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ON THE USE OF WOOD AS AN ENERGY SOURCE IN THE STATE OF MAINE

T. von Foerster
Harvard University
Energy and Environmental Policy Center

MASTER

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REGIONAL STUDIES DIVISION
NATIONAL CENTER FOR ANALYSIS OF ENERGY SYSTEMS

DEPARTMENT OF ENERGY AND ENVIRONMENT

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ABSTRACT

We present a detailed study of the availability and use of wood as an energy resource for the State of Maine. Although there are no good data on the total resources of Maine's forests, the best estimates indicate that one could obtain about 1/2 quad (10^{15} BTU) per year from thinning overstocked stands and harvesting dead trees; current logging operations could produce about the same amount of energy in the form of logging residues and thinnings, an amount that could be increased manyfold by intensive forest management. The costs of wood for fuel can be estimated on the basis of current logging and transportation costs. The corresponding energy prices, while high, are competitive with current fossil fuel prices.

Using any energy source requires not only the fuel but also a furnace. The total energy costs are thus not only the cost of current fuel use but also those of the capital investment in the furnace. We have estimated these for systems of two sizes, one for a small house, the other for an apartment building or small commercial establishment. In both cases, our estimated indicate, that wood-fueled systems can be economically competitive.

Wood is currently used as a fuel on a large scale in the pulp and paper industry. With some increase in wood harvesting efforts and some alterations of furnaces that industry could achieve energy self sufficiency. Other large-scale uses are still speculative but deserve further investigation. A state-owned energy corporation could serve to provide a market for currently wasted wood and to investigate the conversion of wood to other forms of energy.

The combustion of wood is not associated with environmental effects that are different in kind or in magnitude from those associated with the combustion of fossil fuel.

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CHAPTER I

INTRODUCTION

There is no doubt that Maine has a lot of wood. There are roughly seventeen million acres of land sufficiently productive to be classed as "commercial forest" land, or about 86% of the total area of Maine. On that land stand about two thirds of a billion tons of wood (above ground), which, if it were burned with 50% efficiency, would yield about six quadrillion BTU of energy (6×10^{15} Btu, or six "quads"). That is about twenty times the total energy used in Maine in 1974, and about three times the annual energy use in New England. Needless to say, no one could reasonably expect Maine's forests to be cut down over the next few years to supply New England or Maine with energy. However, even the sustainable yield of Maine's forests is enormous. The rate at which the forests become fully enough stocked to harvest for energy has been estimated variously between twenty and fifty years, which is a growth rate of two to five percent. It would thus, in principle, be possible to supply at least one third of Maine's current energy needs from wood alone. Given the amount of nuclear and hydroelectric generating capacity installed already, Maine could thus be a net exporter of energy instead of importing thousands of barrels of oil per year. This, again, is of course not a reasonable prospect, since there are many other, more valuable, uses for much of Maine's wood. The magnitude of the numbers involved, however, should serve as an indication of the magnitude of the potential.

The potential of Maine's forests was recognized very early. The first sawmills in the British colonies were established in Maine in 1631. England was by then thoroughly deforested, forcing her to rely on coal as a fuel and to import much of her lumber. By the late seventeenth century England was relying almost entirely on her American colonies for lumber for construction as well as shipbuilding, reserving the finest logs for masts for the Royal Navy. The colonists relied on the same forests for construction lumber and for fuel. Construction practices adequate for the comparatively mild English winters do not provide for much insulation against a New England winter, and it took a lot of wood to heat one of those houses. And thus the pressure on the forests was such that local shortages began to appear as early as 1720.

In spite of occasional local difficulties--which could always be solved by bringing wood from farther away—the colonists and the mother country used the forests rapaciously, so vast did they seem. The prodigal use of wood astonished many visitors from England and Europe, used to considering lumber as a rare and precious resource to be carefully husbanded; one of them wrote that he "worried lest farmers....not be taught how to manage their forests so as to leave for their grandchildren a bit of wood wover which to hang their kettle."

By the twentieth century, conventional wisdom has it, Maine's forests had been clear cut twice: once for ships and lumber, once for fuel. The current status of Maine's forests thus represents forest management practices of about a century ago, except in those parts which have more recently been used by the lumber and pulp and paper industries. Until the early part of the twentieth century the generally accepted forest management policy in Maine and much of the U.S. was to clearcut as much as one could, and let the area reseed itself in whatever way it could. Man would harvest; God and Nature did the rest.

As the population expanded and moved west it became clear that wood could not supply the entire needs for the country. First coal, then gas and oil became necessary supplements to the fuel supply. For an increasingly energy-intensive economy and an increasingly urban population, the fossil fuels also offer some advantages over wood. Until recently their cost has been considerably lower than wood for the same amount of energy. In part this has to do with extrinsic factors such as monopolistic practices, created demand, and economies of scale, but there are intrinsic factors involved as well. Coal and oil, for example, both occupy less bulk and contain less ash than wood for the same amount of energy; they are therefore cheaper to transport and easier to use than wood. Natural gas is of course, very easy to transport via pipes and leaves no ash at all. In most places, then, when houses were converted to, or built with central heating units, they generally used one of the fossil fuels. More recently the convenience of central thermostatic control has swung the balance almost entirely over to oil and gas, where little auxiliary equipment is needed to supply fuel automatically to the furnace. It is not easy or cheap to design a machine to feed logs into a wood burning furnace when the thermostat calls for it.

The fossil fuels are also relatively easy to extract from the ground--particularly in the case of oil and gas, where a pump does all the extraction. They have, therefore, until recently been relatively cheaper than wood, for the same amount of energy, since wood required a relatively larger amount of labor and effort to cut, split, and transport. Recently, however, the dwindling domestic supply of oil and gas, the rising price of foreign oil and gas, and the rising costs of mining coal have once again made wood an economically attractive fuel. It has further attractions as well. Although it is bulky and contains a lot of ash, it contains very little sulfur and leads to little pollution, particularly if burned efficiently. It derives from a renewable resource, in that a properly managed forest will grow back to its original state, while the fossil fuels, once burned, are more or less gone forever. (They can, presumably, be reproduced only by another several hundred million years of geologic evolution.) The carbon dioxide that is produced by burning wood would have been given up to the atmosphere anyway by its decay and can be recaptured by the growth of new wood. If the total amount of carbon fixed in the forests does not change--i.e., if wood is regrown at the rate at which it is harvested--then wood burning will not increase the amount of carbon dioxide in the atmosphere. The ash, which represents nutrients removed from the ground, can, if necessary, be returned to the forest as fertilizer; the physical characteristics of the ash also make it a good soil conditioner.

Since the energy in wood comes, via photosynthesis, from the sun, burning wood can be thought of as merely another use of solar energy. The leaves or needles are the solar collector, and the tree serves as a storage tank, ready to supply to collected energy when it is needed. Considered merely as a solar collector, a forest is not very efficient, producing less than 1/10 Watt per square foot. A solar cell or solar water heater can convert to man's use at least a hundred times as much energy. But that is all it does, while a forest does much more. Energy efficiency may not be a useful criterion, particularly since the forests, unlike the solar collectors, already exist.

Standing forests provide habitat not only for trees and other plants, but also, of course, for much wildlife. The most diverse communities occur in thinned forests or near the edges of clearings and meadows, which provide food for the herbivores while the trees serve as shelter. Forests also play an important role in controlling erosion and preserving water quality. Trees and fallen leaves reduce the impact of water, roots hold the soil, and shade keeps the water in brooks and streams cool enough for fish and other aquatic life. Although these functions, and the recreational and other values they imply for humans have often been seen as incompatible with commercial uses of the forest, there seems to be no intrinsic reason why a well managed forest cannot satisfy both sets of values.

Thinning of young or overstocked stands can supply fuel or pulpwood, improves the growth of the remaining trees, and enhances accessibility to animals. Clearcutting, when properly managed, can supply lumber and pulpwood and provide meadows and clearings without disrupting the other functions of the forest. For most forests the choice is not one of remaining virgin wilderness or of becoming a devastated mess. It will take centuries of natural growth to restore the New England wilderness to its pre-colonial state: we have already been too rapacious. Nor can any lumber company expect to find another perfect forest over the next ridge of hills so that this forest can be cut, the soil disrupted, and much of the wood left to rot or burn: the forest industries must now make do with what they have and manage it as best they can.

Once cut, a tree has many uses. The structural properties of wood are unique, and make it a building material par excellence. It is only quite recently that one has been able to synthesize materials that match wood in many of its properties; the detailed strucutre of these "composite" materials is modelled on wood-fibers bound in a matrix. Sawdust and shavings can be glued together to make wood substitutes and new materials. The fibers (cellulose) from wood with much of the protein matrix (mostly lignin) removed becomes paper and similar materials. Other components, resins and turpentines, can serve as solvents or other useful chemicals, and any of the components of wood can be converted to various forms of synthetic material.

The least demanding use for wood is as a source of energy. Least demanding in the sense that the widest variety of other materials would do as well: using wood as energy uses none of the other properties of wood. There is, however, a great deal of material that is not otherwise useful: the bark, the tops and branches (becuase of their excess of bark), the trees of non-commercial species, saplings, excessively crooked or rotten trees, and dead trees. This wood is unfit for lumber, and its low fiber content or other properties make it unsuitable, or at best only marginally suitable, for pulp. Such "low grade," or unmercantable wood is always produced in the course of ordinary harvesting and is eminently suitable for fuel or as a feedstock for chemicals. There is currently no large market for wood for either use, so much of it is now left on the ground to rot or burn.

Since roughly half the growth of a forest occurs in such unmercantable wood, i.e., wood that currently has no market, this low grade wood clearly has the potential to make an important contribution to Maine's energy resources.

However, some of this wood may, in the future, find other uses. It may well be that in the future such wood can, with further processing, be used for pulp or various forms of processed wood structural materials. For the present, most of these uses require a fairly high grade input and will still leave a fair amount of wood with little use other than fuel.

Currently there is no market for "waste" wood; the cost of disposal is less than the net cost of harvesting and using it. The use of such wood for energy may, however, be a profitable enough use for waste wood that a market for it develops. If other uses are developed for waste wood, market processes can determine the most appropriate use for each kind of waste.

An energy market for wood could take many forms. The simplest to implement is the use of wood-fired stoves in homes and other small areas. These are usually fired with roundwood and can provide considerable heat cheaply, but with some inconvenience. The recent record sales of wood-stoves and price increases for firewood indicate that this part of the energy market for wood is already growing. The chipped waste wood we have considered above can be burned directly to provide central heat for apartments or commercial establishments or process heat for various industries. The pulp and paper industries already make considerable use of bark and other wastes for both the pulping process and drying the final product. The heat from burning chipped wastes can also be used to generate electricity either separately or in conjection with process heat. Or, as another alternative, the material from the wood wastes can be digested, chemically or biologically, to provide methane, methanol, or other easily transported synthetic fuel.

One can, with sufficient time and effort, construct models for such possible developments and try to guess at potential new technologies. On the basis of such models one can, with further assumptions, lay out paths for the future to follow. But the interactions between economics, technology, public policy, and private policies seem too intricate and the available facts seem too few to make such an approach feasible here. It may be best for now to ensure that the widest number of options are kept open for the future, so that the future itself can decide what it will bring. One should therefore see to it that economic incentives, laws and regulations, and public knowledge and activities, all serve to encourage the widest possible uses of the forest, from unmanaged wilderness to intensively cultivated timber land.

CHAPTER II

WOOD AVAILABILITY

The most desireable wood, and by far the largest proportion of that currently harvested, is that part of the trunk of certain species of trees that meets various minimum standards of size, freedom from defects, etc. It is called the mercantable bole. Most forest surveys record only the volume of mercantable bole, often arranged by species and size classes, since these are the figures that interest most users. As an energy resource, however, and, larely, in some cses, for pulpwood as well, it is the whole tree that is of interest, and all species and qualities of trees can be included in the resource. Wood will burn no matter what its quality or source.

The customary tables of the heating capactiy of wood, such as those available from the U.S. Forest Service, show wide variations from species to species, ranging from about 10 to almost 30 million BTU per cord (see Table 1 for this and other conversion factors). Closer examination of the data, however, shows that nearly all that variation is due to variations in density and moisture content.[1] A pound of hardwood (i.e., wood from deciduous trees) completely dried has an energy content of about 8500 BTU. There are, of course, small variations, but for our purposes that number will be good enough. Resins have a much higher energy content, and therefore softwood (i.e., wood from conifers), with its higher resin content, has a somewhat higher energy content, about 9000 BTU per pound of dry wood. Since Maine's forests contain about twice as much softwood as hardwood, we will use 8800 BTU per pound of dry wood as a convenient average figure.

There is as yet no survey of the mass of wood in Maine. The most complete surverys are those of the U.S. Forest Survey,[2] which, however, list only volume of mercantable bole, together with some data on cull (i.e., non-mercantable bole) and dead trees. However, Professor Harold Young, at the University of Maine in Orono, and his collaborators in the Complete Tree Institute, have done some surveys of standing biomass on various plots,[3] and thus one can start with Young's mass data and use the Forest Survey's complete volume data to extrapolate to the whole state. Such an extrapolation can yield no more than a round estimate, however, and can be no substitute for a proper biomass survey. Such a survey would, in fact, be indispensible as a basis for detailed planning and analysis of wood use, not just for energy but all uses. Many of the data have alaready been collected by the industries, but these data are, with some

TABLE 1

UNITS AND CONVERSION FACTORS

AREA

1 sq mi	=	640 acres	=	2.59 $(km)^2$		
1 acre	=	0.405 ha	=	4.05 10^3 m^2		

VOLUME

1 cu ft	=	12 bd ft	=	7.48 gal	=	2.83 10^{-2} m^3
1 m^3	=	35.3 cu ft				
1 bbl	=	42 gal	=	5.6 cu ft	=	0.16 m^3
1 ccf	=	100 cu ft	=	2.83 m^3		
1 cord	=	128 cu ft				
		contains C. 80 cu ft solid wood plus C.5 cu ft bark				

MASS

1 g	=	10^{-3} kg	=	10^3 mg	=	10^9 mg
1 lb	=	0.454 kg				
1 t	=	2000 lb	=	907 kg		

ENERGY

1 Btu	=	1.05 10^3 τ	=	0.293 Whr	=	0.252 Keal
1 kWhr	=	3.60 10^3 τ	=	3.41 10^3 Btu	=	10^{-3} Mw hr
1 kWyr	=	3.16 10^7 τ	=	2.99 10^7 Btu		
1 quad	=	10^{15} Btu	=	1.05 10^{18} τ	=	293 10^6 Mw hr

justification, seen as proprietary information. There is, therefore, a real need for a public survey of the biomass available in Maine.

The method used here to estimate the biomass in Maine's forests is discussed in Appendix A. The main results are that the woody material above ground in the 16.9 million acres of Maine's commercial foests has a mass (oven dry) of about 6.4 10^8 tons, or about one and a quarter billion pounds. On the average that represents 38 tons per acre. These numbers are roughly the same as those cited by a recent MIT study,[4] but somewhat lower than those given by Young.[5] The differences are probably due to different ways of taking account of overstocked and understocked areas.

Of that total biomass about half is growing stock, i.e. mercantable bole. The tops and brances of a tree make up about 30% of its ground mass, the mercentable bole about 70%. (The stump and roots make up about 20% of the total mass of the tree. However, we shall not consider them here; harvesting them is still impractical--except perhaps in very soft ground--and disrupts the surface of the earth sufficiently that the environmental costs are probably greater than the gain.) The tops and branches of mercantable trees contain about 1.4 10^8 tons of dry wood, about 8 tons per acre. Cull trees, that is poorly shaped, partly rotten, or otherwise undesireable trees represent at least 0.6 10^8 tons (averaging 7 1/2 tons per acre) is made up of saplings, bushes, and other woody material. It should be emphasized that these are only estimates, based on incomplete data.

In order to make use of the natural renewal of the forests one should, obviously, cut no more wood than grows each year. Such an operation reaches a steady state, in which the amount removed equals the natural growth, and the forests remain in some over-all equilibrium. This equilibrium maximizes the long-range rate of return from the forests. It does not maximize what the economists call the present value of capital invested in forest lands. If one wishes to maximize the present value of the forests, taking into account the interest earned on other investments, one should cut considerably more than the annual growth of the forests immediately, since the investment income derived from the profit will more than compensate for the reduced future income from the remaining smaller forest. Such calculations can, of course, be made much more carefully.[6]

The forests in Maine are, however, not yet used at even their current growth rate: from the Forest Service data[7] one can estimate that the forest industry will use the annual growth of Commercial Stock in Maine only after the year 2000. Some companies may, of course, expand faster or have access to

TABLE 2

BIOMASS IN MAINE'S FORESTS

Based on 1970 data. All masses in oven-dry tons; above-ground material only commercial forest area taken as 16.9 10^6 acres.

Mt = megaton = 10^6 tons Gt = gigaton = 10^9 tons

	Growing Stock	Tops & Branches	Cull Trees*	Miscellaneous*	Total
Standing Biomass	0.32 Gt	0.14 Gt	0.06 Gt	0.12 Gt	0.64 Gt
- per area	19 t/acre	8 t/acre	2.5 t/acre	7.5 t/acre	38 t/acre
Net Growth	11 Mt/yr(3½%/yr)	5 Mt/yr	9 Mt/yr**	3 Mt/yr	28 Mt/yr (4½%/yr)
(due to natural causes only)					
- per area	0.63 t/acre-yr	0.28 t/acre-yr	0.56 t/acre-yr	0.20 t/acre-yr	1.67 t/acre-yr
Current Use					
lumber	1.6 Mt/yr	0	0	0	1.6 Mt/yr
pulp	3.2 Mt/yr	(with misc.)	0.2 Mt/yr	0.7 Mt/yr	4.4 Mt/yr***
fuel	0.2 Mt/yr	(with misc.)	0.03 Mt/yr	0.3 Mt/yr	0.6 Mt/yr***
Potential for thinning			9 Mt/yr	9 Mt/yr	18 Mt/yr
- per area			0.5 t/acre-yr	0.5 t/acre yr	1 t/acre-yr

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* Cull includes rough, rotten, recently dead, and non-commercial trees. Miscellaneous includes seedlings, saplings, bushes, etc.

** Includes positive contributions from mortality and cull increment on growing stock.

*** Includes contributions from 0.9 Mt/yr mill wastes from the lumber and pulp industries.

smaller forests than others and may reach that point sooner. However, it does not seem that the Maine forest industry currently has the capacity to maximize the present value of the forests, even were that an appropriate criterion.

It may well be, furthermore, that maximizing the present value of a resource is not an appropriate criterion for its use.[8] The effect is to maximize the benefit for the current users of a resource, to the detriment of future users. In the past one could argue that the growth of new discoveries and alternative resources would more than compensate for the reduced income from the given resource. (It is, in fact, precisely this growth that permits invested capital to draw interest.) It is, however, no longer clear that resources will or can continue to grow exponentially, and it may well be that in the reasonably near future we will have reached some limits on the growth of our extractive industries. In that case a much more appropriate and, in some sense, just criterion for the use of resources is to maximize the number of options mathematically as the present value criterion of the economists, but its qualitative effect is to require that renewable resources be used at more or less their rate of growth, i.e., their sustainable yield.[9]

The rate of growth of wood in Maine's forests is even less well documented than the biomass. Again it seems that the best one can do is to make estimates based on extrapolations of the data given by Young[10] and the Forest Service.[11] These computations are again given in Appendix A.

The Forest Service data show that the net growth of growing stock is about 11 million tons per year, or about 2/3 tons per acre per year. This net growth takes into account the growth of trees and saplings as well as losses due to death, rot, disease, or disfigurement. The associated tops and branches grow at a rate of 5 million tons per year, or a bit more than 1/4 ton per acre per year. The net growth of growing stock is thus about 3.4% per year; equivalently; the characteristic growing time (the reciprocal of the growth rate) is about 30 years. From the same data one can conclude that the gross growth (not counting any losses) is about 5% per year (growing time 20 years).

The net rate at which the mass of rough, rotten, and recently dead trees is increasing is roughly 9 1/2 million tons per year (estimated from Forest Service data), somewhat more than 1/2 ton per acre per year.

If we assume that the gross growth rate of the total biomass is also about 5% per year, a figure which is entirely consistent with Young's data[12] and with data from studies at Hubbard Brook in New Hampshire[13] then the net growth of woody material above ground in Maine is about 29 million tons per year. That corresponds to 1 2/3 tons per acre per year, a growth rate of about 4% per year, or a growing time of 23 years. This growth rate is higher than that of the growing stock since much of it is represented by saplings, seedlings, and bushes which also die quickly; only a very small fraction of seedlings ever grows large enough to be counted as growing stock.

It is, in fact precisely those saplings or seedlings that do not contribute to growing stock that represent an attractive energy resource. Instead of letting them die and rot or pose a fire hazard one can thin them out of the forest and use them. The same can be said for rough, rotten, and recently dead trees. Thinning a forest in fact improves the growth or the remaining trees and improves the wildlife habitat.

Only about one seedling in six grows up to become a growing stock tree; thus, nature removes, on the average, about 8% of all seedlings per year over the 20 or 30 years it takes to become a growing stock tree. If one harvests these trees at the same rate, the potential output is roughly 9 million dry tons per year, of about half a ton per acre per year. Adding to this the cull trees (rough, rotten, and recently dead), the potential yield from thinnings is approximately 18 million tons or a bit more than 1 ton per acre per year, on the average.

2.1 Easily Accessible Sources

Thus far, we have considered only the potential resources without considering their accessibility. It is clearly impractical to make immediate use of all of Maine's forests, for energy or any other purposes. Currently logging operations take place only on a small fraction of the commercial forest area. Approximately two thirds of the commercial forest area is owned or managed by forest industries or related corporations,[14] and is thus a potential site for timber harvesting. The remaining third may or may not be available. Some owners of forest lands will not permit logging operations under any circumstances; others will consent to operations as long as certain criteria are met, such as an nhancement of aesthetic or other values of their land; and some will readily consent to any logging operations.

There are also potential sources of wood in other areas than commercial forests. Although these may not be significant on a statewide basis, since such areas all together make up less than 15% of the total area of Maine, they may have considerable impact locally. These include removal of dead trees from towns and farms, and land clearing operations for farming road-builing, and development.

Some of the cut wood is already being used as firewood, particularly from smaller-scale projects, but large amounts of wood now wind up as landfill. Since much of this wood has never even been surveyed, it is difficult to estimate the quantities involved. A recent study [15] reports that land clearing operations in Southern New England produced about a million tons of wood that was either buried or burned. Maine probably produces much less, since it is considerably less urbanized.

Perhaps the most readily accessible wood for use as an energy resource is that now left as slash at the site of clear cutting operations. Currently (1977) logging operations are taking place on about $4X10^5$ acres per year,[16] leading to the removal of about eight million tons of mercantable bole per year. If we assume that the logged areas contain the average amounts of cull, saplings, tops, branches, etc., then, using our earlier results, the current logging operations also produce about seven million tons of slash. This may well be an underestimate, since, for example Young[17] gives a much larger value of total biomass, and hence slash, than we have used.

Some pulp manufacturers have been able to use an appreciable fraction (up to 20%) of whole-tree wood chips, so that some of the tops, etc. are in fact used instead of being left as slash on the ground. As yet the impact of this use is still small, and we may neglect it in our estimates: the uncertainty in the figures is much larger than the probable impact. The 1975 report on pulpwood production by the Forest Service,[18] for example, does not mention whole tree harvesting.

Current harvesting operations, then, produce roughly seven million tons of logging residues, almost entirely unused, which represents an energy resource of more than 10^{14} BTU per year, about 0.1 "quad" per year. The annual energy consumption of Maine is about three times this amount.

The logging residues can easily be harvested. Although the tops, branches, etc., are too bulky to transport (the chief reason for leaving them in the forest), they can be chipped at the site of the logging operations and transported as chips. Mobile chippers (e.g. Morbard's "Total Chiparvestor") capable of chipping trees up to 12" in diameter were introduced around 1970 and have proved a highly versatile and useful tool. Since the chipper is hauled to the site of logging operations there is no problem about transport of bulky material, except from the stump to the landing.

If the bole only is to be harvested trees are limbed and skidded to a landing where they are cut to suitable lengths and loaded for transport. If the whole tree is to be used it is often easier to skid the entire tree, without stump and roots, to the landing. It may, in fact, be preferable in general to skid entire trees where the terrain permits, since the branches provide a chushion to reduce disruption of the soil. At the landing, trees can, if desired, be separated into those whose trunks will be used separately for sawtimber, pulp, or whatever; those that will be chipped entirely for pulp; and those that will, together with the other residues, be chipped for energy. In many cases such a procedure may not be worthwhile, and it may be more economical to chip the entire harvest together, and then, at a processing plant, to classify the chips into parts appropriate for pulp and for energy. Such chip classifiers (e.g. Morbark's "Class-a-Fiber system") are already in use at some pulping plants to separate wood from bark and sand or soil.

It is, of course, not possible to describe--and it would be foolish to prescribe--general harvesting procedures. We mean only to indicate the feasibility of supplying large quantities of wood chips from material that now remains on the ground, unsightly and potentially hazardous.

It is now, for the most part, uneconomical to harvest logging residues. The existence of a market for these residues (as an energy source, for example) will change the relative economies of dumping and harvesting the residues. As fossil fuel prices increase, the attractiveness of $7X10^6$ tons of logging residues will also increase, and there may ultimately be no need for external incentives for their use, although such incentives may be needed if their current use is to be encouraged.

The State can, if it desires, intervene in several ways to make the harvesting of logging residues more attractive, thereby increasing the total benefit derived from the State's forests. It can intervene economically by, for example,

i) subsidizing the removal of slash, e.g., with tax incentives for purchasing whole tree chippers or similar equipment, or with direct payments to operators who remove the residues of their logging operations;

ii) increasing the property tax so that a greater removal of material becomes economically attractive;

iii) taxing the dumping of slash, e.g., with a severance tax on all timber removals calculated on the basis of whole tree harvesting.

Or it can intervene directly by, for example, passing laws to prohibit the dumping of logging residues at the site of harvesting or imposing other regulations on logging operations.

In many situations, such as protecting the environment from pollutants, direct intervention has seemed to be the most satisfactory way to proceed. In other cases, such as encouraging people to own their domiciles instead of renting them, economic intervention via the tax laws has seemed more satisfactory. In the present case, direct intervention may not be very desireable, since, as we said, it is difficult to make general rules about desireable logging practices. These must change from year to year and forest to forest.

It thus seems that economic intervention may be a more suitable way to affect the use of logging residues. There are other possibilities than the three mentioned above, but these will suffice to examine the issues involved.

i) Direct payment to logging operators who remove residues could be arranged by, for example, having the State purchase the resulting chips for use as a fuel for a State-owned energy corporation. Tax incentives are somewhta more difficult to arrange, since the Federal tax dominates the corporate income tax.

ii) Increasing the property tax also increases the incentive to use the growth of wood as rapidly as possible, thereby encouraging frequent clearcutting and poor forest management practicies.

iii) Imposing a severance tax in addition to the property tax seems unjust and may well be politically infeasible. It can, however, be argued that a severance tax is the most efficient and least economically distorting form of taxation for extractive industries.[19] Specifically, by taxing the actual output of the industry rather than the amount in place, a severance tax does not encourage an excessively rapid use of the resource in order to minimize tax liabilities. A property tax, by contrast, taxes the more valuable resource-bearing property more highly than the exhausted land, and thus encourages rapid extraction.

The Tree Growth Tax Law recently put into effect has some aspects of a severance tax. There has been some dissatisfaction expressed with the current operation of the law,[20] and adjustments in the law have been made. If the effect of these adjustments turns out not to be satisfactory one should consider replacing the Tree Growth Tax with some form of pure severence tax.

2.2 Other Currently Available Sources

Much of Maine's forest is now overstocked. The 1970 Forest Survey Report reports that 54% of all commercial forest land is stocked at more than 130% of the standard value. That such a level of crowding inhibits three growth is indicated by the fact that 95% of all trees of sufficient quality to be classed as "desireable" occur on stands that are stocked at less than 30% of the standard.[21]

If all stands now classed as overstocked were thinned to a medium stocking of 60 to 100 percent of the standard value nearly half the trees on somewhat more than half the area of commercial forest lands should be removed, that is about a quarter of the total above-ground biomass in Maine's forests, roughly 1/8 billion tons of (dry) wood. If we suppose that that material is removed over a span of twenty years, the thinnings will provide for more than six million tons of wood per year, more than 1/3 ton per acre of Maine's forests. That wood can contribute approximately 10^{14} BTU per year of energy, a bit less than a third of Maine's current energy use. These estimates may be high by up to 30% since some owners of overstocked forests may not want to have their forest thinned.

Overstocked stands, precisely because of their dense growth, are difficult to thin. Felling must be carefully arranged so as not to destroy too many of the trees intended to remain, and skidding the felled trees past the obstacle course of standing trees is difficult to do with the large scale harvesting machines now in favor. Unless new machines are designed, thinning will probably continue to be a much more labor intensive operation than clear-cutting, and therefore comparatively more expensive. It is, however, difficult to estimate just what the relative costs are. There are still a few lumbermen who operate with a team of horses and meet competitive prices for wood, so that the cost differences cannot be too great.

Another resource of otherwise unused wood is in the large stands of trees killed by disease, flood, or fire. In general, such trees are not useful for lumber or pulp, but still may serve as an adequate fuel source. About five million acres of forest are now infested with spruce budworm, and the infested trees become unmercantable after several years.[22] The infestation is now in its fifth year, and the sites of the earliest infestations will soon have little value for lumber or pulp.

Since the standing dead trees have been counted in no general survey, it is difficult to estimate the total quantity of wood available from this source.

Monks et al[22] estimate 1/3 billion tons from the spruce budworm infestations; only a small fraction of that is now useless, but in another ten years or so nearly all of it will be. If we add to that the other standing dead, there may be a small fraction of that is now useless, but in another ten years or so nearly all of it will be. If we add to that tne other standing dead, there may be a total of 1/2 billion tons of wood available from these sources. Harvested over 20 years these trees would provide 25 million tons of wood per year, or more than $4X10^{14}$ BTU of energy, more than enough to meet all of Maine's energy needs.

There is no great difficulty in harvesting stands of dead trees, they can simply be clear-cut with standard methods. The major problem is one of providing a suitable market for the material.

Standing dead and thinnings from overstocked stand arer, in a sense, a non-renewable resource; they have accumulated over the years and can no be "mined;" with suitable forest management they will not continue to accumulate but will be thinned out as rapidly as they are generated. Although we can expect that when a market for them begins to develop these resources will initially be "mined" at a considerably smaller rate than indicated, a twenty year lifetime does not seem an excessive underestimate for these resources.

Another potential source of wood for fuel in the residue of mill operations: bark, sawdust, slabs and edgings, veneer cores, and other wastes. Much of this material is put to use, for example as mulch or animal bedding, as raw material for fiberboard, etc., as pulpwood, or as fuel for the mill itself. Approximately half the mill wastes were used in 1971,[24] leaving about 1/2 million tons of bark and about half of that amount in woody material.[25] By 1975 the amount of unused bark had dropped to half its earlier value,[26] and one can suppose the same occurred for other wastes. Since most mills--and nearly all large mills--are already equipped to use some bark and other woody material as a fuel,[27] the rising prices for fossil fuels have apparently made it worthwhile to make considerably greater use of these wastes. If this trend continues, as it almost certainly will, one can expect that there will be very little unused mill waste available outside of the mill that produced it.

In order to encourage the most efficient and sound use of the energy resources available in mill wastes, in standing dead trees, and in thinnings from overstocked stands it seems likely that little more must be done than to provide a market for them. That has, indirectly, already happened for mill wastes when fossil fuel prices rose. If further incentives are seen to be meeded, the considerations of the previous section apply equally well here.

2.3 Future Potential

It is generally agreed that if forests are cultivated while they are growing their yields can be enhanced considerably. Earlier forest practices may be analogous to the hunting-gathering stage of agriculture in which naturally occurring materials are collected and left to regenerate by themselves. The more thorough forms of silviculture would then be analogous to agricultural practices such as planting, fertilizing, weeding, etcc. One can envision intensive silviculture analogous to the most intensive forms of agriculture.[28]

It would, however, not be wise to follow the agricultural model too closely. Most field crops, for example, are planted as monocultures, with large fields of single crops. This allows one to give each crop the specialized treatment that will maximize its yield, but it also increases the susceptibility of the crop to pests and disease. The extra yield and reduced cultivation costs more than compensate for the added cost due to infestations. Trees mature mcuh more slowly than most agricultural crops, so that planting, fertilizing, and other cultivation schedules do not differ drastically from species to species. It therefore seems very likely that the negative aspects of monoculture (increased susceptibility to pests and disease and decreased diversity of wildlife, among others) outweigh the positive aspects. It has been suggested, for example, that the rapid spread of spruce budworm is in part due to an excess of spruce in the affected areas; thus if the forest in the infested areas had been cultivated to contain a greater diversity of species the infestation would have spread much more slowly if at all. How accurate that speculation is is probably hard to assess; however, it serves to emphasize that one of the most important aspects of a natural forest is its diversity and that a reduction in the diversity carries with it a potential reduction in the forest's value, however that value is reckoned, whether economically, aesthetically, or by some other criterion.

One should not, on the other hand, conclude that an unmanaged forest is the best. As we saw, the most desireable trees occur in the thinnest stands, and we have suggested that thin forests are also more attractive to many forms of wildlife than dense forests. In most places also the growth of trees can be enhanced by judicious fertilization without disrupting other processes in the forest.

We noted earlier that using our estimates for current growth rates in Maine's forests, there is a potential for thinning about 1 ton per acre per year, or about 18 million tons per year if all Maine's commercial forest is managed for silviculture. If we exclude that part of commercial forest land not owned or managed by forest industries or related companies (a conservative estimate, in that many private owners are also interested in using the timber on their property) then that estimate is reduced by 1/3 to about 13 million tons per year. Most thinnings are probably not attractive for other uses, such as pulp, since they contain too much bark and other undesireable material. They do, however, make a perfectly adequate fuel, potentially yielding 2 or 3 10^{14} BTU per year, i.e. about 1/3 quad per year, or roughly the same as Maine's 1974 energy use.

Similarly, we have noted that thinning is a more expensive harvesting method than clearcutting for equal amounts of wood. The price received for wood chips from thinnings may thus be near or even below the cost of obtaining them. However, thinning also enhances the growth of the remaining wood, and it seems likely that the increase in value of the standing timber would more than make up for the loss, if any, incurred during thinning operations.

Without actual experience--experience that is beginning to accumulate as some lumber and management companies and private individuals experiement with thinning--it is difficult to estimate how much thinning and related procedures will enhance growth. Current harvesting methods (leaving slash and cull) produce about 2/3 ton of (dry) wood per acre per year. It has been estimated that this could be increased by a factor of 10 or 20 by utilizing wood now wasted and by more thorough silviculture.[29] Since the current total biomass productivity (1.7 tons/acre year) is about four times the growth rate of mercantable bole (2/3 ton/acre year), the increased harvesting potential implies an enhancement of growth by a factor of at least 2 and perhaps 5. These figures are summarized in Table 3.

If we adopt the conservative estimate that growth can be doubled, the average productivity of Maine's forests is then increased to : 1.3 tons per acre per year of growing stock (i.e., mercantable bole), 0.6 tons per acre per year tops and branches, and 1.5 tons per acre per year miscellaneous woody material. Thinning would remove 2 tons per acre per year, leaving 1 ton per acre per year as increase in growing stock and 0.4 tons per acre per year as increase in tops and branches. Managing the forest on a sustained yield basis implies a steady state for the total mass of the forest, so that the increase in growing stock is also to be harvested, albeit on a much slower rotation than the other material. If we suppose that harvested bole is entirely used for lumber and pulp, we are still left with a potential yield of an average 2.4 tons/acre year of thinnings

TABLE 3

ENERGY POTENTIAL OF MAINE'S FORESTS

Standing Resources	Total Available	Lifetime	Harvest Rate	Energy Production Rate
Dead Trees	1/2 Gt	20 yrs	25 Mt/yr	4 10^{14} Btu/yr
Overstocked stands thinned 50%	1/8 Gt	20 yrs	6 Mt/yr	1 10^{14} But/yr

Renewing Resources	Rate of Wood Production		Rate of Energy Production
	Total	Per Area*	
Residue of current logging operations	7 Mt/yr	-	1.2 10^{14} Btu/yr
Current Productivity			
thinnings (potential)	18 Mt/yr	1.1 t/acre-yr	3 10^{14} Btu/yr
logging residues**	5 Mt/yr	0.3 t/acre-yr	1 10^{14} Btu/yr
total	42 Mt/yr	2.4 t/acre-yr	8 10^{14} Btu/yr
Intensive Management			
thinnings	130 Mt/yr	8 t/acre-yr	23 10^{14} Btu/yr
logging residues	40 Mt/yr	2 t/acre-yr	7 10^{14} Btu/yr
total	170 Mt/yr	10 t/acre-yr	30 10^{14} Btu/yr

Based on 1970 data

All masses in dry tons Mt = 10^6 tons, Gt = 10^9 tons Above ground mass only

* 1.69 10^6 acres of commercial forest

** tops and branches of growing stock trees and logging slash. In all of Maine's commercial forest, that comes to over 40 million tons per year, with an energy content of .8 x 10^{15} BTU per year. Since cull trees are included in the sum of material available for energy, one needs to make no separate accounting of them.

A largely mechanized scheme for large scale thinning of forests has been proposed by Riley and Smith of the University of Maine in Orono,[30] and research project to study various aspects of this scheme is just beginning at the University of Maine. Essentially, the life cycle of a stand of trees would be as follows:

i) after clearing the previous stand, the area is allowed to reseed naturally (but this is not necessary);

ii) after a few years narrow permanent lanes cut out of the stand to permit easy access to the entire stand;

iii) the stand is thinned by machines that reach into the stand from the access lanes and remove undesireable trees;

iv) thinning is repeated per iod cally (every 5 uears, perhaps) until the stand has reached its optimum density;

v) when the remaining trees are mature the stand is cleared and the cycle repeated.

Not all the machines for performing these operations have yet been developed, but many of them have, and it seems that this or some similar scheme may well be feasible and, in fact, desireable.

How much such a more intensive silviculture will increase yields is unknown. European forests are much more intensively managed than those in the U.S., and forests with soils and climate roughly equivalent to those in New England tend to have productivities more than 10 times as large than Maine's forests.[31] One may thus be able to expect biomass productivities of more than 15 tons per acre per year, of which perhaps two thirds would be undesireable enough for other purposes to be suitable for fuel. Fewer than two hundred thousand acres would need to be cultivated this intensively to provide for all of Maine's current energy needs; that area would also supply one million tons of roundwood per year, roughly one eighth of the current use. A total of 1.6 million acres cultivated intensively would serve to supply the current (1977) demand for roundwood. That is less than onne tenth of the total area of Maine's commercial forest land. That area would also supply, from slash and thinning, more than eight times the energy currently being used in Maine. It should be emphasized that these are sustained yields and the areas involved are total areas under cultivation, not areas of harvesting operations.

A great deal of new equipment and a considerable amount of skilled labor is required for intensive silviculture; it is likely that a change in philosophy may also be required, a change of emphasis from extractin to management. Such a change in outlook is currently taking place, but the capital investments involved are necessarily slower. It is thus clearly not reasonable to expect that all of even most of Maine's forests will soon be managed as intensively as European forests. It is also clear that even a small amount of careful silviculture can have some impact, and a small amount of intensive silviculture can have considerable impact on the commercial output of a forest. Even intensive forest management, if planned with care, need not be detrimental to the natural diversity of the forest; it may, in some cases even enhance it. We therefore suggest that one of the aims of public policy ought to be to encourage the careful, productive management of much of Maine's commercial forests. That aim is not incompatible with maintaining large tracts of unmanaged land, which also ought to be an aim for public policy, for in order to enhance the number of options for the future we must increase the diversity of the present.

If the payoff from careful or intensive silviculture is as great as indicated above, the economic incentivies alone ought to serve to encourage their practice. the studies at the University of Maine mentioned above should give some indication of the validity of the estimates presented here.[32] Since, apparently, no other data exist yet on the potential effects and costs of careful or intensive silviculture, it is difficult to suggest public policies to encourage their practice beyond supporting research and providing management assistance (e.g., via University extension programs and field stations) to forest land owners who request it.

2.4 Competing Uses

Thus far we have supposed that the harvesting of slash, cull, and thinnings will not affect current use patterns for wood, so that most forestry products (other than energy) will continue to be made from roundwood (i.e., the bole of harvested trees), and that most of the forest residues will be available for energy. That, however, is probably not true, and the use of this wood for energy will have to compete with other uses such as pulp, fiberboard and similar materials, or chemicals.

Currently the major user of wood in Maine is the pulp industry. Since the development of the portable whole-tree chipper, wood from material that would otherwise be left as slash is now being used in increasing quantities. In 1970, according to Forest Service data,[33] the pulp industry in Maine used about 4 1/2 million tons of wood, some 20% of which was what we might call forest by-products: saplings, tops and branches, and rough, rotten or dead trees. The pulp market can thus be in competition with the energy market for a considerable fraction of these forest by-products.

Wood chips can also be classified according to bark content (by density, much as wheat is separated from chaff). As yet chip classifiers are not widely used, since it is easier to separate the bark from the wood before chipping the log. As whole-tree chips come into wider use, however, chip classifers may be used to decrease the bark content of material for pulping. In that case nearly all the material we considered for energy could be sorted, with the woody matter foing to pulp and the remainder to fuel. The pulping industry would then be a competitor with the energy industry for a major portion of the forest by-products.

Such competition would not be serious for quite a while, however. Between 1958 to 1970 the pulp industry has been gorwing at a rate of 3.7% per year.[34] If the industry continues to grow at this rate (an unsafe assumption) from 4 1/2 million tons per year in 1970, it will use less than 14 million tons per year in 2000 A.D. That is less than the current growth rate of poletimber (i.e., growing stock unsuitable for sawlogs) alone. With growth increased by careful silviculture it will be even longer before the forests cannot adequately supply both the pulp and the energy markets.

The competition between the pulp and energy markets will thus chiefly have the effect of setting the price of low-grade wood chips to the value set by the most valuable use. In the absence of an external energy market (the pulp industry uses much of its own waste as a fuel for process heat) the price is set by pulp. If an energy market for these chips develops, the rising cost of fossil fuels may make wood-based energy attractive at a wood price above that currently paid by the pulp industry. The price of wood, and hence of paper, may thus be increased. Such a price increase may not be bad: it would, among other things, reduce the incentive to waste paper, thereby reducing somewhat the vast bulk of municipal wastes we must deal with.

As for other competitive uses, the next largest uses of wood in Maine are for lumber (including veneer and other products), using about 1 1/2 million tons per year; and for fuel, using about 4 10^5 tons per year. None of the material we have considered for fuel would be suitable for sawlogs. Except for several very small industries (on the scale of the total forest industry) such as the manufacture of fencing, there are no other current potential users of forest products in Maine.

It may in the future become feasible to establish a chemicals industry in Maine based on the availability of forest by-products. Such an industry would, of curse, directly compete with the use of the same material as a fuel. In such an industry wood chips are burned incompeltely or digested chemically or biologically to produce a standard feedstock such as methanol (wood alcohol), ethanol (grain alcohol), or sugar. This feedstock can then serve as a basis for various synthetic materials. The feedstocks also have a fairly high energy content and can themselves serve as fuels. Methanol can, for example be added to gasoline, (up to 10%) with actual improvements of automobile engine performance (with only minor carburetor adjustments); there also exist car engines that can run entirely on methanol.[35]

Wood chips, sawdust, and similar materials can also be glued together to make various sorts of particle or fiber boards. Usually lumber mill residues are used for this purpose, and a small fraction are currnetly being used that way. It would also seem possible to use material directly from the forest, if it can be guaranteed to meet certain minimum specifications as to absence of bark, etc. Classified chips from forest by-products may be useful here, too, but in view of the quality of material required it seems likely that this use will have a small impact on the market for forest by-products.

The effects on the forest industry of development of a wood based chemicals industry or of major growth of the particule-board industry would probably be similar to the effects of rapid growth of either the pulp or fuel market for forest by-products: increasing the incentive for careful forest management, and raising the price of wood chips to that of their most valuable use. It would, at this point, be foolhardy to guess what that most valuable use might ultimately be.

2.5 Conclusions

The major conclusions on the total mass of wood in Maine, on its current growth rate, and on its current rate of use, as derived in Appendix A, are shown in Table 2. The table also shows the potential material available in slash and thinnings, assuming current growth rates.

With the practice of more intensive forms of silviculture these growth rates can be multiplied by at least two and perhaps ten. Wood can also be removed from currently overstocked stands and from the "reserve" of dead trees that have accumulated. The quantities of wood and of potential energy available currently and under other harvesting schemes are shown in Table 3.

It is difficult to know what effects various policies may have if one does not know the current state of affairs. There is as yet no completely satisfactory survey of current timber resources and uses in Maine. We therefore recommend that the State Forester or other public agency be suthorized and funded to conduct periodic surveys (perhaps every 10 or 12 years) of all wood resources in Maine and of their use. These results of these surveys should be available to the public.

The practice of more intense forms of silviculture than those currently in use, such as the extensive thinning of forests, can greatly enhance both the quantity and quality of tree growth. Careful silviculture need not be detrimental to other forest uses and may, in fact, improve the use of forests by wildlife and their accesibility for recreation. The increased productivity of managed forests may well reduce the area of forest land under cultivation and increase the area of unmanaged wilderness. For all these reasons it seems desireable to encourage more careful and intensive forms of silviculture. We therefore recommend that any potential changes in tax policy or other regulations affecting the forest industries be examined for their impact on silvicultural practices. Specifically, we suggest that a severance tax on all timber removals calculated on the basis of whole tree harvesting (independent of the method actually used) may serve to encourage use of forest by-products, and that when the current Tree Growth Tax Law is re-examined such a severance tax also be considered.

Many unmanaged forests now are held privately, with owners unwilling or unable to practice careful silviculture.[36] In some cases it may well be desireable to leave a woodlot unmanaged, in others it may be desireable to manage it intensely. Such decisions are best left to knowledgeable owerns or managers and we therefore recommend that the State encourage education in silviculture and provide forest management assistance to small landowners.

The removal of slash and thinnings from the forest requires a market for that wood, and fuel is the major potential user of that wood for the near future and we therefore recommend that the use of forest by-products for fuel be encouraged as much as possible. Specifically, in view of the large amounts of capital involved, Maine should consider establishing a stateowned energy corporation---perhaps on the model of publicly owned or municipal electric utility companies---which would serve as a market for forest by-products and convert them to electricity, methanol, pelletized fuel, or some other easily transported energy source. This recommendation will be discussed in more detail in later sections.

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CHAPTER III

WOOD COSTS

The raw material for fuel wood can be either roundwood, from the bole (or larger branches) of trees, or chips, which can come from any part of the tree. Before it is finally used the raw material can be teated in various ways. Roundwood can be split and is usually dried before use. Wood chips can be burned green but are also usually dried before burning--sometimes by the hot flue gases from combustion. Chips, sawdust, and similar materials can also be processed into wood pellets, characoal, or mixed with wax or similar binding material and formed into artificial logs.

Each step of the various processes of turning forest material into fuel adds its cost to the product. In all cases trees must be felled, skidded to a landing (i.e., a clearing in the forest accessible by road) and chipped or cut into sections; from the landing the wood must be hauled to a processing site or to the site of final use. After processing--which may mean merely stacking and air-drying--the wood must again be transported, whether to the site of final use or to distribution centers and then to final users.

3.1 Roundwood

Roundwood is generally used for fuel in small quantities such as fireplaces or small stoves. In some rural or near-rural areas it may be comsidered essentially free if the wood grows on the user's property; and the labor of harvesting it may even have recreational value for some!

Prices paid for split and air-dried fuel wood range widely, from perhaps as low as $40 per cord near woodlots to sometimes more than $150 per cord in cities. These prices often have little relation to costs and depend more on demand considerations than on harvesting and transportation costs. Thus, for example, wood prices tend to decrease late in the winter when suppliers want to sell their remaining stock, while the same wood will fetch a much higher price in the fall when people are stocking up for the winter. In regions where most homes are centrally heated, wood fires are considered decorative and wood prices need have no relationship to heating value. Should a large market for fuelwood for home heating develop, however, it seems likely that prices will tend to become more uniform and that competition will tend to force prices to more nearly reflect costs.

Several recent reports have tried to estimate wood procurement costs. One of the most thorough recent analyses was performed by the Governor's Task Force on Wood as a Source of Energy in Vermont.[1] The Task Force considered simultaneous harvesting of roundwood and chips, the desireable bole remaining as roundwood and the logging residues being chipped by amobile whole-tree chipper. A crew of 7 (including the owner) oprates $185,000 worth of equipment and produces 3.1 10^3 tons of roundwood per year, at an average cost of $16 per dry ton, together with 3.3 10^4 tons of wood chips per year at an average cost of $14 per dry ton. Total production costs are carefully itemized in this report so that it is easy to bring the calculations up to date as prices change.

A somewhat simpler analysis has been performed by the Maine Office of Energy Resources.[2] Labor and equipment costs for Maine were estimated at $7 per green ton, or $14 per dry ton. A recent study performed at MIT[3] estimated harvesting costs from 1972 Census Bureau data on Maine logging contractors, arriving at about $9 per green ton for ordinary harvesting forest residues. If we estimate that average costs for roundwood to be used as fuel lie between the two, then the cost of harvesting fuelwood in 1972 come to about $15 per dry ton. Assuming an average inflation rate of 5% per year, the 1975 costs could be expected to be $17 per dry ton.

Since the Governor's Task Force study was published in mid 1975, it is probably safe to assume that the prices quoted refer mmore to 1974 than 1975 for comparison (assuming that it is safe to compare labor and equipment costs in Maine and Vermont). The (adjusted) 1975 cost estimated for Vermont is then also $17 per dry ton. In view of the uncertain date of the Maine OER figures, it seems safe to take $17 per dry ton as the cost of harvesting roundwood in 1975.

Before the wood can be harvested the right to do so must be acquired. This may be either by outright purchase of the land or by payment of a stumpage fee to the owner. Since stumpage is paid each time wood is harvested it should be an excellent indication of the value of timber production. The Tree Growth Tax Law, in fact, uses stumpage to calculate the taxable value of Tree Growth lands. Average stumpage costs are tabulated for each county by the Bureau of Taxation. The overall state average (1975) comes to somewhat more than $6 per dry ton of mercantable bole.

If one uses the bole of standing dead or other cull trees for firewood, reserving the good trees for higher uses, one can expect to pay a considerably smaller stumpage price. In some cases owners may be willing to permit removals for stand improvement at no fee. However, as cull trees acquire value for pulp and for fuel such situations are likely to become rare. One can reasonably expect that average stumpage values for cull trees come to half those for growing stock, or about \$3 per dry ton.

Roundwood for fuel can thus be expected to cost (1975) about \$20 per dry ton at the landing. It must then still be cut into convenient lengths, split, dried, and distributed to the user.

If we suppose that the wood is to be used in or near a city some distance away from the forest, it seems most attractive to haul the wood to some central point, there to be split and dried and then sold to the final user. Trucking costs range from \$1 to \$1.75 per loaded mile.[4] For a truck carrying 30 tons a distance of 50 miles charging \$1.50 per mile, the hauling costs come to \$2.50 per ton. Shipping green wood from the landing to the distribution center thus adds \$5 to each ton of oven dry wood finally consumed.

The further labor and equipment costs involved in cutting and splitting the wood are probably no more than half those involved in felling the trees, i.e., about \$8 per dry ton. Adding \$2 per ton for storage, and another \$5 for profit etc., the final price for split and dried fuelwood can reasonably be expected to be \$40 per dry ton, or about \$50 per cord. Hauling the wood another 10 miles from the distribution point would add another dollar or so in fuel and other costs for the consumer.

With inflation currently running about 6% per year, the 1975 prices given above will have grown to \$45 per dry ton (\$56 per cord) by 1977, and to \$54 per dry ton (67 per cord) by 1980. Table 4 gives a list of roundwood prices (1977) and the associated cost of energy.

3.2 Wood Chips

Currently the major market for wood chips is the pulp and paper industry, and there a few large firms dominate the market. In such a situation market forces again distort the pricing, so that open market prices may not reflect the true cost of woodchips.[5] It has, for example, been reported that independent loggers receive lower prices for pulpwood than those paid internally for logging operations on company lands.[6] Although initially the cost of wood chips for energy will be the ucrrent market price for pulpwood chips, the fact that pulpwood and fuelwood are of the same (though there is considerable overlap), and the fact that fuelwood can readily be dumped with essentially zero cost (by simply leaving it on the ground) require that ultimately prices received for fuelwood will have to rweflect costs of harvesting and transporation.

In view of the increasing interest in wood chips as a source of energy, many studies have been made to estimate their potential prices. The Vermont Governor's Task Force[7] cited above estimated harvesting costs of whole tree

TABLE 4

ENERGY PRICES

All prices given are estimates for 1977 values
odt = oven dry ton
Energy content of fuels given in Table 5.

	Unit Price	Material Price	Energy Price (100% efficiency)
Roundwood			
green, at landing	20 \$/cord	25 \$/odt	1.4 $\$/10^6$ Btu
green, 25 mi from landing	22 \$/cord	28 \$/odt	1.6 $\$/10^6$ Btu
cut, split and dried*	56 \$/cord	45 \$/odt	2.6 $\$/10^6$ Btu
delivered**	63 \$/cord	50 \$/odt	2.8 $\$/10^6$ Btu
Chips			
green, at landing	10 \$/ton	20 \$/odt	1.1 $\$/10^6$ Btu
green, at plant***	12 \$/ton	25 \$/odt	1.4 $\$/10^6$ Btu
dried, at plant***	31 \$/ton	31 \$/odt	1.8 $\$/10^6$ Btu
dried, 75 mi from plant	35 \$/ton	35 \$/odt	2.0 $\$/10^6$ Btu
Natural Gas			
Residential	3.0 $\$/10^3$cuft	3.0 $\$/10^3$cuft	3.0 $\$/10^6$ Btu
Industrial	2.1 $\$/10^3$cuft	2.1 $\$/10^3$cuft	2.1 $\$/10^6$ Btu
Imported LNG	3.5 $\$/10^3$cuft	3.5 $\$/10^3$cuft	3.5 $\$/10^6$ Btu
Fuel Oil (No.2 Distillate)			
Residential	50¢/gal	21 \$/bbl	3.4 $\$/10^6$ Btu
Industrial	17\$/bbl	17 \$/ton	2.8 $\$/10^6$ Btu
Coal	50 \$/ton	50 \$/ton	2.4 $\$/10^6$ Btu
Electricity (Residential)	3.5¢/Kwhr	-	10.3 $\$/10^6$ Btu

* Air dried, 15% moisture content.

** Cut split 8 dried, trucked 75 mi. (1 odt = 1.2 tons, air dried)

*** Plant assumed 25 mi. from landing. Chips are kiln-dried.

TABLE 5

MASS AND ENERGY DENSITIES OF COMMON FUELS

	Mass/Volume	Energy/Mass	Energy/Volume
Roundwood (dry)	1.3 t/cord	18 10^6 Btu/t	22 10^6 Btu/cord
	30 lb/cu ft	8.8 10^3 Btu/lb	1.8 10^5 Btu/cu ft
Wood chips (dry)	.63 t/ccf	18 10^6 Btu/t	11 10^6 Btu/ccf
	13 lb/cu ft	8.8 10^3 Btu/lb	1.1 10^5 Btu/cu ft
Bark chips (dry)	.63 t/ccf	20 10^6 Btu/t	13 10^6 Btu/ccf
	13 lb/cu ft	10 10^3 Btu/lb	1.3 10^5 Btu/cu ft
Spent Pulping Liquor (dry)		13 10^6 Btu/t	
		6.5 10^3 Btu/lb	
Coal (average)	3.0 t/ccf	21 10^6 Btu/t	63 10^6 Btu/ccf
	60 lb/cu ft	11 10^3 Btu/lb	6.3 10^5 Btu/cu ft
Oil (distillate)	.16 t/bbl	38 10^6 Btu/t	5.8 10^6 Btu/bbl
	56 lb/cu ft	19 10^3 Btu/lb	11 10^5 Btu/cu ft
Gasoline	42 lb/cu ft	21 10^3 Btu/lb	8.8 10^5 Btu/cu ft
	5.6 lb/gal	21 10^3 Btu/lb	1.2 10^5 Btu/gal
Methanol	50 lb/cu ft	9.6 10^3 Btu/lb	4.8 10^5 Btu/cu ft
	6.8 lb/gal	9.6 10^3 Btu/lb	.65 10^5 Btu/gal
Natural Gas	.045 lb/cu ft	23 10^3 Btu/lb	1.0 10^3 Btu/cu ft

chips at $14 per dry ton. The Maine OER analysis[8] estimated harvesting costs at a little over $4 per green ton, or about $8 per dry ton. And a very thorough analysis by J.P.R. Associates for the Vermont Agency of Environmental Conservation[9] arrives at whole-tree harvesting costs of $9.50 per cord, or a little less than $8 per dry ton (1974 prices) for an operation using mechanical harvesting (fellerbuncher and grapple skidder); and at whole-tree harvesting costs of $15 to $20 per cord, or an average of $1 per dry ton, for conventional harvesting (chain saws and cable skidders). An itemized accounting of costs for a whole-tree chipping operation for Michigan indicates that harvesting costs there are about $12 per dry ton.[10]

The cost estimates for conventional harvesting (with onsite chipping) are more likely to be representative of the costs of using thinnings and slash for fuel. However, the somewhat lower costs cited in the J.P.R. Associates study for mechanical harvesting are likely to be representative for costs of clearing areas of standing dead, as well as for costs associated with the intensive silviculture.[11]

For purposes of further annalysis, we shall assume a harvesting cost of wood chips of about $14 per dry ton (1975). If we again suppose that stumpage for fuelwood is half that for mercantable wood (i.e., growing stock), we must add to the harvesting cost about $3 per dry ton in stumpage fees. The cost at the landing of green fuelwood chips is thus $17 per dry ton (1975 price). Since the inflation rate for the wholesale price index has lately been about 10% per year, the price of the chips in 1977 can be expected to be $20 per dry ton.

Trucking costs for wood chips are highly variable, but tend to be cheaper than trucking costs for logs.[12] Recent prices for trucking wood chips seem to average $2.20 per ton for a trip of 25 miles and $3.40 per ton for 50 miles.[13] If we suppose an average distance of 25 miles between the landing and the processing center, the delivered cost of the green chips is nearly $25 per dry ton (1977 prices).

At the processing plant the chips can be either converted to some other form of transportable fuel or energy (e.g., methanol, charcoal, pellets, or electricity) or used as a source of heat for an industrial process (e.g., papermaking). The chips may also be dried for more efficient hauling and distribution to final consumers.

Wet chips contain approximately 50% water (by weight). Since this water must be evaporated during combustion, the efficiency of burning wet chips is considerably less than when dry chips are burned. The effective heating value of wet wood is only 3900 BTU/lb., compared with 8000 BTU/lb. for oven-dry wood.

Transportation costs for equal amounts of energy are clearly less for dry wood than for wet.

The wood chips can be air-dried to about 10 or 20% moisture content, which requires very large covered storage areas and occasional turning over of the piles. They can also be dried in a simple kiln to about 0 or 5% moisture. The kiln would obviously be fired with wood chips. Since the major cost of kiln-drying is the fuel, we can easily estimate it. Two pounds of green woo contain 1 lb. of wood and 1 lb. of water. To evaporate the water requires 1000 BTU, which can be obtained by burningh a little over 1/4 lb. of green wood. The equipment and operating costs of such an operation will probably not be more than the fuel costs, and are therefore equivalent to about 1/4 lb. of green wood. The effective cost of 1 pound of dry wood is thus the same as 2 1/2 pounds of green wood. The processing plant can thus sell dried fuelwood chips for a little more than $31 per ton (f.o.b. the plant; 1977 price).

If the chips must be trucked another 75 miles to, say, an urban consumer, the trucking cost will add another $4 per ton.[14] The delivered cost of dried fuelwood chips can thus be expected to be $35 per ton. Had the chips not been dried, we would require the delivery of 2 1/4 tons of green chips to provide the same heating value; adding the shipping charges to the cost of green chips brings the price to $37 per ton. It is clearly cost effective to dry the chips before hauling them over large distances. For small distances, of course, the extra processing costs do not make the savings in transportation costs worthwhile.

Since a ton of dry wood contains about 17.6 million BTU, the delivered cost of $35 per ton is equivalent to an energy cost of $2 per million BTU. For comparison, a gallon of no. 2 fuel oil contains 1.5 10^4 BTU and costs at least 45¢; its energy cost is $3 per million BTU. These prices are summarized in Table 4.

As we have mentioned, one of the problems with making use of wood as a fuel, in spite of its economic attractiveness, is that at present there is no one (outside the forest products industry, which uses internally generated wastes as a fuel) equipped to use it on any large scale. In order to take full economic and silvicultural advantage of fuelwood, the State should encourage the creation of a market for chipped fuelwood. Such encouragement could come, for example, in the form of tax benefits or other special incentives for private industries, i.e., in the form of indirect expenditures of public funds; or it could come in the form of the establishment of a state owned enterprise to serve as a user or processor of wood wastes, i.e. in the form of direct expenditures of public funds. Since investments in intermediate or large scale wood-energy technologies is still considered economically risky, it seems that some form of encouragement is needed.

Most processing methods require fairly large amounts of capital (a waste-wood to methanol plant, for example, is estimated to cost about $64 millio for a 50 million gallon per year facility.[15] The carrying charges for these investments may make it unattractive for private enterprise to establish a fuelwood using indstury, especially since the investments will, initailly at least, be considered as risky. Public financing, however, tends to provide cheaper capital than private financing, and the probably social benefits (improvement of forests, more employment in forest industries, reduced payments to out-of-state suppliers of energy) seem to outweigh the possible economic loss. The balance of costs an benefits for a public corporation are therefore much more stongly favorable than in the case of a private corporation. There is, furthermore, a well established (albeit recent) tradition of government supplied funds to provide some of the risk capital in the establishment of new industries, such as nuclear energy, central station solar energy, or aerospace technology. A state-owned corporation would be in a position to reap the benefits as well as take the risks of a large fuelwood industry.

A publicly owned Maine Energy Corporation would serve to provide a large market for wood chips and could experiement with various forms of processing, both in the research and development stages and in the industrial process stages. Initially, perhaps, such a corporation would provide dried wood chips or pelletized wood fuel for industrial or commercial heating units or as a low-sulfur supplement to coal. Another potential would be conversion to methanol, since there is already a considerable market for methanol, both as a fuel and as an industrial chemical.

State enterprises are often associated with ponderous bureaucracies and gross inefficiencies. However, the eminent success of enterprises such as the TVA or the many municipal enelectric companies indicates that publicly owned enterprises can also be efficient and profitable. There is no intrinsic reaon to suppose why managers reporting to a government must have more red (or black) ink in their ledgers than managewrs reporting to a group of stockholders. And in view of the arguments in favor of a State Energy Corporation given above, we feel that Maine ought to give serious consideration to establishing such an enterprise.

3.3 Conclusions

The expected prices (1977), reflecting harvesting and processing costs, or various forms of fuelwood are given in Table 4. The table also indicates the energy price of each form of wood. These are raw energy prices and do not reflect any inefficiencies during combustion. Thus, for dry wood we have used an energy content of 8800 BTU per pound; for air-dried wood (10% moisture), and energy content of 8000 BTU/lb.; and for green wood (50% moisture), and energy content of 4400 BTU/lb. The energy required to evaporate the water contained in the wood is generally accounted for in the overall efficiency of combustion and enters price computations at that point, not here. Table 4 includes, for comparison, typical prices for fossil fuels.

There are many benefits to be derived from a large-scale use of wood as energy. These include an improvement in the quality of the forests, an increase in the number of forest-related jobs, ad a reduction in the amount paid to out-of -state suppliers of fuel. Since large amounts of capital may be involved, together with some risk and a fair amount of initiative, in establishing a large-scale fuelwood market, it may be considerably more favorable for a public corporation to enter the field than a private one. We therefore recommend that Maine seriously consider establishing a State Energy Corporation to serve as a processor of fuelwood. Such a corporation would buy wood chips from forest residues and process them into more readily useable forms of energy, such as dried chips, pellets or synthetic logs, charcoal, or methanol. It would also sponsor research and development of uses for fuelwood.

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CHAPTER IV

SMALL SCALE USES

One of man's earliest tools was fire, used for cooking, for heating, for protection, and, later, for altering other substances such as clay or metals. It is only very recently (only during a tiny fraction if even the recorded span of history) that mankind has learned to use fire fromm substances other than wood on a large scale: until the beginning of the industrial revolution fire, with few exceptions (areas without substantial woody plants, or areas with more than local deforestations, such as England after 1650), meant wood.

Wood still accounts for a small part of the energy budget--about 2% of Maine's energy use in 1974.[1] And, although most people still very much prefer the convenience of letting a thermostat worry about their heating needs, the recent spurt of sales of wood-burning stoves shows that many people are finding the economic advantage of wood sufficiently great that they are willing to put up with the reduced convenience.

As yet, the major growth of wood use has been for residential heating. There have, until recently, not been available wood fired furnances that were appropriately large and sufficiently convenient to make the application of wood furnances in larger structures, such as apartment buildings or stores, practical. On the other hand, the presence of large amounts of wood waste in the forest industries (e.g., sawmills or pulpmills) has always made wood sufficiently attractive that the means for burning wood on a very large scale are very well developed (see Chapter V).

Much of the wood that is burned in homes is cut by the owners of their own land or is directly purchased from the owners of small woodlots. Those transactions are rarely reported to any public agency, and their impact on fuelwood supply is difficult to assess;[2] thus, we have not included them in our earlier figures on firewood use (Table 2).

Residential and commercial uses account for almost 40% or about 1.1 10^{14} BTU per year.[3] Roughly 3/4 of that energy is used for space heating and another 10% to 15% is used to heat water[4] (these are New England figures, but ought to be representative of Maine as well). The remaining 10% or so is used for cooking, lighting, etc. Although wood has, in the past, been used to provide heat for cooking (and there are some cooks who still insist that the steady, even heat provided by a well-stoked wood stove is the ideal), it seems likely that the relative cleanliness and convenience of gas and electricity will continue to give these fuels a near total dominance of that use. Wood also does not seem suited to provide energy for lighting, air conditioning, etc. at the site of use, thought it may make a contribution to electricity used for these purposes.

Space, and water heating, on the other hand, are uses to which wood seems eminently suited. The seven million tons per year of residues from current logging operations would be more than ample (estimated 1.2 10^{14} BTU/yr) to provide the entire energy Maine needs for these purposes.

Furthermore, the requirements for the heat source for space and water heating are not very stringent. Almost anything whose temperature is above 150 degrees F will do very well for either purpose - and, in fact, a 100 degree F source is usually quite adequate for space heating. The potential for using low-temperature sources also makes space-heating an attractive use for the waste heat from industrial processes or electricity generation. Some form of district heating system would be needed to supply the heat to final users; in view of the delivery costs such a system is feasible only for areas with high population densities, such as the metropolitan Portland or Lewiston-Auburn areas. A rough estimate of the costs involved indicates that waste from Maine Yankee or the fossil fueled plants operated by Central Maine Power would be economically competitive sources for heat in those metropolitan areas.[5] Even if such a system were used to the fullest feasible extent, however, that would still have some 95% of Maine's population relying on locally generated heat.

If wood is used as a source of heat it can, as we have indicated, be either in the form of chips or of roundwood. Wood chips provide a much cheaper source of energy than roundwood, and are more easily used in automatic systems. However, they are also considerably more bulky, and thus pose transportation and storage problems. A volume of 100 cubic feet will contain somewhat more than 1 ton (dry weight) of cut and split wood, but only about 2/3 ton (dry weight) of wood chips. These densities correspond to average energy densities of 2 10^5 BTU/cu. ft. and oil 11 10^5 BTU/cu. ft. The volumes of roundwood that must be stored and transported are thus three times larger than those for coal of the same energy content and six times those for oil. The volume of dry wood chips is more than half again as much as that of roundwood for the same energy content; and, if we consider the added inefficiency associated with burning wet chips, their volume is more than twice that of roundwood and perhaps twelve times that of oil for the same energy content.

The efficiency of various forms of combustion is, in part, determined by the chemical and physical process during combustion itself. If a sample of wood is heated slowly in a completely sealed chamber the material will go through several stages as the temperature is raised:[6]

1. Water and other volatile substances escapte from the wood (100-250 degrees F);
2. lignin, cellulose, etc. decompose to produce tars, oils, gases, and residual carbon (charcoal) (500-750 degrees F);
3. The gases, oils and tars themselves decompose into chemically simpler substances (500-4000 degrees F);
4. further heating does little more than melt (at 6300 degrees F) and ultimately vaporize (7600 degrees F) the carbon.

The presence of air alters the picture considerably since at temperatures above 1200 degrees F the charcoal and many of the gases produced by pyrolysis (stage 2) combine with oxygen to produce carbon dioxide and water, together with large amounts of heat. It is the heat produced by the burning of some of the charred wood that provides the heat needed for the pyrolysis of the next; the gases, tars, etc. generally escape from the wood before they heat up enough to ignite, thereby becoming visible flames.

For maximum efficiency, then, one must ensure that the substances driven off during pyrolysis remain hot enough to ignite. If not, the chemical energy represented by their composition is lost as waste in the flue gases. One must further ensure that the flue gases give up as much of their heat energy as possible, since heat sent out with the flue gases is also wasted. There is, in nearly all applications, one unavoidable inefficiency, that is, the heat lost by evaporizing the water contained in the wood or produced during combustion; since that water leaves as vapor with the flue gases its heat of vaporization is a guaranteed loss.

The gases that are left after combustion must still be warmer than the material (air or water) they must heat, otherwise no energy will be transferred between the combustion products and the material. If we put in some allowance for heating air from room temperature to the final temperature of the flue gases, so that the air can flow through the stove to provide oxygen for combustion, the maximum efficiency of a wood-fired stove or furnace is not more than about 90%. That is, even if the combustion is as complete as it can be, about 10% of the energy of the wood goes out the chimney with the hot gases and water vapor. If the wood contains some moisture, it too must be evaporated, which leads to a further reduction of efficiency. For air-dried wood (10% moisture content) the maximum efficiency is 85%, while for green wood (50% moisture content) the maximum efficiency is 75%. (See Figure 1.)

These ideal efficiencies are rarely achieved in practice. Usually there is an excess of air that must be passed through (and heated by) the burning wood in order to ensure that combustion will be fairly complete. The flue gases must be heated even more than we have assumed in order to ensure that there will be enough of a draft through the fire. Even so, combustion is rarely complete, so that the flue gases contain many organic compounds besides carbon dioxide. These appear as gases, tars and oils; some of them escape with the rest of the flue gases, but many are deposited in the chimney as creosote.

Such deposits can also occur with fossil fuels, especially coal. Natural gas, i.e. methane, is a sufficiently simple chemical compound that there are essentially no oils or tars formed during combustion, and hence no creosote. Coal and oil are chemically much more complex, and their combustion products are comparably complex. The odor of a fire, for example, is due to complex products of incomplete combustion. Gas fires have no odor; nearly all wood, coal, and oil fires have distinctive odors.

Creosote together with the fine ash particles that are suspended in the flue gases can foul heat exchange surfaces, leading to reduced efficiency. The creosote itself, since it is flammable, may pose a fire hazard. Both of these effects are to some extent problems with all fuels. They are, however, particularly serious for wood-burning systems, because wood has a relatively greater ash content, and because wood can have a very wide range of moisture content. Wood-burning systems must thus cope with some problems not faced in fossil fuel consumption.

4.1 Roundwood

In view of the difficulty in handling large quantities of roundwood, most systems that burn logs tend to be fairly small. A system that burns fuel at a rate of 100,000 BTU/hr. (typical of the maximum capacity of home heating units) must be stoked with dry wood at a rate of more than 10 pounds per hour. Much larger systems clearly make unreasonable demands for labor required to stoke them, and mechanical stoking becomes preferable.

A very popular way to burn wood in a private dwelling is in a fireplace. In general, however, a fireplace does not seem to be an efficient way to heat a house that also has central heat: it can very easily happen that the cold air entering the house to maintain the draft in the fireplace once the fire has died down requires more energy to heat than the fire has supplied. As home heating units to supplement a central heating system, fireplaces thus have small or even negative efficiencies.[7] Air circulating grates, slot-fire grates, and other innovations in fireplace design,[8] have made fireplaces more efficient, and negative efficiencies tend to be as much due to operating practices as to design. Even so, it seems unlikely that a fireplace can ever be very efficient as a source of heat; its function will thus remain primarily aesthetic.

Wood stoves and furnances, on the other hand, can be highly efficient, delivering up to 60% or 70% of the heat of combustion to the heated rooms.[9] A well designed wood stove can be operated to provide up to 70% of its maximum possible efficience;[10] its net efficiency is then about 60%; that is, 60% of the potential heat of combustion is delivered to the room, the rest is lost. A wood furnance, if it makes use of some form of storage, can be operated with much higher combustion efficiences, and therefore greater overall efficiency.[11]

Many different designs for wood stoves and furnances exist. Each has its advantages and disadvantages and, of course, its proponents and detractors. The net efficiency of any heating unit depands not only on how it is designewd but also on how it is used, and a more efficient is not the most important criterion, and convenience or aesthetics may play a deciding role.

The economics of burning wood or any fuel depend not only on the cost of fuel and the efficiency with which it is consumed, but also on the cost of the equipment used to burn it. It clearly makes little sense to invest large sums of money to provide only a small increase in efficiency and consequent decrease in fuel cost. The economic comparison to be made is the total cost of a heating system, cincluding equipment costs as well as fuel costs.

In Table 6 we compare estimates for equipment costs, fuel costs, and total costs for operating various kinds of heating systems for one year in a typical house in Maine. Although the numbers given in the table are just estimates for an average house, and will, therefore, not necessarily be the values encountered in any particular case, they are probably valid representations of the relative costs of the various heating systems. Details of the calculations are given in Appendix B.

The wood fired furnances, with their relatively high efficiencies, are clearly economically attractive heating systems. The log-burning furnaces have the slight inconvenience of requiring manual stoking. In order to be able to deliver heat when needed, such a system would require a large heat storage capacity, e.g., a hot water tank. That feature makes them an excellent supplement to solar heating systems, since these, too, require a large heat storage capacity. If both heat sources share the smae tank one needs to stoke the furnace only when the sun is inadequate to keep the water temperature stable. Such a combined system is now in use at a building designed for the Maine Audubon Society.

TABLE 6: Annual Costs of Home Heating Systems

Computations & system specifications given in Appendix B.
All prices are estimates for 1977.
Annual costs are rounded to the nearest $5.
Fuel costs are based on a demand of 70 million BTU/yr., delivered to rooms.

	FURNACE			FUEL		SYSTEM
	initial cost* $	annual cost** $/yr.	efficiency	unit cost*** $/10^6 BTU	annual cost $/yr	annual cost $/yr
Oil (new installation)	800	100	0.50	3.4	475	575 $/yr
Gas (new)	650	80	0.60	3.0	350	430 $/yr
Electric resistance (new)	400	50	1.00	10.3	720	770 $/yr
Heat pump (new)	1200	150	1.70	10.3	425	575 $/yr
Wood Stove (new)	800	100	0.45	2.8	435	535 $/yr
Wood furnace (new)	1100	135	0.60	2.8	325	460 $/yr
Wood-Chip furance (new)	2500	315	0.60	2.0	230	545 $/yr
Oil (existing)	0	0	0.50	3.4	475	475 $/yr
Wood furnace (add-on)	300	40	0.60	2.8	325	365 $/yr

*rounded to nearest $50
**0.125 times the initial cost. See Appendix B.
***From Table 4.

Wood for the annual heating needs of a typical house would weigh about 8 or 9 tons (a volume of about 7 cords). If we burn only the trunks of trees that can reasonably be thinned from the forests each year, then the data from Table II-1 show that a single house would need a wood lot of about 10 acres. The annual growth of commercial timber could still be used for other purposes. If the entire annual growth of a woodlot is used, it would need to be only about 5 acres for each house, assuming current average growth rates. The total residential space heating requirement for Maine in 1974 was 6 10^{13} BTU.[11]3 That heating need can be supplied by the roundwood from thinning 4 10^{6} acres at a rate of 1 ton per acre.

Given the economic and other attractions of using wood as a fuel, one can expect that the recent increase in sales and installations of wood stoves will continue.[14] Since many of these units will be bought and installed by people whose previous experience has been with professionally installed central heating units, they may not meet generally accepted safety standards.[14] It would thus seem prudent to undertake some sort of educational programm to point out minimum safety standards (and their reason) for wood burning equipment. One could, for example, require sellers fo wood stoves to include with the stove a list of safety standards to be met by the installation. To be effective, however, such a simple program would have to be supplemented with an effective housing safety inspection program.

4.2 Wood Chips

As Table 6 shows, the low cost of fuel makes wood chip burners quite competitive with other systems, even when the high cost of the furnace is included. It should be emphasized, however, the cost estimates for both the furnance and the wood chips are speculative. As yet, the only wood chip furnances that are of a size to be useful for residential and commercial applications are experimental units not necessarily designed for mass production; their cost thus need not reflect the ultimate price of wood chip furnances. The cost of fuel also is speculative. We have tried, in Table 4 to include estimates for storage and trucking costs for dried chips; final distribution to users and storage near the furnace may well add further costs.

If we suppose that storage and distribution costs add another $5 or $10 to each over-dry ton of wood chips, the associated energy cost becomes 2.3 to 2.6 dollars per million BTU. For the house considered in Table 6 the added cost would be between $35 and $70 per year, enough to make the wood chips less attractive than all the electric resistance heating.

For larger scale heating systems, however, wood chips are likely to continue to be cheaper than other fuels. Furthermore, the costs of larger units do not increase in direct proportion to their size, so that, while the fossil fueled heating units are likely to remain cheapter than the wood-chip units for all sizes, the difference in costs is likely to be proportionately less than the fuel costs.

In order to illustrate the economies involved, we show in Table 7 the results of an analysis of annual heating system costs of a small store or office building (about four thousand square feet) or apartment building (ten units of about 900 sq. ft. each). The details of the analysis are in Appendix C.

The annual heating demand for such a building is about 1/2 billion BTU per year, about 1/5 of that is used during January, less in other months. If dried wood chips are burned (60% efficiency) about 10 tons of chips will have to be delivered during January. A ton of wood chips occupies about 160 cu. ft., so that the supply of wood chips for January occupies about 1600 cu. ft., a volume that can be enclosed in a bin of 15 x 15 x 5 feet and that can be delivered in one or two truckloads. For comparison, an oil supply for January would occupy 180 cu. ft., a volume that can be enclosed in a cylindrical tank 5 ft. in diameter and 9 ft. long. From the estimates given in Table 6 it seems clear that wood-chips can pay the rent for the extra space they occupy.

Given these economic considerations it is clear that dried wood-chips or similar fuel can have a considerable impact on the fuel situation in Maine, particularly in new construction, or in the case of replacement of worn out old heating units.

There seem to be only two problems, albeit interlocking ones, for the widespread adoption of wood-chip fired heating units. One is that in the absence of readily available fuel such heaters must perforce remain experimental or speculative installations. The other is that in the absence of an appreciable demand for the fuel there seems to be no incentive to establish a system for the commercial collection and distribution of chips from waste wood.

It will require considerable further analysis to determine whether it is preferable to develop a market for burning wood chips in small units or to convert the chips to some other fuel or energy source that can fit more easily into the existing distribution and consumption network. The fuel conversion process would take place on a fairly large scale at a central processing plant, and the resulting fuel -- methane, methanol, oils, or electricity -- would be added to the stream of currently used fuels. Some of these processes will be considered in the next section.

TABLE 7: Annual Costs of Commercial Heating Systems

Computations & system specifications given in Appendix B.
All prices are estimates for 1977.
Annual costs are rounded to the nearest $50.
Fuel costs are based on annual heating demand of 500 10^6 BTU.

	FURNACE			FUEL		SYSTEM
	initial cost $	annual cost* $/yr.	efficiency	unit cost** $/$10^6$ BTU	annual cost $/yr)	annual cost
Gas	1000	150	0.6			
residential				3.0	2500	2560
L.N.G.				3.5	2900	3050
Oil	1500	250	0.6			
residential				3.4	3400	3650
industrial				2.8	2800	3050
Wood Chips	6100	950				
green, local			0.5	1.4	1400	2350
dried, distant			0.6	2.0	1650	2600
dried, delivered***			0.6	2.3	1900	2850

*0.158 times the initial cost. See Appendix B.
**from Table 4.
***including $5/ton for handling and delivery.

Among the possible functions of the State Energy Corporation we have described earlier could be an analysis of the potential marketing and consumption problems involved with the use of dried wood chips. If, as our estimates indicate, they are not insurmountable and require mostly the breaking of a vicious circle, then this corporation should be the appropriate processing and marketing agency.

Another encouragement for the use of wood chips would be a demonstration project of the sort recently proposed by a task Force of the Federal Regional Council.[17] Such a project could supplement academic or industrial research and development of wood-chip burning systems.

4.3 Conclusions

It seems clear that wood has, with the recent rise in fossil fuel prices, once again become an economically attractive fuel in forested areas like New England. Tables 6 and 7 show estimates of the annual cost of various heating systems, for home heating and for commercial or apartment block heating, respectively.

For small scale uses (up to 100,000 BTU/hr.) roundwood seems to be the most convenient form of fuel. For larger uses the fact that chips, unlike roundwood, can easily be handled with automatic equipment makes them a more convenient fuel. They are also potentially the cheapest form of fuel readily available in Maine.

Roundwood generally is very vaiable in composition and burning characteristics. These variations as well as the inefficiencies of combustion necessarily encountered in some situations can lead to safety hazards for wood burning systems that are not associated with other heating systems. With the increased number of installed wood-burning stoves one can also expect an increase in the number of heasily installed or poorly designed stoves; these present even greater safety hazards. In order to reduce these hazards we recommend that minimum safety standards for installation of any domestic wood burning appliance be developed and be prominently displayed on every appliance sold. We also recommend that similar safety standards be incorporated in any housing code where they are not already included, and that these standards be publicized periodically. These recommendations are, clearly, not entirely adequtae to ensure safe installation of wood burning appliances; that can only be achieved by a vigorous housing safety inspection program. Such a program, however, tends to be acceptable to the public only after several preventable disasters have occurred.

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CHAPTER IV

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CHAPTER V

LARGE SCALE USES

Wood wastes are produced in large quantities in lumber mills, pulp and paper mills, and other forest industries. Except for bark, the majority of these wastes is already put to some use, either as a fuel for space or process heat or as pulpwood, mulch , or ther material. A large fraction of bark, too, is burned by the pulp and paper industry to provide heat for pulping and for drying. Forest residues can, and sometimes do, supplement the local waste wood as a fuel in some of the forest industries. In principle, of course, such an industry could be entirely self-sufficient for its energy needs, and even sell excess electricity if it so desired; to achieve self-sufficiency it would merely be necessary to burn enough wood to meet the energy needs of the industrial processes. In practice, few industries are self-sufficient or would find it practical to become so. However, with increasing fossil fuel prices it becomes increasingly attractive for any industry to examine alternate fuels.

Wood can, in addition to being burned directly, also be converted to other combustible substances, such as gas, oils, characoal, alcohols of various sorts, or pressed wood briquets and "logs." Charcoal from wood is mostly pure carbon and is a useful fuel or material for numerous industrial processes, especially in the metals and chemicals industries. Methanol (wood alcohol, CH_3OH) and Ethanol (grain alcohol, C_2H_5OH) both can serve as feedstocks for chemical systheses as well as for guels. Pressed wood pellets and "logs" have received some attention recently as a fuel. A plant in Brownsville, Oregon, produces large quantities of wood pellets for fuel. At a price of $22/ton they provide energy at about $1.30 per million BTU, a very competitive price.[1] Several kinds of "artifical logs" for fireplaces and stoves are currently available in supermarkets and elsewhere; their price, however (typically $25 per million BTU) precludes them from any major use, other than decorative, for home heating.

The energy from wood can also be converted into electrical energy. Generally this is done by either burning the wood in a boiler and using the resulting steam to drive a turbine or by partially burning the wood to produce a combustible gas which in turn can be fed into a boiler or into a gas turbine.

At the large scale we are considering there are three ways to use wood as an energy source:

1. Complete combustion. This is generally done in a boiler directly, but some designs have a special, separate combustion chamber from which hot exhaust gases are led to a heat exchanger to raise steam. The resulting

steam can be at least 900 degrees F (a pressure of almost 1500 psig). Capacities of such boilers can be 1/2 10^9 BTU/hr. and more.

2. Pyrolysis. Technically, this involves heating the wood in the absence of oxygen. Practically, however, since the decomposition of wood requires external energy (if it did not, wood would not be the stable material it is) some air is admitted so that the combustion of some wood can supply energy to pyrolize the rest. The result of pyrolysis is a combination of combustible gases, oils, and char. Heating the wood in the pressure of steam produced activated charcoal together with volatile substances, some of which can be used as fules, solvents, etc. All the results of pyrolysis can themselves be burned to yield energy: the gas in a boiler or gas turbine, the oil and charcoal in a boiler.
3. Digestion. This is the chemical or biological decomposition of wood into simpler substances. Most wood pulp is produced by chemically digesting the lignin and other non-fibrous components of wood sufficiently that the fibers (cellulose) can be separated from the rest of the material. The residue after the fibers have been removed is generally burned both to recover the chemicals used in the digestion process and to provide energy for it.

   If the digestion is carried out under more rigorous conditions the cellulose is also broken down into its component sugars; these sugars can then be fermented to provide alcohol (ethanol). There are also some bacteria (e.g., those that inhabit the intestines of termites or of cows) which produce enzymes that have the same effect of turning wood to sugars. As yet no industrial scale process exists to make use of these bacteria.

Electricity can be generated from the mechanical power produced by a gas or steam turbine. Electricity and some of the secondary fuels producible from wood, e.g., alcohol or the oil from pyrolysis, are considerably more easily transported than the wood itself and therefore enhance the versatility of the fuel.

5.1 The Pulp and Paper Industry

The pulp and paper industry uses almost a fifth of all the fossil fuel energy consumed in Maine. It is the largest industrial user of energy in Maine, accounting for more than half the industrial purchases of fossil fuel energy and electricity in Maine. In addition to the purchased energy, the industry generates more than half its electricity and about a third of its heat requirements internally, i.e., from hydroelectric plants and from wood wastes and spent pulping liquors.[2]

The raw material used by the industry is, of course, trees. But not all of the tree winds up as paper. About 1/4 of a tree is tops and branches, which are usually left on the ground; another 1/5 is stem and roots, which are nearly always left in the ground; the remaining 55% is mercantable bole. Of the trunk's dry mass about 8-10% is bark; of the woody material about 45% is cellulose (i.e., fiber), the rest is protein, lignin, and other material. Less than a quarter of the tree actually winds up as paper or pulp, since only the cellulose fiber makes high-quality material. (There are processes which use other components of wood, not just cellulose; however, these account for only a small fraction of the pulp produced).

Producing a ton of paper thus requires the cutting of about 3 1/2 tons of trees (dry material above ground - about 7 tons of green wood). About 1 ton of that is tops and branches (left in the forest), and 0.2 ton is bark (removed before pulping).

The energy required to produce this tone of paper varies from plant to plant and process to process. In New England it seems to average about 31 10^6 BTU per ton, of which 15% is electrical (1.3MWhr). About 1/3 of the heat required is for pulping (and therefore at temperatures of 350-400 degrees F), the remainder is mostly needed to dry the pulp to turn it into paper (at about 250-300 degrees F).[3]

Pulp and paper mills in Maine generate a large fraction of their energy needs themselves. About 80% of the electricity is generated in-plant, partly from fossil fuels and partly from wood;[4] bark, wood wastes, and pulping liquors account for about 25-30% of the fuels used by the industry.[5]

In principle, the fraction of wood used could be even larger. The 0.2 tons of bark represent an energy content of 4 10^6 BTU per ton of paper. The lignin and other material in the spent pulping liquor contains about 16 10^6 BTU, so that using the whole tree could, in principle, make a pulp/paper mill self-sufficient for energy.

In practice, there are always some losses associated with the use of this waste material; furthermore, the woody part of the tops and branches is also attractive material for pulping; and the use of some of the wastes itself requires energy (e.g., for the use of chip classifiers to separate wood from bark in whole-tree chips). Thus, an energy selfsufficient pulp and paper mill would have to purchase extra wood to meet its energy needs beyond what it has felled for use as pulp. This extra material could come from cull trees and other material now left as slash at clearcutting sites, or from material thinned from overstocked or carefully managed stands.

A recent study by the U.S. Forest Service[6] on the Feasibility of utilizing Forest Residues for Energy and Chemicals estimated that for a typical U.S. pulp mill using the Kraft process, each ton of paper produced by an energy self-sufficient mill wuld require the harvesting of about 4.2 tons (oven dry weight) of wood. A bit more than half of that would normally be brought to the mill as roundwood for pulp; a bit more than a quarter consists of tops and branches of trees felled for pulpwood; the remaining 22% (0.9 oven dry tons) is extra wood felled to provide energy.

Given the variations in pulpmill energy requirements and in harvesting methods, it seems likely that most mills could avoid using fossil fuels entirely if they make an extra harvesting effort of perhaps 0 to 50%, and if they chip and burn considerably more - perhaps 3 or 4 times as much - wood waste than they currently do. For many mills this would involve a considerable capital outlay, since they do not currently have the boiler capacity for burning more than 3 tons of wood fuel per ton of paper output. As old boilers become obsolete and as fossil fuel prices continue to rise however, investments in increased wood-fueled and spent-liquor boiler capacity should become more attractive.

As a major use of low temperature heat, the pulp/paper industry is also an attractive site for electricity-steam cogeneration facilities. The hot flames inside a boiler can produce steam with a very high temperature and pressure. An ordinary low-pressure boiler effectively just dilutes the high temperature to the required value. The hot steam can, however, also be made to cool off by doing mechanical work, such as driving a steam turbine and electrical generator. The cooled steam that comes out of the turbine can then be used to heat whatever it was that needed heating. Such a system would typically generate 45 kWhr of electricity for every 10^6 BTU of steam (an electric heat/energy ratio of 1/7), and use about 1/5 more fuel to generate steam plus electricity than to generate electricity along.[8]

Since a pulp/paper mill needs about 15% of its energy as electricity, such a cogeneration scheme would provide an approximately correct mix of energies for the mill. Not all mills, of course, use the same electricity/heat energy mix, and some mills would, accordingly, have an excess or a deficit of electricity, which can be sold to or bought from the regular power company.

Other cogeneration systems produce considerably larger amounts of electricity per unit heat output than steam turbines[8] do. These would therefore produce considerable amounts of excess electricity for sale to the power grid. They would, of course, also require a comparably greater harvest of wood. Such systems involve on ein the complications of the electric utility business and rate structure and we shall not discuss them here.

Johnson has discussed cogeneration extensively in a report to the Office of Energy Resources;[9] his conclusions apply equally well whether the facility burns wood or fossil fuels. Among his recommendations to encourage cogeneration is the suggestion that small electric utility power plants located near pulp/paper mills could supply electric power to meet the utilities' needs and requirements together with steam for the process heat needed by the mills. Such a plant could burn wood waste from the mill as well as other hogged fuel. A municipal or state owned utility, such as the State Energy Corporation discussed earlier, would probably find the investment in such a plant even more attractive than a private corporation.

5.2 Central Station Electric Power

Since a large fraction of the cost of generating electric power is the cost of fossil fuels, many utility companies have begun to investigate other fuel. The political and environmental difficulties encountered by nuclear plants have led to delays and concellations of planned generating stations. The large-scale direct application of solar power seems impractical in New England, where the sunshine is considerably more erratic than in, say, the Southwest.

These considerations leave few alternatives other than the use of biomass as a fuel. Since, as we saw earlier, Maine, like most of New England, has a large amount of wood, much of which is more or less useless for most industrial purposes, the use of forest biomass to generate electricity has already been extensively investigated. The proposed uses range from the fairly modest 50MW(e) power plants proposed in Vermont[10] and in Maine[11] to gigantic energy farms covering much of the state with high yield trees, grown under intensive silviculture, and harvested purely for fuel.[12]

As we indicated earlier, it does not seem wise to dedicate the forests exclusively to one purpose, be it fuel or wilderness. One should, according to our discussion in section II, try to encourage the most diverse set of uses for the forest, thereby retaining, or even enhancing, its natural diversity.

It therefore follows that a large-scale project of intensive energy farms is an unwise use of Maine's forests. On the other hand, the more modest and dispersed projects currently under consideration are entirely consistent with an aim of maximum diversity of uses. In fact, our estimates of currently available biomass indicate that a fairly large fraction of Maine's required electricity could be met by such projects.

The usual method of generating electricity, particularly in facilities intended to supply base-load electric demand (i.e., operating around the clock), is to burn fuel in a boiler and use the resulting steam to drive a turbine coupled to an electric generator. Other methods exist, using, for example, gas turbines or diesel engines to drive the generators, but these cannot readily use wood as a fuel, except indirectly, and they tend to use wood fuel considerably less efficiently than steam raising boilers do.

The efficiencies and economies of using wood as a fuel in a 50MW(e) plant in New England have been extensively studied.[13] Much larger plants seem, at this time, to be impractical for several reasons: the radius from which chips must be hauled to the plant makes the transportation costs and problems excessive; there may be some difficulty in finding enough fuel within a reasonable distance of the plant; the required boilers are larger than those currently available for wood wastes; and there seem to be problems in using the large units that are not encountered in the smaller ones.

The problems involved with large units do not seem insurmountable: the problems involved in transport may, for example, be alleviated by trucking dried rather than green chips; the problems of wood availability depend on location, on owner attitudes, on harvesting methods, and on competing markets, all of which can change; and boiler technology is continually improving.

Even if large electric generating plants that burn wood chips do become feasible, there may still be some advantages for a dispersed network of smaller generating stations. The effects of planned or unplanned shutdowns will be considerably lessened if the capacity of the affected plant is a smaller fraction of the total generating capacity. Industries requiring process heat may be able to use waste heat or cogenerated heat from a generating station located near the plant. And the pollution effects of a network of plants are distributed over a wider area and are thus more easily controlled than for a single large plant.

The several analyses of wood-chip fired electric generating plants all consider fairly similar premises. A 50 MW(e) generator is driven by a standard steam turbine; steam is raised in a wood-fueled boiler of standard design the fuel is green or only slightly dry wood, with roughly 50% moisture content. The fraction of the time for which the power station is not functioning for any reason (down time) has been variously estimated at values ranging from 15% to 35%; the corresponding load factor ("on" times) is 65% to 85%.

The efficiency of a boiler for green wood is about 65%, i.e., 35% of the heat of combustion of the fuel is lost in the flue gases (mostly as water vapor) and elsewhere. The efficiency of the steam turbine and generator is about 40%, which is near the absolute limit set by thermodynamics. The overall plant efficiency is thus around 25%, which is equivalent to a net station heat rate of 14 10^3 BTU/kWhr.

To produce 50 MW of electrical power the plant must burn about 80 tons of green wood per hour, or 5 10^5 (green) tons per year (75% load factor). From our estimates (Table 2) that amount of fuel is available as annual thinnings from about 1/4 million acres per year (currently productivity), or as harvest of 1% per year of the currently standing dead trees. The thinnings would be available within a radius of 11 miles of the plant, assuming a forest of average productivity surrounding the plant. Use of more than just thinnings (e.g., logging residues) and of more than casual silviculture would decrease the collection radius.

The various economic analyses of a wood fueled plant all indicate that it could produce electricity at roughly 45-70 mills per kilowatt hour (mid 1980 prices). The lowest prices would be achieved with some form of public financing,[14] since capital costs make up a considerable fraction of the total annual costs (around 1/2) of a wood fired plant. The only cheaper way to generate electricity seems to be with nuclear power[15]; coal-fired plants seem to produce electricity at about the same cost as wood, while electricity derived from oil is more expensive than any other. As fossil fuel prices continue to climb, wood-derived electricity will no doubt improve its economic advantage.

There are further advantages for Maine to deriving at least some of its electricity from wood. The wood fuel is an indigenous resource, so that reliance on out-of-state fuel supplies is reduced. The money that is spent on fuels for electricity generation in Maine is spent in Maine and serves to create jobs in the Maine forest industry, rather than in Texas or Kuwait. And we have already discussed some of the silvicultural benefits of using currently unmercantable wood (thinnings, slash, standing dead).

Several wood fired electric generating plants have already been proposed, and some are being planned. It therefore does not seem as if further public policy incentives are necessary to encourage such plants. The various regulatory and planning commissions already encourage power companies and teh larger forest industries to consider wood-fueled electric generation or co-generation facilities when they apply for permits to improve or expand existing facilities or to build new facilities. If further incentives are needed, those proposed in Chapter II to encourage the use of forest residues in generatl would probably suffice.

5.3 Conversion to Other Fuels

As we have seen, wood is bulky to transport and awkward to burn in some situations. It is therefore desireable for many purposes to convert the wood to some other fuel. Even though some of the energy content of the wood is lost in the conversion process, the resulting fuel may be sufficiently attractive to make the conversion worthwhile.

There are, as we have mentioned, essentially two ways to convert wood to some other fuel: pyrolyis and digestion. There are several different processes of each kind, and most of them have been developed to deal with municipal refuse or with sewage sludge. Although several of these processes have been tested sufficiently thoroughly to be considered proven and are commercially available (e.g., Union Carbide's PUROX, Energy Resources' Fluidized bed Pyrolyses, Occidental's Flash Pyrolytsis, and others), few of them have been extensively tested with wood chips as a fuel.[16]

Except for the fairly mild digestion that is used to free the fibre in the pulping process, the wood digestion processes are not yet in an advanced state of development. The principle of the process is to use a corosive substance, generally acid, or an enzyme from bacteria or fungi to decompose the long polymers (cellulose, lignin, hemicellulose) into their simpler components, chiefly sugars. The sugars and the various by-products can be used as feedstocks for chemical syntheses, to produce components of plastics, fibers, or solvents. The sugar can be fermented by yeast to produce ethanol (grain alcohol) in the same way that any sweet fruit or vegetable juice can be fermented to produce ethanol. The ethanol, in turn, can be used to synthesize other materials, as a solvent, or as a fuel. At this point most of the products of digestion seems to be too valuable for other uses to make them potential fuels; the various wastes and by-products can be burned, but will probably not supply an excess of energy beyond that needed in the process.

The acid hydrolysis yields a material contaminated with acid and by-products that are difficult to remove and that interfere with the fermentation of the resulting sugars.[17] The enzymatic digestion requires very fienly powdered wood as its raw material, and there is as yet no satisfactory way of recovering the enzyme for re-use.[18] Both processes, however do work i experimental situations, and it seems likely that the problems of the processes can be overcome.

A study of chemicals and fuels producible from wood wastes[19] estimates that a plant producing ethanol by acid hydrolysis and fermentation from wood would cost about 70 million dollars, and could produce 25 million gallons of ethanol per year at about $1.50 per gallon if wood costs $25 per ton. (All prices are for 1975). This is considerably more than the $1/gal. that ethanol cost in 1975. However, a plant that uses the by-products from ethanol to produce furfural and phenol does not require a much larger investment than one producing ethanol alone, and since furfural and phenol are also useful chemicals, the economic efficiency of the plant is increased. Such a plant would require 1500 tons (oven dry) per day of wood wastes (4 10^5t/yr., about 1/8 of the current use for pulp) to produce 25 10^6 gal./yr. ethaol, 75 10^6 lb./yr. furfural, and 52 10^6 lb./yr. phenol. If wood costs $25/t, the plant can sell furfural at 37¢/lb. (market price, 1975), phenol at 27¢/lb. (ditto) and ethanol at 80¢/lb. (below average market price, 1975).

Such a plant could be a worthwhile investment, and it may provide a market for wood wastes whould they turn out not to be useful as an energy reesource. However, since theprocesses have not been proven at the scale needed, considerable further study would be needed before it could be planned. Given the usual experience, that things always seem cheaper to do before they're tried, it is likely that the cost estimates given in the Forest Service study cited above are low. On the other hand, the cost of wood waste is rising more slowly than the cost of fossil fuels. Thus, although it is unlikely in the near future, it is possible that waste wood can serve as the feedstock for a major xylochemical industry to displace a part of the petrochemical industry.

Another digestion process makes use of the ability of some bacteria to produce methane from organic materials. These bacteria are currently used in some sewage treatment plants as well as a few farms to providew fuel for local consumption. If pre-digested wood wastes (digested to split the ploymers into their constituent parts) are fed to these bacteria they will produce methane from wood wastes. The gas contains carbon dioxide and water vapor as well as methane, but these can be removed, and the resulting gas is of pipeline quality. As yet this process is still in the experimental stage for wood wastes.

The pyrolysis of municipal wastes and sewage sludge is now a proven process that is slowly developing into a major use opf these materials. Wood wastes can, of course, also be burned in such systems, sometimes with minor adjustments. In fact, since wood is a considerably more consistent material than the usual haul of municipal refuse, wood fueled pyrolysis plants can be simpler and can have a more consistent output than those fueled with wastes.

The output of a pyrolyzer is a char consisting mostly of carbon; a heavy oil; and a low energy content gas containing carbon monoxide, hydrogen, water vapor, etc. The proportions of these outputs can be altered by varying the conditions of the process. The char and oils can, for example, be fed back into the pyrolyzer to be burned, thereby providing the energy for the pyrolysis of the remaining material.

The composition of the product gas also varies with the conditions of the pyrolysis and the composition of the feedstock. In some cases (e.g., municipal wastes in the ERCO fluidized bed reactor) the gas contains a great deal of nitrogen;[21] in others (e.g., wood chips in Union Carbide's PUROX reactor) the gas contains essentially no nigrogen[22]. In all cases the gas can readily be burned as a clean fuel; sometimes it contains enough energy (c. 300 BTU/cu/ft) to make it worthwhile to pipe it for a few miles, but not much further. In those cases where nitrogen is present, the gas is not well suited for conversion to methane or methanol;[23] however, the nitrogen can be removed, leaving a gas suitable for methanol synthesis.[24]

Methanol can be produced from gases containing carbon monoxide and hydrogen by passing them over a zinc-chromium catalyst. If one counts the energy required by the process, about 38% of the energy content of wood can be converted to methanol.[25]

A recent Forest Service study estimated plant, operating, and fuel costs for plants synthesizing methanol from various feedstocks.[26] A plant producing 50 million gallons methanol per year was estimated to cost (1975) more than $6 10^7; it would require almost 1500 tons/day of wood wastes (4 10^5t/yr if it operates 75% of the time). With wood wastes costing $25/ton the plant could produce methanol for about 70¢/gal. Although that is considerably higher than for methanol produced from natural gas at $2 per 1000 cu. ft., it seems unlikely that natural gas prices will continue to reamin so low. The wood-derived methanol is competitive with methanol from coal at $25/ton.

The processes for converting wood wastes to methanol are considerably more advanced than those for ethanol or any other fuel, other than the gas output from pyrolysis. Methanol is easily shipped and stored. It can be added to gasoline as a sort of "fuel extender" for use in ordinary internal combustion engines. Pure methanol can be burned in internal combustion engines with only slight modifications from current designs. Methanol is currently used less as a fuel than as a solvent and feedstock for further chemical syntheses. However, at 40¢/gal. (1975 price) it provides energy at $\$5/10^6$BTU. That is the same energy price as gasoline about 65¢/gal. It thus seems likely that in the not too distant future wood derived methanol will be a competitively priced fuel.

A methanol producing plant thus seems like a rather more worthwhile investment than an ethanol, etc., producing one, at least in the near future. The methanol plant would provide the same benefits to Maine as those we mentioned above for the ethanol plant. And since the processes for producing methanol from waste wood are much closer to commerical realization than those for producing ethanol, the economic estimates are much less speculative.

Pyrolysis also produces a char and an oil. These can be returned to the phyrolysis chamber to improve the yield of gas, or they can be removed. The oil is a fairly heavy oil that may be able to supplement or replace residual fuel oil. It can also be stored at the plant to provide a fuel for pyrolysis in case the ordinary fuel supply is interrupted.[27]

The char is a reasonably pure carbon and may be an adequate material for charcoal briquettes and other uses requiring a high-carbon fuel (some metallurigcal processes, for example). If steam is supplies during pyrolysis, activated carbon can be produced; this is a very valuable material for filtering and many other uses. If the char turns out not to be a useful by-product, it can always be returned to the pyrolyzer to be converted to gas.

5.4 Conclusions

The large scale, i.e., industrial, use of wood is quite feasible at this time: it is, in fact done. The forest industries burn waste wood and by-products to provide space or process heat and, sometimes, mechanical or electrical energy for their processes as well. As yet no industry seems to be entirely self-supporting, deriving all its energy as well as material from the forests. In principle, however, that is an achievable goal. For a large pulp mill it would require the purchase of additional wood (from logging residues and elsewhere) and the burning of perhaps 3 or 4 times as much wood as the mill now burns for it to be energy self-sufficient.

Electric power generation from wood fuel is currently a practical and economical process. Although generating stations of a size currently preferred by electric utilities are probably not optimal for burning wood, units of about 50 MW capacity may have offsetting advantages as base-load generating plants to make up for their smaller size. Since several such plants are already being investigated or planned, it seems that little further action is required to encourage their construction. At this time there do not seem to be serious regulatory constraints or political difficulties in constructing wood fired electric generating plants.

In order to reduce its reliance on out of state energy sources, Maine should encourage its forest based industries and its electrical utilities to replace existing or planned fossil fuel fired devices with wood fired ones wherever it is practical. The regulatory agencies of the state are already providing some encouragement in this direction. Any activity that enhances the economic attractiveness of wood chips, such as the recent price rise of fossil fuels or the development of the whole-tree chipper, will also serve the same goal.

The most efficient use of fuel is achieved in systems that generate useful heat and electricity together. Such cogeneration facilities are already in fairly widespread use, especially in the pulp and paper industry. There is, however, still a considerable potential for further expansion.

In order to use its fuels most efficiently, Maine should encourage cogeneration of heat and electricity as much as possible. The regulatory agencies are already providing some encouragement here also. The increasing cost of all forms of energy in providing a further incentive toward efficient fuel use.

The conversion of wood to other fuels, such as gas, methanol, charcoal, oil, ethanol, etc., is not yet practiced on an industrial scale. Of the various processes to produce synthetic fuels, pyrolysis is the most throughly developed. Its most useful outputs are char and a combustible gas; volatile compounds, for solvents and other uses, can also be obtained. The gas can be converted to methanol.

Processes that involve digestion of wood to produce fuels or chemicals are generally still experimental. However, it is possible that the need for organic feedstocks for synthetic chemicals, solvents, etc., can in the future be partly met by materials derived from wood wastes.

None of the processes that yield synthetic fuels from wood wastes are yet proven commercially. The most nearly practical is the production of methanol from gas produced by pyrolysis. Preliminary estimates indicate that wood wastes could be converted in the near future to methanol at a price competitive with methanol from fossil fuels.

If, as we recommended earlier, a State Energy Corporation is established, it should clearly investigate the economic feasibility of a methanol producing plant in considerably greater detail than we have been able to do here.

In view of the fact that there may be benefits for Maine from increased use of wood as a fuel that may not be as easily calculated as the costs, such as an increase in the number of jobs and a decrease of payments to out-of-state energy suppliers, it may be desireable to extend the usual accounting procedures to include such effects.[28] Such a procedure would be particularly appropriate for State-financed operations and for State-owned corporations.

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CHAPTER VI

ENVIRONMENTAL EFFECTS

The use of wood as a fuel has environmental effects in two locations: at the harvest site, where material that would be left by nature is removed, and at the combustion site, where heat and matter are dumped into the environment.

6.1 Harvesting

Removing trees from a forest removes not only the carbonaceous matter that is almost entirely derived (via photosynthesis) from carbon dioxide and water in the atmosphere, but also material derived from the soil. The materials in the atmosphere are an abundant resource; in some areas water is scarce and may be a limiting resource, but that is not the case in Maine. The materials from the soil are, however, much less abundant. Some of them, like nitrogen, are obtained by bacterial action on either decaying organic matter or air; other, such as calcium, are mostly derived from the weathering of rocks.

Leaves and needles contain a significantly larger proportion of the soil-derived nutrients than does the wood part of a tree.[1] The decomposition of fallen leaves, twigs, and trees accounts for a substantial part of the source of these nutrients, ranging from about 40% of potassium to 85% of the nitrogen.

Although the fallen needles and leaves provide an ongoing recirculation of nutrients, the removal of the last crop of needles or leaves together with the rest of the tree removes a significantly larger amount of nutrients from the forest than does harvesting the bole only. Although only 30% more wood is removed at rates 2 or 3 times larger than for conventional harvesting.

In addition to the export of nutrients removed with the wood, the removal of slash exposes the soil to considerably greater erosion and leaching by rain, leading to further nutrient removals. Runoff itself is increased, excerbating the problem. It may take as much as 60 to 80 years to fully restore nutrients and biomass lost after a whole-tree harvest, based on data from runoff samples.[2] Other data, based on gross nutrient budgets, indicate a restoration time of roughly 45 years.[3]

A carefully managed forest need not take that long to recover its nutrients and biomass, however. It would be possible to sow some rapidly growing grasses or other plants at the logging sites to reduce runoff; if the sown plants include clover or other nitrogen-fixing plant, the ground cover can serve to replenish the nutrients in addition to reducing runoff. Further nutrients can, if necessary, be restored by fertilizing. The ash from burning wood clearly makes an ideal fertilizer, returning the soil-derived nutrients in just the proportion in which they were removed. It is also a useful soil conditioner.

The effects of whole-tree harvesting are not well documented, and, as in any form of agriculture, the needs of forests differ from region to region. Any extensive use of whole-tree harvesting or of any form of thorough silviculture must thus be followed or accompanied by a careful monitoring of nutrient flows, erosion, and other aspects of the forest ecosystem.

Any logging operation does some damage to the soil. Logging roads, skidding trails, and landings all involve disruption of the soil surface by vehicles and felled trees, and damage to other plants that should have remained standing. The effect of whole-tree harvesting depends in large part on the vehicles used. Rubber tired vehicles do the greatest damage, horses the least. The crown of the felled tree serves as a chushion during skidding, so that the soil is disrupted less from this cause than in conventional harvesting.

Permanent logging roads and landings are considerably less subject to erosion and themselves are considerably less damaging than roads and landings cut ad hoc. Whether or not permanent roads are worthwhile depends on how often one needs to get into the forest. In case the forest is cultivated and thinned periodically, permanent loggings roads and landings become a necessity; they are also easier to maintain if they are used regularly.

An intensive program of thinning followed by clear-cutting can remove nutrients from the soil at a rate larger than natural replenishment under current conditions. Physical damage to the soil is likely to be less, however. Careful forest management can, furthermore, minimize the detrimental impact of these removals. These practices include

1. limiting regions of intensive silviculture to fairly level areas with fairly fertile soils;
2. keeping clear-out areas small enough to permit rapid reseeding from adjacent areas and to minimize excess runoff;
3. assuring that harvesting operations, both for thinning and clear-cutting, are carried out in a way that keeps damage to the forest floor to a minimum;
4. leaving strips of uncut forest next to streams to reduce silting of the stream and damage to the stream bands;
5. monitoring nutrient flows and other ecological variables, and correcting them (e.g., with fertilizer) when necessary;
6. removing trees at an average rate no longer than that at which the forest can recover.

Most of these are well known practices[4], and are employed by any careful forest management concern.

6.2 Combustion

Wood is, as we have mentioned, a fairly clean fuel. It contains very little sulfur; it burns at relatively low temperatures, so that its combustion releases relatively little nitrogen oxide. Wood does, however, contain fairly large amounts of ash. And if combustion is not complete, the smoke contains a considerable amount of suspended organic matter, some of it hazardous.

Typically, dry wood contains about 51% by weight of carbon, 42% of oxygen, 6% of hydrogen and 1% of ash.[5] These values vary from species to species. Ash content, for example, varies from 0.2% to more than 2% of the dry weight; bark contains up to 5% ash. The ash itself contains calcium, potassium, and other elements. Sulfur accounts for less than 0.1% of the dry mass of wood.

To compare these values with other fuels it is convenient to express them in terms of the heat content of the fuel. The potential pollutants for wood are thus:

ash (1% by weight) 1 lb./10^6 BTU
S (0.1% by weight) 0.1 lb./10^6 BTU.

For comparison, a typical low sulfur bituminous coal contains:

ash (4% by weight) 2.6 lb./10^6 BTU
S (0.6% by weight) 0.4 lb./10^6 BTU.

A high sulfur coal might contain

ash (10% by weight) 8 lb./10^6 BTU
S (3% by weight) 2 lb./10^6 BTU.

High sulfur fuel oil contains

ash (negligible)
S (2% by weight) 1 lb./10^6 BTU.

The pollutants in wood are clearly not outside the range of current emission control technology: any system that will control emissions from a facility that burns low sulfur coal will be more than adequate to deal with the emissions from wood fires.

For large scale systems the combustion is essentially complete, so that the only noxious mmaterial emitted in the smoke is the fly ash and nitrogen in the air. The Environmental Protection Agency has collected estimates of emissions from numerous processes.[6] For wood waste combustion boilers the nitrogen oxide emission factor is 10 lbs. per ton of fuel, that is, between 1/2 and 1 lb./10^6 BTU, depending on the moisture content of the fuel. This level of NO_x emission may conflict with the newest EPA standards. The proper emission factor is, however, still quite uncertain, and the estimate about[7] may well be too large.[8] If No_x does turn out to be a problem, its level can be reduced by regulating the amount of excess air for combustion.

Particulates emitted from an industrial boiler vary between 10 and 100 lbs. per ton of fuel, depending on the fuel and the manner of combustion. At such levels some form of control is necessary. There are numerous control methods available, from cyclones to electrostatic precipitators and fabric filters.[9]

With current pollution control methods, emissions from a large wood-fired system should be no greater than those for an equivalent fossil fuel fired plant, and may well be less.

The situation for small (home-sized) units is rather different. With the exception of the recently designed, very efficient furnaces, most wood burning stoves and furnaces send a considerable amount of unburned material out with the smoke. The emissions from such stoves have not been measured. We can, however, estimate them from the EPA data.[10] Particulates emitted (including organic material in an aerosol as well as fly ash) from a properly fired conical incinerator amount to about 1 lb. per ton of fuel; from a typical forest fire they are about 20 lbs./ton. Combustion in a home fireplace of furnace is likely to be in between these values, say 5 lbs./ton (green), or about 1/2 lb./10^6 BTU.

An average house burning wood on a cold night in winter at a rate of 10^5 BTU/hr. would thus dump .05 lbs. suspended particulates into the air each hour. In a typical suburb there are about 1300 such houses per square mile. If there is only a slow wind (1 mi./hr.) and a fairly low mixing height (200 ft.) the concentration of suspended particulates can rise to 0.2 mg/m^3. For comparison, typical urban concentrations of particulates are about 0.1 mg/m^3; in remote sites the concentrations are about one fifth of that.[11] The EPA primary standard is 0.26 mg/m^3 for a 24 hour period.

Clearly, the widespread adoption of wood buring stoves can have serious effects on air quality, particularly during times when the air is stagnant, as often happens on clear, cold nights. It should be emphasized that our estimate of the magnitude of the effect is purely speculative; actual values will depend very muchn on the nature of the situation and can easily be very different from the order of magnitude estimate given above.

Many of the products of incomplete combustion are carcinogenic and have other effects on health and well-being. The composition and amounts of the organic chemicals in smoke and similar aerosols vary widely, and the effect of each substance is difficult to assess. It is therefore customary to take one typical substance, usually benzo(a)pyrene as an indicator, and use its level to indicate the potential toxic effects of the atmosphere.

Wood fires produce about 50 mg. of benzo(a)pyrene for every 10^6 BTU of fuel comsumed.[12] The more complete combustion in efficient furnaces or stoves would lead to a smaller amount. Under the same conditions considered earlier (cold night, suburban density of housing), the concentration of bezo(a)-pyrene would reach 6 mg/m^3. Inhaling that atmosphere for a day is roughly equivalent to smoking 2/3 of a cigarette,[13] as far as risk of cancer, heart disease, etc., is concerned.

From the data on deaths due to lung cancers of people who smoke,[14] we can estimate that if that pollution level were sustained for a year it would lead to an excess of about 3 deaths per 100,000 people due to lung cancer. Heart disease and other causes would roughly quadruple that figure.

The average rate at which fuel is burned during a year is only one tenth of the peak value used above, however, and the atmospheric conditions are usually likely to lead to considerably better dispersal of the smoke. We should thus expect an excess of no more than about 10 deaths per year per million people in a population that uses wood to heat their homes. People who smoke one cigarette per day, by contrast, have an excess death rate due to all cuases of about 200 per year per million people.

Burning oil or gas in home furnances produces less than one fiftieth the amount of benzo(a)pyrene produced by burning wood.[15] There is thus a small but noticeable effect on public health that can be attributed to a major conversion to wood fuel. Since, however, some of the recently designed wood furnaces achieve essentially complete combustion, such units should alleviate the potential health hazard considerably.

There are as yet insufficient data to assess accurately the effects on public health of widespread use of wood fuels. It is therefore impossible to suggest what measures may be worthwhile to deal with these effects. We have estimated that the effects are small; in the case of large-scale industrial units they are likely to be no greater than those of burning the equivalent amount of fossil fuels, while in the case of small scale home units they are sufficiently dispersed in time and space that their impact is unlikely to be severe. We suspect that there is enough time to gather and evaluate data about the public health effects of wood combustion before the public health is noticeably affected.

Burning wood rather than fossil fuel has one potential beneficial impact on the atmosphere. The carbon dioxide released by the combustion has only recently been fixed into wood, while that released by burning fossil fuels was removed from the atmosphere long ago. Burning fossil fuels thus increase the total amount of carbon dioxide that circulates between the atmosphere and the biosphere. Burning wood or other fresh biomass, on the other hand, can be considered as merely enhancing the rate at which CO_2 is released to the atmosphere from the decay of organic material; that is, it can be considered as merely increasing the rate at which CO_2 circulates between the atmosphere and the biosphere. If the total amount of organic matter in the biosphere remains constant, burning wood or other biomass will thus lead to no net increase in CO_2 levels. Since increasing carbon dioxide levels my pose an environmental problem, burning wood may be beneficial. However, the total carbon dioxide cycle is not yet well enough understood to make any clear predictions.[16]

6.3 Conclusions

The environmental effects of using wood as a fuel can be divided into two categories: the effects on the soil and streams where the wood is harvested, and the effects on the air where the wood is burned.

Whole-tree harvesting, intensive thinning, and use of cull and dead trees will remove considerably larger amounts of nutrients from the forest than do conventional harvesting methods. Careful foreset management practices should, however, be able to minimize the adverse effects of harvesting while maintaining or even improving the growth of the foresets and their suitability for wild life and for recreational uses. We have already recommended (in Chapter II) that Maine should encourage education in proper silvicultural practices and provide forest management assistance to small landowners.

Wood is, because of its composition, a fairly clean fuel. It contains negligible amounts of sulfur. Its combustion releases comparatively little nitrogen oxide, although the actual amounts are still uncertain. It contains less ash than many kinds of coal. There are many well developed methods of controlling potential air pollution effects of burning wood.

There may be an environmental hazard associated witht he incomplete combustion that frequently takes place in fireplaces and stoves in homes. Some of the chemicals released may cause cancer and may lead to an increased risk of heart disease and other illnesses. Widespread use of wood as a fuel in home heating units may produce temporary concentrations of these substances whose public health effects are equivalent to smoking a cigarette or two. Wood differs from the other fossil fuels in this respect. The small scale (inefficient) combustion of oil and natural gas is relatively clean; coal, the other potentially dirty fuel, is rarely burned in small and inefficient units anymore. For largescale units pollution control systems are called for in all cases, and here wood does not differ from other fossil fuels; in fact, wood is a considerably cleaner fuel than many kinds of coal.

The public health effects of burning wood are still uncertain. If, after further research, it seems that there is a serious hazard involved, corrective steps can be taken. These include conversion to heating units that are designed to achieve complete combustion and banning the use of fireplaces on days or nights when atmospheric conditions lead to local accumulations of smoke and fumes. In order to encourage the use of stoves and furnances that achieve complete combustion of wood, it would probably suffice to undertake an educational campaign. We have already suggested that wood stoves be sold with improved instructions for safe installation (Chapter IV). These instuctions could also contain information about the beset ways to achieve complete combustion and the potential hazards of not doing so.

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APPENDIX A

Wood Resources and Growth Rates

References:

FS USDA Forest Service Bulletin NE-26.[1]

YP Biomass Sampling Methods for Puckerbrush Stands.[2]

TB Biomass Inventory of some Public Land in Maine.[3]

The Forest Service has collected data on the volume of Growing Stock, i.e. mercantable bole, for the State of Maine (FS). To convert these data to biomass estimates, as given in Table 2, we have assumed:

1. wood has an average density of 30 lbs. (oven dry) per cubic foot;
2. milling produces, on the average, 5.4 board feet of lumber from a cubic foot of bole, together with 0.55 cubic foot of waste. This is consistent with the data in (FS) and with the International 1/4" rule;
3. tops and branches represent about 30% of the above ground mass of a tree, the bole the remaining 70% (YB).

Young has given estimates of total biomass standing on a wide variety of lands (YB). Since the distribution of the various stocking classes in the stands examined by Young may not be representative of the State as a whole, one should adjust Young's data accordingly. As a first approximation to this adjustment we have assumed:

1. That sawtimber stands (FS) correspond, more or less, to mature stands (YB). these account for 36% of the total forest area in Maine and for 37% of the area studied by Young.
2. That poletimber stands (FB) correspond roughly to second growth stands (YB). These account for 32% of the total forest area of Maine and for 58% of the area investigated by Young.
3. That sapling-seedling and non-stocked stands (FS) correspond, at least in their average biomass content, to regeneration stands (YB). Such stands account for 32% of the total area and 5% of the area examined by Young.

Table 8 shows the results of computations for growing stock, cull, and total biomass in Maine. Tops and branches contain, as we have assumed, 3/7 times the biomass of growing stock. Bushes, saplings, and non-commercial trees make up the remainder.

TABLE: 8 TIMBER RESOURCES IN MAINE

Computed from data in [FS] and [YS].
All weights given are of oven-dry wood.
Biomass refers to above ground material only.

	Sawtimber Stands	Poletimber Stands	Regeneration Stands	Total
Area in Maine	6.14 10^6 acres	5.34 10^6 acres	5.41 10^6 acres	16.89 10^6 acres
Sawtimber	6.6 10^7 t	2.2 10^7 t	0.8 10^7 t	9.6 10^7 t
Growing Stock	16 10^7 t	12 10^7 t	4 10^7 t	32 10^7 t
Cull				6 10^7 t
Biomass/area	62t/acre	48t/acre	18t/acre	38t/acre
Biomass	33 10^7 t	23 10^7 t	8 10^7 t	64 10^7 t

The growth rates for various classes of timber have been estimated in the Forest Service survey (FS). Young has estimated growth rates for total biomass (YP). There is a slight problem involved in extrapolating these estimates to total growth rates, since it is unclear whether the growth of a stand of trees is proportional to the area of the stand (linear growth) or to the existing biomass (exponential growth). Young's data (YP) are consistent with either hypothesis; the latter has some theoretical justification,[4] while the former is the one most commonly used in practice. We shall here adopt the latter hypothesis, that growth is proportional to standing timber.

Puckerbrush stands grow at an average rate of 5.6% per year (YP). Growing stock grows at a rate of 4.0% per year (FS). Since puckerbrush may grow at a rate slightly faster than average, while the growth of growing stock is decreased by the cull increment, the average growth rate of biomass is probably between these rates. We have estimated it at 5.0% per year.

Table 9 shows the results of calculations of growth rates for various classes of timber in Maine.

TABLE: 9 GROWTH RATES FOR TIMBER IN MAINE

All data are averages for 1958-1970, computed from [FS] except as noted.
Masses are for oven dry wood; Mt = 10^6t.
Mercantable bole only; multiply by 1.43 to estimate above ground mass.

TO: \ FROM:	Sawtimber	Poletimber	Samplings & Miscellaneous	Cull Trees	All Sources (=net growth)
Sawtimber	0.8 MT/yr.	2.6 MT/yr.	0	0	3.4 MT/yr.
Poletimber	0	0.5 MT/yr.	7.5 MT/yr.	0	8.0 MT/yr.
Growing Stock	0.8 MT/yr.	3.1 MT/yr.	7.5 MT/yr.	0	11.8 MT/yr.
Cull	1.0 MT/yr.	1.0 MT/yr.	0.6 MT/yr.*	2.4 MT/yr.*	5.0 MT/yr.
Dead	0.6 MT/yr.	1.4 MT/yr.	2.5 MT/yr.*	0.6 MT/yr.*	5.1 MT/yr.
Harvest	4.2 MT/yr.	0.9 MT/yr.	1.0 MT/yr.	0.2 MT/yr.	6.3 MT/yr.

*cull increment of saplings, etc. = 1/2% per year
*mortality of saplings, etc. = 1% per year
*ingrowth of cull = 4% per year
*mortality of cull = 1% per year

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APPENDIX B

Estimates of Heating System Costs

The estimates given in this appendix and summarized in Table 6 and 7 are only intended to be a rough indication of heating system costs in some typical situations. The methods used should be generally applicable, however, and should give results analogous to those indicated in the tables.

Single Family Dwelling

A typical single-family house with reasonable insulation (16,000 sq. ft. floor area; storm windows, double doors, insulated walls, attic, and floors) requires about 70 million BRU per year in energy delivered to the living areas.[1] More thorough insulation, as is commonly installed in all-electric houses, can bring that requirement down to 60 million BTU per year; older, less well insulated houses may require 90 million BTU per year. We shall suppose an annual requirement of 70 million BTU. This is the total energy requirement for heating the house; it will determine the total fuel cost.

The heating system must keep the house warm on even cold nights, and the size (or heating capacity) of the system is determined by the rate of heat-loss from the house at the coldest expected time. For our typical house, that is about 7 10^4 BTU per hour. (For New England there are about 5000 heating hours per year - i.e., hours during which the heat must be on. The average energy consumption is 2 10^4 BTU/hr. The heat loss is proportional to the temperature difference between inside and outside. The average temperature difference is 28 degrees F. If we suppoe that the lowest outside temperature is -35 degrees F, the maximum temperature difference is 100 degrees F, about 3 1/2 times the average. The maximum heat loss is then also 3 1/2 times the average. If the installed heating capacity is much less, the house may get cold on very very cold nights, but if its capacity is much greater one is paying for something one does not need.

The total cost associated with a capital expense must include a reasonable allowance for interest and depreciation. For purposes of calculation let us suppose that the expense is added to a 20 year mortgage carrying 10% intereste, and that depreciation is accounted for by investing in a sinking fund (6% interest) that will provide 100% of the cost of the item (uninflated) after 20 years. Total costs are then 2.84 times the initial cost (cash value) of the item. Over 20 years, the average annual payment is 0.142 times the initial cost.

Most homeowners itemize income tax returns; interest payments and depreciation are deductible items. If the homeowner is in the 40% bracket then each $1 of interest reduces his tax liability by $0.40. The total interest paid on the mortgage is 1.32 times the initial cost; from that amount must be subtracted the amount of interest earned by the sinking fund, viz. 0.48 times the initial cost. Over a 20 year period, then the total tax liability is decreased by 0.33 times the intial cost. The effective annual payment after taxes is therefore 0.125 times the initial cost, on the average over 20 years.

To compute annual fuel costs we must take into account the efficiency with which the energy contained in the fuel is converted to useful heat in the desired rooms. The efficiencies listed in Table 6 take into account not only the energy lost in the combustion process but also that lost in delivering heat to the house.[2]

The systems compared in Table 6 are:

1. Oil furnace: forced air central heating unit; 140,000 BTU/hr. capacity (fuel input); efficiency, 0.50 (estimate); available from Sears, Roebuck, $300.
2. Gas furnace: forced air central heating unit; 105,000 BTU/hr. capacity (fuel input; this is a little undersized); efficiency, 0.60; available from Sears for $340; ductwork, $300.
3. Electric resistance; baseboard plug-in heating units 71,000 BTU/hr. capacity (21 kW electric); efficiency 1.00 (this assumes somewhat better insulation than average on the electricity heated home thereby counteracting the distribution losses, which in any case, are smaller than for central heating furnaces); available from Sears for $410.
4. Electric heat pump; heating/air conditioning unit; 12 kW electric input; efficiency, 1.70; cost estimated from Sears' air conditioning units as $900; ductwork $300.
5. Wood stove; controlled draft room heating units; one unit has a 50,000 BTU/1w capacity, the other 25,000 BTU/1w (delivered heat); efficiency, 0.45; Jotul 118, $500, Jotul 602 $300, available from Bow and Arrow Stove Co. or from Kristia Associates.

6. Wood furnace: high-efficiency experimental design of Prof. R.C. Hill, Department of Industrial Cooperation, University of Maine at Orono, intended for use with a circulating hot water system; can be installed for use with existing central heating units; overall efficiency estimated at 0.60 (75% furnace efficiency); cost estimated at $300 for the wood burner added to an existing system, with heat exchanger, water tank, and pipes adding $700. A larger water tank to provide even greater heat storage and operating convenience and would add another $100.
7. Automatic stoking wood chip furnace: experimental unit designed by Prof. J.G. Riley, Department of Agricultural Engineering, University of Maine at Orono. Prof. Riley's unit is about twice as large as is needed. To scale the costs down we have assumed that costs go as size raised to the 0.6 power. (This is an empirical relation valued for Sears' prices as well as for larger units[3] and seems likely to hold in general.) For a 120,000 BTU/hr. unit (efficiency 0.60) costs are thus estimated at $2500.

Multi-Family or Commercial

Estimates for the heating needs of residential and commercial units are given in studies done at the Brookhaven National Laboratory.[4] From these data we estimate that, on the average, a commercial structure (office, school, store, hospital, etc.) requires approximately 13 10^4 BTU/yr. per square foot of floor space for space and water heating. (About 5/8 of that is for space heating, 1/8 for hot water.) For a small structure with 4000 square feet of floor space, the heating demand comes to 5 10^8 BTU/yr.

For the same set of BNL data we also estimate that a typical small apartment building (10 units, 900 sq. ft. per unit) uses about 35 to 40 million BTU per household per year for space heating and an additional 15 million BTU/yr. per household for hot water. The total heating needs for such a house would thus also be about 5 10^8 BTU/yr.

As in the case of single-family dwellings, the maximum heating demand will be about 3 1/2 times the average heating demand. The installed capacity should thus be about 350,000 BTU/hr. assuming 5000 heating hours per year.

Since the wood-chip burners of this size range are all still experimental units it is difficult to estimate their probably market price. Prof. Riley has variously estimated that for his 200,000 BTU/hr. unit, the cost would be about 3-

to 5 times the equivalent oil burning unit ($690 at Sears, Roebuck and Co.)[5], and that it would be less than about $6000.[6] As a reasonable intermediate estimate for such a heating unit we shall take $3200. To estimate the costs for different size units we shall assume, as before, that costs are proportional to size raised to the 0.6 power. Since oil is burned (typically) with an efficiency of 0.5, while wood chips burn with an efficiency of 0.6 or more the burners will have to have different capacities to meet the expected heating demand. The appropriate estimated costs are thus:

gas	6 10^5 BTU/hr.	$1000
oil	7 10^5 BTU/hr.	$1500
wood	6 10^5 BTU/hr.	$6100

(rounded to $100; uninstalled)

The annual costs associated with the capital outlay depend very much on the nature of the financing used and on the way in which depreciation and other costs are accounted; tax liabilities will also vary considerably from case to case. Since, however, we are interested in a comparison of the costs of several equivalent systems, a crude estimate will suffice. We thus suppose that the system is financed with a 20 year loan at 12% interest, and that depreciation is accounted for by a sinking fund at 6%; other charges and credits we may suppose more or less concel each other. The annual cost thus averages 0.158 (or about 16%) times the price of an item.

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APPENDIX B

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