial Timberland is 0.7 Quad; Very Little is Harvested
- Total Annual Production and Salvage from U.S. Timberlands is 8.1 Quads

FIGURE 3

Disposition of Forest Biomass

(Annual Growth and Salvage—Quads)

consists of salvable dead trees, nearly all of which are located in the western U.S. Two-thirds of the total includes cull hardwood trees which are more common in the east. The remainder consists of cull softwoods which are evenly divided between the east and west.

The wood which can be effectively harvested/collected from this reservoir could contribute substantially to the nation's near-term energy supplies while other sources of biomass such as energy farms are developed. Furthermore, the proper harvest and subsequent restocking of underutilized forest land could result in improved commercial timber yields in the future.

Annually renewable wood resources which could contribute to near-term fuel supplies include mill residues, forestry residues and surplus merchantable growth (Figure 3). For example, approximately one-half quad of mill residue remains unused each year. Essentially none of the 2 quads of forestry residue generated annually is presently used. Merchantable timber growth still exceeds removals by nearly 1 quad annually but will decrease to about 0.4 quad by 1990.

Some of this fiber will be used to produce forest products, some would be difficult, expensive or unwise to collect. Nevertheless, it is unlikely that the resource base would limit the expanded use of wood fuels in the near-term. Enough wood-fuel is probably available at a cost of $0.75 to $1.50/MMBtu (1976 dollars) to replace all of the oil and natural gas used by the forest products industry each year.

NEAR-TERM WOOD-FUEL TECHNOLOGIES

The forest products industry has been identified as a potential candidate for an expanded use of wood fuel in the near-term. It has a large energy need, it has access to a potentially sizable fuel supply and it possesses the technological expertise to economically convert the fuel resource to suitable energy forms. The forest products industry will, therefore, be used to illustrate how the use of wood as a fuel might be increased in the near-term. A similar approach could be applied to industries with related energy needs and resources. Wood is a potential fuel/feedstock for all of the direct combustion and conversion processes which can utilize various types of biomass and organic wastes. These processes include:

- direct combustion to produce steam for process heat and electricity;
- thermochemical processes to produce synthesis gas, liquid fuels, gaseous fuels and char;
- anaerobic digestion to produce substitute natural gas; and
- hydrolysis and fermentation to produce ethyl alcohol.

Some of these processes are currently available on a commercial basis and others are in various stages of development. Regardless of their state of development, however, wood will probably never be an equally suitable feedstock for all of the processes. This is largely due to the presence of the complex chemical compounds lignin and hemi-cellulose which currently limit the potential of both anaerobic digestion and fermentation. Lignin and hemi-cellulose do not seriously interfere with direct combustion or thermochemical conversion processes. It is in these areas, therefore, that wood-fuels have the greatest near-term potential. The technologies which are commercially available[*] today, and can be utilized by existing demand sectors include:

- direct combustion to produce process heat/steam and electricity;
- thermochemical gasification to produce low-Btu fuel gas (LBG);
- pyrolysis to produce LBG, fuel oil and char; and
- densification to produce fuel pellets.[**]

Direct Combustion of Wood

Wood-fired boilers have been used for decades to produce process steam for industrial use. Most of these boilers have capacities of 15,000 to 100,000 lbs of steam per hour, although some boilers have been built as large as 350,000 lbs. of steam per hour.

Wood can be used in utility boilers to produce high pressure steam for the generation of electricity. However, wood-fired utility boilers would be smaller than coal or nuclear installations and the costs of electricity, therefore, would be higher. A wood-fired plant,

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[*] "Commercially available" indicates that units are currently offered for sale and used in commercial processes or that vendors are available to design, fabricate and install a particular system when a feedstock and product are specified. A partial list of manufacturers, Architecture and Engineering firms, and users with experience in wood-fuel facilities is presented in Appendix A.

[**] Preliminary step to direct combustion in existing coal-fired plant.

for example, would have a generating capacity of 50 or 100 MW. A modern coal-fired facility, on the other hand, could be as large as 880 MW and have a generating capacity of 6.4 million lbs of steam per hour.

Several types of wood-fired combustion systems are currently available. Prior to 1950, the dutch oven was the most commonly used system (Figure 4). Wood is fed into the oven from the top and falls onto a water-cooled grate where most of it is gasified. The gases produced are mixed with air and travel to a combustion chamber where they are burned to produce the heat required for steam generation. Though dutch ovens are still used today, they are being replaced by larger and more efficient combustion systems.

Today, the most commonly used combustion system for wood-fired boilers in all size ranges is the spreader-stoker (Figure 5). Fuel is blown into the combustion chamber where a large part of it is burned in suspension. The remainder falls onto a grate where combustion is completed. This type of furnace can be equipped with either a stationary or travelling grate. The grates are often water cooled to prevent overheating.

Several companies have purchased and are operating systems which utilize fluid-bed technology (Figure 6). These systems can effectively use nonuniform fuels which contain considerable noncombustible material such as dirt and stones and whose moisture content is greater than 50 percent.

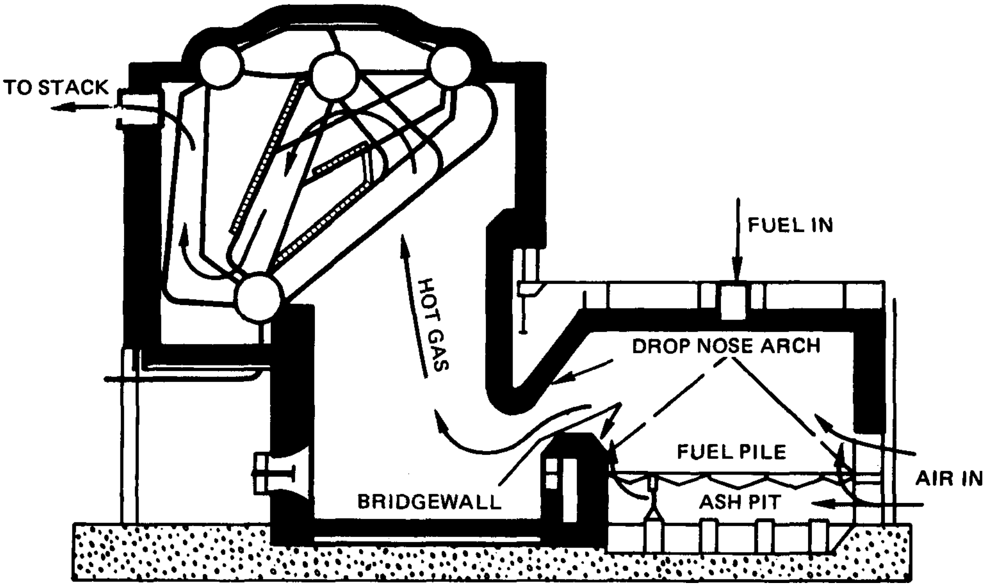
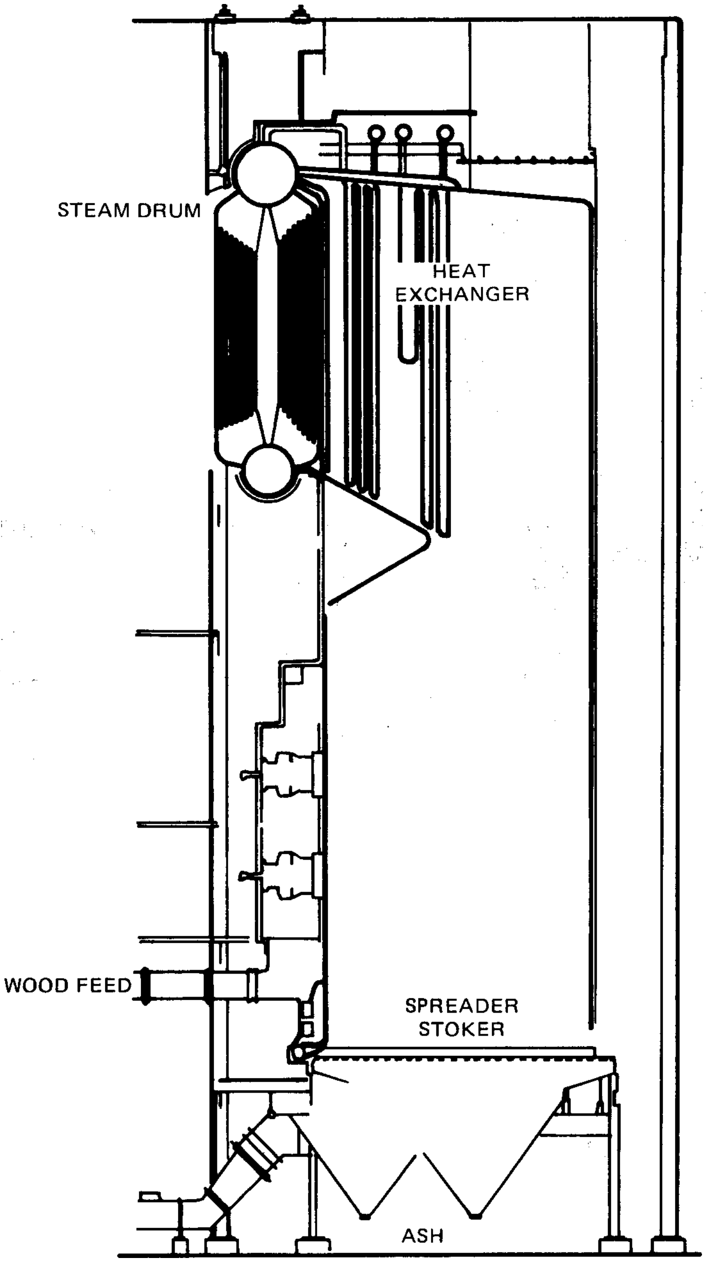


FIGURE 4
TWO-STAGE DUTCH-OVEN FURNACE



SOURCE: FOSTER WHEELER, LTD., BULLETIN C76,
ST. CATHERINES, ONTARIO, CANADA.

FIGURE 5
TYPICAL MODERN WOOD/BARK FUEL WATER TUBE STEAM GENERATOR
(350,000 LBS/HR STEAM)

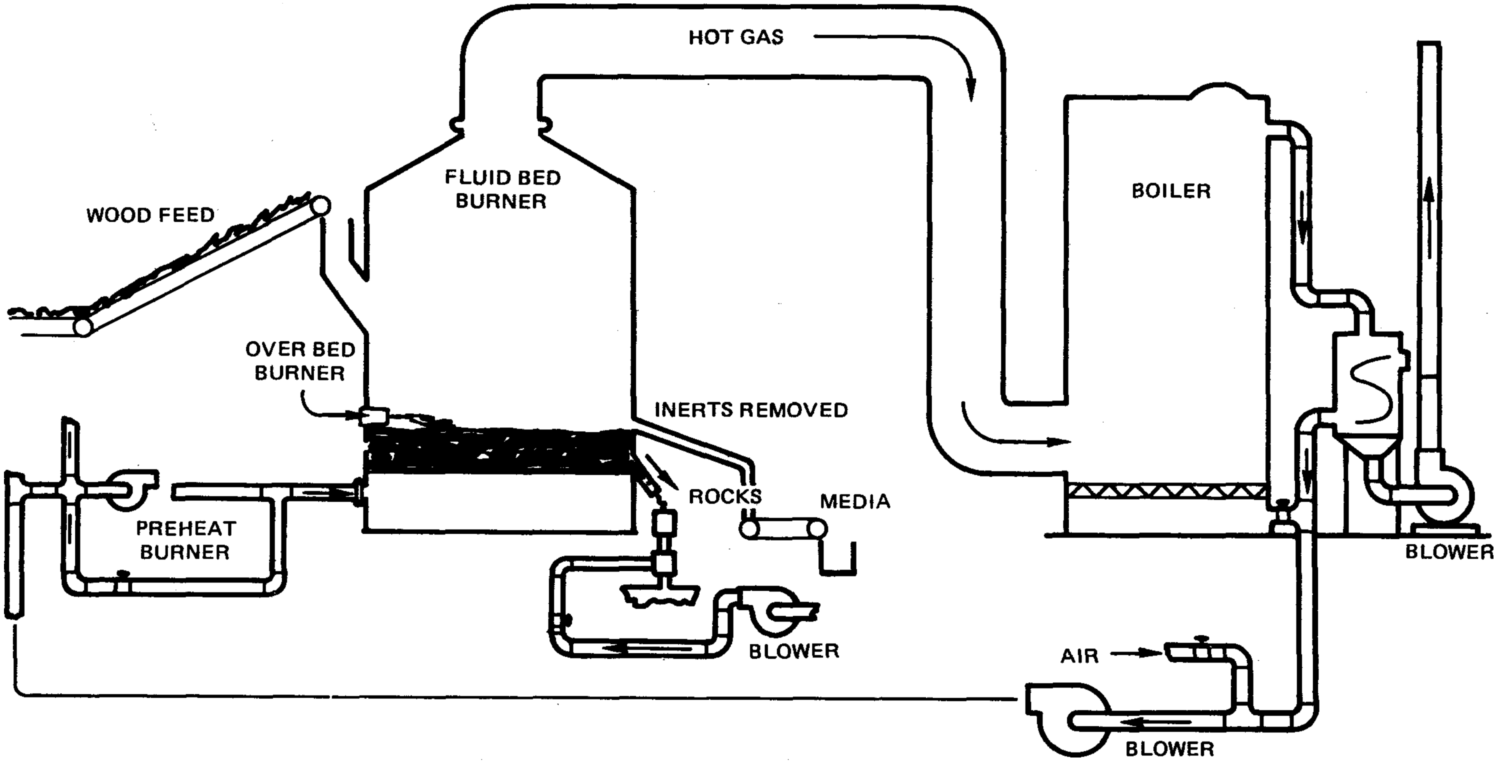


FIGURE 6
SCHEMATIC FLOW FLUID-BED
WOOD-FIRED STEAM GENERATION

Fluid-bed systems essentially separate fuel combustion from steam generation. The fluid-bed is established and maintained by air flowing through an inert material, such as sand or pebbles, at a rate which causes the particles to go into suspension. Fuel is slowly fed into the bed from the top of the boiler and air is introduced from the bottom. Combustion of fuel in the bed produces hot gases which are conveyed to an adjacent boiler to give up their heat for steam generation prior to being exhausted.

Technological advances in fluid-bed combustion are occurring rapidly. Though the maximum capacity of current units is approximately 40,000 lbs of process steam per hour, larger units are expected to become available in the near future.

MITRE/Metrek estimated the "plant-gate" selling prices of electricity and various energy-related products during its recently completed analysis of wood conversion processes and costs. Estimates were based on conceptual designs in those cases where a conversion process is still being developed. These comparative cost estimates, which are summarized in Table II, provided an indication of the current potential for commercialization of various conversion technologies.

The same procedures and assumptions which were used to estimate these "plant-gate" selling prices for electricity and various fuels have been used to calculate prices for process steam. These prices

TABLE II

ESTIMATED "PLANT-GATE" SELLING PRICES[1] FOR ENERGY PRODUCTS DERIVED FROM WOOD[2]
($\$/10^6$ Btu Heating Value)

	PLANT SIZE	
	850 DRY TONS/DAY	1700 DRY TONS/DAY
Process Steam	2.70	
Low-Btu Fuel Gas	2.70	
Medium-Btu Fuel Gas	3.10	2.60
Charcoal Without Credits	4.90	4.60
Charcoal With Steam Credit	2.10	1.90
Substitute Natural Gas	4.60	3.80
Ammonia	5.50 ($107/ton)	4.43 ($88/ton)
Methanol	7.60 ($0.50/gal)	6.20 ($0.40/gal)
Ethanol	20.40 (1.65/gal)	17.50 (1.40/gal)
Electricity	11.80 (40 mills/kWh)	8.80 (30 mills/kWh)

[1] Calculated from data reported in Bliss, C. and D. O. Blake, Silvicultural Biomass Farms: Conversion Processes and Costs, 1977, MTR-7347, Volume V, MITRE/Metrek, McLean, VA.

[2] Wood cost is $\$1.00$ per 10^6 Btu.

are summarized in Table III and Figure 7. The capital and O&M costs used in the analysis are presented in Table B-I in Appendix B.

The price of process steam produced in small boilers such as a 78,000 lbs/hr (170 ODT/D,* equivalent to approximately 10 MW_e) facility is relatively high compared to that produced in large installations (387,000 lbs/hr. 850 ODT/D). The price calculated for a 170 ODT/D process-steam plant was $4.00/MMBtu and for an 850 ODT/D facility it was $2.70/MMBtu. Wood-fuel cost was assumed to be $1.00/MMBtu in both cases. Some of the advantages of using wood-fuel to produce process steam include:

- conversion costs are low;
- experience with a wide range of sizes and types of wood-combustion systems is extensive;
- potential users of wood-fuel combustion systems have access to relatively inexpensive fuel; and
- wood is a cleaner fuel than coal and would reduce demands on oil and gas reserves.

Disadvantages include:

- the energy density of conventional wood-fuel is lower than that of oil, gas and coal;
- problems associated with wood-fuel handling, combustion and emissions are greater than those encountered with oil and gas; and
- the use of wood as a fuel competes with its use as fiber.

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*Oven dry tons of fuel/feedstock per day.

TABLE III

ESTIMATED "PLANT-GATE" SELLING PRICES FOR PROCESS STEAM ($\$/10^6$ Btu Heating Value)

PLANT SIZE	WOOD-FUEL COST ($\$/10^6$ Btu Heating Value)			
(ODT/D)*	0.50	1.00	1.50	2.00
170	3.28	3.96	4.64	5.32
340	2.44	3.12	3.80	4.48
510	2.30	2.98	3.66	4.34
680	2.13	2.81	3.50	4.18
850	2.04	2.72	3.40	4.08

*An 850 oven dry ton per day (ODT/D) facility produces 387,000 pounds steam per hour.

SOURCE: Calculated from generic design data developed by MITRE/Metrek.

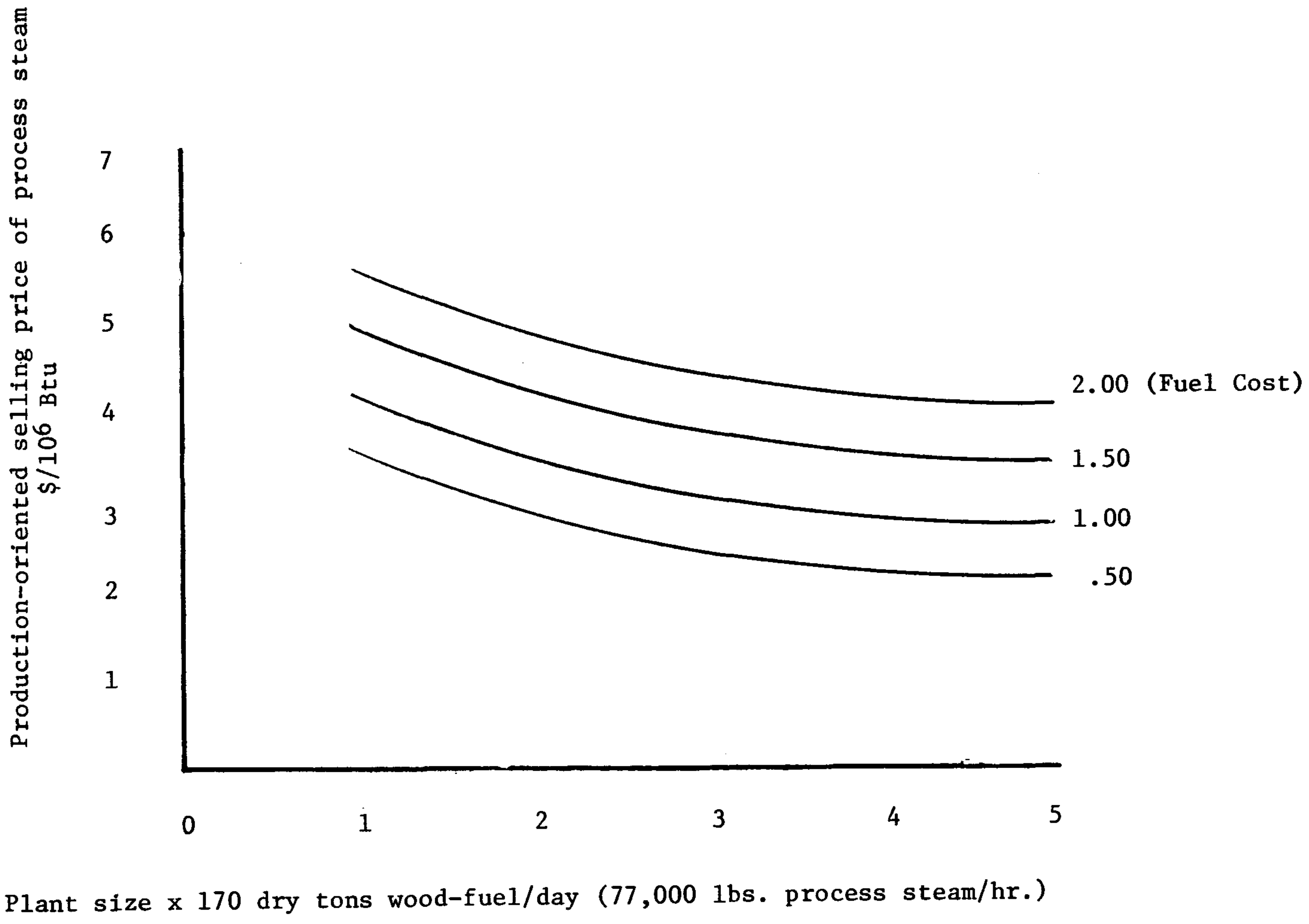

FIGURE 7
PRODUCTION-ORIENTED SELLING PRICE OF PROCESS STEAM

Thermochemical Gasification

Low-Btu gas, with a representative heating value of 140 Btu/scf, is formed when organic material is decomposed by heating the material in the presence of air. Medium-Btu gas (MBG), with a representative heating value of 280 Btu/scf, is produced when decomposition occurs in an atmosphere of oxygen. An illustrative schematic drawing of a gasification system is presented in Figure 8.

Commercial wood to MBG systems are still being developed and, therefore, are not generally available. Furthermore, LBG is often considered a more attractive alternative than MBG because of the capital expense and technical problems associated with construction and operation of an oxygen plant for an MBG facility. Costs of an oxygen plant can be 40-45 percent of the total capital expenditure for a gasification facility.

The average thermal conversion efficiency of producing MBG (75 percent), however, can be 10-15 percent higher than that of LBG assuming a system similar to that previously described by Metrek.* Therefore, less feedstock would be required to produce MBG with a heating value equivalent to that of LBG. This greater thermal efficiency of an MBG system is offset, however, by the lower capital cost associated with a LBG plant. The net results of these

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*Costs associated with LBG production are based on a modification of the MBG facility described in: Bliss, C. and D.O. Blake, Silvicultural Biomass Farms: Conversion Processes and Costs, 1977, MTR-7347, Volume V, MITRE/Metrek, McLean, VA (see pp 144-147).

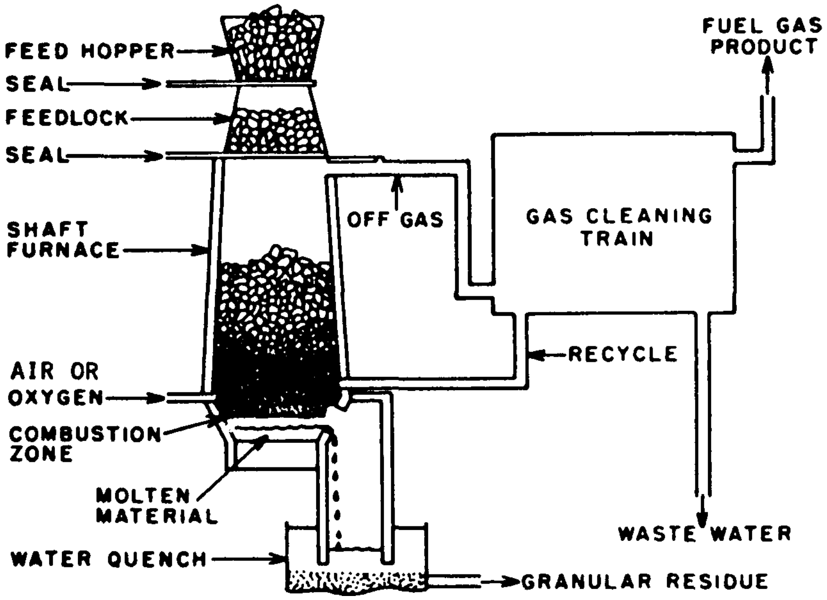


FIGURE 8
SCHEMATIC DRAWING OF A SYSTEM
FOR PRODUCING FUEL GAS FROM WOOD
(Union Carbide Purox System)

differences are reflected in the production costs of the desired end products. For a 850 ODT/D facility and a feedstock cost of \$1.00/MMBtu, LBG would cost about \$2.70/MMBtu to producers whereas MBG would cost \$3.10/MMBtu. (See Table II.) The production costs of LBG produced in facilities varying from 170 to 850 ODT/D are summarized in Table IV and Figure 9. Capital and O&M costs for an 850 ODT/D LBG facility are presented in Table B-II in Appendix B.

The price of LBG produced in small installations such as a 1.9×10^9 Btu/day facility (170 ODT/D) would be relatively high compared to that produced in large plants (850 ODT/D). The price calculated for a 170 ODT/D low-Btu gasification plant was \$3.80/MMBtu and, for an 850 ODT/D facility it was \$2.70/MMBtu. Wood-feedstock cost was assumed to be \$1.00/MMBtu in both cases.

A wide range of estimates exists for the thermal efficiency of LBG production. Many of the differences in these estimates can be attributed to the use of different assumptions. For example, about 15 percent of the heating value of an ODT of wood is needed to dry as-fired wood if that wood is green (50 percent moisture). This factor alone can reduce thermal efficiency to 85 percent before specific heat and other losses are even considered. Despite these differences, an overall efficiency of 80 percent for dry wood is often assumed. This would be reduced to about 65 percent when wet feedstock is used.

TABLE IV

ESTIMATED "PLANT-GATE" SELLING PRICES FOR LBG ($/10^6 Btu Heating Value)

PLANT SIZE	WOOD-FUEL COST ($/10^6 Btu Heating Value)			
(ODT/D)*	0.50	1.00	1.50	2.00
170	3.01	3.78	4.55	5.32
340	2.52	3.29	4.06	4.83
510	2.25	3.02	3.80	4.57
680	2.08	2.85	3.62	4.39
850	1.95	2.72	3.49	4.26

*An 850 oven dry ton per day (ODT/D) facility with a thermal efficiency of 65% produces 9.39 x 10^9 Btu of low-Btu fuel gas per day.

Assumes the use of green wood containing 50 percent moisture.

SOURCE: Calculated from generic design data developed by MITRE/Metrek.

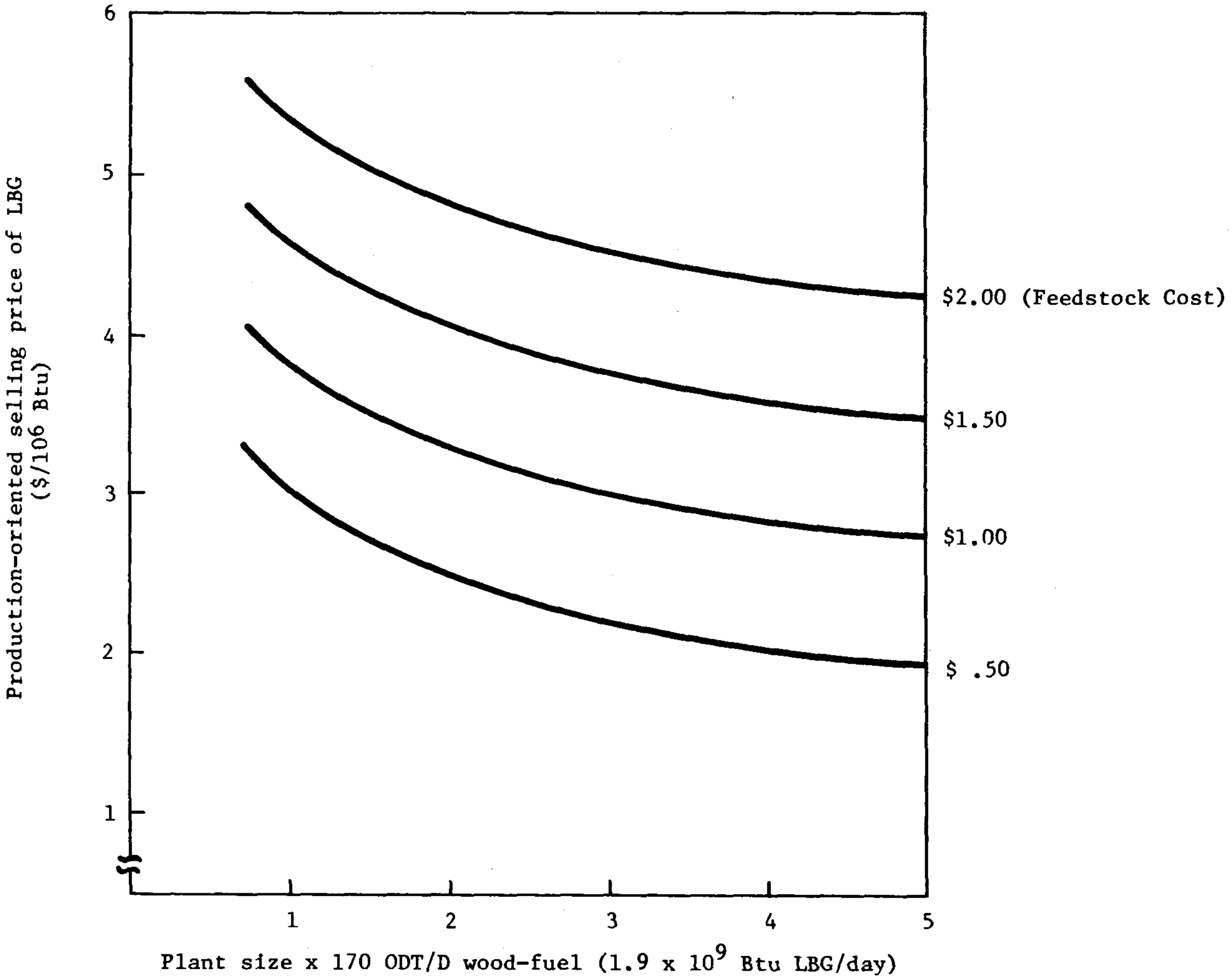


FIGURE 9
PRODUCTION-ORIENTED SELLING PRICE OF LBG

A detailed evaluation of thermal losses associated with LBG production was not within the scope of this analysis. However, it was considered necessary to address the issue of cost versus thermal efficiency. An analysis of the sensitivity of plant-gate selling price to thermal efficiency, therefore, was performed. The restuls of that sensitivity analysis are reported in Table V. Two plant sizes were examined and it was shown that for each increase of 10 percent in efficiency, costs could be reduced by about $0.45 in 340 ODT/D facilities and $0.35 in 850 ODT/D facilities. These costs represent an average over a 0.55-0.75 efficiency range and a feedstock cost of $1.00/MMBtu.

The economics associated with applications such as generating process steam for pulp mills will probably require burning wood directly--instead of gasifying it first. Factors such as conversion costs and boiler derating will limit the use of LBG in applications which can burn wood directly.

In other boiler related applications where oil or gas would normally be used, the costs of the competing fuels, the costs of the boiler conversions and the impact of boiler derating required for LBG (see Table VI) will determine the economic feasibility of using LBG as a substitute.

Some of the advantages of low-Btu gasification using wood as a feedstock include:

- existing gas and oil-fired boilers could be easily converted to low-Btu fuel gas;

TABLE V

EFFECT OF THERMAL EFFICIENCY ON ESTIMATED "PLANT-GATE" SELLING PRICES FOR LBG*
($/$10^6$ Btu Heating Value)

PLANT SIZE	THERMAL EFFICIENCY (Btu out/Btu in)		
(ODT/D)	0.55	0.65	0.75
340	$3.89	3.29	2.85
850	3.21	2.72	2.36

*Assumes a feedstock cost of $1.00/MMBtu.

TABLE VI

PERCENTAGE OF MAXIMUM CONTINUOUS RATING WHEN LOW-BTU GAS IS USED IN OIL AND NATURAL GAS BOILERS

HEATING VALUE OF LOW-BTU GAS	ORIGINAL DESIGN FUEL	
	OIL	GAS
292 Btu/scf	100%	100%
179 Btu/scf	70%	70%
128 Btu/scf	65%	60%
105 Btu/scf	50%	50%

SOURCE: Fernandes, J. H., "Wood Energy Systems: State-of-the-Art and Developing Technologies," paper presented at *The Future of Wood as an Energy Source*, Gorham, Maine, June 20-22, 1976.

- capital cost of low-Btu gasification equipment is low; and

- low-Btu gas is a clean, easy-to-use fuel and would minimize the expense and problems associated with hogged-fuel and coal combustion, stack emissions, and effluent treatment.

Some of the disadvantages include:

- LBG must be used on-site;

- existing gas/oil fired boilers would be derated when LBG is used as a fuel; and

- experience with large-scale wood gasification systems is limited.

Pyrolysis

Pyrolysis, or destructive distillation, occurs when a feedstock such as wood is heated in the absence of oxygen. The principal product of pyrolysis is char if a relatively low temperature such as 600°C is maintained in a reactor. Metrek estimated "plant-gate" selling prices for charcoal to be \$4.90/MMBtu (Table II) when charcoal is produced in an 850 ODT/D facility from \$1.00/MMBtu feedstock. This cost could be reduced to \$2.10/MMBtu by assuming a steam byproduct credit because 12.5 tons of steam are produced for each ton of charcoal. Charcoal could be substituted for wood-fuel or coal which can be obtained for a price closer to \$1.00/MMBtu than \$2.00-5.00/MMBtu. Furthermore, char cannot be used in existing gas/oil fired boilers without retrofitting. The value of char as an industrial fuel is limited therefore, and the plant-gate selling price appears relatively high. The value of char is probably greater when it is used for other purposes such as barbeque briquettes and activated charcoal for water treatment, etc.

Pyrolysis systems to produce a combination of char, fuel oil and LBG have been under development for some time and commercial systems have appeared on the market. One of these systems was developed at the Georgia Institute of Technology and has been licensed to the Tech-Air Corporation, Atlanta, Georgia.

Tech-Air has reported that about 8 percent of the input feedstock-energy is lost as heat and the conversion process, therefore, has a thermal efficiency of 92 percent. Approximately 22 percent of the input energy can be distributed to LBG, 35 percent to char and 35 percent to fuel oil.

Life-cycle costs for pyrolysis products produced in a hypothetical plant similar to a 6 ODT/hour (144 ODT/D) Tech-Air installation were estimated with the same model used for conversion processes reported in Table II. An average plant-gate selling price for conversion products was between \$2.45 and \$2.85/MMBtu assuming an as-fired thermal efficiency of 65-75 percent and a feedstock cost of \$1.00/MMBtu (see Table VII). The average plant-gate selling prices might be reduced to about \$2.00-2.30 if plant capacity could be increased to 24 ODT/hour (576 ODT/D). Systems with a throughput of 24 ODT/hour are not currently available but are under consideration.

TABLE VII

EFFECT OF PLANT SIZE, CAPITAL COST AND THERMAL EFFICIENCY ON ESTIMATED "PLANT-GATE" SELLING PRICES FOR PYROLYSIS PRODUCTS[1]

($/$10^6$ Btu Heating Value)

SYSTEM SIZE (ODT/D)	COST[2]		THERMAL EFFICIENCY (Btu out/Btu in)	
	TOTAL CAPITAL (\$ 10^6)	ANNUAL O&M[3] (\$ 10^3)	0.65	0.75
144	2.0	257	2.70	2.30
144	2.5	257	2.85	2.45
144	3.0	257	3.00	2.60
576	4.0	693	2.20	1.90
576	5.0	693	2.30	2.00
576	6.0	693	2.40	2.10

[1] Calculated from information supplied by Tech-Air, Atlanta, GA.

[2] A feedstock cost of $1.00/MMBtu was assumed.

[3] A 10 percent change in O&M costs changes product costs $0.05-0.06/MMBtu in 144 ODT/D systems and $0.03-0.04/MMBtu in 576 ODT/D systems.

The production of fuels in pyrolytic systems followed by their combustion appears more expensive than the direct firing of wood. However, large pyrolytic systems should be able to compete with natural gas and oil if they can be operated at the costs reported here. Actual investment decisions will involve consideration of factors other than the direct costs considered in the above analysis. These include: reliability of current fuel supplies, by-product markets, reliability of pyrolysis systems and feedstock availability.

Densification

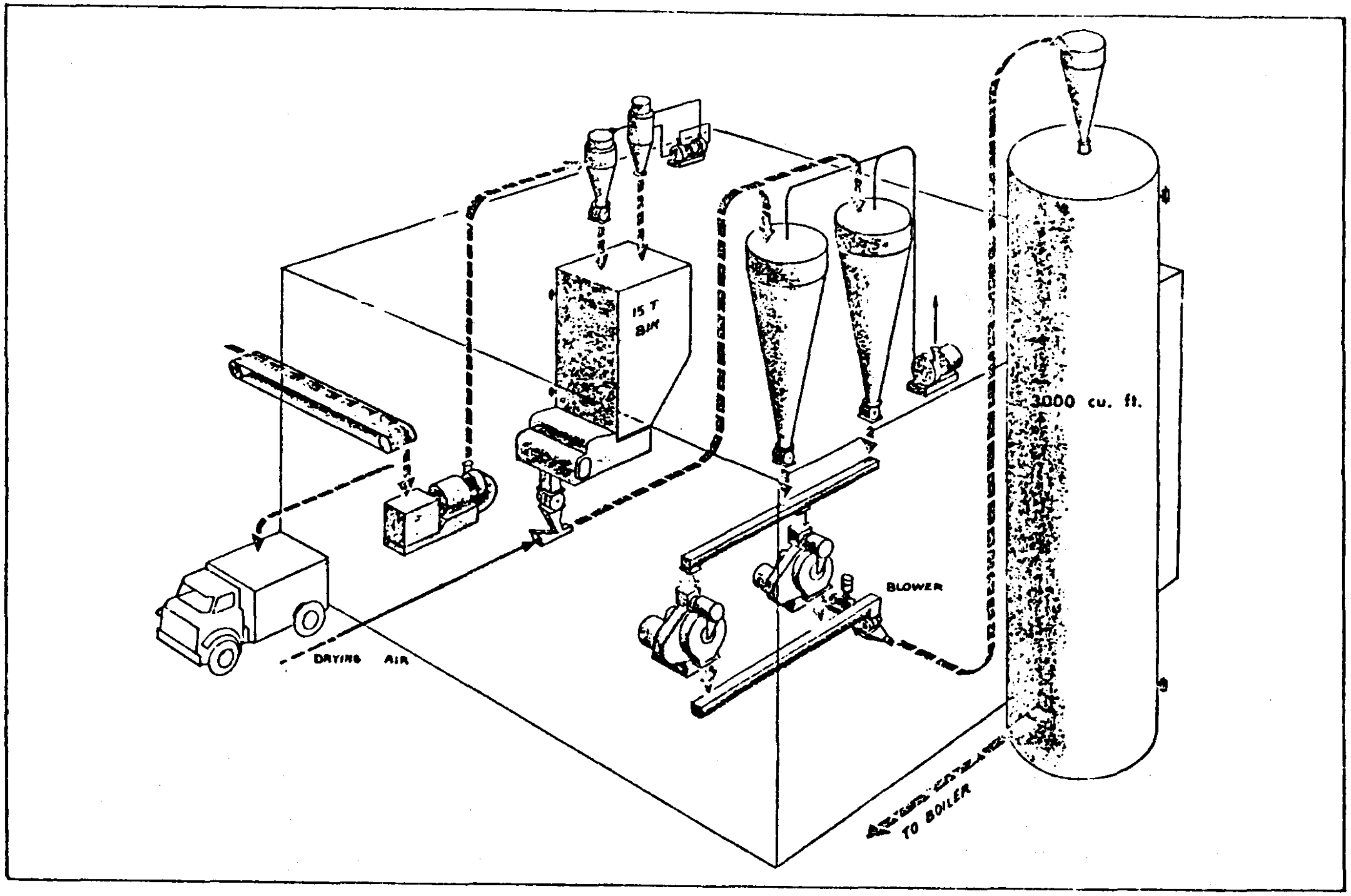
Most wood-fuel that is burned in commercial and industrial boilers today is derived from mill residues. Wood residues are reduced by a process called "hogging." The wood fuel is more difficult to handle, transport and meter than fossil fuels because its weight, size and moisture content are variable.

Renewed interest is being shown in the densification of wood because densification could provide a solution to many of the problems associated with conventional wood-fuel. During the 1930's, wood was densified to produce "stoker fuel" which was commonly used in the Northwest in commercial and industrial boilers. Other cellulosic materials such as alfalfa, bagasse and peanut hulls have been densified into pellets for decades. The technology of making wood pellets, therefore, is well known. Rising fuel prices and environmental concerns have encouraged several companies, which have been pelletizing fibrous materials for animal feeds, to undertake densification of wood residues. There are also several new companies marketing patented wood pellets and the equipment to produce them. At the present time there are two large pellet mill manufacturers and several smaller ones. These are listed in Appendix A.

Commercial densification plants (Figure 10) typically have a production capacity of at least 300 tons per day. Although capacities of 600 or 900 tons a day are feasible and would result in the production at a lower product cost, plant size is often limited by the availability of residues in a given area. A typical plant can be constructed and commissioned in about 9 months at a cost between $1 and $2 million.

Wood residues are thoroughly dried as the first step in the densification process. The dry residues are then shredded and fed through a density mill under high pressure. Pellets which are about 1/4 inch in diameter and 1/2 inch in length emerge from the mill. Representative pellets weigh about 30-40 pounds per cubic foot and have a moisture content of about 12 percent. The objective of wood densification is to remove as much moisture as possible to increase the heating value of wood to that of coal or other fossil fuels.

Overall processing costs, including drying, shredding and pressing are approximately $15 to $20 per ton. One pellet manufacturer has estimated production costs to be $15 per ton, including feedstock purchases. The pellets are sold at $22 per ton ($1.30/10^6 Btu), FOB, from the production plant. Although it is easier and



Source: Sprout, Waldron and Company, Inc.
Muncy, PA

FIGURE 10
DENSIFICATION MILL

more economical to transport pellets than mill residues, it becomes uneconomical to do so for distances greater than 200 or 300 miles. It has been suggested that densified wood remains competitive with other fuels when transportation costs are no more than \$5-\$10 per ton.

The density of pelletized wood is about 1.3 times that of conventional wood-fuel and it is easier to handle than hogged fuel. It flows freely and can be loaded easily from a bin into a truck. It is easily metered by volume and can be fed into any furnace designed to burn wood or coal. Pelletized fuel, however, must be stored under cover to prevent deterioration. Grain-type silos can be used for this purpose. There is generally no greater danger of spontaneous combustion with this type of storage than there is with coal storage.

Wood pellets can be either burned directly as a fuel or gasified thermochemically to produce a boiler fuel. Pellets are a good gasification feedstock because auxiliary equipment costs are decreased as the moisture content of the biomass decreases. Pellets can also be ground into a fine powder and burned with coal in a suspension-type boiler.

Some of the advantages of pelletization include:

- reduced bulk which facilitates transport and storage;
- reduced moisture content for increased heating value per unit weight;
- low ash compared to coal, and easier to dispose of in an environmentally acceptable manner;

- no retrofitting of equipment where coal has been used; and

- costs are currently competitive with fossil fuels in some parts of the country.

Some disadvantages are:

- comparatively new technology to present users;

- less convenient to handle than either fuel oil or natural gas;

- cost-effective transportation distance is limited to about 300 miles; and

- lower heating value per unit volume than coal.

NEAR-TERM INCENTIVES TO ENCOURAGE USE OF WOOD AS A FUEL

The forest products industry is the largest user of wood-fuel in the United States. It used about 3 quads of energy in 1975 and 1.1 quads were biomass-derived. It is expected that the industry will use 3.7 quads of energy by 1985 and at least 2.5 quads will be obtained from wood. A Federal government incentives program could increase this use of wood significantly, depending on the nature of the incentives provided. In this section, the impact of two possible incentives will be considered for four possible cases where either one or both of the incentives are applicable. Two possible incentives which might be used effectively to expand the use of wood-fuel have been identified: an investment tax credit (ITC) that is larger than the current 10 percent and an early retirement tax credit (RTC) which could be applied to the full remaining lifetime of gas and oil-fired boilers.[*]

Four cases have been identified in which the incentives, taken separately or together, could be used. These are:[**]

- Conversion of existing oil and gas-fired boilers to use wood fuel directly;
- Conversion of existing oil and gas-fired boilers to burn LBG produced from wood;

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[*] See also: Gsellman, L., Retirement Tax Credit: An Efficient Technique for Achieving Near-Term Reductions in Oil and Gas Use; M78-24, MITRE/Metrek, McLean, VA.

[**] The first three cases analyzed are not independent; they are mutually exclusive alternatives to reducing the consumption of oil and gas in existing facilities.

- Early retirement of existing oil and gas-fired boilers; and
- Increased purchases of new wood-fired boilers for facilities for expansion and expected retirements.

Each of these cases will be discussed and the impact that applicable incentives may have on each case is described. Finally, the results of an integrated analysis which addresses the impact and cost of the two incentives is presented.

Case 1: Conversion of Existing Oil and Gas Boilers to Direct Firing of Wood

About 1.3 quads of oil and gas were used by the forest products industry in 1974. It may be possible to substitute wood-fuel for oil and gas in some of these boilers through retrofits. The economic feasibility of doing so will depend on capital, operating and fuel cost savings; boiler derating; and changes in boiler heat rates. The most difficult retrofits involve conversion of boilers using gas and oil to direct combustion of wood.

Such a conversion involves more than a simple fuel substitution. The furnace must be replaced, the operating costs will increase, and the heat rate of the boiler will increase. Furthermore, because the boiler cannot accept the same number of Btu's of wood per unit of time that it can for oil, it will have to be derated, i.e., it will produce fewer pounds of steam per hour. Thus, if an oil-fired boiler producing 387,000 lbs/hr of steam is converted to wood and derated to 80 percent of its original capacity it will only produce 309,600 lbs/hr of steam. The remaining 77,400 lbs/hr of steam will have to be obtained from a new boiler. An alternative to converting an oil/gas-fired boiler to the direct use of wood would be to install several wood incinerators to burn the wood and to convert the oil/gas boiler to a water heat boiler. Hot flue gases from the incinerator would be used as the energy source for the converted boiler. If a sufficient number of incinerators is used, it may not be necessary to derate the boiler, although this will depend on the volume and the content of the entering flue gas.

While a detailed assessment of the economics of retrofitting is beyond the scope of this report, a general assessment seems to indicate that the economics appear to be promising for facilities having an economic life of about 10 years. This can best be illustrated by examining the general costs associated with converting a 1400 bbl/day oil-fired process steam boiler to a 850 ODT/D wood burning system. This conversion would result in the following costs:

- Furnace replacement and changes in fuel handling equipment - $13 million
- New boiler-designed to replace capacity loss (20 percent) as a result of converting original boiler- $8.5 million
- O&M - $4.0 million/year ($1.7 million/year for original oil boiler)
- Fuel - $4.2 million/year ($8.4 million/year for oil)[1]

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[1] Assumes oil costs $2.00/MMBtu and wood costs $1.00/MMBtu

The above boiler retrofit would result in an additional capital investment of $21.5 million; an increase in annual O&M of $2.3 million and a decrease in annual fuel cost of $4.2 million.

The decision to retrofit would be based on the present value of future costs, since all prior expenditures are sunk and not retrievable. The present value of all future operating and fuel costs can be computed for the retrofit and non-retrofit cases and the capital costs of converting and adding a new boiler can be added for the former. Present values of all expenses for each case as a function of remaining life of existing facilities are presented in Table VIII. The results presented are based upon a 12 percent time value of money and assume no constant dollar increase in fuel and operating costs.

The savings associated with lower wood-fuel costs exceed the costs of retrofitting, higher operating expenses and the penalties associated with derating for boilers having remaining lifetimes of 10-15 years. The decision to retrofit would be based as much upon the expected availability of wood-fuel and the availability of capital needed as on the longer term economic advantages of using wood as a fuel. While the capital cost of retrofitting is not a major component of the present value of all future costs (about 13 percent for a 10-year remaining life) it is significant and the initiation of an investment tax credit applied toward this expense could serve to stimulate retrofits.

TABLE VIII

PRESENT VALUE OF LIFE CYCLE COSTS: RETROFIT TO WOOD

REMAINING ECONOMIC LIFE (Yrs)	PRESENT VALUE OF EXPENSES (Million $)	
	OIL	RETROFIT TO BURN WOOD
5	64.1	70.9
10	177.1	157.9
15	376.1	311.2

Case 2: Conversion of Existing Oil and Gas Boilers to LBG

It was previously indicated that boilers in the pulp and paper industry which use gas and oil as fuels could be converted to LBG but that the cost of so doing would be high when compared to the continued use of conventional fuels. Fuel-wood which costs $1.00/MMBtu and is used in a gasifier with a throughput of 850 ODT/D would produce LBG costing $2.70/MMBtu as compared with oil and natural gas in the $2.00/MMBtu range. A substantial ITC for gasifier construction might result in some conversion. It should be noted, however, that the gasifier capital cost of $6.9 million is a relatively small percentage of its total life-cycle costs. About 8 percent of the present value of all life-cycle costs can be accounted for by capital assuming a 10 percent ITC and about 6 percent if the ITC is increased to 30 percent. Therefore, the impact of increasing the ITC from 10 percent to 30 percent would be to reduce present value of the life cycle costs by $2.5 million and to reduce the cost of producing the gas by only $0.10/MMBtu. Therefore, an ITC is not an effective incentive to encourage the conversion of existing boilers from natural gas and oil to LBG produced from wood.

Case 3: Early Retirement of Existing Oil and Gas Boilers and Replacement with New Wood-Fired Boilers

Existing oil and gas-fired boilers in the pulp and paper industry used about 1 quad of fuel in 1974. It has been estimated that up to 0.4 quad of this could be converted to wood-fuel with an early retirement tax credit (RTC).[*] This would require about 100 850 ODT/D or 400 350 ODT/D installations assuming a heating value of 17 x 10^6 Btu/ODT for wood and a capacity factor of 0.8. A total of 250 [illegible] burning boilers have been sold in the U.S. during the past 10 years.

An RTC is an incentive which encourages the early retirement of existing gas and oil-fired boilers, and thereby encourages the investment in new wood-fired facilities. Under this incentive, the remaining capital value[**] of a boiler would be allowed as a tax credit for the year in which the boiler is retired.[***] Thus, if the remaining capital value of a facility is $10 million then a tax credit slightly greater than $10 million would induce the owner to retire the facility early and replace it with the best available alternative.

The retirement tax credit (RTC), if implemented to the maximum allowable amount, could provide a strong incentive for early retirement of facilities. As with the ITC, the RTC would be treated as a reduction of Federal income tax payments for the year in which the facility is retired. This credit, to be effective, should be

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[*] Gsellman, L., R. Inman and D. Salo, <u>Wood as a Fuel in the Near-Term</u>, 1978, M78-42, MITRE/Metrek, McLean, VA.

[**] Remaining capital value is defined as the present value of the differences between continuing the use of the existing facility and the best alternative.

[***] See also: Gsellman, L., <u>Retirement Tax Credit: An Efficient Technique for Achieving Near-Term Reductions in Oil and Gas Use</u>, 1978, M78-24, MITRE/Metrek, McLean, VA.

contingent on replacement with wood-fired boilers and may be linked with an increased ITC for new wood-fueled systems.

Case 4: Increased Purchase of New Wood-Fired Boilers for Facilities for Expansion and Expected Retirements

The ITC on qualified depreciable property is treated as a reduction in Federal income tax payments for the year in which equipment is placed in service and results in a reduction in carrying charges for the item. Increasing the ITC from its current 10 percent would result in decreased income tax payments or increased net income for those who take the credit.

An assessment of the life cycle costs of producing process steam using direct combustion of wood, oil, gas and coal indicates that wood would be the least expensive fuel to use. Coal would compete with wood to a limited degree, oil and gas, however, are more expensive than wood. Therefore, only a very few oil and gas facilities are expected to be purchased by the pulp and paper industry.

1.6Q of the total 1985 forest products industry consumption of 3.7Q can be classified as resulting from industry expansion or expected retirement. MITRE estimates that 0.7Q of the 1.6Q will be produced from wood and 0.3Q will be from coal. The remaining 0.6Q will be from spent liquors and purchased electricity.

An ITC of up to 30 percent, applied to new wood-burning boilers as an incentive, could increase wood-fuel use in the forest products industry by shifting the relative economies of the use of coal and wood. A 30 percent ITC would be sufficient to shift 0.3 quad of coal facilities to wood burning facilities. It should be pointed out, however, that wood-fired boilers are not capital intensive. About 22 percent of the life-cycle cost of an 850 ODT/D boiler can be accounted for by capital assuming a capital cost of $24.4 million, an annual O&M cost of $2.8 million and an annual fuel cost of $4.8 million for $1.00/MMBtu wood. The percentage of life-cycle cost accounted for by capital would be 17 percent if the ITC was increased from 10 percent to 30 percent. In other words, the present value of the life cycle costs would decrease by $8.75 million as a result of the higher ITC and while this is a non-trivial saving, it is not substantial when compared with total costs of about $140 million over the life of the boiler.

Integrated Analysis

Three of the four cases described above are not independent of each other. Therefore, to estimate the total impact and cost of the government incentives suggested, one must perform an integrated analysis which considers the interactions among the alternatives discussed. The results of a preliminary analysis to estimate the impact and cost of the two incentives are presented in Figure 11.*

The ITC cost and impact curve was developed by varying the ITC from 0 to 30 percent. As the ITC percentage increases, both the government cost (lost revenues) and the impact increases. The reason

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*For details see "Wood as a Fuel in the Near-Term," 1978, M78-42, MITRE/Metrek, McLean, VA.

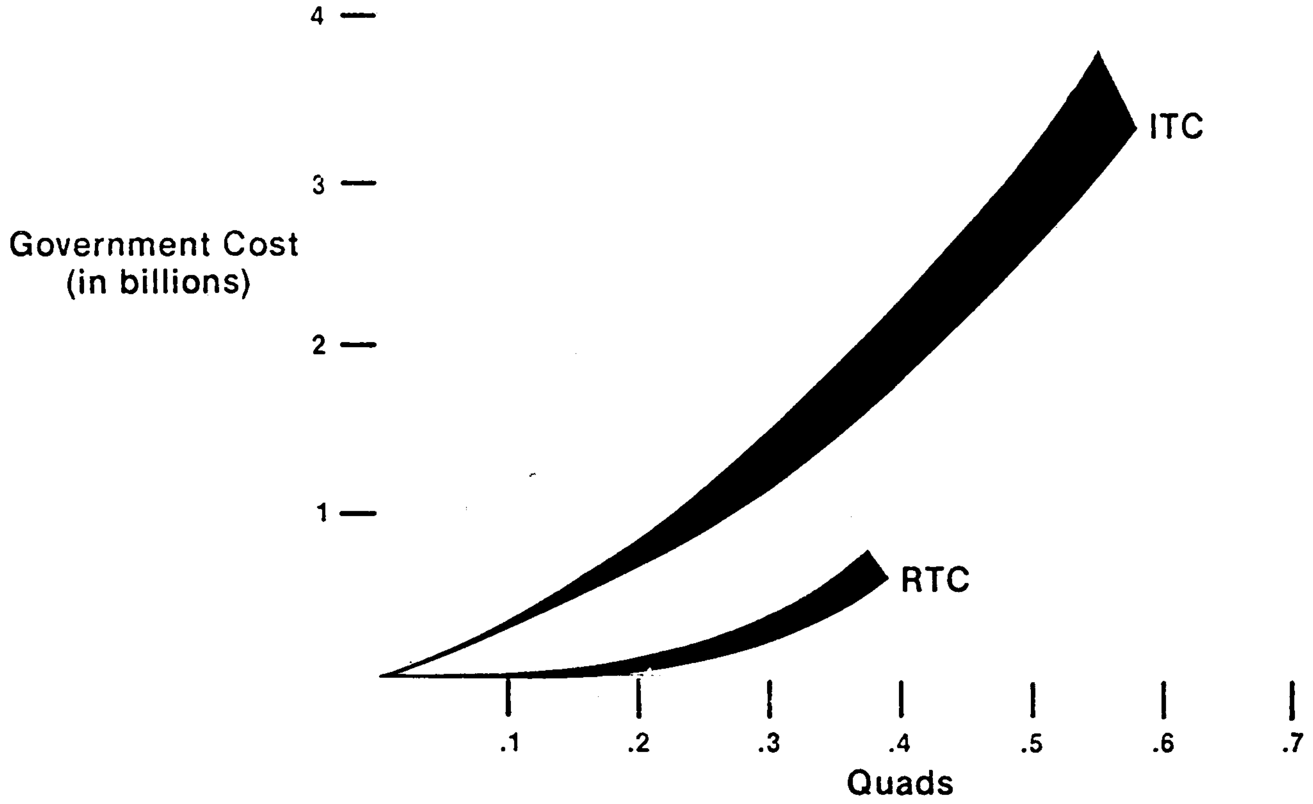

FIGURE 11
COMPARISON OF COSTS AND IMPACTS* OF AN INVESTMENT TAX CREDIT AND A RETIREMENT TAX CREDIT ON WOOD-FUEL USAGE IN THE NEAR-TERM

SOURCE: MITRE/Metrek.

*Impact is additional quantity (quads) of wood consumed in 1985 as a result of introducing incentives.

for the increased government cost is obvious. The increased impact is due to two factors:

- the economic life of existing oil and gas facilities decreases as the ITC increases thereby increasing the number of "early retirements," and
- fewer coal facilities are purchased for expansion and expected retirements since increasing the ITC changes the relative economies of coal versus wood in favor of wood.

The RTC cost and impact curve was developed by varying the number of years of "early retirement" to which the credit would apply. Of course, if the RTC applies to zero years of early retirement, the cost and impact are zero. However, as the number of years for which the credit applies increases, both the cost (lost revenues) and impact increase because plants are retired earlier. Since the RTC applies only to existing facilities, its maximum impact (0.4 quad) is less than that related to the ITC (0.6 quad). The ITC affects replacement and expansion decisions as well as "early retirement" decisions. However, because the RTC is more efficient, from an economic point of view, its cost per unit of impact is much lower than the ITC incentive.

APPENDIX A

LIST OF WOOD SYSTEMS MANUFACTURERS, ARCHITECTURE AND ENGINEERING FIRMS, AND USERS

APPENDIX A

LIST OF WOOD SYSTEMS MANUFACTURERS, ARCHITECTURE AND ENGINEERING FIRMS, AND USERS

North American companies which are involved in the design development, manufacture, sale and installation of wood-fuel conversion systems are listed in Appendix A. Manufacturers of combustion, gasification and densification systems are identified. Only those firms involved in the conversion of wood have been identified. Some firms involved in the conversion of municipal solid waste or densification of animal foods, have not been listed. Architecture and Engineering (A/E) and Research and Development (R&D) firms are listed together because a single company is often involved in both A/E and R&D activities.

Direct Combustion

American Fyr-Feeder Engineers
1265 Rand Road
Des Plaines, IL 60026
312-298-0044

Atlas Boiler & Equipment Co.
W. 29 Spokane Falls Blvd.
Spokane, WA 99211
503-747-6001

Automated Combustion
P. O. Drawer 9
Lake Oswego, OR 97304
503-636-4569

Babcock & Wilcox Company
20 S. Van Buren Avenue
Barberton, OH 44203
216-753-4511

Bagot (Herman) and Company
3143 N. Nottingham
Chicago, IL 60634
312-637-6037

Basic Environmental Engineering, Inc.
21 Hill Street
Glen Ellyn, IL 60137
312-469-5340

Bigelow Company
P. O. Box 706
New Haven, CT 06503
203-772-3150

Bumstead Woolford Company
P. O. Box 448
Woodinville, WA 98072
206-485-9646

Burnham Corporation
P. O. Box 27
Lancaster, PA 17604
717-397-4701

Burt Power Inc.
6405 New Tampa Highway
Lakeland, FL 33802
813-876-5329

Combustion Engineering, Inc.
900 Long Ridge Road
Stamford, CT 06902
203-688-1911

Copeland Systems, Inc.
200 Spring Road, Suite 300
Oak Brook, IL 60521
312-654-2820

Detroit Stoker Company
Monroe, Michigan 48161
313-241-9500

Eclipse Lookout Company
P. O. Box 4756
Chattanooga, TN 37405
615-265-3441

Energex, Ltd.
P. O. Box 4208
North Portland, OR 97208
503-286-8231

Energy Control Engineering Corp.
P. O. Box 3064
Charlotte, NC 28203
704-375-1701

Energy Products of Idaho
P. O. Box 153
Coeur d'Alene, ID 83818
208-667-6439

Environmetrix
4725 University Way NE
Seattle, WA 98115
206-524-6350

Direct Combustion (Continued)

European Woodworking Machinery Co.
P. O. Box 452
Franklinton, NC 27525
919-494-7455

Foster Wheeler Energy Corporation
110 South Orange Avenue
Livingston, NJ 07039
201-533-1100

Gaskell Company, Inc.
P. O. Box 13225
Memphis, TN 38113
901-775-3222

Harvey Engineering and Manufacturing Corp.
Route 2, Box 478
Hot Springs, AR 71901
501-262-1010

Industrial Boiler Company
221 Law Street
Thomasville, GA 31792
912-226-3024

International Boiler Co.
E. Strousburg, PA 18301
717-421-5100

Irvington-Moore Division of USNR
P. O. Box 40666
Jacksonville, FL 32203
509-747-7965

Johnston Boiler Company
Ferryburg, MI 49409
616-842-5050

Keeler (E.) Company
238 West Street
Williamsport, PA 17701
717-326-3361

Kewanee Boiler Corporation
101 North Franklin Street
Kewanee, IL 61443
309-853-3541

Kipper and Sons Engineers, Inc.
2616 Western Avenue
Seattle, WA 98121
206-622-4545

Lamb-Grays Harbor Company
Hoquiam, WA
206-532-1000

Lasker Boiler & Engineering Corp.
3201 S. Wolcott Avenue
Chicago, IL 60608
312-523-3700

Marden, Inc.
3129 E. Washington Avenue
Madison, WI 53704
608-244-3331

McBurney Corporation
P. O. Box 47848
Atlanta, GA 30362
404-448-8144

McConnell Industries
Box 26210
Birmingham, AL 35226
205-942-3321

Mechanical Equipment Company
7212 Woodlawn Avenue, NE
Seattle, WA 98115
206-523-8526

Moore-Oregon-Canada
P. O. Box 4208
Portland, OR 97208
503-286-8231

Direct Combustion (Concluded)

Peabody Engineering Company
Stamford, CT
203-327-7000

Peabody Gordon-Piatt, Inc.
Box 650
Winfield, KS 67156
316-221-4770

Pyrotechnic Industries, Ltd.
Box 629
Cochrane, Alberta, Canada
403-932-2274

Ray Burner Company
1303 San Jose Avenue
San Francisco, CA 94112
415-333-5800

Riley Stoker Company
9 Neponset Street
Worcester, MA 01613
617-852-7100

Rogers (John) Co.
4605 Illinois Avenue
Louisville, KY 40213
502-458-5400

Seattle Boiler Company
5237 Marginal Way
Seattle, WA 98134
206-762-0737

Smith (Perry) Co., Inc.
P. O. Box 21282
Chattanooga, TN 37421
615-982-7130

Stearns-Roger, Inc.
P. O. Box 5888
Denver, CO 80217
303-758-1122

Steel Craft Corporation
Box 12408
Memphis, TN 38112
901-452-5200

Vogt (Henry) Machine Company
P. O. Box 1918
Louisville, KY 40201
502-634-9411

Woodamation, Inc.
P. O. Box 1365
Chalmette, LA 70044
504-279-1010

Wyatt Engineers, Inc.
3214 16th Avenue, SW
Seattle, WA 98134
206-682-2501

York-Shipley Inc.
P. O. Box 349
York, PA 17405
717-755-1081

Zurn Industries, Inc.
2214 West 8th Street
Erie, PA 16512
814-455-0921

Gasification

Alberta Industrial Development, Ltd.
1704 Cambridge Building
Edmonton, Alberta, Canada T5J 1R9
403-429-4094

Garrett Energy Research & Engineering
Box 21
Claremont, CA 91711
714-593-7421

Monsanto Enviro-Chem Systems, Inc.
800 N. Lindburgh Blvd.
St. Louis, MO 63141
314-694-1000

Nichols Engineering & Research Corporation
Homestead and Willow Road
Belle Mead, NJ 08502
201-359-8200

Occidental R&D Company
10889 Wilshire Blvd.
Los Angeles, CA 90024
213-879-1700

TechAir Corporation
2231 Perimeter Park, Suite 16
Atlanta, GA 30341
404-458-9096

Union Carbide Corporation
270 Park Avenue
New York, NY 10017
212-551-2345

Weyerhaueser Company
Tacoma, WA 98041
206-259-0425

Densification

Agnew Environmental Products
211 S. E. 10th P. O. Box 1168
Grants Pass, OR 97526
503-479-3396

Bio-Solar Corporation
P. O. Box 762
Eugene, OR 97401
503-686-0765

Bonnot Company
805 Lake Street
Kent, OH 44240
216-673-5829

California Pellet Mill Company
1800 Folsom Street
San Francisco, CA 94013
415-431-3800

Fourply, Inc.
P. O. Box 890
Grants Pass, OR 97526
503-479-3301

Guaranty Performance Co., Inc.
P. O. Box 748
Independence, KS 67301
316-331-0027

Hobbs (C. B.) Company
Elk Grove, CA 95624
916-685-3925

Papakube
931 East Harbor Drive
San Diego, CA 92101
714-231-1490

Sprout Waldron and Co., Inc.
Muncy, PA 17756
717-546-8211

R&D and A/E Firms

British Columbia Research
3650 Wesbrook Ma.
Vancourver, BC V6S2L2
604-224-4331

Brown and Root, Inc.
4100 Clinton Drive
Houston, TX 77020
713-676-3011

Can-Am Sales Corporation
P. O. Box 158
Skaneateles, NY 13152
315-685-5611

Combustion Equipment Assoc., Inc.
555 Madison Avenue
New York, NY 10022
212-980-3700

Combustion Power, Inc.
1346 Willow Road
Menlo Park, CA 94025
415-324-4744

Energy Resources Co., Inc.
185 Alewife Brook Parkway
Cambridge, MA 02138
617-661-3111

Forest Fuels, Inc.
7 Main Street
Keene, NH 03431
603-357-3311

Kemp Reduction Corporation
2410 Anacapa Street
Santa Barbara, CA 93105
805-966-7556

Main (Charles T.) Inc.
Prudential Center
Boston, MA 02199
617-262-3200

Nor'west Pacific Company
Plaza 600 Building
Seattle, WA 98101
206-623-7224

Pope, Evans and Robbins
320 King Street
Alexandria, VA 22314
703-549-2884

Pyrotek, Inc.
2716 South Grand Avenue
Santa Ana, CA 92705
714-979-2075

Rust Engineering, Inc.
1130 22nd Street
Birmingham, AL 35205
205-254-4000

Ultrasystems, Inc.
2400 Michelson Drive
Irvine, CA 92715
714-752-7500

Wheelabrator Clean Fuel Corp.
1700 K Street, NW
Washington, DC 20036
202-296-5173

Wood Energy Institute
Box 1, Fiddlers Green
Waitsfield, VT 05673
802-496-2508

Wood Fuel System Users

Densification

Applied Engineering Company
Box 1337
Orangeburg, SC 29115
(803) 534-2424

Collins and Aikman
701 McCullough Drive
Charlotte, NC 28232
(704) 596-8500

Edward Hines Lumber Company
Hines, OR 97738
(503) 573-2091

Minnesota, State of
Department of Corresctions
Metro Square Building
Seventh and Robert Streets
St. Paul, MN 55101
(612) 296-3529

Sierra Power Corporation
9893 N. Blockstone Street
Frenso, CA 93710
(209) 439-6601

Pyrolysis

California, State of
Solid Waste Management Board
P.O. Box 160908
Sacramento, CA 95810
(916) 322-3330

Maryville College
Maryville, TN 37801
(615) 982-6412

Pyrolysis (continued)

Rockwell International
Marysville, OH 43040
(513) 644-3015

Weyerhaueser Company
Tacoma, WA 98401
(206) 259-0425

Gasification

Interpine Lumber Company
Picayune, MS 39466
(601) 798-5912

Kearsarge Reel Company
Warner, NH 03278
(603) 938-2266

Direct Combustion*

American Fyr-Feeder Engineers
1265 Rand Road
Des Plaines, Il 60026
(312) 298-0044

Ray Burner Company
1303 San Jose Ave.
San Francisco, CA 94112
(415) 333-5800

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*These companies are among many which will provide on request lists of facilities using wood-fired boiler equipment.

APPENDIX B

CAPITAL AND OPERATING COSTS FOR WOOD-FIRED PROCESS STEAM GENERATION AND LOW-BTU GASIFICATION

APPENDIX B

TABLE B-I

CAPITAL AND OPERATING COSTS FOR WOOD-FIRED PROCESS STEAM GENERATION

PLANT SIZE	155,000 lb/hr	386,660 lb/hr
Front End	.73	1.50
Steam Generator	3.50	6.08
Water Treatment Plant	.14	.25
HP/HT Valves	.12	.16
Control Valves	.24	.40
Control Panels	.20	.20
Transducers	.20	.20
Condenser	.16	.35
G.P. Valves and Pumps	.06	.10
Cooling Tower	.50	.11
Mechanical	.55	1.30
Electrical	.60	1.50
Instruments and Controls	.55	1.20
Supplementary Fuel System	.03	.06
General Construction	2.00	3.50
Site Preparation	.41	17.61
Engineering and Fee 10%	.92	1.75
Commissioning and Contingency	1.52	2.89
Working Capital	1.10	2.21
TOTAL CAPITAL COST	12.80	24.37

TABLE B-I

CAPITAL AND OPERATING COSTS FOR WOOD-FIRED PROCESS STEAM GENERATION (Concluded)

PLANT SIZE	155,000 lb/hr	386,660 lb/hr
<u>OPERATING AND MAINTENANCE COSTS</u>		
Direct Labor Cost	.20	.40
Labor Related Cost	.20	.40
Other Utility Cost	.13	.25
Maintenance Cost	.55	1.16
Miscellaneous Equipment Repair Cost	.35	.50
TOTAL ANNUAL COST	1.43	2.81

TABLE B-II

CAPITAL AND OPERATING COSTS FOR PRODUCING LOW-BTU GAS

ITEM OF COST	
Feed Capacity, ODT/day	850
Plant Fuel Gas Output - Btu/day	0.939×10^{10}
CAPITAL COSTS	
Front End Process	1.50
Shaft Furnace	.50
Electrostatic Precipitator	.28
Product Gas Compressor Unit	.50
Product Gas Condensing Unit	.10
Oil Separator	.05
Storage	.20
General Mechanical and Plumbing	.20
Process Controls and Instrumentation	.04
Plant Services - Air, Water, etc.	.02
Electric Supply and Distribution	.50
Cooling Tower and Water Treatment	.60
Buildings and Structures	.30
Site Development	.17
Engineering and Fee - 10%	.50
Commissioning and Contingency @15%	.82
Working Capital	.62
TOTAL CAPITAL COST	6.90

TABLE B-II

CAPITAL AND OPERATING COSTS FOR PRODUCING LOW-BTU GAS (Concluded)

<u>OPERATIONS AND MAINTENANCE COST</u>	
Direct Labor Cost	.85
Labor Related Costs	.80
Power Cost	.25
Other Utility Cost	.20
Maintenance Cost	.35
Miscellaneous Equipment Repair Cost	.06
TOTAL ANNUAL COST	2.51

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