Energy Properties of Wood

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ABSTRACT

Wood is an alternative source of energy that will not displace fossil, nuclear or other renewable sources. However, it can provide 7-10% of our total needs. There is some question about current usage of wood fuels, but DOE has recently published some definitive figures. For 1981, these are 0.820 quad in residential applications, 0.016 quad commercial, 1.374 quad industrial and 0.001 quad utility. This amounts to 2.211 quads and is in line with Forest Service estimates.

The Forest Service estimate of unused wood suitable for fuel uses produced annually is 600 million dry tons. Of this, perhaps one-half would harvestable at a cost of $35 to $40 per overdry ton. This would amount to 5.1 additional quads.

There are various ways in which wood might be used for energy purposes. Direct burning of wood is a simple and efficient, and is the way in which almost all energy from wood is produced now. Minor amounts of wood are converted to improved fuels by charcoaling and densification processes. Pyrolysis, gasification, and lique faction processes are promising for the future.

At the Forest Products Laboratory we are studying improvements for using wood in direct burning applications, conversion of wood to alcohol and petrochemical substitutes, conservation of energy in processing forest products, and uses of wood in solar energy applications. Previously, we have also worked in conversion of wood to charcoal and to briquettes and pellets.

We have made good progress in our major effort to develop optimal technology for production of ethanol from wood in the near term. We are recommending a process that we believe is best suited for making ethanol from hardwoods today, and we are continuing to work on Process improvements. We are also persuing the production of other energy chemicals and petrochemical substitutes from wood.

Our second priority for energy production research at FPL is expansion of our effort on belter combustion processes, with particular emphasis on combustion kinetics. We will also continue to place major emphasis on conservation of energy through improvements in wood processing and application.

Introduction

In the six years that I have worked on wood as a source of energy, there have been many questions raised, and we have done our best to supply some answers. Unfortunately, the answers have been fewer than the questions, and on different days we may have given different answers to the same questions.

Some of the most persistent questions have been (1) What happens to forest soils if we increase the biomass removed during the harvest? Or, if we remove the above-ground biomass, will the soils be depleted? (2) How much wood is available or can be made available for energy? (3) How much energy is being obtained from wood now? (4) How can wood be converted to motor fuel? (5) Is densified wood economical? (6) How about using wood ash for fertilizer? (7) What is the best wood stove to use to heat my home? (8) How many British thermal units (Btu) are there per pound in pussy willow or another minor species? (9) How many tons of wood can be grown per acre per year? (10) How can we help developing countries improve their fuelwood supplies? (11) How can I burn wood safely? (12) How can the costs of using wood for fuel be reduced?

Knowing the Resource

Current Usage

Fundamental to finding answers to questions on using wood for enerqy is an analysis of the current consumption of wood for this purpose. Loqically, one might expect to find pertinent statistics on this subject in publications by the Department of Energy (DOE). Unfortunately, up to several months ago this was not the case.

DOE has published and still publishes a Monthly Energy Review that is designed to provide a running record of energy production, consumption, and cost by type of fuel and end-use sector. It provides a good rundown for coal, natural gas, petroleum, and hydro-electric power. Wood is included under "other energy." This means that wood used for production of electricity is factored into the statistics, but wood used for residential heating and industrial boiler fuel is not. Only 0.127 quad in the "other energy" category was reported in 1981. DOE has recognized the deficiency in reporting wood for energy figures, and recently they have made a start in improving the statistics. In august 1982 they published an extensive report on "Estimates of U.S. Wood Energy Consumption from 1949 to 1981" including the total wood energy consumption estimates by sector for 1949 to 1981 from this publication (table 1) (7).[1]/

The total of 130,018,000 dry tons of wood consumed for energy in 1981 is equivalent to 130,018,000 x 17,000,000 = 2.2 quads of energy. This is significantly higher than the estimates we have been using. In "A National Energy Program for Forestry," we estimated that about 1.3 quads of energy used annually in the United States comes from wood and wood byproducts (5).

Let us take a closer look at each of the sectors individually and the figures that DOE reports for them in 1981.

Residential	$48{,}215 \times 10^{3} \times 17 \times 10^{6} =$	0.820 quad
Commercial	$920 \times 10^{3} \times 17 \times 10^{6} =$	.016
Industrial	$80.798 \times 10^{3} \times 17 \times 10^{6} =$	1.374
Utility	$85 \times 10^{3} \times 17 \times 10^{6} =$	.001
		2.211 quads

Compared to the residential and industrial sectors, consumption of wood for energy in the commercial and utility sectors is relatively insignificant.

This agrees with past analyses we have made. A report we sponsored in cooperation with the National Science Foundation and the Federal Energy Administration in 1975 indicated that about 0.924 quad of energy from residue or process waste was consumed by the forest products industry (4). This compares with the DOE statistics of

$$61{,}818 \times 10^{3} \times 17 \times 10^{6} = 1.051 \text{ quad for 1975.}$$

For residential fuelwood usage, we have been using figures that are about 50 percent or less of the DOE figure for 1981. The DOE figure for 1975 is 51 percent of the DOE 1981 figure for residential. In "A National Energy Program for Forestry," we indicate 0.3 quad for residential and 1.0 quad for forest industries.

I conclude that the D0E analysis provides a good estimate of the wood use for fuel situation today, I would like to have your thoughts on this.

Available Material

If we understand the situation on wood usage for energy, perhaps a more pressing question is how much wood could we or should we be using for energy? The publication, "A National Energy Program for Forestry: contains the estimates of unused wood available for energy (table 2) (5).

Given the estimates of unused wood available, we have tried to determine what might be economically available. We arbitrarily chose 50 percent as being harvestable and usable at costs of $30 to $40 per ovendry ton. This would mean 300 million additional dry tons or 5.1 additional quads. In addition to the existing 2.2 quads, this would total 7.3 quads from wood or about 9 percent of a total annual usage of 80 quads. A figure we have used in the past for the potential fraction of our energy that might be obtained from wood is 7 percent. Other estimates have ranged up to as much as 20 percent.

Wood for Fuel

Let us look next as how we might use wood for energy to best advantage. We are most interested in how wood can be converted to energy with minimum waste of heat and with maximum ease in handling. These goals are usually incompatible with one another, and compromises are therefore necessary. Direct burning of wood is often most efficient for energy recovery, but conversion of wood to a liquid fuel makes it easier to handle and more suitable for use in an internal combustion engine.

Direct Burning

We saw previously that the bulk of our use of wood for energy is in the industrial sector. This is primarily the use of black liquor from the kraft pulping process and hog fuel burned in various types of boilers. A few utilities around the country also burn hog fuel as chips in boilers for steam to run turbines. Some schools use green sawdust in special sawdust burners. Residential usage is based mostly on the burning of short logs in fireplaces, stove, and furnaces.

1/ Underlined numbers in parentheses refer to literature cited at end of this report.

Some current applications of wood used for fuel are certainly cost effective, especially in industrialized countries such as the United States. In some developing countries, on the other hand, wood is used for fuel at great sacrifice. In these countries, family members sometimes spend most of their waking hours gathering wood for cooking fuel at distances up to 50 kilometers from their homes, or they spend hard cash, of which they have very little, to buy charcoal. In the other extreme, John Hornick and I recently visited the Jari pulpmill in Brazil where wood fuel means the difference between being able to stay in business or having to close down.

The Jari pulpmill and the entire community is powered by electricity generated by a 55-meqawatt plant. This is the largest electrical generating plant powered by wood. Generation of electricity requires 2,000 green tons of wood per day at a cost of $12 per green ton. If oil had to be used instead of wood, the cost for fuel would be four times as much. For industries in the United States, wood at $65 per green ton could probably compete with oil at $1.20 per gallon.

With representatives from the Southern Forest Experiment Station, the Forest Service Washington Office, and the University of Idaho, FPL produced a comprehensive report for the U.S. Agency for International Development (AID). The report, "Forestry Assistance and Deforestation Problems in Developing Countries," provides information on assistance to developing countries on forestry problems most often related to overcutting for fuelwood (8).

Wood can certainly be a money saver for residential heating. I recently talked to a man from Antigo, Wisconsin, who heats his home with a wood-burning furnance. To fire this furnace, he buys pulpwood in 100-inch lengths, mostly maple, at $40 per cord. He crosscuts and splits this wood and stores it to dry for about the length of a heating season. This man, too, finds that he saves much money compared to what it would cost him for heating oil.

Pyrolysis of Wood-to-Liquid, Solid and Gaseous Fuels

Work at FPL on pyrolysis of wood-to-liquid, solid and gaseous fuels has always been limited to a minor research effort and, in recent years, has been restricted to servicing requests for information on charcoal production and use.

The FPL research on charcoal has dealt with byproduct recovery plant practice, continuous distillations of wood fines, and the adaptability and use of masonry-block kilns in the range of 3 to 10 cords' capacity (3). Twelve such experimental kilns were built in Collegeville, Minnesota; Three Lakes, Wisconsin; Milwaukee, Wisconsin; Marquette, Michigan; Elizabethtown, North Carolina and Athens, Georgia.

During World War II, FPL had a research project on gas generators (commonly called gasogens) for motor vehicles. A gasogen was designed, constructed, and fitted to a 2-ton truck. The machine was road tested, and performance data were published.

Densified Wood Fuels

During the past few years, there has been a tremendous interest in wood pelleting or briquetting to densified wood fuels. Unfortunately, there has not been a concomitant record of successful commercialization of this idea. Pellet plants of 300-ton-per-day capacity have been in and out of operation. There have been problems with rapid wear of pellet dies and crumbling of pellets when exposed to moisture or even during ordinary storage. Today I only know of several plants operating in northern Wisconsin and Minnesota and a rather extensive operation by Shell in Canada.

Even considering the savings evident from using wood as an alternative fuel now, the benefits we might achieve in the United States in a relatively short time of ten years or less could be four times what it is. But to accomplish this will require the cooperation of us in research and extension supported by adequate government and industry programs. It also requires that we take the necessary steps to ensure that the additional use of wood for energy will not cause any undue adverse environmental impacts.

Past research at Forest Products Laboratory (FPL) and elsewhere has contributed significantly to our knowledge and application of the energy properties of wood. But there is a crying need to improve this situation if we are to attain the extensive economic benefits from increased use of wood fuels, let alone the benefits of improved forest management from cleanup of waste and cull forest biomass.

Chemicals from Wood

Energy Chemicals

A major area of emphasis in the FPL Energy Research, Development and Application Proqram has been the production of energy chemicals from wood. This is a logical development, since FPL researchers have long been at the forefront in the development of basic information for production of energy chemicals and chemicals that are suitable alternatives to those produced from petroleum. In the past, some of the chemicals in these categories produced by FPL-developed technology were ethanol, furfural and glycerol. The so-called Madison process for ethanol production from wood was the basis for a plant built in the United States during World War II. Other similar plants were built in Russia and are still operating. Demonstration plants are now planned for Brazil. It has been reported that a pilot plant is to be constructed in Arkansas.

Early in 1980, in response to a national commitment for producing alternative fuels from biomass, a plan was developed to initiate a new ethanol research program based on the concept of increasing sugar yield by a two-stage hydrolysis. To utilize the basic research skills of FPL for establishing technology that could be implemented in the short run, a cooperative agreement was made with the Tennessee Valley Authority (TVA). This agreement provides for the application of engineering design skills of the TVA to conceiving and constructing pilot and commercial plants on the basis of jointly developed technology. The research has progressed to the definition of a process for optimal production of ethanol from low-grade hardwoods in the TVA area. Plans are now to proceed with the construction of a pilot plant based on this knowledge, although projected yields of alcohol from the hardwood feedstock are low. Ultimately, with a viable process for making ethanol from wood, up to 10 percent of the Nation's fuel, now supplied by gasoline) could come from wood. This would be equivalent to 1.38 quads.

Another project for utilization of low-grade hardwoods for chemicals and pulp has just been initiated in cooperation with the University of Wisconsin. The objective of this research is to determine whether hydrolysis preceding kraft pulping can reduce the chemical requirement for pulping and reduce processing in the chemical recovery furnace while generating useful pulps. Possible products include acetic acid, hemicellulose-derived sugars, and furfural. Wood species being used are white birch and red oak. Besides answering questions on the suitability of prehydrolysis for kraft pulping, the research will also provide improved analytical methods for acetic acid and other acetyl compounds and basic information on reactions involved in the two-stage saccharification process.

In cooperation with Dartmouth College, we are conducting other research to facilitate use of the two-stage saccharification Process. This work *will* develop basic information on rheology of prehydrolyzed lignocellulose and lignocellulase suspensions in order to understand how to pump these suspensions through an acid hydrolysis process in a cost-effective way. Variables under study are (1) ratios of solids to liquid, (2) degree of prehydrolysis, (3) particle size and shape and (4) temperature.

At Mississippi State University, we are completing a cooperative research program to utilize byproducts from the two-stage saccharification process. This work will explore production of glycolic, succinic, acetic and formic acid from the wet oxidation of process waste and byproduct streams.

Another cooperative research project at the University of Wisconsin will make an economic assessment of available technology for saccharification of wood, with emphasis on two-stage, dilute acid hydrolysis. Ethanol for motor fuel and industrial alcohol will be assessed and compared to other alternative products. The study will become a part of continuing assessments of the overall objective of producing fuels and chemicals from woodwaste and will assist in optimizing the program.

Alternative Source for Adhesives

One of the most promising areas for substituting wood-derived chemicals is in adhesives used by the forest products industry. A limited inhouse and extramural program on wood-based adhesive manufacture and use is being conducted by the FPL Improved Adhesive Systems Research Work Unit.

Alternative Sources for Petroleum-Derived Materials

The FPL Improved Chemical Utilization of Wood Research Work Unit has a continuing assignment to find and develop processes for recovery of chemical products from carbohydrates in pulping waste streams and production of chemicals from softwood resins. The FPL Microbial Technology in Wood Utilization Research Work Unit has made important discoveries in modification of lignin by microbiological means and in the fermentation of pentosans. These pathways may also lead to production of petrochemical substitutes from wood.

Wood in Solar Energy

Design of Wood Buildings

Wood construction offers more design flexibility in accommodating active and passive solar heating than does construction of more massive materials such as brick and concrete masonry. Frame houses usually are more readily insulated, and they are more adaptable to active and passive *solar* heating. FPL has developed some pace-setting house designs for attaining energy efficiency through use of passive solar concepts. Passive solar energy saving techniques used and demonstrated include site orientation and fenestration to benefit from southern exposure to the sun and northern shielding from the elements, overhangs, and plantings to utilize direct solar radiation in the winter and shade the sun in.the sumner and ridge ventilation for summer heat control.

Wood Equipment Components

In response to many questions raised on the suitability of wood as a material for use in solar collectors, FPL tested wood and plywood collectors with varying design characteristics and published a report on collector performance (2).

Solar Drying of Lumber

The seasoninq of wood is a substantial use of energy in the production of lumber and has been the subject of much research aimed at reducing its cost. Among the approaches has been the development of solar kilns and more extensive use of air drying.

Different solar dry kiln designs have been developed and tested v FPL. All of them have disadvantages of being significantly slower than normal kilndrying operations. This slow-down has been unacceptable to U. S. operations, which are geared to high output, but developing countries generally have more readily available labor and are not as concerned with productivity per employee hour. As a result, FPL-designed solar lumber kilns have been or will be built in Sri Lanka and Indonesia, and other developing countries are interested in them. FPL has also designed a solar dry kiln for the occasional user of small quantities of seasoned wood. These kilns are being built and used by wood hobbyists in the United States.

The September 1982 issue of the Forest Products Journal (1) has an article on an experimental solar-dehumidifier kiln developed by researchers at the North Central Forest Experiment Station, at the Forestry Sciences Laboratory, and the Department of Thermal and Environmental Engineering of Southern Illinois University, and at Kimberly-Clark. It was found that solar-dehumidification dried wood faster with less drying degrade than did solar drying. Energy costs for the solar-dehumidifier kiln were only 82 percent of those for solar drying.

Wood Energy in Wood Processing

Papermaking

Since artificial drying of wood is very energy intensive, wood-seasoning research to increase process efficiency has a high payoff in reduction of energy required and in improved quality control.

In the production of paper the drying process is one of the most energy-intensive elments. FPL has made an important breakthrough in the reduction of energy needed in the manufacture of paper from hardwoods or softwoods with a press-drying process. Press drying can save about 19 percent of the total energy required by the conventional papermaking process. If all paper except tissue were made by this process, 229 trillion Btu's per year could be saved.

Other papermaking research at FPL could have an additional impact on the energy consumed in manufacturing paper by the groundwood process. The groundwood process, even in the portion of the forest products industry that is most energy-intensive, is somewhat more energy demanding. However, work at FPL has shown how substituting a refining process combined with grinding could save significant amounts of energy. Coarse grinding followed by refining could save 20 percent of the total energy used. If 20 percent of the energy used in production of groundwood paper could be saved each year, this would amount to an additional 13.6 trillion Btu.

Additional wood-processing research, even if it results in only a modest 2 percent energy reduction, would save apoproximately 50 trillion Btu in the United States every year.

processing, Transporting and Storing Residues

FPL participated in an onsite study of forest and primary manufacturing residues and fuel requirements of paper-manufacturing plants (6). This study, in cooperation with the North Central Station Forestry Sciences Laboratory, Houqhton, Michigan, provided a site-specific example of forest industry wood fuel use in the Upper Peninsula of Michigan and northern Wisconsin. An extensive report "Forest Residues Energy Program" was published.

Priorities for Future Research

We have made good progress in our major effort to develop optimal technology for the production of ethanol from wood in the near term. We are recommending a process that we believe is best suited for making ethanol from hardwoods today, but there are a number of other problems remaining. Solutions to these problems could significantly change the viability of an ethanol -fromwood process over the long term. Our first priority is, therefore, continuation of the ethanol (and other organic fuel chemicals-from-wood research with the objective to provide a more efficient process for future use. Important research considerations fare the possibilities for production of energy chemicals in conjunction with other manufacturing operations such as pulping, high-temperature chemical fractionation of wood, solvent (aliphatic and aromatic) rielignification of wood, hydrolysis catalysts other than dilute sulfuric acid, saccharification in inert aromatic solvents, and utilization of softwoods instead of hardwoods to obtain higher yields. We propose, however, to shift the emphasis in our research program in this area from primary focus on ethanol production perse to a stronger focus on the related chemical reactions basic to production of a broad array of chemicals from the various major constituents of wood including biotechnological approaches. This would include energy chemicals.

Our second priority for energy research at FPL is expansion of the effort on better combustion processes. Our research is aimed primarily at obtaining basic information on combustion kinetics. Direct combustion of wood for production of heat is the most efficient way to produce energy from wood. Important research considerations beyond the combustion operations themselves are pollution control and optimal use of the heat generated throuqh cogeneration and other conservation practices.

As has already been noted, research in energy conservation has a potential for dramatic contributions to meeting our energy needs. Research in energy conservation in wood processing and use will be carried forward as an integral part of broader research programs in wood engineering, processing of solid wood and wood fiber, and wood preservation.

Also contributing significantly to meeting energy needs could be research on pyrolysis (gasification) and production of methanol. Gasification of wood and production of methanol has the potential for becoming a preferred pathway for conversion of wood to liquid fuel. The main difficulty is the production of synthesis gas. Much equipment developmental work on research is needed to obtain a reliable wood gasifier. FPL does not have scientists with experience in this area of research or equipment needed for development of the gasification process. The expense of gearing up for this work would be much higher than for continuation of work in ethanol and related fuels and direct combustion.

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Past Research: Improved performance of wood in light-frame construction; use of wood light-frame construction in conjunction with conventional and solar heating and cooling systems.
Current Research: Conversion of wood to fuel alcohol and other chemicals; wood combustion fundamentals; wood gasification.

Courtesy Georgia Forestry Commission

Table 1. --Total wood energy consumption estimates by sector for 1949 through 1981

Year	Sector				Total
	Residential	Commercial	Industrial	Utility	
	1,000 tons				
1949	61,348	1,162	27,226	359	90,095
1950	58,461	1,109	30,944	359	90,873
1951	55,710	1,058	32,147	383	89,298
1952	52,277	995	32,073	461	85,806
1953	48,369	915	32,901	352	82,537
1954	46,497	882	33,500	161	81,040
1955	45,062	855	36,694	171	82,782
1956	42,948	815	38,454	85	82,302
1957	40,803	775	35,839	85	77,502
1958	40,026	761	36,026	74	76,887
1959	37,612	715	40,231	46	78,604
1960	36,432	690	39,527	49	76,698
1961	34,120	648	40,431	46	75,245
1962	32,563	618	42,336	56	75,573
1963	31,219	591	45,049	60	76,919
1964	29,015	550	48,066	58	77,689
1965	27,218	515	49,706	81	77,520
1966	26,452	501	52,437	103	79,493
1967	25,231	484	52,015	77	77,807
1968	24,739	473	57,090	93	82,395
1969	24,131	457	58,967	80	83,635
1970	23,301	438	59,239	139	83,117
1971	22,202	418	60,465	114	83,199
1972	22,080	418	64,690	141	87,329
1973	20,587	390	67,724	141	88,842
1974	21,567	408	67,388	75	89,438
1975	24,733	469	61,818	11	87,031
1976	28,002	529	70,923	49	99,503
1977	31,499	598	74,491	133	106,721
1978	36,154	688	81,420	54	118,316
1979	42,330	803	81,678	115	124,926
1980	47,543	903	80,439	93	128,978
1981	48,215	920	80,798	85	130,018

Table 2. --**Estimated unused wood available annually for energy in the United States**[1/]

	Forest biomass	
	Weight	Energy
	Million dry tons	Quads
Forest		
Harvest sites		
Logging residues from growing and nongrowing stock	160	
Standing live and dead trees	20	
Commercial forest land		
Excess growing stock	215	
Mortality	95	
Total, forest	490	8.3
Urban		
Tree removals and wood wastes	70	1.2
Other		
Forest products industrial waste	20	
Waste wood from land clearing	20	
Total, other	40	.7
Total, all sources	600	10.2

1/ Based on resource data from Forest Statistics of the United States, 1977, U.S. Department of Agriculture, Forest Service.

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