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**ISSUES IN THE USE OF WOOD
AS AN ENERGY SOURCE
IN THE NORTHEASTERN U.S.**

J.S. MUNSON, EDITOR

May 1980

MASTER

**DIVISION OF REGIONAL STUDIES
NATIONAL CENTER FOR ANALYSIS OF ENERGY SYSTEMS
DEPARTMENT OF ENERGY AND ENVIRONMENT**

**BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973**

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DIVISION OF REGIONAL STUDIES
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Under Contract No. DE-AC02-76CH00016 with the
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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy \$10.00; Microfiche \$3.50

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ABSTRACT

This report analyzes some of the concerns surrounding the use of wood for energy in the Northeast. It reviews the information on resource availability and ownership patterns in the Northeast, then focuses on New England, to assess the affect of potential resource constraints on the supply of wood available for energy and the effects of wood energy use on land use patterns. Finally, the application of specific technologies in settings that may experience significant wood energy use in the future is considered, including an assessment of the regional employment and income benefits of a major woodfuel installation.

ACKNOWLEDGMENTS

The authors acknowledge the many contributions of their colleagues at Brookhaven who have aided in the preparation of this report, especially Dr. Peter Meier and Laine McCarthy who were free with both their critical comments and their editorial assistance.

We are indebted to Robert Stern for his help with graphics preparation and to Pat Miller and June Martino for typing through repeated revisions.

However, the responsibility for the accuracy and content of the report is solely that of the authors.

CHAPTER I

INTRODUCTION

As is apparent from recent activities, the use of wood for energy is attracting increased attention. At present, wood is used as fuel in a moderate number of residential, commercial, and industrial establishments as well as for one small electric generating unit in the Northeast. The wood so used represents a fourfold increase over the use of wood for energy in the early 1970's. Anticipated uses would seem to indicate an even more rapid rate of growth, as well as changes in the scale of each anticipated use: for example, 50-MW wood-fired electric generating stations as opposed to the 10-MW combined fired station in existence; or large commercial heating systems as opposed to single residence systems. On the other hand, potential policy changes such as the inclusion of wood heating systems in tax rebate or write-off programs encourage wood energy uses of any size.

In light of these trends, and in view of recent energy price increases for the traditional fuels and electricity, it would appear that the use of wood for energy will increase dramatically over the next decade. There are many questions to be answered, however, if we are to avoid indiscriminate and undesirable uses of our forests: How much wood is available for energy use on a renewable basis? What are the competing uses? Where are the areas most likely to supply the necessary volume of wood for large users? Is wood fuel demand and existing and future timber and paper product demand compatible or competitive? If compatible, under what circumstances? What type and intensity of timber management will be necessary to supply both product and energy uses in the future? How will a forest management system affect the growth rate and speciation of existing forest areas? What will be the local, regional, and national socio-economic effects of partially replacing traditional fuels with wood fuels? Are a large number of small-scale wood energy users (say, domestic users) compatible with large-scale wood energy users? How will increased wood use affect land use and environmental factors? Will environmental factors restrain the use of wood for energy? If so, are they amenable to mitigating strategies? Will environmental protection measures affect the cost of using wood for energy? If so, will wood costs still be competitive with fossil fuel or electric costs? In sum, we seem to know less about the factors that affect and are affected by wood use than we do about other fuels.

We can, however, state with some certainty that the benefits derived from our forests differ not only in kind but in degree from the benefits to be obtained from using wood to provide energy or product alone. For example, forest land in the Northeast provides the largest recreation area available in the region and use of these areas is second only to use of coastal recreation areas. The diverse Northeastern forests provide habitat for all manner of fish and wildlife, some having economic and environmental value. They are self-sustaining, and forest litter provides the necessary nutrients for their continuity. Their root systems, trunks, and associated shrubbery provide unparalleled soil stability and protection. Their presence along water courses provides passive flood control without the associated costs of flood control structures. In sum, both their practical and amenity values are large.

Past experience with other types of environmental development (particularly water resources development) has shown that the importance of nonquantifiable factors is extremely difficult to estimate. Many aesthetic and ecologic amenities thus have little influence in decisions, and others are included only insofar as their importance can be estimated (for example, recreation). The extension of such a limited focus to a resource whose areal dimensions are so large, and whose relationship to associated ecosystems are so profound, would be a travesty. Under these circumstances it would seem that both moderation and knowledge are desirable before a decision to promote widespread wholesale wood energy use is taken.

It could, on the other hand, be argued that our forest resources are larger now than at any time in the past several hundred years and represent an untapped energy resource of considerable size. While true (as will be noted in the following papers), it is important to realize that forest have many uses and multiple value while coal, oil, and natural gas can be used only as fuels or feedstocks. Yet the price of wood on the market represents only its economic value. It does not reflect the intrinsic value of the standing resource. Nor does it reflect the value of a limited resource in high demand. Yet our domestic wood resources are approaching the point of resource limitations. Nonetheless, wood energy is at present attractive. It is, for some uses, cheap. It is relatively benign. It is available. And, best of all, it is potentially renewable.

The chapters of this report, prepared with help from Dartmouth College and Harvard, provide information on some of the questions asked previously. Chapter II looks at the forest resources in the Northeast (defined here as New England, New York, New Jersey, Pennsylvania, Maryland, and Delaware) in an attempt to determine how much wood is available, how much wood will be available in the future, where the greatest forest resources are to be found, and the nature of the prevailing forestland ownership pattern. Chapter III looks at a region of smaller size (New England) to assess the effect of wood energy use on land use and to determine how resource constraints may affect the supply of wood for energy and industrial uses. Chapters IV to VI, prepared by Thomas von Foerster at Harvard, look at Maine (the state with the highest concentration of forest in the Northeast) and relate resource factors to potential energy uses in a state that will experience significantly increased wood use in the near future. Finally, in Chapter VII, P. VanderWerf of Dartmouth presents an analysis of the regional employment and income benefits derived from a major wood burning project.

CHAPTER 11

WOOD FOR ENERGY IN THE NORTHEAST*

by

James S. Munson

While the use of wood for energy has never been completely discontinued in the Northeast, only recently has its potential as a primary fuel for both large- and small-scale applications attracted serious attention. The number of current activities and proposals for the use of wood as a fuel, including residential heating, fuel replacement in the wood industry, and electric generation at modest central facilities, seem to be sporadic. Without a better understanding of the resource base and forest dynamics, the potential for unwise use and resource abuse is great.

Land Use

As shown in Table 1, commercial forestland (land capable of producing more than 20 cubic feet of wood per acre and not withdrawn from timber use) in the Northeast accounts for approximately 60% of the total area of the region.

TABLE 1
LAND AREAS IN THE NORTHEAST BY MAJOR CLASSES OF LAND AND
STATE. JAN 1, 1977
(Thousand Acres)

	Commercial Forest	Productive Res./Def	Other Forest	Rangeland	Other ^a	Total ^b
Connecticut	1805.6	30.5	24.7	c	1250.9	3111.7
Maine	16894.3	220.7	633.6	0.4	2039.8	19788.8
Massachusetts	2797.7	104.5	50.1	0.1	2056.2	5008.6
New Hampshire	4692.0	83.7	237.8	c	763.8	5777.3
Rhode Island	395.3	8.9	c	c	267.2	671.4
Vermont	4429.9	61.5	20.3	c	1419.2	5930.9
Delaware	384.4	1.8	5.6	c	876.7	1268.5
Maryland	2522.7	108.9	21.6	83.7	3593.3	6330.2
New Jersey	1856.8	34.0	37.6	60.5	2824.5	4813.4
New York	14489.0	2480.9	407.8	1.8	13232.3	30611.8
Pennsylvania	17478.0	194.0	160.0	c	10946.2	28778.2
Total	67,745.7	3329.8	1599.1	146.5	39270.1	112,090.8

^aIncludes pasture, swampland, industrial and urban areas and other nonforest land.

^bU.S. Department of Commerce, Bureau of Census, Area Measurement Reports, GE-20 No. 1, p. 22, 1970.

^cNo data or negligible amounts.

Source: Forest Statistics of the U.S., 1977, USDA-FS, Table 1

*This chapter was originally presented to the Wood Energy Workshop, Northeast Solar Energy Center, Sept. 1978

Figure 1. Percent of total state land area in commercial forest.

Figure 2. Percent of total Northeastern commercial forest by state.

Figure 3. Commercial forest land area as a percent of total county area.

Figure 4. Change in forest acreage in New Hampshire.

These commercial forest lands are not, however, uniformly distributed throughout the region (Figure 1). Over 80% of the land area of the Northern Tier of New England is in commercial forest. But only 56 to 61% of the land area in the Southern Tier and New York and Pennsylvania is similarly classified, while in New Jersey, Maryland, and Delaware commercial forests drop below 40% of the total state land area.

Yet, as shown in Figure 2, these data are somewhat misleading. Three states (Maine, New York, and Pennsylvania) account for over 70% of the total commercial forest land in the region. New Hampshire and Vermont have 13.4% of the total commercial forest area. Thus, in terms of contribution to total commercial forest acreage, the area of maximum forestland concentration lies in an inland arc from Maine to Pennsylvania. Conversely, the six coastal states from Massachusetts to Maryland (excluding New York) have the smallest areas of commercial forest: less than 17% of the region's total.

These data, however, provide only a modicum of information concerning the areal density of forest resources: a matter of some concern to potential large-scale wood energy users. Figure 3 shows the area of commercial forestland by county in the Northeast. Central Pennsylvania and the Northern Tier of New England have the largest concentration of commercial forest area per county, and hence, are areas of potential resource development.

While reliable data are not available on changes in regional forestation and land use patterns over a long period of time, it seems likely that the patterns of change were not unlike that of New Hampshire (Figure 4): after colonization forest area declined until, following the replacement of wood with fossil fuels in the late 19th century and the decline of agriculture in the Northeast, the demand for wood and the demand for agricultural land lessened. Passive albeit rapid reforestation then occurred and continued up to the middle of the twentieth century. Between 1952 and 1970 this trend slowed until, between 1970 and 1977, there was a decline in regional commercial forest area (Table 2). Only Vermont showed a net increase in commercial forest area between 1970 and 1977. It would seem, then, that conflicting uses (for example urban development) and competing demand (wilderness areas and wildlife sanctuaries) have most probably put a lid on the increase in commercial forest area.

Forest Land Ownership

The potential for large-scale long-term use of timber sources is partially dependent on resource control, either through direct ownership or through the acquisition of logging rights in commercial forest areas. Commercial forest land which is dedicated to nontimber uses or industrial wood uses (other than energy) will, most probably, not be available for fuel uses (although logging residues and commercially undesirable wood may be available as a by-product). As shown in Table 3, the forest industry owns approximately 17.5% of the region's commercial forest land. The majority of industry-owned land (98%) is in five states (Maine, New Hampshire, Vermont, New York, and Pennsylvania). One state alone, Maine, accounts for 70% of all forest industry land in the region (Table 3). Thus, in the five states with the largest commercial forest areas, the forest industry controls about 20% of the forest resource base.

TABLE 2
CHANGE IN THE AREA OF COMMERCIAL FOREST LAND BY STATE, 1952-1977^a
(Thousand Acres)

	1952	1962	1970	1977
Connecticut	1973.0	1893.7	1823.2	1805.6
Maine	16609.4	16779.4	16894.3	16894.3
Massachusetts	3259.0	3040.6	2846.3	2797.7
New Hampshire	4818.6	4937.6	4806.8	4692.0
Rhode Island	430.0	429.0	429.0	395.3
Vermont	3845.9	4210.9	4364.0	4429.9
Delaware	392.0	391.0	390.0	384.4
Maryland	2854.7	2845.7	2673.6	2522.7
New Jersey	2050.0	2262.0	1978.5	1856.8
New York	11952.2	13417.2	14489.0	14489.0
Pennsylvania	14574.0	16279.0	17478.0	17478.0
Northeast Total	62758.8	66486.1	68172.7	67745.7

^aData for 1952, 1962 are as of Dec. 31. Data for 1970, 1977 are as of Jan 1.

Source: USDA-FS 1977, Table 2.

Another 10% of the commercial forest area is publicly owned: the federal government holds 2%, state governments 6.8%, and local governments 1.1%. As shown in Table 3, these holdings are unevenly distributed through the region. For example, almost 50% of the region's federally owned land is in New Hampshire and Vermont. This amounts to 7.5% of the commercial forest area of these two states. Over one-half of the land owned by state governments in the Northeast is in Pennsylvania (or about 15% of all the commercial forest land in the state).

Private owners, both corporate and individual, control the largest area of commercial forest land in the region (72.5%). Agricultural owners control 17% of the commercial forest area, of which most (two-thirds) is in New York and Pennsylvania (Ferguson, 1968 and Ferguson, 1970). Private owners of the remaining commercial forest area include public utilities, real-estate developers, recreational concerns, and individuals.

TABLE 3
AREA OF COMMERCIAL FOREST LAND BY OWNERSHIP AND STATE, 1977
(Thousand Acres)

	Federal	State	Local	Forest Industry	Farm and Other Private
Connecticut	2.4	119.8	24.4		1659.0
Maine	73.3	163.0	75.2	8255.0	8327.8
Massachusetts	9.6	240.1	115.7	30.1	2402.2
New Hampshire	471.6	79.2	28.9	946.9	3165.4
Rhode Island		20.1	12.0		363.2
Vermont	212.8	168.2	41.0	666.3	3341.6
Delaware	0.6	13.4		29.7	340.7
Maryland	24.9	185.2	32.9	139.2	2140.8
New Jersey	27.7	245.9	45.3	16.3	1521.6
New York	57.5	711.4	123.1	1180.3	12416.7
Pennsylvania	515.0	2646.0	242.0	610.0	13465.0
Northeast Total	1395.4	4592.3	740.2	11873.8	49144.0

Source: USDA-FS, 1977 (Table 2)

The size of commercial forest holdings by individuals and groups varies. In southern New England, individuals holding 24 acres, on average, control 88% of the privately owned commercial forest land: corporations control only 12% (Kingsley, 1974). In New Hampshire, the average private ownership is 46.7 acres, but 65% of the owners hold less than 10 acres. Those with larger holdings control 96% of privately owned commercial forest land (Kingsley, 1976). In New Jersey, individuals own 54% of all commercial forest land, corporations only 24% (Ferguson, 1974). Because of its unique system of land ownership, specific holdings of forestland in Maine are difficult to determine. While more than 8 million acres of commercial forest land are privately owned, slightly less than 40% are managed by professional organizations responsible for all forest decisions (Meadows, C.E.).

If, as discussed above, 28% of the commercial forest area of the region is removed from primary consideration for large-scale wood fuel recovery systems -- that land being owned by the forest industry or held in the public trust -- the stress of increased timber resource development will fall on privately owned lands. The number of owners, the size of each holding, and the spatial distribution of privately owned forest land will then be resource decision factors in wood energy projects. In addition, the willingness of individual or corporate landowners to dedicate their forest holdings to renewable resource development is an important consideration.

Wood Resource

The resource available for wood energy uses (on a renewable basis) is a function of the current volume of the resource, the rate of growth, and losses to nonenergy uses. Windfall resources such as those from land clearing or diseased trees may provide substantial quantities of wood over a short period of time but are problematic for large-scale long-term wood energy development: the wood supply available from land clearing for a reservoir may be

large, but the reservoir removes land from production, forcing the wood users to look elsewhere for their future supply.

Not surprisingly, the volume of wood is greatest in those states with the largest area of commercial forestland (Table 4). According to the Forest Service estimates (USDA-FS, 1977) Maine, New York, and Pennsylvania together account for approximately 71% of the net volume of timber on commercial forest land in the region. New Hampshire and Vermont account for another 15%. Thus, the distribution of standing timber resources is approximately proportional to the distribution of commercial forest land.

TABLE 4
NET VOLUME OF TIMBER ON COMMERCIAL FOREST LAND IN THE NORTHEAST,
Jan. 1, 1977
(Million Cubic Feet)

	Softwood	Hardwood	Rough	Rotten	Total
Connecticut	425.0	2237.4	133.7	53.2	2849.3
Maine	16365.9	6551.9	1479.8	1490.2	25887.8
Massachusetts	1438.7	2454.3	484.2	101.9	4479.1
New Hampshire	3525.8	3760.4	593.4	359.0	8238.6
Rhode Island	107.9	304.1	60.2	8.2	480.4
Vermont	1825.6	3164.7	880.3	357.5	6228.1
Delaware	168.5	456.2	29.8	7.9	662.4
Maryland	793.0	2699.1	285.0	111.7	3888.8
New Jersey	251.4	1282.1	105.8	31.3	1670.6
New York	3604.3	9958.7	1652.5	1181.9	16397.4
Pennsylvania	1846.5	22576.7	2126.5	803.8	27353.5
Northeast Total	30352.6	55445.6	7831.2	5506.6	98136.0

Source: USDA-FS, 1977 (Table 10).

The average volume of timber on commercial forest land in each state varies, however, ranging from highs of 1856 cubic feet per acre in New Hampshire and 1723 cubic feet per acre in Delaware to a low of 900 cubic feet per acre in New Jersey.¹ The average timber density in the Northeast is about 1448 cubic feet per acre.

Such figures are not entirely accurate reflections of the volume of biomass on commercial forest land or site specific stand density.² The growing stock volume (as reported by the U.S. Forest Service) is the "net volume of live growing stock trees that are 5.0 inches in diameter at breast height and over, from a 1-foot stump to a minimum 4.0-inch top diameter outside bark of the central stem, or to the point where the central stem breaks into limbs." Branch wood, bark, twig, leaf and root biomass, all potentially useful for energy, are not currently reported by the Forest Service.²

Independent measurements and estimates of standing biomass in discrete live stands are shown in Table 5. (All the original data were converted to cubic feet for ease of comparison.) In these stands, stem biomass was as much as double the growing biomass reported by the Forest Service.³ Total

aboveground biomass was from 2 to 3 times the Forest Service estimates of growing stock. Thus, for the Northeast, the average aboveground biomass available for energy uses, if all aboveground parts of the trees were used, may be as much as three times greater than the growing stock volume alone.

TABLE 5
ABOVEGROUND BIOMASS SUMMARY
(Cubic Feet Per Acre)

Measurements	Foliage	Branches	Stem	Root	Total
<u>Hubbard Brook^a</u>					
Low	92.7	1260.5	3418.2	910.0	5687.3
Mid	88.2	1342.1	3033.3	956.3	5423.8
High	113.5	844.5	1484.4	697.6	3700.3
<u>Brookhaven^b</u>					
Oak/Pine	139	474	1290.9		

^aThese measurements given in dry g/m² in Table 5 have been converted to cubic feet per acre.

^bEstimated from Table 4, Pat D.

Source: Whittaker, R.H., Bormann, F.H., Likens, G.E., and Siccama, T.G. (1974).

Some of the difference between the Forest Service estimates and the site-specific measurements shown in Table 5 can be attributed to the fact that the Forest Service does not include estimates of the volume of wood in the sapling stock; thus, it can be inferred that biomass in the sapling stock is significant. In addition, the Forest Service estimates do not include estimates of biomass off the commercial bole on growing stock. A recent study at Dartmouth College (Hewett, 1978) presented information on total above-ground forest biomass as a percent of a standard merchantable bole inventory (Table 6). These figures, derived from studies in both North America and Scandinavia, show whole-tree harvest resulting in yields equal to 128 to 397% of those expected from merchantable bole inventories (Hewett, 1978). In view of the variation between these data, between these data and the Forest Service estimates, and the scarcity of corroborative data specific to the Northeast, it would be unwise to attempt to apply these data to estimates of total above-ground biomass at the regional, state, or even site-specific level.⁴

Table 7 shows the level of stocking of commercial forestland in the region; that is, the degree of occupancy of land by trees, measured in terms of the basal area of trees in a stand compared to the basal area of trees required to utilize fully the growth potential of the land. To a certain extent, the level of stocking is an indication of stand density and growth potential. Extensive forest areas in southern New England, Maine, Vermont, and New York do not meet the standard 75 square feet of basal area per acre. Almost all of the states have extensive areas of overstocked forestland.

Annual Growth, Cut, and Removals

According to the Forest Service, changes in growing stock volume are a composite of several factors: the increment in net volume of trees reaching poletimber size during the period, minus the net volume of trees that died during the period, minus the net volume of trees that became rough or rotten (cull increment) during the period. While total growth in the sapling stock (growth in trees less than 5.0 inches d.b.h.) is not included in the Forest Service surveys, a portion of it is eventually accounted for as ingrowth (the net volume of trees reaching poletimber size).

Table 8 shows net annual growth, removals, and mortality of growing stock on commercial timberland in the Northeast. Total growth for the region was approximately 2.7 billion cubic feet or about 40 cubic feet per acre; however, the average rate of growth varied from a high of 53.5 cubic feet per acre in New Hampshire to a low of 14.5 cubic feet per acre in New Jersey. Timber

TABLE 6
BIOMASS OF TREE PARTS AS PERCENTAGES OF MERCHANTABLE BOLE^a

Study	Tops	Large Branches	Foliage & Small Branches	Bark	Bole	Total Biomass
# 1	8	5	20	10	100	148
# 2	-	19	12	9	100	140
# 3	-	27	9	15	100	151
# 4	-	17	8	14	100	139
# 5	64	22	18	25	100	229
# 6	-	15	5	8	100	128
# 7	-	23	12	10	100	145
# 8	-	-	-	-	100	218
# 9	-	42	3	9	100	154 ^a
#10	-	-	-	-	100	397 ^a
#11	-	-	-	-	100	224 ^a
#12	-	-	-	-	200	223 ^a

1 Data from NRC, 1976.

2 Combined data from 8 Scandanavian spruce stands; Tamm, 1975.

3 Combined data from 5 Scandanavian pine stands; Tamm, 1975.

4 Data from a Scandanavian birch stand; Tamm 1975.

5 Data from a Quebec black spruce stand; Wheetman and Webber, 1972.

6 Data from a Finnish pine stand; Malkonen, undated.

7 Data from a Finnish spruce stand; Malkonen, undated.

8 Data from a Wisconsin aspen mixed hardwood stand; Boyle et al., 1973.

9 Application of Whittaker equations to Bartlett Experimental Forest data; Hornbeck, undated.

#10 Data from a Vermont mixed stand; Bradley and Stevens, 1978.

#11 Data from a mixed hardwood stand; Anon #1, 1978.

#12 Data from a mixed hardwood stand; Anon #2, 1978.

^aAnalysis conducted in New England.

Source: Hewett, 1978.

TABLE 7
LEVEL OF STOCKING OF COMMERCIAL FOREST LAND
(% Area)

	Over- stocked	Fully Stocked	Medium Stocked	Poorly or Nonstocked
Southern New England	14	40	37	9
Maine	26	38	29	6
New Hampshire	51	43	5	1
Vermont	34	48	14	4
New York	31	42	18	9
Pennsylvania				
New Jersey	21	74	3	2
Delaware	39	60	1	-
Maryland	36	49	11	14

TABLE 8
NET ANNUAL GROWTH, REMOVALS, MORTALITY AND
CULL INCREMENT OF GROWING STOCK ON COMMERCIAL TIMBERLAND
(Thousand Cubic Feet)

	Growth ^a	Mortality ^a	Cull Increment	Removals ^a
Connecticut	81,823	16,267	13,902 ^b	16,767
Maine	750,272	284,778	113,792 ^c	446,137
Massachusetts	141,806	18,391		35,354
New Hampshire	251,692	14,709	19,633 ^d	69,241
Rhode Island	17,359	1,421		3,029
Vermont	108,973	31,465	45,525 ^e	68,671
Delaware	19,972	3,974	1,226 ^f	11,190
Maryland	110,000	16,100	6,817 ^g	63,475
New Jersey	27,013	11,916	3,561 ^h	11,917
New York	308,548	132,066	52,608 ⁱ	164,503
Pennsylvania	878,271	99,896	(j)	245,210
Total	2,696,729	630,983	276,974	1,135,494

^aUSDA - FS, 1977.

^bKingsley, 1974, Connecticut, Rhode Island, and Massachusetts combined.

^cFerguson and Kingsley, 1972.

^dKingsley, 1976.

^eKingsley, 1973.

^fFerguson and Mayer, 1974.

^gUSDA, unpublished draft data.

^hFerguson and Mayer, 1974.

ⁱFerguson and Mayer, 1970.

^jNo estimate.

removals were about 1.1 billion cubic feet (or an average of about 16.7 cubic feet per acre) with about 74% of total removals coming from three states: Maine (39%), Pennsylvania (21%), and New York (14%). The highest per acre removals, however, were in Delaware (29.1 cubic feet per acre).

Annual mortality on growing stock was 631 million cubic feet or 23% of net annual growth. The cull increment, shown for previous years -- not included in the Forest Service update (USDA-FS, 1977) -- was over 277 million cubic feet. The net addition to growing stock volume (net growth minus net removals) varies in the region. Pennsylvania, New Hampshire, and the three southern tier New England states had net additions of over 35 cubic feet per acre in 1976. Maine, Delaware, and Maryland had net additions of between 23 and 18.4 cubic feet per acre while Vermont, New Jersey, and New York all showed net additions of under 10 cubic feet per acre.

The Forest Service information on growth on growing stock does not account for all aboveground production. As shown in Table 9, aboveground production in three measured stands exceeds the state growth averages derived from Table 8. Perhaps of more importance for deriving estimates of aboveground production is the breakdown of the percent of net (aboveground) production in different tree components shown in Table 10. In this case, production in the stem component varied from 18.7 to 41.4% of total aboveground production, or, for stands and species common to the Northeast, from 18.7 to 28.8% of total aboveground production. If this holds true, then the average productivity in the region is from two to three times the Forest Service estimate.

It is not likely that all of this production will be available for energy uses; nor is a straightforward estimate of total aboveground growth in the region possible from these different sets of data. Apart from differences in measurement and presentation of data, which make analysis difficult, the information shown in Tables 9 and 10 cannot be considered typical of the region without extending such measurements to other forest areas. Further, the use of twig, leaf, and fruit biomass as an energy resource is not common. If such is the case, only stem and branch wood and bark production contribute to the biomass available for energy uses. Since the production of stem bark and branches, as a percent of total aboveground production, is approximately equal to production in the stem, the total production useful for energy is at least twice the Forest Service estimate of growth on growing stock. If the measurements at Hubbard Brook are more typical of the Northeast than those at Brookhaven, then the total production useful for energy could be greater. Without further field measurements, however, such an estimate cannot be supported.

Projections of Growth, Cut and Inventory

The Forest Service Timber Resource Reports normally presents estimates of future growth, removals, and net inventory of growing stock on commercial forest land: these estimates are displayed for the region in Figures 5 and 6.⁵ On the basis of these projections, the net volume of growing stock will continue to increase through the year 2000. The ratio of removals to growth will continue to increase in the most heavily lumbered states and will approach parity in the year 2000. At that time, states will near their maximum renewable yield under existing timber consumption and management practices.

The uncertainty of these projections is mirrored by the uncertainty of the assumptions under which they are developed. For example, the projections

presented in Figures 5 and 6 are based on the objective of bringing net annual growth and removals into balance in 30 years. A second projection (for a few states only), based on the assumption that the trend of timber removals from 1958-1970 will continue over the next thirty years, results in a harvest that is greater than growth by the year 2000.

Unforeseen changes can also affect the pattern of growth and removals in the future. Only a small portion of the commercial forest land in the region is professionally managed, and these experience a higher growth rate than unmanaged lands. A decrease in the area of commercial forest land will result in a decrease in the volume of growing stock. Changes in the speciation of forest stands can result in an increase or decrease in growth rates, depending on the replacement species.

The utility of these projections for renewable wood energy projects is suspect. They are based on projections of change in the inventory, growth, and removals of growing stock; mortality and the cull increment are not specified, nor are net additions to the inventory off the commercial bole. These would, in all cases, increase the volume of wood available for energy uses. If these factors change at a rate consistent with their treatment in the previous section, then the volume of wood potentially available for energy uses will be from two to three times the projected growth.

TABLE 9

PRODUCTION SUMMARY^a
(Cubic feet per acre per year)

Measurements	Foliage	Branches	Stems	Roots	Totals
<u>Hubbard Brook</u>					
Low (56-60)	123.5	97.6	103.8	66.1	391.1
(61-65)	98.1	77.3	91.4	52.4	319.1
Mid (56-60)	114.9	88.3	96.7	59.9	359.8
(61-65)	91.2	67	79	45.6	282.7
High (56-60)	94.8	61.3	67	41.3	264.4
(61-65)	90.7	42.4	53.1	32.2	218.4
<u>Brookhaven</u>					
Oak/Pine	126.9	57.4	52	(n.c.)	236.4

^aOriginal data, given in g/m²/yr and percent, have been converted to cubic feet per acre per year.

Source: Whittaker, R.H., Bormann, F.H., Likens, G.E., and Siccama, T.G., 1974, Table 4, Part. E.

TABLE 10

PERCENT PRODUCTION IN ABOVEGROUND TREE COMPONENTS

	Hubbard Brook, elevation belts			Brookhaven		Great Smoky Mountains			
	Low	Mid	High	Oak, pine, young	Red oak, white oak	Gray beech, north	Gray beech, south	Upper cove forest	Tulip tree, young
Percents in stem wood	28.5	28.8	26.6	18.7	20.3	24.5	29.7	42.0	41.4
Percents in stem bark	3.0	3.1	3.1	3.3	3.2	2.6	2.4	4.7	5.7
Percents in branches	29.7	29.1	27.2	24.3	17.7	18.3	19.1	16.5	30.8
Percents in twigs and leaves	35.7	36.3	39.7	50.9	58.8	54.6	48.8	36.8	22.7
Percents in fruits, etc. ^a	3.1	2.7	3.4	2.8	-	-	-	-	-

^aFruits plus flowers and bud scales.

Source: Whittaker, R.H., Bormann, F.H. Likens, G.E., and Siccama, T.G., 1974, Table 4, Part E.

Figure 5. Projected Changes in Growth and Removals of Growing Stock in the Northeast

Figure 6. Projected Changes in the Inventory of Growing Stock in the Northeast

Residues

The volume of unused residue from commercial logging, land clearing operations, and primary manufacturing is shown in Table 11. Column 4 is the volume of residue off the commercial bole (estimated at 35% of the net annual removals of growing stock shown in Table 8). Column 3 shows the net volume of growing stock trees removed from the inventory by cultural operations, land clearing, and changes in land use. For example, land clearing operations in southern New England generated an average of 36.3 million cubic feet of wood per year from 1952 to 1971. Only 6.9 million cubic feet were used, the remainder was buried, burned, or otherwise destroyed (Kingsley, 1974). Column 2 shows the unused portion of poletimber or sawtimber trees cut or killed by logging but does not include those portions of growing stock trees off the commercial bole. Column 1 (regional total only) shows wood material from primary manufacturing plants not used for any product.

The amount of residue shown in Table 11 may represent the upper limit of residues available at logging sites and manufacturing plants. Improved logging practices and harvesting technologies are making better use of wood previously discarded. In addition, wood manufacturing plants in the region are improving use of their own residues. For example, in 1952 only 700,000 cubic feet of plant residues were utilized; in 1973 more than 100 million cubic feet of such residues were recovered for use as fiber. If such trends continue, the volume of residue available for wood energy uses will increase dramatically.

TABLE 11				
RESIDUES (Thousand Cubic Feet)				
	Residues at Primary Manufacturing Plants ^a	Logging (Growing Stock) ^c	Logging (Other) ^d	Other Removals ^c
Connecticut		949	5,868	10,408
Maine		63,685	156,148	15,826
Massachusetts		1,947	12,374	20,340
New Hampshire		11,284	24,234	12,450
Rhode Island		217	1,060	1,602
Vermont		12,477	24,035	71,579
Subtotal	20,708	90,559	223,718	71,579
Delaware		2,167	3,916	2,259
Maryland		13,981	22,216	8,020
New Jersey		1,048	4,172	5,866
New York		27,957	57,576	17,740
Pennsylvania		55,298	85,823	21,602
Subtotal	31,465 ^b	100,451	173,703	55,487
Total	52,173	191,010	397,422	127,066

^aUSDA-FS, 1977, Table 68.

^bIncludes West Virginia.

^cUSDA-FS, 1977, Table 69.

^dResidue from that portion of the tree off the commercial bole, estimated at 35% of total growing stock removals.

Wood for Energy in the Northeast

The volume of growing stock wood estimated to be available for energy uses in the region is shown in Table 12. Individual line items in this table were developed from Forest Service data based on the following assumptions:

- Baseline fuelwood use. The current volume of wood used for energy forms a base below which the future availability of wood for energy will not fall.
- Cull inventory increment. The standing volume of rough and rotten (cull) trees not currently used for commercial purposes is available for energy uses. This standing inventory will be recovered over a thirty-year period.
- Cull increment. Net yearly additions to the rough and rotten inventory will be used as they occur. These estimates were based on the average annual cull increment as a percent of net growth in each state, e.g., in New York, the average annual net growth from 1950-1967 was 245.5 thousand cubic feet and the cull increment was 52.6 thousand cubic feet or 21.4% of the average annual net growth.

- Mortality increment. All dead trees are available for energy uses. These estimates were based on the average annual mortality increment as a percent of net growth in each state, e.g., in New York where the average annual mortality from 1950-1967 was 104.9 thousand cubic feet or 42.7% of the average annual net growth.
- Growth minus removals. The difference between net annual growth and net annual removals is available for energy uses.
- Residues. The volume of growing stock and nongrowing stock residues is available for energy uses; however, because of technology improvement, the availability of residues for energy will decline as a percent of total removals. In 1977, the volume of residue was about 67.6% of total removals. This will drop to about 60.8% in 1980, 50.7% in 1990, and 33.8% in 2000.

With the exception of a specific amount of residue, the estimates in Table 12 show only the growing stock volume. As discussed previously, the actual volume of wood available for energy uses may be substantially greater but will depend on the technology used to harvest the wood, process the wood into a fuel or use it directly, and the volumetric relationship between wood on and off the commercial bole. Tables 5 and 6 give some examples of the latter relationship. In Table 5, total aboveground biomass was from 139.5 to 150.7% of stem biomass. In Table 6, biomass of all aboveground tree parts was from 140 to 397% of biomass on the commercial bole alone. Given the diversity of these data, their application for estimating total aboveground biomass

TABLE 12
AVAILABILITY OF WOOD FOR ENERGY USE IN THE NORTHEAST
(Million Cubic Feet)

	Present	1980	1990	2000
Baseline fuelwood use ^a	62.2	62.2	62.2	62.2
Cull inventory increment ^b	444.6	444.6	444.6	444.6
Cull increment ^c	374.7	426.9	472	502.1
Mortality ^d	630.1	505.3	558.7	597.3
Growing stock growth minus removals	1561.2	1090.2	766.2	286
Residues ^e	767.7	909.3	1094.6	941.7
Total	3840.5	3438.5	3398.3	2833.9

^aThis is the volume of growing stock and residue currently used for fuel (USDA-FS, 1977).

^bThe standing growing stock volume of rough and rotten trees recovered over a period of 30 years.

^cAn estimate of additions to the standing rough and rotten inventory based on average additions in the preceding reporting period.

^dAn estimate of additions to the mortality inventory based on average additions in the preceding reporting period.

^eBased on the assumption that the availability of forest and plant residues will decrease as a percentage of total removals: 10% by 1980, 25% by 1990, and 50% by 2000.

potentially available for energy use in the Northeast is suspect. A conservative estimate (that is, a low estimate) would have total aboveground biomass amounting to 150% of growing stock biomass alone. Thus, for the Northeast, the volume of wood potentially available for energy uses will be at least 5 million cubic feet in 1980, 4.9 billion cubic feet in 1990, and 4.1 billion cubic feet in 2000.

Conclusions

The availability of wood for energy is not, at the moment, resource constrained as the potential volume of wood available for energy uses is some 60 to 90 times greater than Forest Service estimates of current wood fuel use. As this potential supply does not take into account a variety of economic and market constraints (let alone environmental factors), it cannot be considered an achievable level of supply without further analysis. Nonetheless, the sheer volume of wood potentially available makes it an attractive alternative energy resource.

While there is a plethora of information available concerning wood supply for industrial purposes, there are very few reliable data with which to estimate the potential wood supply for energy uses at a regional level. Further, changes in land use and industrial demand may effect a decrease in the availability of wood for energy; however, such changes are inestimable. Some specific information needs are as follows;

Land Use: changes in the area of commercial forest land, or, as an alternative, changes in the demand for land for nonforest uses; estimates of the use of noncommercial forest land to supply wood for energy uses.

Land Ownership: estimates for future changes in land ownership by the wood industry; estimates of the removal of commercial timber land through increased public ownership; estimates of privately-owned land available for timber uses (attitudinal and market surveys).

Wood Resources: whole-tree or aboveground biomass data by species for "representative" sites in the region; improved growth data for different species in different geographic and climatologic settings; improved biomass and growth data under different management practices; biomass recovery data for different logging practices including potential use of cull trees by the wood industry.

NOTES TO CHAPTER 11

1. A major reason for the low average volume in New Jersey is the presence of extremely poor stands of scrub oak and pitch pine in the Pine Barrens.
2. Until recently, the U.S. Forest Service was legislatively restricted from including total aboveground biomass considerations in their surveys; thus, biomass off the commercial bole (nongrowing stock) is not included in their reports.
3. These two stands represent radically different climatologic and geographic regimes. Although they may be representative of a number of other commercial forest sites in the region, a specific relationship cannot be determined without further field studies. Further, nomenclature varies from one study to the next: for example, stem used in the Hubbard Brook study is not comparable with growing stock (commercial bole) used in the Forest Service inventories. Thus, without further field and interpretive work, these studies cannot be used to modify the Forest Service data to estimate aboveground biomass.
4. One of the points hammered home again and again at the Wood Energy Workshop, Northeast Solar Energy Center, by both public and private foresters, is the need for more and better field studies.
5. The U.S. Forest Service has prepared a number of projections. For information on the model used for this work, see Larsen and Gafarth, TRAS-A Timber Volume Projection Model.

REFERENCES TO CHAPTER II

Dalton, M.M., Durgin, O.B., Herrington, J.H., and Andrews, R.A., "Household Fuelwood Use and Procurement In New Hampshire," Research Report No. 59. Oct. 1977, N.H. Agricultural Experiment Station, University of New Hampshire, Durham, New Hampshire.

Ferguson, R.H., The Timber Resources of Pennsylvania, USDA Forest Service Resource Bulletin NE-8, 1968.

Ferguson, R.H. and Kingsley, N.P., The Timber Resources of Maine, USDA Forest Service Resource Bulletin NE-26.

Ferguson, R.H., and Mayer, C.E., The Timber Resource of Delaware, USDA Forest Service Resources Bulletin, NE-32, 1974.

Ferguson, R.H., and Mayer, C.E., The Timber Resources of New Jersey, USDA Forest Service Resource Bulletin, NE-34, 1974.

Ferguson, R.H., and Mayer, C.E., The Timber Resources of New York, USDA Forest Service Resource Bulletin NO-20, 1970.

Hewett, C.E., The Availability of Wood for a 50-MW Wood Fired Power Plant in Northern Vermont, June 1978, Thayer School of Engineering, Dartmouth College, Hanover, New Hampshire 03753.

Kingsley, N.P., The Forest Resources of New Hampshire, USDA Forest Service Resource Bulletin NE-43, 1976.

Kingsley, N.P., The Forest Resources of Vermont, U.S. Forest Service Resource Bulletin NE-46, 1977.

Kingsley, N.P., The Timber Resources of Southern New England, U.S. Forest Service Resource Bulletin NE-36, 1974.

Larson, R.W., and Gafarth, M.H., TRAS: A Timber Volume Projection Model, USDA Forest Service Technical Bulletin No. 1508.

Meadows, C.E., "Private Ownership of Maine Timberlands: Their Stewardship and Management," Seven Islands Land Company, Bangor, Maine.

Office of Energy Resources, Maine, "Collected Working Papers on the Production of Synthetic Fuel from Wood," March 1975.

Sherwood, L., and Meadows, D., "The Fuel Requirements of a 50-MW Wood-Fired Electrical Generating Facility in Northern Vermont," July 1978, Thayer School USDA Forest Service, Forest Statistics of the U.S., 1977, GPO Stock No. 001-001-00437-5.

USDA Forest Service, Unpublished draft data for Maryland.

REFERENCES TO CHAPTER II (continued)

von Foerster, T., "On the Use of Wood as an Energy Resource in the State of Maine," Energy and Environmental Policy Center, Harvard University, BNL 50898, Sept. 1978.

Whittaker, R.H., Bormann, F.H., Likens, G.E., and Siccama, T.G., "The Hubbard Brook Eco-System Study: Forest Biomass and Production," Ecol. Mono., Vol. 44, No. 2 (1974).

CHAPTER III

CONSIDERATIONS OF SCALE: WOOD FOR ENERGY IN NEW ENGLAND*

by

James S. Munson

To a certain extent the availability of a large supply of unused wood in New England is a striking example of benign neglect. Until the middle of the nineteenth century, wood was a primary fuel in the region; residential wood use reached a peak of about 33 million cords of 0.6 quads around 1850 (Figure 7). Following the transition from wood to fossil fuels and the decline of agriculture, passive, albeit rapid, reforestation took place and continued until 1970. Since that date the region has experienced a net loss in commercial forest acreage. Nonetheless, New England has, at present, greater forest resources than at any time since the late eighteenth century: over 65 billion cubic feet of wood on 76.9% of the total land area of New England (Table 13).

Current Wood Energy Use

Today, faced with increasingly restrictive energy supply and demand problems, New England is involved in energy programs intended to ease dependence on expensive and precarious supplies of imported fossil fuels. As a result,

Figure 7. Trends in wood energy use and commercial forest area.

the use of wood for fuel is growing rapidly. Recent surveys in the Northern Tier states place domestic wood use at about 90 million cubic feet per year: Maine - 468,000 (Swain, 1978), New Hampshire - 300,000 cords (Dalton, 1979), and Vermont - 300,000 cords (Turner, 1978). Elizabeth Swain reports an annual compound growth rate of wood energy use in Maine of nearly 12% from 1970 to

*This Chapter was originally presented at the Annual Meeting of the American Society of Civil Engineers, Boston, Mass, April 6, 1979.

Table 13

FOREST CHARACTERISTICS

	Commercial Forest Area (thousand acres)	Commercial Forest as a Percent of State Land Area	Percent Change in Commercial Forest Area 1970-1977	Growing Stock Volume (million cubic feet)	Growing Stock Density (cubic feet per acre)	Growing Stock Removals (million cubic feet)	Growing Stock Growth (million cubic feet)
Connecticut	1,805.6	58	-0.96	2849.3	1578	16.3	81.8
Maine	16,894.3	85	-	25887.8	1532	446.1	750.3
Massachusetts	2,797.7	56	-1.7	4479.1	1601	35.3	141.8
New Hampshire	4,692	81	-2.4	8238.6	1755	69.2	251.7
Rhode Island	395.3	59	-7.8	480.4	1215	3.	17.4
Vermont	4,479.9	75	+1.5	6228.1	1405	68.7	109.
Total	31,014.8	76.9	-0.5	48,163.3	1553	639.1	1352.

Source: USDA-FS, Forest Statistics of the U.S., 1977, Review Draft

1978 and an increase in annual per capita consumption of from 0.2 to 0.44 cords per year. Similarly, the percentage of homeowners using wood as a primary heat source in Vermont increased from 7 to 18% between 1976 and 1978, and the contribution of wood energy to home heating for these homeowners increased from 26 to 41% over the same period. Approximately one-half of all homeowners in Maine and New Hampshire and two-thirds of all homeowners in Vermont are reported to burn wood for space heating.

A study underway at Dartmouth for the New England Regional Commission estimates that industrial wood energy use has replaced the equivalent of 33.8 million gallons of fuel oil (Mildner, 1979). While the amount of wood thus used has not been reported, it may range from 24 to 36 million cubic feet. In addition, Burlington Electric has recently converted a 10-MW power plant to wood use and plans to add another 6.5 MW of wood-fired capacity in the near future.

The total volume of wood used for energy in New England is, thus, over 144 million cubic feet (23.9 trillion Btu or about 11% of the total energy consumption in the residential and industrial sectors in the Northern Tier). In addition to energy uses about 639 million cubic feet of wood was removed from the forest inventory and used to produce 570 million cubic feet of wood products. Assuming that all industrial wood energy and some domestic wood energy comes from logging or mill residues, total removals for both energy and industrial uses (in 1977) was on the order of 700 million cubic feet.

The Cost of Operating Wood Energy Systems

As suggested by the increase in wood energy uses, the costs of heating or steam generation with wood are, at present, generally competitive with other fuels (the costs of processed fuels such as wood pellets or methanol are

currently greater than the cost of fossil fuels and about twice the cost of a similar Btu value of wood for direct firing). For example, Table 14 from von Foerster, 1978, compares the costs of traditional domestic heating systems with current and anticipated wood heating systems in providing the total space heating needs of an average household in Maine. These data show domestic wood space heating to be competitive with other fuels in home heating.

It is, however, not clear that the costs discussed by von Foerster are representative of the costs incurred by current domestic wood uses (see Chapter VI for details). As shown by the studies in the Northern Tier states, existing wood heating systems are supplemental and presumably heat a smaller unit of space or a fewer number of rooms. In addition and more important, the majority of domestic wood users supply their own fuel at a minimal acquisition cost. As fuel costs are the single largest operating expense, the availability of a quasifree supply makes wood use enormously attractive. When wood is purchased, however, the comparative economics become extremely sensitive to wood quality (particularly moisture content) and heat box efficiency. Figure 8 shows equivalent costs for oil and cordwood at various wood stove efficiencies. If the price of home heating oil is fifty cents per gallon, a homeowner can afford to purchase a cord of wood for fifty dollars (at 35% heat box efficiency), sixty five dollars (at 45% efficiency), and eighty dollars (at 55% efficiency).

Figure 8. Equivalency costs of oil and wood at various wood stove efficiencies.

Numerous studies have considered the economics of modest wood fired electric generation facilities and found them to be competitive with coal and nuclear generation and slightly more expensive than oil. A comparison of the estimated annual costs of using wood and coal to generate electricity in Vermont in 1980 is shown in Table 15 (E.H. Hall et al., 1976). Other studies in the region show a range of 40 to 60 mills/kWh (in 1976 dollars) for a 50-MW wood-fired power plant (Schultz, 1977 and Segerson, 1977).

Table 14
ANNUAL COSTS OF HOME HEATING SYSTEMS IN MAINE, 1977

Annual costs are rounded to the nearest \$5.

Fuel costs are based on a demand of 70 million Btu/yr, delivered to rooms.

	Initial Cost* \$	Furnace Annual Cost** \$/yr	Efficiency	Fuel Unit Cost \$/10 ⁶ Btu	Annual Cost \$/yr	System annual cost \$/yr
Oil (new installation)	800	100	0.50	3.4	475	575 \$/yr
Oil (existing)	0	0	0.50	3.4	475	475 \$/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 furnace (new)	2500	315	0.60	2.0	230	545 \$/yr
Wood furnace (add-on)	300	40	0.60	2.8	325	365 \$/yr

*Rounded to nearest \$50.

**0.125 times the initial cost.

Source: T. von Foerster, 1978 (Table 6).

Table 15
THE ESTIMATED COSTS OF USING VARIOUS FUELS TO GENERATE ELECTRICITY IN VERMONT - 1980

Cost Element	Green Wood		Low Sulfur Coal (Wyoming),		Cleaned Coal (Pennsylvania),		High-Sulfur Coal Stack Gas Cleaning (Pennsylvania),		75% Green Wood 25% Cleaned Coal,	
	\$M/yr	Mills/kWh	\$M/yr	Mills/kWh	\$M/yr	Mills/kWh	\$M/yr	Mills/kWh	\$M/yr	Mills/kWh
Procurement	205	0.67							154	0.50
Harvesting	4,366	14.24							3,280	10.70
Chipping	824	2.68							619	2.02
Mining			1,088	3.55	4,022	13.12	4,218	13.76	1,115	3.64
Cleaning					843	2.75			234	0.76
Transportation	718	2.34	5,800	18.92	2,880	9.39	2,872	9.37	1,265	4.13
Plant	6,230	20.32	6,500	21.20	6,500	21.20	6,500	21.20	6,650	21.70
Emission control	690	2.25	970	3.16	970	3.16	2,850	9.30	970	3.16
Operation & Maintenance	710	2.32	710	2.32	710	2.32	710	2.32	750	2.45
Total	13,743	44.82	15,068	49.15	15,925	51.94	17,150	55.94	15,037	49.06

Source: E. H. Hall et al., 1976 (Table 39).

The largest cost variables for wood-electric plants are plant capacity factors, plant efficiencies, and the price and moisture content of the fuel. In her work, for example, Segerson showed that increasing a plant's capacity factor from 75% (estimated by Schultz) to 95% (based on work by Sherwood, 1977) resulted in a decrease in the cost of electricity from 53.93 to 46.82 mills/kWh. On the other hand, with less optimistic assumptions about moisture content (45 to 50% versus 35 to 40% wet basis), heating value (4250 Btu/lb versus 5000 Btu/lb), and fuel prices (\$20/green ton versus \$15/green ton), Segerson calculated the fuel costs to be 32.12 mills/kWh (13.84 mills/kWh more than Schultz's fuel cost of 18.28 mills/kWh) and the total generating cost (at an 85% capacity factor) to be 59.55 mills/kWh.

The costs of wood energy use in the wood industry are extremely difficult to get a handle on primarily because of the great variety of scale and energy uses. For example, a recent study by the North Central Forest Experiment Station considered the costs of conversion for 10 pulp and paper mills in Wisconsin and Michigan. The plants currently fire from 0.6×10^{12} to 11.8×10^{12} Btu and complete conversion to wood energy at each of the mills would require from 0.07 to 1.1 million tons of wood per plant per year. Total capital costs were from \$2.1 to \$23.5 million per plant and additional annual costs ranged from \$0.5 to \$8.8 million per plant.

The additional cost per million Btu (the differential cost of wood-based fuels over current fossil fuels) that the plants could afford to pay and still maintain an economic justification for switching to wood ranged from \$0.83 to \$1.53 per million Btu or from \$6.12 to \$15.22 per green ton.

The review above shows that existing wood energy technologies are often, but not always, economically competitive with fossil fuel technologies that supply the same end use whether it be home heating, industrial steam demand, or electric generation. It is clear that the capital costs of existing wood energy systems do not account for significant economic savings; thus, factors such as fuel availability, quality, and cost assume increasing importance.

In this regard, it should be noted that current wood energy demands are met with extremely cheap and available wood supplies. Residential users, usually supply their own fuel wood. Industrial and electric generation wood demands are filled by bark and mill and forest residue for which no competitive market exists at present. Once this cheap and readily available supply of fuel wood has been committed, the wood energy market will become increasingly competitive and its ultimate structure will reflect a number of supply and demand characteristics.

Each of the end uses discussed above requires a different level of wood supply. This is reflected in the type and intensity of the process used to recover wood from the forest. Residential users supply their own cordwood or, less often, purchase it from independent small loggers. The demand exerted, although large in terms of existing wood energy use, is essentially diffuse: each user or supplier cutting from his own or other available forest land. Unit demands by industrial or electric generating users are, on the other hand, significantly larger. Thus the supply process is intense, reducing logging, chipping, and transportation costs.

The demand for wood can be translated into a demand for land required to supply this wood. Table 16 shows estimates of the land required to supply wood for energy and product under a variety of conditions. In 1977, the area of land required to provide wood for industrial product ranged from 237,000 to 412,000 acres. The area of land required to provide the same volume of product on a renewable basis is, however, much larger: certainly no less than 7.1 million acres and perhaps as much as 14 million acres. The exact area of land needed to provide both the annual and the renewable volume of wood for product is related to the type of product produced and the method used in logging. For example, the pulp and paper industry uses more of the tree than the lumber industry, which can only use the commercial bole.

Table 16
ESTIMATES OF LAND REQUIRED TO PROVIDE WOOD FOR ENERGY AND PRODUCT

	Wood Requirement per Unit	Characteristics of Process of Supply Wood	Land Required To Supply Annual Unit Demand at 2700 ft ³ /acre	To Supply Annual Unit Demand Using Logging Residue (1150 ft ³ /acre)	To Supply Unit Demand on a Renewable Basis (at 90 ft ³ /acre/yr.)	Land Required To Supply Current Demand on a Renewable Basis
Residential Space Heat	Less than 8 cords per year (680 cubic feet)	Diffuse	N/A	N/A	8 acres (at 1 cord per acre per yr.)	1.06 million acres
Industrial	Variable, depending on mill type and size, 3.1 to 48 million cubic feet	Concentrated mill and forest residues contract supply	1148 to 17,777 acres	2,695 to 41,739 acres	34,444 to 533,333 acres	266,000 to 400,000 acres
Electric Generation (50 MW)	Variable depending on plant capacity factor, boiler efficiency and fuel quality 18 to 31 million cubic feet	Concentrated contract supply	6666 to 11,481 acres	15,625 to 26,956 acres	200,000 to 344,444 acres	40,000 to 68,000 acres
Industrial Product	639 million cubic feet removals at present, increasing to 1244 million cubic feet of removals in the year 2000	Concentrated contract or corporate supply	237,000 acres	412,200 acres (using growing stock at 1550 ft ³ /acre)	7.1 to 14.655* million acres (assuming that all industrial product comes from growing stock at 43.6	7.1 to 14.655 million acres

The area of land required to supply fuel wood varies greatly with the level of demand and the yield per acre. Estimates of the wood required to provide fuel for industrial and electric generating units are also shown in Table 16. These data show land requirements for specific units; the land requirements for a specific Btu demand can be estimated from Figure 9.

Wood Availability

Approximately 31 million acres, over 76% of New England's land area, in are commercial forest (Table 13). While this represents a slight decline in

Figure 9. Forest area required to provide a trillion Btus at various recovery rates and heating values.

forest area, since 1970 the actual volume of growing stock (wood on the commercial bole) has increased and presently stands at over 48 billion cubic feet. The total volume of wood both on and off the commercial bole may be in excess of 70 billion cubic feet. The average regional density of growing stock is 1553 cubic feet per acre and state averages range from 1200 to 1755 cubic feet per acre.

It is the renewable yield of available unused wood, however, that will determine the potential for increased wood energy use in New England. For purposes of this discussion, the renewable yield is composed of several factors: current growth plus the mortality increment plus the cull increment plus an increment of the standing cull inventory plus unused residues from forest or plant operations. An estimate of the current renewable yield from growing stock alone (adapted from USDA-FS, 1977, Review Draft, and modified with data from the individual state timber resource reports) is shown in Table 17. This estimate can be adjusted upward by 150 to 200% to account for biomass off the commercial bole.

It must be emphasized, however, that this yield is hypothetical and amounts to a manipulation of the statistical data presented in current

inventories. The actual renewable yield of New England forests is speculative at best. Although there has been a variety of research, most notably the MITRE Corporation work on biomass plantations, such a concept is

TABLE 17
AVERAGE PER ACRE GROWING STOCK VOLUME AVAILABLE FOR
ENERGY USES ON A RENEWABLE BASIS
(CUBIC FEET)

	Growth	Mortality	Cull Increment	Cull Inventory ^b	Total
Connecticut	45.3	9	2.8 ^a	3.6	60.7
Maine	44.4	16.8	7.9	5.9	75.
Massachusetts	50.7	6.6		7.0	64.3
New Hampshire	53.6	3.2	4.2	6.8	67.7
Rhode Island	43.9	3.6		5.3	52.8
Vermont	24.6	7.1	10.3	9.3	51.3
New England Average	43.6	11.8	6.9	6.4	68.7

^aConnecticut, Massachusetts, and Rhode Island combined.

^bThe standing inventory of cull trees harvested over a 30-year period.

not readily applicable to the region, thus the potential yields available from such a concept are not generally anticipated in New England. In his study von Foerster suggests that future growth, under managed conditions may be from two to ten times the current rate. Similarly, the New England Energy Congress estimated that the yearly wood energy potential in New England is 0.7×10^{15} Btu per year between 1975 and 1985 and increases to 1.56×10^{15} Btu by 2000, with the increase coming through an expected doubling of the growth rate. This implies an average yield of between 77 and 107 cubic feet per acre per year at present and a yield of between 160 and 240 cubic feet per acre per year by the year 2000 (depending on the heating value used to convert biomass estimates to wood energy potential). On the other hand the projections of net annual growth stock presented by the U.S. Forest Service (NE-26, NE-36, NE-43, and NE-46) differ with the Congress data in that they show a much smaller increase in growth.

Anticipated growth rates notwithstanding, a conservative estimate for the present would place the potential renewable yield (both on and off the commercial bole) at about 90 cubic feet per acre per year. The renewable yield from all commercial forest land in New England is, thus, approximately 2.8 billion cubic feet per year or from 0.42 to 5.8 quads (roughly equal to the N.E. Energy Congress estimate after deductions for renewables).

Resource Constraints

Whether 2.8 billion cubic feet of wood are actually available is another matter. Access limitations impose both physical and economic restraints to logging. In his work in Vermont, Hewett concluded that physical access limitations will restrain somewhat less than 45% of the commercial forest area

studied. If such limitations restrain 20% of the total commercial forest area of the region, then only 2.2 billion cubic feet of wood are available (Table 18). Further, it is not clear that the owners of all commercial forest land will allow their land to be used. More than 65% of the commercial forest land in the region is owned by private groups or individuals. If only 10% of the commercial forest area is removed from wood use, the volume of wood available for industrial product and energy is on the order of 2 billion cubic feet. As discussed previously, about 700 million cubic feet are removed annually for energy or product; thus, 1.3 billion cubic feet per year are available to absorb increased demand for wood.

The actual extent of logging operations on commercial forest land is unclear. In 1977, if loggers removed only the average growing stock volume per acre, over 312,000 acres were cut to provide 639 million cubic feet of removals. But, in fact, the dedicated land requirements to provide a similar volume of wood on a renewable basis are much larger. For example, to provide 639 million cubic feet of commercial wood each year at current growing stock growth rates ($43.6 \text{ ft}^3/\text{acre}/\text{year}$) would require over 14 million acres of forest land. This is over 45% of the total commercial forest area of the region or more than 65% of the commercial forest area estimated to be available. In addition to this demand, approximately 90 million cubic feet of wood were used for home heating and, in contrast with industrial operations land use to supply residential wood is primarily diffuse in character. Estimates vary but at an average of one cord per acre per year, somewhat less than one million acres are required to supply wood for residential use. This land may already represent land exempt by ownership.

The above considerations, extended out to the year 2000, are reviewed in Table 18. Under the assumed conditions, the demand for wood for product will increase and most, if not all, available commercial forest land will be required for the sustained production of wood for growing stock renewals. Some share of removals and plant residues will be available for energy uses, as will 963 million cubic feet of nongrowing stock wood.

Conclusion

The pattern that emerges from the preceding discussion is one in which a certain amount of land is set aside for residential energy uses or is exempt from logging for physical, economic, or ownership reasons. Commercial wood on the remaining land seems destined for the wood industry, while logging and mill residue will be available for energy uses.

A commitment to complete use of forest resources, however, should be made with our eyes open. While we have a tendency to genuflect to the West when we think of strip mining, what we are discussing here amounts to the same thing and may be no less drastic. As they stand, our forests have many uses - including watershed control, soil stabilization, recreation, fiber, and habitat. While a management system could be designed to counteract detrimental impacts and improve forest yield, it cannot be expected to completely mitigate undesirable land use impacts.

TABLE 18

THE EFFECT OF LAND RESTRICTIONS OF THE
VOLUME OF WOOD AVAILABLE FOR ENERGY USES

	1977	2000
1. Total Commercial Forest Area (thousand acres)	31,014.8 ^a	28,611.9 ^b
2. Access Limitations (thousand acres)	6,202.9 ^c	4,291.8 ^d
3. Ownership Restrictions (thousand acres)	2,481.2 ^e	2,432 ^e
4. Available Commercial Forest Area (thousand acres)	22,330.7	21,888.1
5. Total Growing Stock Growth (million cubic feet)	2,352 ^a	1,441 ^a
6. Total Noncommercial Renewable Yield (million cubic feet)	1,439	1,443
7. Total (million cubic feet)	2,791	2,884
8. Unavailable Renewable Yield (million cubic feet)	781 ^f	677 ^f
9. Growing Stock Removals (million cubic feet)	639.1 ^a	1,244
10. Available Renewable Yield (million cubic feet)	1,370.9	963

^aUSDA-FS, 1977, Review Draft.^bTotal commercial forest area estimated to decrease at 0.35%.^cTwenty percent of total commercial forest area.^dFifteen percent of total commercial forest area.^eTen percent of line one minus line two.^fAll renewable yield from land with access and ownership restrictions will be available.

REFERENCES TO CHAPTER III

Bradburd, R. M., et al., "The Use of Wood for Fuel: Historical Series and Projections to the Year 2000," Department of Economics, Williams College.

Dalton, M. M., et al., "Household Fuel Wood Use and Procurement in New Hampshire," RR #59, New Hampshire Agricultural Experiment Station, University of New Hampshire, Durham, New Hampshire; October 1977.

Ferguson, R. H. and Kingsley, N. P., The Timber Resources of Maine, USDA Forest Service Resource Bulletin NE-26.

Hall, E. H., et al., "Comparison of Wood and Fossil Fuels," EPA-600/2-76-056, Battelle-Columbus Laboratories, March 1976.

Hewett, C. E., "The Availability of Wood for a 50 Mw Wood Fired Power Plant in Northern Vermont," Research Program on Technology and Public Policy, Thayer School of Engineering, Dartmouth College, June 1978.

Kingsley, N. P., The Forest Resources of New Hampshire, USDA Forest Service Resource Bulletin NE-43, 1976.

Kingsley, N. P., The Forest Resources of Vermont, U.S. Forest Service Resource Bulletin NE-46, 1977.

Kingsley, N. P., The Timber Resources of Southern New England, U.S. Forest Service Resource Bulletin NE-36, 1974.

Mildner, C., New England Regional Commission (NERCOM).

New England Energy Congress, "New England Rural Energy Resources: Wood, Small-scale Hydro, Direct Solar and Wind - An Assessment of Near-Term Potential," February 1979.

New England Energy Congress, "Preliminary Report for Public Review," November 1978.

Schultz, A. J., "Feasibility of a 50-Mw Generating Plant Using Wood for a Fuel," Study for the Vermont Public Service Board January 1977.

Segerson, K. T., "Estimating the Cost of Wood - Generated Electricity: A Broader Perspective," DSD #91, Dartmouth System Dynamics Group, Thayer School of Engineering, Dartmouth College October 1977.

Swain, E. W., "Final Report: Maine Firewood Study," Wood Fuel Program, Maine Audubon Society November 14, 1978.

Turner, Action Research Inc., "Final Report on the Use of Wood as a Heat Source and The Quality of Insulation in Vermont Households," prepared for the Vermont Energy Office June 1978.

USDA-FS, "Forest Statistics of the U.S., 1977: Review Draft."

REFERENCES TO CHAPTER III (continued)

U.S. DOE, "Forest Residues Program: Final Report," TID-28416, North Central Forest Experiment Station, Forest Service - USDA April 1978.

von Foerster, T., "On the Use of Wood as an Energy Resource in the State of Maine," Energy and Environmental Policy Center, Harvard University (Prepared for the Energy Policy Analysis Division, Brookhaven National Laboratory), BNL 50898, September 1978.

CHAPTER IV

WOOD AS AN ENERGY SOURCE IN MAINE: AVAILABILITY*

by

T. Von Foerster

The most desirable 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 merchantable bole. Most forest surveys record only the volume of merchantable bole, often arranged by species and size classes, since these are the figures of interest to most users. As an energy resource and lately in some cases 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 capacity 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 19 for this and other conversion factors). Closer examination of the data, however, shows that most of this 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 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 surveys are those of the U.S. Forest Survey,² which list only volume of merchantable bole together with some data on cull (i.e., nonmerchantable bole) and dead trees. However, Professor Harold Young, at the University of Maine at 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 indispensable as a basis for detailed planning and analysis of wood use, not just for energy but all uses. Many of the data have already been collected by the industries, but these data are, with some justification, seen as proprietary information. There is, therefore, a real need for 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 show that the woody material above-

*This Chapter is extracted from T. Von Foerster "On the Use of Wood as an Energy Source in the State of Maine," Energy and Environmental Policy Center, Harvard University, Sept. 1978. BNL 50898.

TABLE 19

UNITS AND CONVERSION FACTORSArea

$$1 \text{ sq mi} = 640 \text{ acres} = 2.59 \text{ (km)}^2$$

$$1 \text{ acre} = 0.405 \text{ ha} = 4.05 \cdot 10^3 \text{ m}^2$$

Volume

$$1 \text{ cu ft} = 12 \text{ bd ft} = 7.48 \text{ gal} = 2.83 \cdot 10^{-2} \text{ m}^3$$

$$1 \text{ m}^3 = 35.3 \text{ cu ft}$$

$$1 \text{ bbl} = 42 \text{ gal} = 5.6 \text{ cu ft} = 0.16 \text{ m}^3$$

$$1 \text{ ccf} = 100 \text{ cu ft} = 2.83 \text{ m}^3$$

$$1 \text{ cord} = 128 \text{ cu ft}$$

contains 0.00 cu ft solid wood plus 0.5 cu ft bark

Mass

$$1 \text{ g} = 10^{-3} \text{ kg} = 10^3 \text{ mg} = 10^9 \text{ } \mu\text{g}$$

$$1 \text{ lb} = 0.454 \text{ kg}$$

$$1 \text{ t} = 2000 \text{ lb} = 907 \text{ kg}$$

Energy

$$1 \text{ Btu} = 1.05 \cdot 10^3 \text{ J} = 0.293 \text{ Whr} = 0.252 \text{ Kcal}$$

$$1 \text{ kWhr} = 3.60 \cdot 10^3 \text{ Btu} = 3.41 \cdot 10^3 \text{ Btu} = 10^{-3} \text{ Mw hr}$$

$$1 \text{ kWyr} = 3.16 \cdot 10^7 \text{ Btu} = 2.99 \cdot 10^7 \text{ Btu}$$

$$1 \text{ quad} = 10^{15} \text{ Btu} = 1.06 \cdot 10^{18} \text{ J} = 293 \cdot 10^6 \text{ Mw hr}$$

ground in the 16.9 million acres of Maine's commercial forests has a mass (oven dry) of about $6.4 \cdot 10^8$ tons, or about one and one-quarter billion pounds. On the average, this represents 38 tons per acre. These numbers are roughly the same as those cited by a recent MIT study,⁴ (See Table 20) 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., merchantable bole. The tops and branches of a tree make up about 30% of its aboveground mass, the merchantable 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 merchantable 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 undesirable trees represent at least 0.6×10^8 tons (averaging 7.5 tons per acre), made up of saplings, bushes, and other woody material. It should be emphasized that these are only estimates, based on incomplete data.

TABLE 20

BIOMASS IN MAINE'S FORESTS

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

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

	Growing Stock	Tops & Branches	Cull Trees ^a	Miscellaneous ^a	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	5 Mt/yr	9 Mt/yr ^b	3 Mt/yr	28 Mt/yr
(due to natural causes only)	(3-1/2%/yr)				(4-1/2%/yr)
- 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 ^c
fuel	0.2 Mt/yr	(with misc.)	0.03 Mt/yr	0.3 Mt/yr	0.6 Mt/yr ^c
Potential for thinning			9 Mt/yr	9 Mt/yr	18 Mt/yr
- per area			0.6 t/acre-yr	0.5 t/acre yr	1 t/acre-yr

^aCull includes rough, rotten, recently dead, and noncommercial trees. Miscellaneous includes seedlings, saplings, bushes, etc.

^bIncludes positive contributions from mortality and cull increment on growing stock.

^cIncludes contributions from 0.9 Mt/yr mill wastes from the lumber and pulp industries.

In order to make use of the natural renewal of the forest 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 overall 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

To date the forests in Maine are not yet used at even their current growth rate: from the Forest Service data⁷ it is estimated that the forest industry will use the annual growth of commercial stock in Maine only after the year 2000. Some companies may expand faster or have access to 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 if this was an appropriate criterion.

It may well be 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 a given resource. (It

interest.) However, it is no longer clear that resources will or can continue to grow exponentially, and it may well be that in the near future we will have reached some limits on the growth of our extractive industries. In that case a much more appropriate and 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 Young¹⁰ and the Forest Service¹¹ (Appendix A).

The Forest Service data show that the net growth of growing stock is about 11 million tons per year, or about two-thirds or 0.66 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 one-quarter or 0.25 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 9.5 million tons per year (estimated from Forest Service data), somewhat more than one-half 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 data¹² and with data from studies at Hubbard Brook in New Hampshire,¹³ then the net growth of woody material aboveground in Maine is about 29 million tons per year. That corresponds to 1.67 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 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, they can be thinned out of the forest and used. The same can be said for rough, rotten, and recently dead trees. Thinning a forest in fact improves the growth of 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 of about 8% of all seedlings per year over the 20 or 30 years it takes to produce a growing stock tree. If one harvests these trees at the same rate, the potential output is roughly 9 million dry tons per year, or about one-half ton per acre per year. Adding to this the cull trees (rough, rotten, and recently dead), the potential yield from thinning is approximately 18 million tons or a bit more than one ton per acre per year.

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 purpose. Currently, logging operations take place on only 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 enhancement 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 areas other than commercial forests. Although they 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 sources include wood obtained by removal of dead trees from towns and farms, and land clearing operations for farming, road-building, 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 study¹⁵ reports that land clearing operations in Southern New England produced about one 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 4×10^5 acres per year,¹⁶ leading to the removal of about eight million tons of merchantable bole per year. If we assume that the logged areas contain the average amounts of cull, saplings, tops, branches, etc., then, on the basis of our earlier results, the current logging operations also produce about seven million tons of slash. This may well be an underestimate since, for example, Young¹⁷ gives a much larger value of total biomass, 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, branches, 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 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 total annual energy consumption of Maine is only 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., Morbark's "Total Chiparvestor") capable of chipping trees up to 12 inches 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 only the bole 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 cushion to reduce disruption of the soil. At the landing, trees can be separated into those whose trunks will be used separately for sawtimber, pulp, or whatever, those to be chipped entirely for pulp, and those together with the other residues to 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. Then, at a processing plant, the chips can be classified into parts appropriate for pulp and for energy. Such chip classifiers (e.g., Mörbark's "Class-A-Fiber System") are already in use at some pulping plants to separate wood from bark and sand or soil.

It is not possible to describe - and it would be foolish to prescribe - general harvesting procedure. 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.

For the most part, it is 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 7×10^6 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 required 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 the State forests. For example, the state can intervene economically

- 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 passing laws to prohibit the dumping of logging residues at the site of harvesting or imposing other regulations on logging operations, for example.

In many situations, such as protecting the environment from pollutants, direct intervention has seemed to be the most satisfactory way to proceed. In others, such as encouraging people to own their domiciles instead of renting

them, economic intervention via the tax laws has seemed more satisfactory. To promote desirable logging practices, direct intervention may not be a good choice since, as we said, it is difficult to make general rules about desirable logging practices. Such practices must change from year to year and forest to forest.

Thus it 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.

- Direct payment to logging operators who remove residues could be arranged by having the state purchase the resulting chips for use as a fuel for a state-owned energy corporation, for example tax incentives are somewhat more difficult to arrange since the federal tax dominates the corporate income tax.
- 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 practices.
- Imposing a severance tax in addition to the property tax seems unjust and may well be politically infeasible. It can be argued however, 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, replacing the Tree Growth Tax with some form of pure severance tax should be considered.

Other Currently Available Sources

Much of Maine's forest is now overstocked. The 1970 Forest Survey Report reveals that 54% of all commercial forest land is stocked at more than 130% of the standard value. Such a level of crowding inhibits tree growth as indicated by the fact that 95% of all trees of sufficient quality to be classed as "desirable" grow 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% of the standard value, nearly half of the trees on somewhat more than half of commercial forest lands should be removed; that is, about one quarter of the total aboveground biomass in Maine's forests, roughly one-eighth billion tons of (dry) wood. If we suppose that this 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 one-third ton per acre of Maine's forests. This wood can contribute approximately 10^{14} Btu per year of energy, a bit less than one-third of Maine's current energy use. These estimates may be high by as much as 30% since some owners of overstocked forests may not want to have their forests thinned.

Overstocked stands, 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 use. 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 the cost differences cannot be too great.

Another resource of otherwise unused wood is 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 no general survey of standing dead trees has been done, it is difficult to estimate the total quantity of wood available from this source. Monks et al.²² estimate one-third billion tons from the spruce budworm infestations; only a small fraction of these trees are useless now, but in another 10 years or so nearly all of it will be unmercantable. If we add the other standing dead trees, there may be a total of one-half billion tons of wood available as an energy resource. Harvested over 20 years, these trees would provide 25 million tons of wood per year, or more than 4×10^{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 providing a suitable market for the material.

Standing dead trees and thinnings from overstocked stands are, in a sense, a nonrenewable resource; they have accumulated over the years and cannot be "mined." With suitable forest management they will not accumulate but will be thinned out as rapidly as they are generated. As a market for this resource begins to develop, they will initially be mined at a considerably smaller rate than indicated; a twenty-year lifetime does not seem excessive for these resources.

There is 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, as mulch or animal bedding, raw material for fiberboard, etc., pulpwood, or as fuel for the mill itself. Approximately one-half the mill wastes were used in 1971,²⁴ leaving about one-half 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 fuel,²⁷ the rising prices for fossil fuels have apparently made it worthwhile to make greater use of these wastes. If this trend continues, as it almost certainly will, we can expect that there will be very little unused mill waste available outside of the mill that itself.

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

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, etc. One can envision intensive silviculture analogous to the most intensive forms of agriculture.²⁸

It would not be wise, however, to follow the agricultural model too closely. Most field crops are planted as monocultures, with large fields of single crops. This allows each crop to receive 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 much 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 (such as increased susceptibility to pests and disease, and decreased diversity of wildlife) outweigh the positive aspects. It has been suggested 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. It is hard to assess the accuracy of that speculation, but 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 noted the most desirable 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, the growth of trees can also be enhanced by judicious fertilization without disrupting other processes in the forest.

As we noted earlier, on the basis of our estimates for current growth rates in Maine's forests, there is a potential for thinning about one ton per acre per year, or about 18 million tons per year if all of 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, as private owners are also interested in using the timber on their property), then that estimate is reduced by one-third 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 undesirable material. They do, however, make a perfectly adequate fuel, potentially

yielding $2-3 \times 10^{14}$ Btu per year, about one-third 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 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 any loss incurred during thinning operations.

Without actual experience - experience that is beginning to accumulate as some lumber and management companies and private individuals experiment 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 two-thirds 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 merchantable bole (0.67 tons/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 21.

TABLE 21
ENERGY POTENTIAL OF MAINE'S FORESTS

<u>Standing Resources</u>				
	<u>Total Available</u>	<u>Lifetime</u>	<u>Harvest Rate</u>	<u>Energy Production Rate</u>
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} Btu/yr
<u>Renewing Resources</u>				
	<u>Rate of Wood Production</u>		<u>Rate of Energy Production</u>	
	<u>Total</u>	<u>Per Area^a</u>		
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 ^b	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.

^a 1.69×10^6 acres of commercial forest.

^bTops and branches of growing stock trees.

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., merchantable 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 and logging slash. For all of Maine's commercial forest, that comes to over 40 million tons per year, with an energy content of 0.8×10^{15} Btu per year. Since cull trees are included in the sum of material available for energy, no separate accounting of them is necessary.

A largely mechanized scheme for large-scale thinning of forests has been proposed by Riley and Smith of the University of Maine at Orono,³⁰ and a 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 re-seed naturally (but this is not necessary);
- ii) after a few years narrow permanent lanes are cut out to permit easy access to the entire stand;
- iii) the stand is thinned by machines that reach from the access lanes and remove undesirable trees;
- iv) thinning is repeated periodically (every 5 years, 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, desirable.

To what extent 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 greater than Maine's forests.³¹ One can thus expect biomass productivities of more than 15 tons per acre per year, of which perhaps two-thirds would be sufficiently undesirable for other purposes to be suitable for fuel. Fewer than 200,000 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 one-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 are required for intensive silviculture; it is likely that a change in philosophy may also be required, a change of emphasis from extraction 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 or 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. 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 incentives alone ought to serve to encourage its practice. The studies at the University of Maine mentioned above should give some indication as to the validity of the estimates presented here.³² Since, no other data exist as yet on the potential effects and costs of careful or intensive silviculture, it is difficult to suggest public policies to encourage its practice beyond supporting research and providing management assistance to forest land owners who request it (e.g., via university extension programs and field stations).

Competing Uses

Thus far we have supposed that the harvesting of slash, cull, and thinnings will not affect current use patterns for wood, so most forestry products (other than energy) will continue to be made from roundwood (i.e., the bole of harvested trees), and most of the forest residues will be available for energy. This 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 4.5 million tons of wood, some 20% of which was what might be called forest by-products: saplings, tops and branches, and rough, rotten or dead trees. Thus the pulp market can 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 classifiers may be used to decrease the bark content of material for pulping. In that case, nearly all the material considered for energy could be sorted,

with the woody matter going to pulp and the remainder to fuel. The pulping industry could then compete with the energy industry for a major portion of the forest by-products.

Such competition would not be serious for quite a while, however. From 1958 to 1970, the pulp industry has been growing at a rate of 3.7% per year.³⁴ If the industry continues to grow at this rate (an unsafe assumption) from 4.5 million tons per year in 1970, it will use less than 14 million tons per year in 2000. That is less than the current growth rate of poletimber (i.e., growing stock unsuitable for sawlogs) alone. With growth increased by careful silviculture, the forests will continue to supply both the pulp and the energy markets for a long time to come.

The competition between the pulp and energy markets will chiefly effect the price of low-grade wood chips. 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 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.

As for other competitive uses, the next largest uses of wood in Maine are for lumber (including veneer and other products), using about 1.5 million tons per year, and for fuel, using about 4×10^5 tons per year. None of the material 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. This industry would compete directly with the fuel market. In such an industry, wood chips are burned incompletely 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 currently 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 currently being used in this 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 particulate-board industry would probably be similar to the effects of rapid growth in either the pulp or fuel market for forest by-products: increasing the incentive for careful forest management, and raising the value of wood chips.

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 20. 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 has accumulated. The quantities of wood and the potential energy available currently and with new harvesting schemes are shown in Table 21.

It is difficult to know what effects various policies may have. 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 agencies, be authorized and funded to conduct periodic surveys (perhaps every 10 or 12 years) of all wood resources in Maine and their use and that these results be made 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 accessibility 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 these reasons, it seems desirable 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 silviculture 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 are now privately owned, with owners unwilling or unable to practice careful silviculture.³⁶ In some cases it may well be desirable to leave a woodlot unmanaged; in others, it may be desirable to manage it intensely. Such decisions are best left to knowledgeable owners 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 the major potential use of that wood in the near future is for fuel. 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 state-owned 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.

NOTES TO CHAPTER IV

1. J. Shelton (part I) and A. B. Shapiro (parts II & III), The Woodburner's Handbook, Vermont Crossroads Press, Waitsfield, Vermont (1976).
2. R. H. Ferguson and N. P. Kingsley, "The Timber Resources of Maine," USDA Forest Service Bulletin NE-26 (Northeastern Forest Experiment Station, Upper Darby, Pennsylvania, 1972).
3. H. E. Young, "Biomass Sampling Techniques for Puckerbrush Stands," in: Forest Biomass Studies, IUFRO Working Group on Forest Biomass, Section 25, p. 179-190 (1971). Available from the Complete Tree Institute, University of Maine at Orono.

H. E. Young, L. Hoar, and T. C. Tryon, "A Forest Biomass Inventory of Some Public Land in Maine," in: Oslo Biomass Studies, p. 1-10 (1976). (Available from the Complete Tree Institute, University of Maine at Orono.)
4. W. Jones and M. Ruane, personal communication, MIT Energy Laboratory (1977).
5. H. E. Young, "The Enormous Potential of the Forests - A Positive Rebuttal to Grantham and Ellis," Journal of Forestry, 73, 2, p. 99-102.

H. E. Young, personal communication, University of Maine at Orono (1977).

See P. A. Samuelson, "Economics of Forestry in an Evolving Society," Economic Inquiry, XIV, 4, p. 466-492, December 1976; and C. W. Clark, Mathematical Bioeconomics: the Optimal Management of Renewable Resources, (J. Wiley & Sons, New York, 1976).
7. Ferguson and Kingsley, op. cit.
8. T. Page, Conservation and Economic Efficiency (Resources for the Future/ Johns Hopkins Press, Baltimore, 1977).
9. It may, in fact, ultimately turn out that with appropriate adjustments the present value criterion may arrive at the same result, but that is a matter of debate among economists.
10. Young, note 3, supra.
11. Ferguson and Kingsley, op. cit.
12. Young, note 3, supra.
13. Rich and Bauer, "The Feasibility of Generating Electricity in the State of Vermont using Wood as a Fuel," a study J. P. R. Associates, Inc. Vermont, Department of Forests and Parks, August 1975.
14. Ferguson and Kingsley, op. cit.

NOTES TO CHAPTER IV (Continued)

15. Pecoraro et al., "The Potential of Wood as an Energy Resource in New England Wood Utilization Work Group," New England Federal Regional Council (Federal Energy Administration, September 1977).
16. Forest Products Council, 1977, cited in H. E. Young, personal communication, University of Maine at Orono.
17. Young, note 5, supra.
18. J. T. Bones and D. R. Dickson, "Pulpwood Production in the Northeast - 1975," USDA Forest Service Bulletin NE-45 (Northeastern Forest Experiment Station, Upper Darby, Pennsylvania, 1976).
19. Page, op. cit.
20. R. Parlow, "Axes and Taxes: The Taking of Resources and Revenue from the Maine Woods," (Allagash Environmental Institute, University of Maine at Portland-Gorham, 1977).
21. Ferguson and Kingsley, op. cit.
22. S. G. Monks et al., "Maine Methanol," Collected working papers on the production of synthetic fuel from wood (Maine Office of Energy Resources, March 31, 1975).
23. Ibid.
24. Maine Office of Energy Resources, fact sheets on wood residues (1977).
25. Ferguson and Kingsley, op. cit.
26. Monks et al., op. cit.
27. S. E. Nydick, "A Study of Inplant Electric Power Generation in the Chemical, Petroleum Refining, and Paper Industries," #TE5429-97-76, (1976) Thermoelectron Corporation, Waltham, Massachusetts.
28. See e.g., Jones and Ruane, op. cit.; R. E. Inman, "Silvicultural Biomass Farms, Vol. 1 - Summary," #MITRE-TR-7347 (1977) MITRE Corporation, (Available from NTIS, Springfield, Virginia); A. L. Hammond, "Photosynthetic Solar Energy: Rediscovering Biomass Fuels," Science, V197, p. 745-746, (1977), and C. E. Calef, "Not Out of the Woods," Environment, 18, 7, p. 17-25, (1976).
29. Monks et al., op. cit.
30. J. G. Riley and N. Smith, "Solar Energy Utilization of Photosynthetic Production of Solid Fuel," (American Society of Agricultural Engineers, Saint Joseph, Missouri, 1977).
31. Rich and Bauer, op. cit.

NOTES TO CHAPTER IV (Continued)

32. Riley and Smith, op. cit.
33. Ferguson and Kingsley, op. cit.
34. Bones and Dickerson, op. cit.
35. See e.g., U.S. Department of Energy Symposium on Utilization of Alternative Fuels for Transportation, University of Santa Clara, Santa Clara, Calif., June 19-23, 1978.
36. P. Bofinger, "Better Forestry Through Fuelwood Harvesting," in Wood Heating Seminar, 2, Wood Energy Institute, Waitsfield, Vt. (1977).

CHAPTER V

WOOD AS AN ENERGY SOURCE IN MAINE: COST CONSIDERATIONS*

by

T. von Foerster

The raw material for fuelwood 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 treated 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, charcoal, 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.

Roundwood

Roundwood is generally used for fuel in small quantities in fireplaces or small stoves. In some rural or near-rural areas it may be considered 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 fuelwood 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 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 of these 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 desirable bole remaining as roundwood, and the logging residues being chipped by a mobile

*This Chapter is extracted from T. von Foerster, "On the Use of Wood as an Energy Source in the State of Maine," Energy and Environmental Policy Center, Harvard University, Sept. 1978.

whole-tree chipper. A crew of seven (including the owner) operates \$185,000 worth of equipment and produces 3.1×10^5 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 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 MIT³ estimated harvesting costs from 1972 Census Bureau data on Maine logging contractors 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 came to about \$15 per dry ton. Assuming an average inflation rate of 5% per year, the 1975 costs could 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 more 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 merchantable bole.

If the bole of standing dead or other cull trees is used for firewood, reserving the good trees for higher uses, the stumpage fee could be considerably smaller. 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. The average stumpage values for cull trees could reasonably be half the stumpage values of growing stock, or about \$3 per dry ton.

Thus, roundwood for fuel can 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 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 adds \$5 to each ton of oven-dry wood finally consumed.

The 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 could reasonably be around \$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 (167 per cord) by 1980. Table 22 gives a list of roundwood prices (1977) and the associated cost of energy.

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 wood chips.⁵ It has 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 current 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) will ultimately require prices received for fuelwood to reflect costs of harvesting and transportation.

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 Force⁷ (cited above) estimated harvesting costs of whole-tree chips at \$14 per dry ton. The Maine OER analysis⁸ estimated harvesting costs at a little over \$4 per green ton, or about \$8 per dry ton. A very thorough analysis by J.P.R. Associates for the Vermont Agency of Environmental Conservation⁹ arrived 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 whole-tree harvesting costs of \$15 to \$20 per cord, or an average of \$1 per dry ton, for conventional harvesting methods (chain saws and cable skidders). An itemized accounting of costs for a whole-tree chipping operation in Michigan indicates that harvesting costs there are about \$12 per dry ton.¹⁰

The cost estimates for conventional harvesting (with on-site 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 analysis, 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 merchantable 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

TABLE 22
ENERGY PRICES

	Unit Price (dollars)	Material Price (dollars)	Energy Price (100% efficiency) \$/10 ⁶ Btu
Roundwood			
green, at landing	20/cord	25/odt	1.4
green, 25 mi from landing	22/cord	28/odt	1.6
cut, split and dried ^a	56/cord	45/odt	2.6
delivered ^b	63/cord	50/odt	2.8
Chips			
green, at landing	10/ton	20/odt	1.1
green, at plant ^c	12/ton	25/odt	1.4
dried, at plant ^c	31/ton	31/odt	1.8
dried, 75 mi from plant	35/ton	35/odt	2.0
Natural Gas			
Residential	3.0/10 ³ ft ³	3.0/10 ³ ft ³	3.0
Industrial	2.1/10 ³ ft ³	2.1/10 ³ ft ³	2.1
Imported LNG	3.5/10 ³ ft ³	3.5/10 ³ ft ³	3.5
Fuel Oil (No. 2 Distillate)			
Residential	.50/gal	21/bbl	3.4
Industrial	17/bbl	17/ton	2.8
Coal	50/ton	50/ton	2.4
Electricity (Residential)	.035/kWh	-	10.3

^aAir dried, 15% moisture content.

^bCut split and dried, trucked 75 mi. (1 odt = 1.2 tons, air dried).

^cPlant assumed 25 mi. from landing. Chips are kiln-dried.

All prices given are estimates for 1977 values.

odt = oven dry ton.

Energy content of fuels given in Table 23.

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 transportable fuel or energy (e.g., methanol, charcoal, pellets, or elec-

making). 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 dry chips. 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 to 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 wood contain 1 one pound of wood and 1 one pound of water. To evaporate the water requires 1000 Btu, which can be obtained by burning a little over one-quarter pound 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 one-quarter pound of green wood. The effective cost of one pound of dry wood is about the same as 2.5 pounds of green wood. Thus, the processing plant can 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 could be about \$35 per ton. Had the chips not been dried, we would require the delivery of 2.25 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 \$.045 its energy cost is \$3 per million Btu. These prices are summarized in Table 22.

As we have mentioned, one of the problems with making use of wood as a fuel, in spite of its economic attractiveness, is that presently there is no one (outside the forest products industry, which uses internally generated wastes as a fuel) equipped to use it on a large scale. In order to take full economic and silvicultural advantage of fuelwood, the states should encourage the creation of a market for chipped fuelwood. Such encouragement could come 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.

Conclusions

The expected prices (1977), reflecting harvesting and processing costs, for various forms of fuelwood are given in Table 22. This 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, we have used an energy content of 8800 Btu per pound for dry wood, 8000 Btu/lb for air-dried wood (10% moisture), and 4400 Btu/lb for green wood (50% moisture). 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 22 includes, for comparison, typical prices for fossil fuels.

NOTES TO CHAPTER V

1. Lloyd et al., Governors Task Force on Wood as a Source of Energy, State of Vermont, 1975.
2. Maine Office of Energy Resources, "Fact Sheet on Wood Pricing," Maine Office of Energy Resources, 1975.
3. W. Jones and M. Ruane, personal communication, MIT Energy Lab, 1977.
4. Lloyd et al., op. cit.
5. R. Parlow, "Axes and Taxes: The Taking of Resources and Revenue from the Maine Woods," Allagash Environmental Institute, University of Maine at Portland-Gorham, 1977.
6. Ibid.
7. Lloyd et al., op. cit.
8. Maine Office of Energy Resources, "Fact Sheet on Wood Pricing," Maine Office of Energy Resources, 1975.
9. Rich and Bauer, "The Feasibility of Generating Electricity in the State of Vermont using Wood as a Fuel," Report by J.P.P. Associates, Inc., Vermont Department of Forests and Parks, August 1975.
10. Cited in Rich and Bauer, op. cit.
11. J. G. Riley and N. Smith, "Solar Energy Utilization by Photosynthetic Production of Solid Fuel," (1977) American Society of Agricultural Engineers, Saint Joseph, Missouri,.
12. Lloyd et al., op. cit.
13. Pecoraro et al., "The Potential of Wood as an Energy Resource in New England Wood Utilization Work Group," New England Federal Regional Council (Federal Energy Administration, September 1977).
14. Ibid.

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CHAPTER VI
SMALL SCALE USES OF WOOD*

by

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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 (during a tiny fraction of even the recorded span of history) that mankind has learned to use fire from 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 thermostats worry about their heating needs, the recent spurt in 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 in residential heating. Until recently, wood-fired furnaces that were large enough and sufficiently convenient were not available to make the application of wood furnaces practical in larger structures, such as apartment buildings or stores. 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.

Much of the wood that is burned in homes is cut by the owners on their own land, or is purchased directly from the owners of small woodlots. Those transactions are rarely reported to any public agency and their impact on the fuelwood supply is difficult to assess²; thus, we have not included them in our earlier figures on firewood use.

Residential and commercial uses account for almost 40% or about 1.1×10^{14} Btu per year.³ Roughly three-quarter of that energy is used for space heating, and another 10% to 15% is used to heat water⁴ (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 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 cooking. Wood also does not seem suited to provide energy for lighting, air conditioning, etc. at the site of use though it may make a contribution to electricity used for these purposes.

*This Chapter is extracted from T. von Foerster, "On the Use of Wood as an Energy Source in the State of Maine," Energy and Environmental Policy Center, Harvard University, Sept. 1978.

Space- and water-heating, on the other hand, are uses to which wood seems eminently well-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 all the energy Maine needs for these purposes.

Furthermore, the requirements for a heat source for space and water heating are not very stringent. Almost anything whose temperature is above 150°F will do very well for either purpose - and, in fact, a 100°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 uses, but, 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 possible 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 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 one ton (dry weight) of cut and split wood, but only about two-thirds ton (dry weight) of wood chips. These densities correspond to average energy densities of coal at 2×10^5 Btu/ft³ and oil at 11×10^5 Btu/ft³. 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 escape from the wood (100 to 250°F);
2. lignin, cellulose, etc., decompose to produce tars, oils, gases, and residual carbon (charcoal) (500 to 750°F);
3. the gases, oils, and tars themselves decompose into chemically simpler substances (500 to 4000°F);
4. further heating does little more than melt (at 6300°F), and ultimately vaporize (7600°F) the carbon.

The presence of air alters the picture considerably since, at temperatures above 1200°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

TABLE 23

MASS AND ENERGY DENSITIES OF COMMON FUELS

	Mass/Volume	Energy/Mass	Energy/Volume
Roundwood (dry)	1.3 t/cord 30 lb/ft ³	18 10 ⁶ Btu/t 8.8 10 ³ Btu/lb	22 10 ⁶ Btu/cord 1.8 10 ⁵ Btu/ft ³
Wood chips (dry)	0.63 t/ccf 13 lb/ft ³	18 10 ⁶ Btu/t 8.8 10 ³ Btu/lb	11 10 ⁶ Btu/ccf 1.1 10 ⁵ Btu/ft ³
Bark chips (dry)	0.63 t/ccf 13 lb/ft ³	20 10 ⁶ Btu/t 10 10 ³ Btu/lb	13 10 ⁶ Btu/ccf 1.3 10 ⁵ Btu/ft ³
Spent Pulping Liquor (dry)		13 10 ⁶ Btu/t 6.5 10 ³ Btu/lb	
Coal (average)	3.0 t/ccf 60 lb/ft ³	21 10 ⁶ Btu/t 11 10 ³ Btu/lb	63 10 ⁶ Btu/ccf 6.3 10 ⁵ Btu/ft ³
Oil (distillate)	0.16 t/bbl 56 lb/ft ³	38 10 ⁶ Btu/t 19 10 ³ Btu/lb	5.8 10 ⁶ Btu/bbl 11 10 ⁵ Btu/ft ³
Gasoline	42 lb/ft ³ 5.6 lb/gal	21 10 ³ Btu/lb 21 10 ³ Btu/lb	8.8 10 ⁵ Btu/ft ³ 1.2 10 ⁵ Btu/gal
Methanol	50 lb/ft ³ 6.8 lb/gal	9.6 10 ³ Btu/lb 9.6 10 ³ Btu/lb	4.8 10 ⁵ Btu/ft ³ 0.65 10 ⁵ Btu/gal
Natural Gas	0.045 lb/ft ³	23 10 ³ Btu/lb	1.0 10 ³ Btu/ft ³

charred wood that provides the heat needed for the pyrolysis of the next step; the gases, tars, etc., generally escape from the wood before they heat up enough to ignite, thereby becoming visible flames.

To ensure, maximum efficiency, the substances driven off during pyrolysis must remain hot enough to ignite. If not, the chemical energy represented by their composition is lost as waste in the flue gases. Also, the flue gases must give up as much of their heat energy as possible, since heat sent out with the flue gases is heat wasted. There is one unavoidable inefficiency in nearly all applications; 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 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 allow 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 from 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%.

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. These effects are problems with all fuels to some extent. 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.

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. However, a fireplace generally 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. Thus, as home heating units to supplement a central heating system, fireplaces 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, but 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 most likely remain primarily aesthetic.

Wood stoves and furnaces, 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 efficiency¹⁰. 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 furnace, if it makes use of some form of storage, can be operated with much higher combustion efficiencies, and therefore greater overall efficiency.¹¹

Many different designs for wood stoves and furnaces exist. Each has its advantages and disadvantages, and, of course, its proponents and detractors. The net efficiency of any heating unit depends not only on how it is designed but also on how it is used, and convenience or aesthetics may play an important 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, including equipment costs as well as fuel costs.

Table 24 compares 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 furnaces, with their relatively high efficiencies, are clearly economically attractive heating systems. The log-burning furnaces have the slight inconvenience of requiring manual stoking. 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 same tank, the furnace need only be stoked 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.

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 as the data from Table 21 show, a single house would need a woodlot 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 five acres for each house, assuming current average growth rates. The total residential space-heating requirement for Maine in 1974 was 6×10^{13} Btu.¹³ That heating need can be supplied by the roundwood from thinning 4×10^6 acres at a rate of one ton per acre.

Given the economic and other attractions of using wood as a fuel, we can expect that the recent increase in sales and installations of wood stoves will

TABLE 24

ANNUAL COSTS OF HOME HEATING SYSTEMS

	FURNACE			FUEL SYSTEM		
	Initial cost ^a \$	Annual cost ^b \$/yr	Efficiency	Unit cost ^c \$/10 ⁶ Btu	Annual cost \$/yr	Annual cost \$/yr
Oil (new installation)	800	100	0.50	3.4	475	575
Gas (new)	650	80	0.60	3.0	350	430
Electric resistance (new)	400	50	1.00	10.3	720	770
Heat pump (new)	1200	150	1.70	10.3	425	575
Wood stove (new)	800	100	0.45	2.8	435	535
Wood furnace (new)	1100	135	0.60	2.8	325	460
Wood-Chip furnace (new)	2500	315	0.60	2.0	230	545
Oil (existing)	0	0	0.50	3.4	475	475
Wood furnace (add-on)	300	40	0.60	2.8	325	365

^aRounded to nearest \$50.

^b0.125 times the initial cost. See Appendix B.

^cFrom Table 22.

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.

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 program to point out minimum safety standards (and their reason) for wood-burning equipment. For example, sellers of wood stoves could be required 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.

Wood Chips

As Table 24 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, that cost estimates for both the furnace and the wood chips are speculative. As yet, the only wood chip

furnaces that are of a size to be useful for residential and commercial applications are experimental units not necessarily designed for mass production; thus, their cost need not reflect the ultimate price of wood-chip furnaces. The cost of fuel is also speculative. In Table 25, we have tried 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 oven-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 24, the added cost would be between \$35 and \$70 per year, enough to make the wood chips less attractive than all but 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 cheaper 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 25, the results of an analysis of annual heating system costs of a small store or office building (about 4000 square feet) or apartment building (ten units of about 900 square feet each).

The annual heating demand for such a building is about one-half billion Btu per year, about one-fifth 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 cubic feet, so that the supply of wood chips for January occupies about 1600 cubic feet, 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 24 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 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

TABLE 25

ANNUAL COSTS OF COMMERCIAL HEATING SYSTEMS

	FURNACE			FUEL SYSTEM		
	Initial cost \$	Annual cost ^a \$/yr	Effi- ciency	Unit cost ^b \$/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				2.0	2000	3050
Wood Chips	6100	950				
green, local			0.5	1.4	1400	2350
dried, distant			0.6	2.0	1650	2600
dried, delivered ^c			0.6	2.3	1900	2850

^a0.158 times the initial cost. See Appendix B.

^bFrom Table 22.

^cIncluding \$5/ton for handling and delivery.

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 500 10⁶ Btu.

plant, and the resulting fuel -- methane, methanol, oils, or electricity -- would be added to the stream of currently used fuels.

Among the possible functions of the State Energy Corporation 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. Such a project could supplement academic or industrial research and development of wood chip burning systems.

Conclusions

With the recent rise in fossil fuel prices, it seems clear that wood has, once again become an economically attractive fuel in forested areas like New England. Tables 24 and 25 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 valuable 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, we can also expect an increase in the number of hastily 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 adequate 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.

REFERENCES TO CHAPTER VI

1. A. C. Page et al., "Maine Comprehensive Energy Plan, 1976 Edition," Maine Office of Energy Resource, 1976.
2. Ibid.
3. Ibid.
4. J. Lee, "Future Residential and Commercial Energy Demand in the Northeast," BNL 50552, March 1976, Brookhaven National Laboratory, Upton, New York.
5. K. E. Johnson, "Possibilities for Electricity-Steam Cogeneration Systems in Maine," Maine OER, Draft Report, March 15, 1977.
6. See T. B. Reed, Net Energy Available from Wood, 1977, and J. Sheldon (part I) and A. B. Shapiro (parts II & III), The Woodburner's Encyclopedia, 1976 (Vermont Crossroads Press, Waitsfield, Vermont).
7. Ibid.
8. P. M. Sturges, "Heat Recovery for Efficient Fireplace Operation," in: Wood Heating Seminar 2, Wood Energy Institute, Waitsfield, Vermont, 1977, and L. Cranberg, "The Domestic Fireplace and the Energy Crisis," in: Wood Heating Seminar 2, Wood Energy Institute, Waitsfield, Vermont, 1977.
9. Sheldon and Shapiro op. cit., and R. C. Hill, personal communication, University of Maine at Orono, 1977.
10. Kristia, Jotul Catalog, Kristia Associates, Portland, Maine, 1976.
11. R. C. Hill, "The Efficient Use of Wood for Space Heating," preprint, 1977.
12. R. C. Hill, "The Integration of Wood Heating and Solar Collection - the Maine Audubon Building," in: Wood Heating Seminar 1, Wood Energy Institute, Waitsfield, Vermont, 1977.
13. A. C. Page et al., op. cit., and J. Lee, op. cit.
14. See several articles in U.S. News & World Report (1977).
15. See e.g., Sheldon and Shapiro, op. cit.; P. F. Di Matteo, "Building Codes and Woodburning Appliances," in: Wood Heating Seminar 2, Wood Energy Institute, Waitsfield, Vermont, 1977; and B. Pitkin, "Installations: Safety and Code Requirements," in: Wood Heating Seminar 2, Wood Energy Institute, Waitsfield, Vermont, 1977.
16. Pecoraro et al., "The Potential of Wood as an Energy Resource in New England," Wood Utilization Work Group, New England Federal Regional Council, Federal Energy Administration, September 1977.

CHAPTER VII

REGIONAL EMPLOYMENT AND INCOME EFFECTS OF A 50-MW WOOD-FIRED POWER PLANT*

by

Pieter VanderWerf

The introduction of an industrial facility has a number of social and economic consequences for the surrounding region, some beneficial and some detrimental. It stimulates the local economy; it thus increases corporate and personal income and creates jobs. On the other hand, the process of adjustment to these new levels of business activity may cause disruption, waste, and personal loss within the region. Also, various activities associated with the introduction of an industrial plant can arouse social dissatisfaction even though they may be legal and economically justifiable. This Chapter evaluates the consequences of the construction and operation of a proposed 50-MW wood-fired power plant (WFPP) in northern Vermont.

New industrial facilities affect regional business activity through both purchases and sales. In buying the productive inputs they need, the operators of a facility invariably pass some money on to other regional firms and laborers, who then respond a part of their new income by transferring it to other regional parties, and so on until the original expenditure passes entirely out of the region to secure imported goods and services. All corporate recipients in this chain of spending may hire extra workers to increase their output until it satisfies the increased demand for their goods. The net effect is an increase in regional income, both business and personal, greater than the amount of the original expenditures alone, and an increase in regional employment greater than the employment provided directly by the industrial facility originating the growth. The sales of a new facility affect regional business activity through the same process, but with a different beginning: by selling a product formerly unavailable in the region or by selling at a lower price a product already available, a new facility makes it attractive for regional firms that use that product to expand operations. In expanding, these firms will spend money and hire new workers, beginning the type of spending chain described above.

Of the two channels through which a small plant could affect the surrounding economy, the impact of the sales side is negligible. Electricity is sold through an area-wide power grid, not directly to regional consumers.¹ A plant in a region with an established grid could not affect the local economy through its sales by increasing the availability of electricity; it could only lower the price. But a 50-MW power plant is not likely to do even that to a significant degree; its electricity is quite expensive and its output is too small to affect the average price of electricity in the region.

The problem of evaluating the impact of a wood-fired generating facility on the regional business level reduces to estimating the changes in regional income and employment that the expenditures associated with the plant will

*This Chapter as originally prepared as report DSD 90 by Dartmouth College to the BNL Regional Studies Program.

induce by initiating a chain of regional spending. However, merely estimating future changes in regional income and employment will not tell how the regional economy will be affected by the process of change. Therefore, we also consider directly the nature of the adjustment process in order to identify the problems it may cause and suggest measures to minimize them.

METHODS OF ANALYSIS

There are several established methods for estimating the impact on regional income and employment, also called the "multiplier effect," of new expenditures. One of the most commonly used is the economic base study, which is inexpensive and requires modest amounts of data. However, it yields only one number: a single multiplier that tells how much extra income (or employment, depending on the method of calculation) an initial expenditure should create directly and indirectly in the region under study. Regional econometric studies give much more information, but they are expensive, necessitate long development periods involving highly trained specialists, and require large amounts of data.

We therefore elected to base the study of multiplier effects on an input-output (I-O) analysis. Forecasting the changes in income resulting from new expenditures in the area is the express purpose of I-O, and it is probably the most sophisticated technique in general use. The necessary input-output data, normally difficult to obtain, were supplied by the Regional Economic Analysis Division (READ) of the Bureau of Economic Analysis, U.S. Department of Commerce. Our assessment of the qualitative effects of new expenditures -- regional economic adjustments and noneconomic problems -- was based on subjective data and personal communications.

Estimating Multiplier Effects with Input-Output Analysis

I-O is a method of data organization and manipulation designed to estimate the multiplier effect of any new expenditure within an economy. The data are first collected and organized for a specific economic region, such as a country, a state, a county, or a metropolitan area. Once this is done, the analyst specifies a set of hypothetical expenditures to be made within the region. It is necessary to specify both the dollar amount of each expenditure and the industry in which it will be made. The result is a set of estimates that tell how much extra income should ultimately accrue to each industry, including households, within the study region as a result of the expenditures.

For example, according to the I-O data used in the analysis for this report, if \$100 were spent by sawmills in northern Vermont (say, for lumber), regional lumber and wood products firms should receive about \$46 of extra income through direct and indirect channels as a result. Households in the area should get about \$49 of extra income, and northern Vermont farmers should get an extra \$3 after the multiplier effect had fully worked itself out. This is all in addition to the original \$100 expenditure to the sawmills. For the purposes of an I-O analysis, such income figures can also be interpreted as changes in sales and output. The firms of the lumber and wood products industry received the extra \$146 because they sold, and therefore produced, an extra \$146 worth of lumber, veneer, wooden crates, and so forth. To get the extra \$49, members of the households did work of that value, and the farmers had to produce the extra \$3 worth of food they sold.

To estimate the combined multiplier effect of the expenditures arising from the introduction of a new industrial facility, the changes in regional income brought about by each individual purchase are added together. Data on the average employment per dollar of sales in different industries then permit us to convert I-O estimates of income changes into estimates of employment changes.

Estimating Regional Expenditures of the Plant

The list of plant expenditures were divided into two main categories: construction phase expenditures and operation phase expenditures (the latter subdivided into operation activities, wood harvesting, and wood transportation expenditures). This permitted the calculation of separate multiplier effect estimates for each aspect of the plant's activities and thus permit generalizations to be made about the impact of the multiplier effect over time and across the study region.

Estimates of the expenditures associated with constructing and operating a typical 50-MW wood-fired facility have been made by Wheelabrator Cleanfuel Corporation in Washington, DC, and Rust Engineering Company in Birmingham, Alabama, for a U.S Department of Energy project; many of their estimates were used in this analysis. Because the technologies that will be used in the wood harvesting and wood transportation parts of the operation phase of these projects have not been selected, we considered several reasonable alternatives before establishing a final list of expenditures for both of them. In general, however, we adopted a single estimate for each expenditure. If an expenditure could plausibly have been anywhere within a range, we chose an estimate in the middle. Whenever there was doubt about the proportion of an expenditure that would be spent regionally (a common problem with expenditures for labor), it was consistently assumed that a large, though still plausible, fraction would go to regional parties. The purpose of this latter decision was to obtain I-O estimates that reflect the maximum reasonable impact of plant-related operations.

Sources of Error in the Input-Output Calculation

Partly because of the difficulties involved in separating out multiplier effects from general business activity, there are no reliable empirical studies of the predictive accuracy of I-O analysis. But it is possible to consider the sources of inaccuracy.

Inaccuracy can enter I-O analysis from two sources. First, the analysis itself is based on several unrealistic assumptions about the way economic processes work. These assumptions must be made if the technique is to work, but they may allow its results to be inaccurate or misleading. Second, the I-O data used had their own unique limitations because of the methods used by the READ to prepare them.

I-O analysis is based on two major assumptions involving instantaneous adjustment and linearity. The assumption of instantaneous adjustment means that I-O calculations assume all industries can increase their output by any amount, and that they do so immediately as sales increase. In reality, there will be delays between the time a firm receives extra income and the time it spends that income to increase its output. These delays are not shown anywhere in the results of an I-O analysis, so those results are somewhat mis-

leading. What I-O calculations present as the immediate multiplier effect of an expenditure is actually a flow of dollars, which will take some time to materialize fully. Further, the production adjustments of the firms involved may be incomplete. Especially in the case of a large expenditure, the buyer is likely to purchase some of the goods or services he needs from firms outside the immediate region rather than wait for local companies to develop the capacity to supply him with as much as he wants. In this way, dollars can leave a regional economy sooner than I-O analysis would predict, and so I-O estimates of regional multiplier effects can be too high.

The assumption of linearity in I-O implies that firms and people always spend their income in the same pattern, irrespective of scale. In fact, this is not true. A business that receives an increase in income might not need any more machinery, but could decide to hire more workers. Or, it might begin to use new production techniques that require the purchase of a new mix of materials. When a household's income increases, the family is likely to buy less soup and more steak. Thus, I-O techniques are likely to trace some dollars from an initial expenditure through the wrong channels, making some industry income forecasts too high and other too low. These problems are especially severe when a large facility is placed in a rural area; the facility's expenditures push local businesses far beyond their normal range of operation.

The particular I-O data supplied by READ suffer some inaccuracy because they are adapted from national data, and so do not in all ways reflect the peculiar characteristics of the study region to which they are adapted.² To construct its regional I-O data, READ began with the United States national I-O data compiled by the Bureau of Economic Analysis. READ then adjusted these data to account for the fact that businesses and households in a smaller region spend more of their income outside of that region than they do if the region is much larger (i.e., the United States). It is impossible to determine the accuracy of the adjustment. The I-O data correction could either over- or underestimate the fraction of new expenditures that remain in the region. The READ adjustments of national data also ignore local differences in buying patterns; the READ I-O data assume that, in any region, the firms of any given industry spend their income in the same way as the average United States firm of that industry.

All things considered, we judge that the income and employment changes forecasted by I-O analysis are:

- best considered as "ballpark" estimates: good as indicators of the general pattern of distribution of multiplier effects, but certainly inaccurate in their absolute amounts;
- more likely to be a little high than too low;
- more detailed and accurate than the estimates an analyst could produce if he were relying merely on his own judgment.

Delineating the Study Region

The READ data are available for any single county or group of counties, and three counties in north central Vermont -- Caledonia, Lamoille, and Washington -- were chosen as the study region for several reasons. First, the

three-county region is roughly the size of the area that will be affected by the introduction of the plant. If the WFPP is built there, almost all of the expenditures for plant-related operations made within Vermont can be made in those three counties. Local firms can probably transport the wood fuel to the plant; wood chips can be shipped by any conventional trucking operation, and available data show that there exists within the region a large trucking industry.³ Those inputs required for construction and operation that would have to be purchased outside the region -- such as heavy power generating machinery and wood harvesting equipment -- are not manufactured anywhere else in Vermont either.

Second, the area is a likely location for a WFPP because it is the heart of the probable wood supply region in the Green Mountains. Third, counties on the Canadian border were not included because it is likely that WFPPs in these locations would harvest part of their wood in Canada, taking the impact of the plant outside the study region.⁴ We also excluded Chittenden County, because much of it is agricultural land.

Construction Phase Forecasts

Construction of a 50-MW WFPP requires almost two years.⁵ During that time, the construction project would employ as many as 500 workers on site and contribute millions of dollars to the regional economy. Particularly in a rural area, the economic impact of the project would be major; it would certainly be greater than the impact of the plant and related activities once operation begins.

To use the Department of Commerce I-O data in calculating income and employment effects of the plant's construction, it is possible either to express construction expenditures as a total sum or to indicate the total purchases within several major categories. The first approach implicitly assumes that the expenditures will be allocated among the same bundle of goods and services and in the same proportions as the average national construction project. This is quite inaccurate since the power plant construction will use more specialized heavy equipment and less conventional construction materials than typical construction efforts. Therefore, we estimated total expenditures for each category of construction inputs identified in the I-O industrial data and available within the study region.

Estimates of Construction Phase Expenditures

Most of the construction cost figures used here were provided directly by Project Manager Brown Milligan of Rust Engineering Company in Birmingham, Alabama, the design engineers for the proposed Wheelabrator Cleanfuel Corporation plant in Maine. These figures correspond closely to the cost estimates made for a 50-MW plant by the MITRE Corporation.⁶ Rust did not separately estimate the cost of some items, primarily construction materials, for which we made our own estimates from the Wheelabrator Cleanfuel plant description and building cost estimation materials.⁷

From the Wheelabrator Cleanfuel project description, six major sources of income were identified for the three-county region during plant construction: wages for labor, the sale to the plant of three construction materials, and the wholesale and shipping markups on diesel fuel used by construction equipment. The final estimates showed labor to be by far the most significant

TABLE 26

ANNUAL LABOR COSTS TO CONSTRUCT A 50-MW WOOD-FIRED POWER PLANT

<u>Contracted Labor</u>	Cost
Supervisors (8 @ \$29,000/year)	\$ 232,000
Construction workers (240 x 52 weeks/year x 40 hours/ week x \$8.84/hour)	4,413,000
<u>Subcontracted Labor</u>	
All workers	5,250,000
TOTAL	<u>\$9,895,000</u>

Source: Milligan, Note 8.

expense for the plant, but all categories were included to ensure a complete analysis.

Labor: Estimates for labor costs of the project are shown in Table 26. All contracted labor is unionized. The construction worker wage of \$8.84/hr includes foremen and other secondary supervisors who earn more than rank-and-file workers. Rust Engineering estimated that of the \$21 million expected to go to subcontractors, one-half, or \$10.5 million, would go to labor. In the absence of precise information about how these labor payments would be distributed over time, we assumed that half, \$5.25 million, would be paid out during each of the two years of construction.

For a site on the border of the study region, e.g. St. Johnsbury, the estimate of total annual payments to labor (\$9,895,000) is certainly too high; many of the construction workers will commute to work, and therefore spend much of their incomes outside of the study region. But to obtain a set of 1-0 forecasts that reflect the "maximum reasonable impact" of the project on the study region, we retained the original figure.

Construction materials: Only three major construction materials needed for the project are produced in the study region: construction lumber, concrete slab for roofing, and ready-mix concrete. Estimates of the total project requirements of these materials were based on the plant description.⁹ To get annual expenditure estimates, we divided the current cost of the materials by two, assuming that their purchases would be evenly divided between the two years of construction. The final estimates were about \$5,000 per year for construction lumber, about \$7,500 for concrete slab for roofing, and about \$55,000 for ready-mix concrete, totaling \$67,500 annually. According to the 1-0 classification scheme used in the data supplied by the READ, these expenditures are made to the sawmill, concrete products, and ready-mix concrete industries, respectively.

Fuel: The diesel fuel consumed by the construction project is relevant to the analysis even though it is not produced in the region, because regional wholesalers and truckers would each gain a markup on the fuel sold to the contractor. Thus, the construction project would give money to the regional wholesale trade and motor freight industries. Rust Engineering estimates that the project will consume about \$135,000 worth of diesel fuel per year. According to one Vermont wholesaler, about 5% of the wholesale price of diesel fuel is the wholesaler's markup, and another 5% goes to the trucking company that ships it.¹⁰ Thus, the project will expend about \$6,750 in the region annually for wholesale trade services related to fuel, and another \$6,750 for transportation of fuel.

Other expenditures that might be made to local industry were deemed too small to merit consideration. The complete set of regional construction phase expenditures is shown in Table 27.

Forecasts of New Income and Employment

Indirect employment and income estimates provided by the I-0 calculations for the set of expenditures given in Table 27 are tabulated in Table 28.

Income: "New Income" in Table 28 includes all income to each industry that accrues within the study region as a direct or indirect result of the original expenditures. For example, the regional "Lumber and Wood Products" industry receives \$5,000 in income directly from the construction expenditures because this amount is paid to the regional firms in one of its component industries, sawmills. It receives an indirect income of \$18,500 from the sale of products to other industries and households that have themselves experienced a rise in income directly or indirectly from the original expenditures. Likewise, the \$11,600,000 of new income listed as received by

TABLE 27			
TOTAL ANNUAL REGIONAL CONSTRUCTION EXPENDITURES BY A WOOD-FIRED POWER PLANT (1977 dollars)			
	Receiving Industry	Product	Annual Expenditure
Labor	Households	Labor	\$9,895,000
	Sawmills	Lumber	5,000
Construction Materials	Concrete	Concrete	
	Products	Slab	7,500
	Ready-mix Concrete	Ready-mix Concrete	55,000
Fuel	Wholesale	Fuel	
	Trade	Markup	6,750
	Motor Freight	Fuel Shipping	6,750
TOTAL			\$9,976,000

TABLE 28

MODEL FORECASTS OF REGIONAL INCOME AND EMPLOYMENT INCREASES FROM CONSTRUCTION
OF WOOD-FIRED POWER PLANT

Annual Expenditures:	Labor	\$9,895,000
	Lumber	5,000
	Concrete slab	7,500
	Ready-mix concrete	55,000
	Wholesale trade	6,750
	Shipping	6,750
		<hr/>
		\$9,976,000

Industry	New Income ^a	New Employment ^a
Farms	\$ 242,000	9.8
Agricultural services	14,600	0.6
Nonmetallic mineral mining & quarrying	8,290	0.2
Contract construction	43,600	1.1
Food & kindred products	475,000	9.2
Textile mill products	111,000	3.1
Apparel & fabricated textile products	280,000	5.1
Lumber & wood products, exc. furniture	23,500	0.5
Furniture & fixtures	24,300	0.8
Printing, publishing, & allied products	37,600	1.5
Chemicals and allied products	67,500	1.3
Rubber and misc. plastic products	14,600	0.1
Stone, clay, & glass products	69,000	2.0
Fabricated metals products	4,230	0.1
Machinery exc. electrical	2,170	0.0
Electrical machinery	3,490	0.1
Misc manufacturing	30,200	0.8
Motor freight trans. & warehousing	96,500	2.9
Air transportation	4,170	0.1
Trans services, incl. carrier affiliates	2	0.0
Communications	161,000	3.6
Public utilities	279,000	3.8
Wholesale trade	438,000	23.4
Retail trade	1,470,000	92.7
Banking	97,700	4.1
Credit agencies & holding & invest. Co.	9,050	0.8
Security & commodity brokers	5,580	0.3
Insurance carriers, incl. solicitors	217,000	8.2
Insurance carriers, brokers and services	50,300	2.6
Real estate and combinations	261,000	0.5
Lodging places	36,200	2.3
Personal & misc. repair services	163,000	8.3
Misc. business services	19,400	1.5
Auto repair & services	155,000	4.6
Motion pictures	8,350	0.4
Amusement & recreation services	20,200	1.4

TABLE 28 (Continued)

Industry	New Income ^a	New Employment ^a
Medical & other health services	353,000	24.9
Legal and misc professional services	56,200	3.9
Private educational services	175,000	11.9
Households	11,600,000	5.5
TOTAL	17,100,000	244.0

^aIncome estimates are rounded to three significant figures; employment estimates are rounded to the nearest tenth. Estimates should be considered upper bounds to actual increases.

households includes the \$9,895,000 of original construction wages, plus \$1,705,000 - all wages paid to the workers hired as an indirect result of the original expenditures. These are workers hired by regional industries because the industries themselves are receiving some new income, either directly or indirectly, from the construction project. In the case of an industry like farming, which does not receive direct expenditures from the construction project, all new income is received indirectly.

The income figures in Table 28 show income beyond that normally received. For example, if the plant is built, the lumber and wood products industry gains about \$23,500 over its income from normal business.

The income figures can be interpreted as output and sales. To get its extra \$242,000 of income, the farming industry must produce and sell that dollar amount worth of extra crops; the lumber and wood products industry must produce and sell an extra \$23,500 worth of output to earn its bonus, and so on. The total of the new incomes can therefore be interpreted as the total increase in gross regional product brought about by the construction project in the study region.

Employment: The estimates under "New Employment" in Table 28 can be misleading. Consider the banking industry. Its new income is listed as \$97,700. The 4.1 after that in the "New Employment" column means simply that surveys of bank financial statements and employment records show the average bank to have a little over four employees for each \$97,700 of gross income. Therefore, the best guess is that when the region's banking industry experiences an increase in income of this amount, it will hire four new employees. The lumber and wood products industry, in contrast, will receive only about half the new income that it typically must receive before a new employee is hired. This is evidenced by the 0.5 entered as its new employment. Such fractional new employment estimates are best interpreted as effectively zero new employment in the industry. In the case of households, "New Employment" means workers hired by households (gardeners, servants). The work done by the members of households to get their new income is considered the product, not the employment, of the households industry. The employment of individuals is counted under the industry that hires them, not under households.

The total of the new employment in all industries, about 244, includes only the employment created indirectly by the construction project. Because their income was treated as an original expenditure (to households), the 500 or so construction workers are not counted as new employment in Table 28.

The impact of the plant's construction in northern Vermont is primarily the result of new consumer spending, according to the forecasts in Table 28. Because the construction expenditures made in the region go predominantly to labor, the households sector experiences the greatest increase in income. The next greatest beneficiaries are the industries in which households make their major purchases. In order of decreasing importance after households, the industries registering the greatest new incomes are retail trade, food and kindred products, wholesale trade, medical services, apparel and textile products, public utilities, real estate, farms, and insurance carriers.

In absolute numbers, the retail trade industry experiences the greatest expansion, hiring about 93 new workers. But it is already a large sector. Department of Commerce data for 1973 put the number of retail sales employees in the three counties of the study region at 5,313.¹¹ Setting it at 6,000, by subjective extrapolation, for the starting year of plant construction, the additional 93 jobs mean an increase in retail employment of only 1.6 percent.

Estimates of new income and employment for the "Lodging Places" industry are probably much too low in the I-O results. Because it assumes that all households spend new income in the same "average" way, the I-O analysis neglects the differences in lifestyle of different people. Many of the construction workers for the plant project are likely to relocate temporarily nearer the site in apartments, boarding houses, and hotels. This should lead to significant increases in the income and employment of the lodging industry that are not shown in the results. Considerations of dynamic economic adjustment that might affect the forecasts presented in Table 28 are discussed in the next section.

The new employment estimates yield some idea of the effect of plant construction on regional employment. Indirectly, the construction expenditures would create about 244 regional jobs. Working on the construction project will be another 248 workers earning \$4.65 million a year, plus \$5.25 million annually in subcontracted labor. There are no independent estimates of the number of workers employed by subcontractors. By assuming that the wage/worker ratio is the same for both subcontracted and contracted labor, we estimated that subcontracts will provide 280 jobs. This brings total new employment in the area to 280 (subcontracted) plus 248 (contracted) plus 244 (indirect), or 772 workers.

The question of where the new employees come from is critical. If workers migrate into the study region to fill these new jobs, the number of unemployed there will not fall, though the number of employed will rise. At the very least, the project supervisors are bound to be brought in from outside. To estimate the maximum reasonable effect of the construction project on regional unemployment, assume that 772 new jobs go to regional residents. Statistics of the Vermont Department of Employment Security set the average number of unemployed people in the Lamoille, St. Johnsbury, and Barre-Montpelier labor areas in 1976 at 4,702, and the total civilian labor force at

50,683.¹² Thus, the regional unemployment rate for 1976 averaged 9.3%. Hiring 772 people in the region in new jobs would bring the unemployment rate down to 7.8%.¹³

It must be remembered that these are maximum impact figures. Especially if the plant is built on the edge of the study region, many of the newly created jobs are likely to go to people outside the region who commute or move into the region, not to the currently unemployed within the region. Also, for reasons more thoroughly discussed in the following section, it may be that not all of the 244 indirect jobs estimated by the I-O analysis will actually be created.

Considerations of Economic Adjustment

Three important dynamic considerations neglected in the I-O estimates are the migration of people into the study region, the delays involved in the process of regional economic expansion, and the policies used by firms to expand their output. Immigration could cause both the regional employment to change and the distribution of new income to differ from the I-O forecasts. A result of the delays in expansion is that the construction project will not achieve its peak impact until well after the start of construction. Also, the methods used by firms to expand could cause the peak to be lower than estimated.

The new jobs created by the plant construction project should attract some workers into the region. This would reduce the project's impact on unemployment below levels forecast in the study. Further, new residents would need housing and this would cause sales in the regional construction and supporting industries to increase. To the extent that the construction project causes immigration, the forecasted unemployment level of 7.8% is probably low as are the forecasts of new income and employment in construction-related industries shown in Table 28.

The construction project impact outlined in Table 28 is supposed to apply to the study region for the entire two-year period of construction. But the changes involved would not be instantaneous in the real economy. Construction laborers would receive their first pay checks and gradually spend them. Regional businesses would then experience a rise in sales, increasing as the multiplier effect worked itself out and businesses began buying more from one another. For a highly flexible industry like insurance sales, adjustments could be made quickly. When insurance carriers begin selling more policies, they can hire more clerks, and even open new offices in a short time. In contrast, a farmer might not be able to increase his output for more than a year after he realized his sales prospects had gone up. Furthermore, new farms take years to establish. Especially in industries like farming and other capital- and land-intensive businesses, the short-run effects of increased demand are likely to be shortages, higher prices, and increased imports. Only after a delay can most businesses expand their output. As a result, the actual peak of the business expansion may not come until over a year after the beginning of construction.

For these reasons, regional businesses may not expand to the full extent predicted by the I-O forecasts. The first reaction of most businesses to an increase in sales is to utilize existing equipment and labor more intensively. Business people will avoid major permanent expansions such as constructing new

buildings and entering long-term contracts with new employees, especially if the increase in sales is thought to be temporary. Businesses selling directly to the construction project or its workers are especially liable to realize that their good fortune is temporary, and thus take easily reversible measures to increase output. The effect of such actions would be to reduce somewhat the multiplier effect of the construction expenditures, cutting down the indirectly-derived new income and new employment.

Noneconomic Problems Arising from the Construction Project

The construction contractors interviewed identified three characteristics of a large construction project that can stimulate community dissatisfaction: temporary facilities, construction noise, and the uneven distribution of wealth.

For large projects in rural areas, temporary living quarters sometimes have to be erected near the site for workers who need to relocate in the area but who cannot find other housing. The temporary housing may be an eyesore, and the concentration of residences may cause traffic and sewage problems. Our sources agreed, however, that for the particular project proposed this is not likely to be a great problem.¹⁴ The primary plant sites considered in the High report are all populated densely enough to allow construction workers to live within commuting distance.¹⁵ Those who do not can generally find spots in existing apartments, hotels, or boarding houses.

Noise is sometimes a nuisance to neighbors of a construction project. However, according to a study sponsored by the U.S. Environmental Protection Agency, the volume of noise from construction equipment drops fairly rapidly over distance and through barriers.¹⁶ The plant would be built on a large plot of cleared land, according to most plans. It would not likely be placed very near a large urban area, so it should be quite distant from any high concentration of residences or working places. Noise should not be a significant problem.

The expenditures of a construction project often boost the incomes of some local businesspeople greatly, but scarcely reach others. This can cause jealousy among citizens. This is a difficult problem to assess, and there is no good solution for it. For a project of the magnitude considered here, it could be a real problem, but probably not great enough to merit special concern.

In general, the construction project studied here is too small to cause much public dissatisfaction.

OPERATION PHASE FORECASTS

The operation of a WFPP, in comparison to its construction, will have a smaller, more diffuse, and longer lasting effect on the surrounding region. Primary plant expenditures will still be for labor, but the amount spent annually will drop significantly from spending levels during construction. Of special interest, therefore, is the impact of the transition between the two periods, as well as the impact of the WFPP's operation itself.

Estimates of Operation Phase Expenditures

Estimated expenditures and I-O forecasts were made for three categories of activity in the plant's operation: operation activities, wood harvesting, and wood transportation. However, expenditures for wood harvesting and transportation will vary with the wood procurement technology used. There are two reasonable procedures for chipping and transporting wood for a WFPP. For each of these two procedures, various capital-labor mixes could be used.

The scheme employed by many large paper mills uses concentration yards. With this approach, harvesters deliver roundwood to two or three receiving sites. At these receiving sites, or concentration yards, the roundwood is stockpiled; then it is chipped and shipped to the plant by rail as required. The alternative scheme is on-site chipping. According to this plan, the trees harvested are chipped in the field and the chips are loaded immediately into semitrailers. The trucks convey the chips to the plant for storage and eventual burning.

With either of these two chipping and transporting schemes, the wood can be harvested in a variety of ways. The most capital-intensive procedure uses a feller-buncher (a machine that scissers through trees at the base and stacks them together on the ground) and skidders or forwarders to bring the trees to the loading site. Another technique, involving less capital and more labor, employs a harvesting crew with a pair of chain saws in place of the feller-buncher. There are also operations that use tractors or horses instead of skidders.

To calculate the I-O expenditure figures, we used data for an on-site chipping operation that harvests with chain saws; on-site chipping was chosen primarily because better data is available from such operations. However, an on-site chipping operation and a concentration yard operation can both be expected to have about the same costs. Both perform the same functions with similar machinery and labor, but differ in the sequence of their operations. It also happens that the industrial classification scheme into which the READ I-O data are arranged includes both truck and rail shipping in the same industry -- motor freight transportation and warehousing. Thus, for the purposes of this I-O analysis, it is unnecessary to differentiate between expenditures made for truck and for rail services. Consequently, our expenditure estimates for wood harvesting and transportation derived from an on-site chipping system can be considered roughly representative of a concentration yard procedure.

Operation activities: The two expenditures of plant operation that would provide income to regional interests are labor and office supplies, the latter because the retail markup would be received by local stores. The plans of Rust Engineering Corporation call for seven plant supervisors earning \$17,500 per year and 25 to 30 other plant workers paid \$12,500 per year each.¹⁷ This means a total annual labor expenditure of about \$472,500: $(7 \times \$17,500) + (28 \times \$12,500)$.

In addition, Rust estimates the plant would require about \$50,000 in supplies annually. Much or all of this would probably be purchased from local retail outlets, which can be expected to retain as much as 40% of that amount in the form of their retail markup.¹⁸ Thus, \$20,000 in retail trade was included in the set of regional operation activities expenditures.

Wood harvesting: The Vermont Governor's Task Force Report¹⁹ and several foresters and harvesters were used as a source of data on wood harvesting. Especially helpful was Chester McLain, who runs an on-site chipping crew in Vermont and New Hampshire of approximately the same configuration considered here.

To calculate the labor costs of wood harvesting, average salary and number of workers must be estimated. Salaries vary, but harvesters earn about \$300 per work week in New England.²⁰ The number of workers needed depends in part on certain limitations on harvesting time: crews can harvest only about 48 to 50 weeks per year because of bad weather; they can harvest only a little over four days per week because it is necessary to devote some time to equipment maintenance²¹ (McLain 1977; Kroplin 1977). Our calculations for the number of crews required to supply a 50-MW WFPP (16.7), the total number of harvesters (116.9), and the total annual harvester payroll (\$1,753,500) are shown in Table 29.

Harvesting crews typically must pay a stumpage fee to the owner of the land from which they take wood. In Vermont, the stumpage fee is generally about \$1 per ton of green wood removed.²² Therefore, the wood harvesters for the WFPP should pay about \$800,000 to regional landowners (based on figures from Sherwood & Meadows).²³ In northern Vermont, the landowners are predominantly private individuals, so this \$800,000 can be treated as an expenditure to households. The stumpage fees paid to landowners living outside the study region should not be included in this figure. But the total of these fees is highly uncertain. Thus, to obtain estimates giving the greatest impact, we assumed that all fee recipients were local residents.

The final relevant expenditure of the wood harvesting operation is the purchase of diesel fuel, for which the wholesale and transportation markups are retained by local merchants. The only report of fuel consumption for a complete harvesting crew was provided by McLain.²⁴ His seven-man crew with chain saws, skidders, a whole-tree chipper, and a tractor uses 1,000 gallons of diesel per work-week. Therefore, the 16.7 crews working 50 weeks per year use 835,000 gallons of diesel each year. With the wholesale and transportation markups for a gallon of diesel fuel at \$0.02 each, this sets the payments of the wood harvesters to regional wholesalers for providing fuel at about \$16,700 per year. Payments to truckers for transporting the fuel would be the same.

Wood transportation. A WFPP could use one of two systems to haul wood from the harvest areas to the plant: hire a private trucking firm, or purchase its own trucks and run its own operation. To obtain the maximum impact on the area, we assumed the plant would choose the latter. There are no firms in the three-county region that sell tractor-trailer rigs, so these expenditures will be made outside the area in any case. However, there are new construction and labor expenses in the second system that are not reflected if a private trucker is contracted. For example, the plant, in starting up a trucking operation, will have to build a maintenance shed and hire people to run it. Also, we assume that the WFPP will hire truckers who are not currently employed, rather than diverting already employed workers.

TABLE 29

CALCULATIONS FOR NUMBER OF WOOD HARVESTERS AND TOTAL ANNUAL PAYROLL REQUIRED
FOR THE OPERATION OF A WOOD-FIRED POWER PLANT

Number of Crews Required

$$\frac{(F/R) \times H}{(D \times K)} = \frac{(800,000/225) \times 8}{(34 \times 50)} = 16.7 \text{ crews}$$

- F = Total wood fuel required by the plant annually - 800,000 green tons of chips^a
 R = Harvesting rate of a seven-man crew - 225 green tons of chips per day^b
 F/R = Crew-days of harvesting required per year
 H = Hours in crew's work day - 8
 (F/R) x H = Crew-hours of harvesting required per year
 D = Hours per week a crew devotes to harvesting - 34^c
 K = Harvesting work weeks per year - 50
 (D x K) = Hours per year a crew devotes to harvesting

Number of Wood Harvesters

$$\text{No. of crews} \times \text{workers/crew} = 16.7 \times 7 = 116.9 \text{ harvesters}$$

Total Annual Harvester Payroll

$$\begin{aligned} \text{No. of harvesters} \times \text{average weekly pay} \times \text{harvesting work weeks/year} \\ = 116.9 \times \$300 \times 50 = \$1,753,500 \end{aligned}$$

^aBased on Sherwood & Meadows, Note 23.

^bBased on McLain, Note 20.

^cBased on McLain, Note 20, and Kroplin, Note 21.

On the basis of Adler et al.,²⁵ we estimate that the 32 truck drivers necessary to run the fleet will receive \$640,000 in wages each year. Currier²⁶ and Berwick²⁷ estimate that the maintenance operation will require four mechanics and one secretary-bookkeeper. The salary requirements of these workers will be about \$200 and \$150 per week respectively, totaling \$49,400 [(\$10,400 x 4) + \$7,800]. Annual labor expenditures will therefore be \$689,400.

To compute the cost of building the maintenance shed, we inputted into the model only those products manufactured in the region (as in the calculations for the construction phase of the plant). The products are lumber, concrete slab, and ready-mix concrete. Currier and Berwick estimated that 55 of the construction materials cost (totaling about \$30,000) will go to lumber, and about 20% each to concrete slab and ready-mix concrete. The amounts are therefore estimated at \$1,500, \$6,000, and \$6,000, respectively.

Adler et al. estimated the total annual fuel cost of the 32-truck fleet at \$160,000.²⁸ On the basis of our previous assumptions, 5% of the wholesale price of diesel fuel is the wholesaler's markup, and 5% goes to the company that ships it. Therefore, fuel expenditures are set at \$8,000 and \$8,000.

A summary of the estimates of the annual regional expenditures for the operation of the WFPP is provided in Table 30. The total annual expense is \$3,798,300.

Forecasts of New Income and Employment

The I-0 forecasts for the economic impact of operation activities, wood harvesting, and wood transportation in the WFPP's operation phase are listed in Tables 31 through 33. Separate forecasts for each subactivity are provided because the magnitude of their impacts will be different and will be spread out through the region. The business expansion resulting from plant operation expenditures should be concentrated near the plant site, while the effects of the harvesting should be diffused throughout the woodland communities. The effects of the trucking should be divided among the towns in which the trucking operations are based.

As in the construction phase, the major impact of the operations phase on the study region comes from the wage payments to local workers. As a result, the economic profile presented by the I-0 estimates in Tables 31 through 33 suggests an impact similar in pattern to, but smaller in scale than, the impact of the construction expenditures. The strongest effects are on house-

TABLE 30

ANNUAL REGIONAL EXPENDITURES FOR THE OPERATION OF A 50-MW WOOD-FIRED POWER PLANT

	Receiving Industry	Product	Annual Expenditure
Operation Activities	Households	Labor	\$ 472,500
	Retail trade	Markup on office supplies	20,000
Wood Harvesting	Households	Labor	1,753,500
	Households	Stumpage fees	800,000
	Wholesale Trade	Markup on fuel	16,700
	Motor Freight and Warehousing	Transportation of fuel	16,700
Wood Transportation	Households	Labor	689,400
	Sawmills	Lumber	1,500
	Concrete products	Concrete slab	6,000
	Ready-mix concrete	Ready-mix concrete	6,000
	Wholesale trade	Markup on fuel	8,000
	Motor Freight and Warehousing	Transportation of fuel	8,000
TOTAL			\$3,798,300

TABLE 31

MODEL FORECASTS OF REGIONAL INCOME AND EMPLOYMENT INCREASES FROM OPERATION
ACTIVITIES OF WOOD-FIRED POWER PLANT

Annual Expenditures: Labor	\$472,500	
(1977\$) Retail Trade	20,000	
	<u>\$492,500</u>	
Industry	New Income ^a	New Employment ^a
Farms	\$ 12,000	0.5
Agricultural services	729	0.0
Nonmetallic mineral mining & quarrying	72	0.0
Contract construction	2,270	0.1
Food & kindred products	23,300	0.5
Textile mill products	5,480	0.2
Apparel & fabricated textile products	13,700	0.3
Lumber & wood products, exc. furniture	803	0.0
Furniture & fixtures	1,190	0.0
Printing, publishing, & allied products	1,880	0.1
Chemicals and allied products	3,320	0.1
Rubber and misc. plastic products	753	0.0
Stone, clay, & glass products	212	0.0
Fabricated metals products	206	0.0
Machinery exc. electrical	105	0.0
Electrical machinery	173	0.0
Misc. manufacturing	1,470	0.0
Motor freight trans. & warehousing	4,140	0.1
Air transportation	204	0.0
Trans services, incl. carrier affiliates	0	0.0
Communications	8,020	0.2
Public utilities	14,000	0.2
Wholesale trade	21,200	1.1
Retail trade	92,000	5.8
Banking	4,970	0.2
Credit agencies & holding & invest. co.	446	0.0
Security & commodity brokers	275	0.0
Insurance carriers, incl. solicitors	10,700	0.4
Insurance carriers, brokers and services	2,510	0.1
Real estate and combinations	13,400	0.0
Lodging places	1,770	0.1
Personal & misc. repair services	8,080	0.4
Misc. business services	981	0.1
Auto repair & services	7,680	0.2
Motion pictures	409	0.0
Amusement & recreation services	999	0.1
Medical & other health services	17,300	1.2
Legal and misc. professional services	2,880	0.2
Private educational services	8,580	0.6
Households	567,000	0.3
TOTAL	<u>\$855,000</u>	<u>13.1</u>

^aIncome estimates are rounded to three significant figures; employment estimates are rounded to the nearest tenth.

TABLE 32

MODEL FORECASTS OF REGIONAL INCOME AND EMPLOYMENT INCREASES FROM
HARVESTING FOR WOOD-FIRED POWER PLANT

Annual Expenditures: (1977\$)	Labor	\$1,753,500	
	Stumpage Fees	800,000	
	Wholesale Trade	16,700	
	Shipping	16,700	
		<u>\$2,586,900</u>	
Industry	New Income ^a	New Employment ^a	
Farms	\$ 63,000	2.6	
Agricultural services	3,840	0.2	
Nonmetallic mineral mining & quarrying	369	0.0	
Contract construction	11,300	0.3	
Food & kindred products	123,000	2.4	
Textile mill products	28,900	0.8	
Apparel & fabricated textile products	72,700	1.3	
Lumber & wood products, exc. furniture	4,220	0.1	
Furniture & fixtures	6,310	0.2	
Printing, publishing, & allied products	9,800	0.4	
Chemicals and allied products	17,500	0.3	
Rubber and misc. plastic products	3,820	0.0	
Stone, clay, & glass products	1,110	0.0	
Fabricated metals products	1,100	0.0	
Machinery exc electrical	568	0.0	
Electrical machinery	930	0.0	
Misc. manufacturing	7,770	0.2	
Motor freight trans. & warehousing	40,900	1.2	
Air transportation	1,080	0.0	
Trans services, incl. carrier affiliates	5	0.0	
Communications	42,000	0.9	
Public utilities	72,300	1.0	
Wholesale trade	129,000	6.9	
Retail trade	381,000	24.1	
Banking	25,400	1.1	
Credit agencies & holding & invest. co.	2,350	0.2	
Security & commodity brokers	1,450	0.1	
Insurance carriers, incl. solicitors	56,600	2.2	
Insurance carriers, brokers and services	13,100	0.7	
Real estate and combinations	67,900	0.1	
Lodging places	9,370	0.6	
Personal & misc. repair services	42,400	2.2	
Misc. business services	5,010	0.4	
Auto repair & services	40,900	1.2	
Motion pictures	2,160	0.1	
Amusement & recreation services	5,230	0.4	
Medical & other health services	91,400	6.4	
Legal and misc. professional services	14,900	1.0	

TABLE 32 (Continued)

Industry	New Income ^a	New Employment ^a
Private educational services	45,400	3.1
Households	3,010,000	1.4
TOTAL	\$4,450,000	64.0

^aIncome estimates are rounded to three significant figures; employment estimates are rounded to the nearest tenth.

TABLE 33

MODEL FORECASTS OF REGIONAL INCOME AND EMPLOYMENT INCREASES FROM
TRANSPORTATION FOR WOOD-FIRED POWER PLANT

Annual Expenditures:	Labor	\$689,400
(1977\$)	Lumber	1,500
	Concrete slab	6,000
	Ready-mix concrete	6,000
	Wholesale trade	8,000
	Shipping	8,000
		\$718,900

Industry	New Income ^a	New Employment ^a
Farms	\$17,400	0.7
Agricultural services	1,070	0.0
Nonmetallic mineral mining & quarrying	1,060	0.0
Contract construction	3,230	0.1
Food & kindred products	33,900	0.7
Textile mill products	7,970	0.2
Apparel & fabricated textile products	20,000	0.4
Lumber & wood products, exc. furniture	3,400	0.1
Furniture & fixtures	1,730	0.1
Printing, publishing, & allied products	2,710	0.1
Chemicals and allied products	4,830	0.1
Rubber and misc. plastic products	1,060	0.0
Stone, clay, & glass products	13,000	0.4
Fabricated metals products	324	0.0
Machinery exc. electrical	180	0.0
Electrical machinery	262	0.0
Misc manufacturing	2,180	0.1
Motor freight trans. & warehousing	16,000	0.5
Air transportation	297	0.0
Trans services, incl. carrier affiliates	2	0.0
Communications	11,700	0.3
Public utilities	20,000	0.3

TABLE 33 (Continued)

<u>Industry</u>	<u>New Income^a</u>	<u>New Employment^a</u>
Wholesale trade	39,200	2.1
Retail trade	105,000	6.6
Banking	7,070	0.3
Credit agencies & holding & invest. co.	646	0.1
Security & commodity brokers	400	0.0
Insurance carriers, incl. solicitors	15,700	0.6
Insurance carriers, brokers and services	3,670	0.2
Real estate and combinations	19,000	0.0
Lodging places	2,570	0.2
Personal & misc. repair services	11,600	0.6
Misc. business services	1,500	0.1
Auto repair & services	11,500	0.3
Motion pictures	593	0.0
Amusement & recreation services	1,430	0.1
Medical & other health services	25,100	1.8
Legal and misc. professional services	4,250	0.3
Private educational services	12,400	0.8
Households	823,000	0.4
TOTAL	\$1,250,000	18.4

^aIncome estimates are rounded to three significant figures; employment estimates are rounded to the nearest tenth.

holds and retail trade, but they are only about one-third to one-half as great as in the construction phase forecasts.

To estimate the impact of the operation of the plant on regional unemployment, we assumed the same base employment figures for the study region used for the construction phase estimates, or about 4,702 unemployed of a labor force of 50,683 in the Lamoille, St. Johnsbury, and Barre-Montpelier areas. This estimate deliberately omits the employment gained by the construction phase.

Table 34 shows the total number of new jobs created by the WFPP's operation. The 96 indirectly created jobs are the sum of new employment from Tables 31 through 33. The bottom total shows the distribution of the jobs across industries, for comparison with Table 28. Counting the number of jobs created directly (189), the total number of unemployed should come down to 4,417 and the regional unemployment rate should drop from 9.3 to 8.7 percent.

Economic Adjustment During the Transition Phase

The primary economic adjustment problem in the region is a shift from the inflated level of business activity during the intensive construction effort to the lower level during the plant's operation. In general, the problem is greatest in those industries that experience the largest increases in income and employment as a result of the construction project. However, not all industries and communities will experience a uniform decline in income and

TABLE 34

TOTAL INCREASE IN REGIONAL EMPLOYMENT FROM OPERATION
OF A WOOD-FIRED POWER PLANT

<u>Direct Employment</u>	<u>Number of Jobs</u>
Operation activities	35
Wood harvesting	117
Truckers	32
Maintenance shed	5
	<hr/>
	189
 <u>Indirect Employment*</u>	
Operation	13.1
Harvesting	64.0
Transportation	18.4
	<hr/>
	95.5 (96)
 Total Employment	 285
 *Indirect employment ¹ in:	
Retail trade	36.5
Wholesale trade	10.1
Medical & other health services	9.4
Other	39.5
	<hr/>
	95.5

¹From Tables 31 through 33.

employment during the transition period. Theoretically, some industries not favored by construction spending could experience a small boom, while those favored previously will decline either precipitously or slowly.

In absolute numbers, the most strongly affected industry (after households) is retail trade, with a drop in income of \$892,000 and a drop in employment of about 56 workers, according to the I-0 forecasts. As pointed out earlier, however, the retail trade industry is the largest in the region (not counting households), and can more readily accommodate a pulse in its sales. In fact, if local businessmen realize that the increased business they experience during plant construction is temporary, they can minimize the ill effects of the subsequent loss of business by avoiding the temptation to make large, permanent expansions that might later leave them with excess capacity. During the construction period, this would mean a slightly reduced expansion for the regional economy. However, at the end of the period, it would result in a smoother, less wasteful adjustment to the lower level of business.

The shift in the distribution of the multiplier effect during the transition should not be great, because in both phases most of the original expenditure money goes to households, which always spend their income in the same patterns (according to I-0 assumptions). The operation phase expenditures are lower so that business falls off generally (the level of new income drops roughly 50 to 60%), but no particular industry should experience severely sharp or mild business reductions.

The probable exceptions to this are the lodging and the construction industries. As mentioned earlier, many construction workers are likely to live temporarily near the construction site in apartments, boarding houses, and hotels. In fact, the increased income and employment of the lodging industry is likely to be much higher than the I-0 forecasts for the construction phase indicate, because the forecasts do not take into consideration the special circumstances of the construction workers. When the project is over, the construction workers will leave their temporary lodgings. The recipients of the wages paid for the plant and harvesting operations will probably already have homes or apartments, and so be much less inclined to rent rooms. Thus, the drop in business should be sharper for the lodging industry than for regional industry generally.

The disproportionately rapid decline in the business of the construction industry could produce a serious unemployment problem. With completion of the plant's construction, about 520 workers employed directly and through subcontracts will be laid off. Construction companies interviewed generally agreed that unemployment is not usually a serious problem at the end of a construction project because the workers know when their jobs will end and prepare for it.²⁹ However, it is still likely that at the beginning of the operation phase there will be many temporarily unemployed construction workers, raising the regional unemployment rate above the base 9.3 percent level assumed at the beginning of the operation phase.

The probable shift in the location of economic impact will be as important as the change in the sectors benefiting from the expenditures. During construction, the impact of the expenditures should be concentrated in the communities near the plant site. During operation, the expenditures should be spread throughout the harvesting region. Thus, the economy of the community immediately around the plant should be especially hard hit by the halt of construction, while outlying areas might even experience a small business increase.

The problem presented by the slowdown of construction and the beginning of operation is one of preparation. If local merchants and producers foresee the inevitable shift in business, they can avoid steps that will commit them to high levels of production and ultimately prove wasteful. Some business decline, leading eventually to a partial loss of newly gained employment, seems inevitable, however.

Conclusions

The economic impact of constructing and operating a 50-MW WFPP in three northern Vermont counties will be primarily the result of the money paid in wages to individuals. These expenditures, along with those for construction

materials, fuel, office supplies, harvesting fees, and transportation of fuel, will circulate through the regional economy to produce new annual income almost twice the amount of the original plant expenditures. For the construction phase (about two years), the plant's \$9,976,000 annual expenditure will produce about \$17,100,000 in new income annually; during operation (about 20 to 30 years), a \$3,795,300 yearly expenditure will create \$6,555,000 in income regionally.

This income will result in the creation of new jobs in the area -- about 244 during construction and 96 during operation. Counting those workers hired directly by the WFPP, the total jobs created will be about 772 during construction and 285 during operation. With little immigration of workers, these levels should be sufficient to lower regional unemployment by about one-half of one percent.

The adverse socioeconomic effects of the plant on the surrounding region should be minor. The most serious problem is the drop in business and employment for merchants and workers in communities near the site when plant construction ends. However, if institutions and individuals are well informed of the construction schedule of the WFPP, they should be able to protect themselves.

NOTES TO CHAPTER VII

1. This assumes the WFPP is not a private cogenerating (i.e., producing both steam and electricity) facility.
2. For a more complete and technical description of the methods the READ uses to construct its I-O data, see Appendix C.
3. Social and Economic Statistics Administration, County Business Patterns 1971: Vermont, VERMONT CBP-72-47, U.S. Department of Commerce, Washington, DC (1972).
4. C. High, "Evaluation of Locations for a 50-MW Wood-Fired Power Plant in Northern Vermont," DSD #115, Thayer School of Engineering, Dartmouth College, Hanover, NH (1978).
5. Wheelabrator Cleanfuel Corporation, "Proposal for Advanced System Demonstration for Utilization of Biomass as an Energy Source," submitted to the U.S. Energy Research and Development Administration in response to ERDA RFP No. EG-77-R-06-1036, WCC, Washington, DC (1977).
6. C. Bliss and D. O. Blake, "Silvicultural Biomass Farms: Vol. V: Conversion Processes and Costs," MITRE Technical Report No. 7347, Vol. V, MITRE Corporation, METREK Division, Washington, DC (1977).
7. See McKee-Berger-Mansueto, Inc., Building Cost File: 1975 Unit Prices, New York: Construction Publishing Co., 1974; and Frank R. Walker Company, The Building Estimator's Reference Book, Chicago: F. R. Walker Co., 1973.
8. S. B. Milligan, Project Manager, Rust Engineering Company, Birmingham, AL, personal communication (1977).
9. Wheelabrator, op. cit.
10. Bradford Oil and Gas Co., Bradford, VT, personal communication (1977).
11. Social and Economic Statistics Administration, op. cit.
12. Vermont Department of Employment Security, Area Supplement to Annual Planning Report, Montpelier, VT (1977).
13. Together, these three labor areas comprise all of the study region, part of Essex County, and most of Orange County. Department of Employment Security statistics are not collected by county, so they could not be tabulated for the precise study region.
14. Mr. Morrissey, Wright and Morrissey Construction Co., Burlington, VT, personal communication (1977).
15. High, op. cit.

NOTES TO CHAPTER VII (Continued)

16. Bolt, Beranek, and Newman, "Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances," prepared for the U.S. Environmental Protection Agency under contract 68-04-0047, BBN, Arlington, VA (1971).
17. Mulligan, op. cit.
18. J. Cartwright, Regional Economic Analysis Division, U.S. Bureau of Economic Analysis, Washington, DC, personal communication (1977).
19. S. Lloyd et al., Governor's Task Force on Wood as a Source of Energy, report to the Governor of the State of Vermont, Montpelier, VT (1975).
20. Personal communication with C. McLain, chipping contractor, Guildhall, VT., and C. Laferrier, Ward Lumber Co., Waterbury, VT.
21. B. Kroplin, Brown Paper Co., Berlin, NH, personal communication (1977).
22. Lloyd, op. cit., p. 30.
23. L. Sherwood and D. Meadows, The Fuel Requirements of a 50-MW Wood-fired Electrical Generating Facility in Northern Vermont, DSD #106, Thayer School of Engineering, Dartmouth College, Hanover, NH (1978).
24. Personal communication.
25. T. Adler, M. Blakey, and T. Meyer, The Direct and Indirect Costs of Transporting Wood Chips to Supply a Wood-fired Power Plant, DSD #103-1, Thayer School of Engineering, Dartmouth College, Hanover, NH (1978).
26. Mr. Currier, Currier Trucking Co., Gorham, NH, personal communication (1978).
27. Mr. Berwick, Berwick and Sons (barrel truckers), Plainfield, NH, personal communication (1978).
28. Adler et al., op. cit.
29. Morrissey, op. cit.

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APPENDIX A

WOOD RESOURCES AND GROWTH RATES

References:

- FS USDA Forest Service Bulletin NE-26.¹
YB 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., merchantable bole, for the State of Maine (FS). To convert these data to biomass estimates, as given in Table 21, we have assumed:

1. that wood has an average density of 30 lbs. (oven dry) per cubic foot;
2. that 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 one-quarter inch rule;
3. that 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, Young's data should be adjusted 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 35 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 noncommercial trees make up the remainder.

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

TABLE 35

TIMBER RESOURCES IN MAINE

	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 +	2.2×10^7 +	0.8×10^7 +	9.6×10^7 +
Growing stock	16×10^7 +	12×10^7 +	4×10^7 +	32×10^7 +
Cull				6×10^7 +
Biomass/area	62t/acre	48t/acre	18t/acre	38t/acre
Biomass	33×10^7 +	23×10^7 +	8×10^7 +	64×10^7 +

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

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

TABLE 36

GROWTH RATES FOR TIMBER IN MAINE
(in meters/year)

	FROM: Sawtimber	Poletimber	Saplings & Miscellaneous	Cull trees	All Sources (=net growth)
T0:					
Sawtimber	0.8	2.6	0	0	3.4
Poletimber	0	0.5	7.5	0	8.0
Growing Stock	0.8	3.1	7.5	0	11.8
Cull	1.0	1.0	0.6	2.4	5.0
Dead	0.6	1.4	2.5	0.6	5.1
Harvest	4.2	0.9	1.0	0.2	6.3

^acull increment of saplings, etc. = 1/2% per year.

^bmortality of saplings, etc. = 1% per year

^cingrowth of cull = 4% per year.

^dMortality of cull = 1% per year.

All data are averages for 1958-1970, computed from [FS] except as noted.

Masses are for oven dry wood; Mt = 10^6 t.

Mercantable bole only; multiply by 1.43 to estimate above ground mass.

NOTES TO APPENDIX A

1. R. H. Ferguson and N. P. Kingsley, "The Timber Resources of Maine," USDA Forest Service Bulletin NE-26, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania, 1972.
2. H. E. Young, "Biomass Sampling Techniques for Puckerbrush Stands," in: Forest Biomass Studies, IUFRO Working Group on Forest Biomass, Section 25, p. 179-190 (1971), (Available from the Complete Tree Institute, University of Maine at Orono).
3. H. E. Young, L. Hoar, and T. C. Tryon, "A Forest Biomass Inventory of Some Public Land in Maine," in: Oslo Biomass Studies, p. 1-10, (Available from the Complete Tree Institute, University of Maine at Orono).
4. C. W. Clark, "Mathematical Bioeconomics: The Optimal Management of Renewable Resources," J. Wiley & Sons, New York, 1976.

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APPENDIX B

ESTIMATES OF HEATING SYSTEMS COSTS

The estimates given in this appendix and summarized in Table 24 and 25 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 Btu per year in energy delivered to the living areas.¹ More thorough insulation, as 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 and will determine the total fuel cost.

The heating system must keep the house even on 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, this 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°F. If we suppose that the lowest outside temperature is -35°F, the maximum temperature difference is 100°F, about 3.5 times the average. The maximum heat loss is then also 3.5 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% interest, 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 initial cost. The effective annual payment after taxes is therefore 0.125 times the initial 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 24 take into account not only the energy lost in the combustion process but also lost in delivering heat to the house.²

The systems compared in Table 24 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, 170; 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/lw capacity, the other 25,000 Btu/lw (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 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 units³ 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 63% of that is for space heating, 12% 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 also be about 5×10^8 Btu/yr.

As in the case of single-family dwellings, the maximum heating demand will be about 3.5 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 probable 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 but less than \$6000.⁶ As a reasonable intermediate estimate for such a heating unit, we shall use \$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. Thus the appropriate estimated costs are:

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 the way in which depreciation and other costs are accounted; tax liabilities will also vary considerably from case to case. However, since we are interested in a comparison of the costs of several equivalent systems, a crude estimate will suffice. So we 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 may more or less cancel each other. The annual cost averages 0.158 (or about 16%) times the price of an item.

NOTES TO APPENDIX B

1. R. Daifuku, "Residential Space Heating and Cooling in New England, 1972-2000," BNL #50614, Brookhaven National Laboratory, Upton, New York, December 1976.
2. See BNL #50614, Brookhaven National Laboratory; J. Shelton (part I) and A. B. Shapiro (parts II & III), The Woodburner's Encyclopedia (Vermont Crossroads Press, Waitsfield, Vermont, 1976; R. C. Hill, personal communication: University of Maine at Orono, 1977; R. C. Hill, "The Integration of Wood Heating and Solar Collection - the Maine Audubon Building," in: Wood Heating Seminar 1, Wood Energy Institute, Waitsfield, Vermont, 1977; and J. G. Riley, "Development of Automatic Wood Burning Equipment," in: Wood Heating Seminar 1, Wood Energy Institute, Waitsfield, Vermont, 1977.
3. S. E. Nydick, "A Study of Inplant Electric Power Generation in The Chemical, Petroleum Refining, and Paper Industries," (1976), Thermoelectron Corporation, Waltham, Massachusetts, #TE5429-97-76 and Zerbe et al., "The Feasibility of Utilizing Forest Residues for Energy and Chemicals," #PB-258 630 (March 1976), prepared by the USDA-Forest Service for the NSF, (available from NTIS, Springfield, Virginia).
4. J. Lee, "Future Residential and Commercial Energy Demand in the Northeast," BNL #50552, Brookhaven National Laboratory, Upton, New York, March 1976 and R. Daifuku, op. cit.
5. J. G. Riley, op. cit.
6. J. G. Riley and N. Smith, "Solar Energy Utilization by Photosynthetic Production," American Society of Agricultural Engineers, Saint Joseph, Missouri, 1977.

APPENDIX C

DOCUMENTATION OF INPUT-OUTPUT DATA*

For any county or group of counties in the United States, the Regional Economic Analysis Division (READ) of the U.S. Bureau of Economic Analysis is equipped to calculate complete data for a regional input-output (I-O) analysis, including: 1) the equivalent of a regional direct requirements matrix, 2) the equivalent of a regional Leontief inverse matrix, and 3) the data necessary to calculate industrial employment multipliers. This appendix describes these data and the methods the READ uses to calculate them.

Section 1 of this appendix presents the concepts and terms of general I-O theory referred to in subsequent sections. Section 2 discusses the historical development of the READ data system. Section 3 explains the concept of the location quotient, which lets the reader understand Section 4. Section 4 contains the technical details of the construction of the first two READ data sets, which fall under the category of expenditure multipliers; Section 5 does the same for the third data set, the employment multiplier data.

1. Notes on Input-Output

The basic equation of input-output theory is:

$$\bar{y} + A\bar{x} = \bar{x}.$$

- $\bar{y}$ is an n-entry vector whose *i*th entry is the total dollar final demand for the output of industry *i*. Final demand is usually defined as purchases of goods and services for consumption, for investment, or by the government or foreign parties.
- A is an $n \times n$ matrix called the direct requirements matrix. Its *ij*th entry is the dollar value of all of the output of industry *i* that industry *j* needs to produce one dollar's worth of its own output.
- $\bar{x}$ is an n-entry vector whose *i*th entry is the total dollar output of industry *i*.

The final demands for production within an economy ($\bar{y}$) and the economy's interindustry structure (A) are both measurable. With their values and the equation, the output of each industry necessary to yield some specified final demand can be calculated ($\bar{x}$). The desired $\bar{x}$ is calculated as follows:

$$\bar{y} + A\bar{x} = \bar{x}$$

$$\bar{y} = \bar{x} - A\bar{x}$$

$$\bar{y} = (1 - A)\bar{x}$$

$$(1 - A)^{-1}\bar{y} = \bar{x}.$$

*This appendix is extracted from P. VanderWerf "Appendices to DSD#90, "The Regional Employment and Income Effects of a 50 MW Wood-Fired Power Plant," Report DSD 122, Thayer School of Engineering, Dartmouth College, August 1978.

The matrix $(1 - A)^{-1}$ is sometimes called the Leontief inverse matrix. It can be calculated from the A matrix without additional data; with the set of final demands ($\bar{y}$) and no other data, the Leontief inverse matrix can be used to calculate the output of every industry in the region characterized by the A matrix and the y vector.

Changes in industrial output resulting from changes in final demand can be computed as easily. The final equation for this is:

$$(1 - A)^{-1} \Delta \bar{y} = \Delta \bar{x}.$$

The ijth entry of a Leontief inverse matrix is equal to the dollar increase in the output of industry i that results from a one-dollar increase in the output of industry j. Thus, the sum of all entries in column j is equal to the dollar increase in total industrial output resulting from an increase of one dollar in the output of industry j. The sum of all entries in column j of an $(1 - A)^{-1}$ matrix is an industrial multiplier for industry j in the regional economy under consideration; if the final demand for the output of industry j is increased by \$k and the sum of the jth column of the $(1 - A)^{-1}$ matrix for the region is m_j , the total increase in industrial output in the region should be $\$(k \times m_j)$.

By assuming that employment is directly proportional to output within any one industry, it is possible to convert the output calculations from an I-O analysis to employment estimates. The basic equations are:

$$\bar{x} \times \bar{r} = e$$

$$x_i \times r_i = e_i.$$

- $\bar{x}$ is the output vector described above. x_i is its ith entry.
- $\bar{r}$ is an n-entry vector whose ith entry (r_i) is the observed ratio of employees to dollar output within industry i. r_i is sometimes called the employment multiplier of industry i.
- e is the number of workers required to produce the outputs listed in vector $\bar{x}$, or the total employment in the region.
- e_i is the number of workers required to produce the output of industry i (x_i), or the total employment of industry i in the region.

It follows from the direct proportionality assumption that changes in employment can be calculated from changes in output as follows:

$$\Delta \bar{x} \times \bar{r} = \Delta e$$

$$\Delta x_i \times r_i = \Delta e_i.$$

For a more thorough background in input-output and its use in the estimation of regional multiplier effects, refer to Elliot-Jones (1971) and Richardson (1972).

2. The Regional and Industrial Multiplier System

Between 1974-1976, the READ developed a method of estimating industrial

multipliers called the Regional Industrial Multiplier System (RIMS). The RIMS method is faster and cheaper than constructing an entire A matrix for the study region, taking its Leontief inverse, and adding up the entries in each column. In particular, the RIMS method does not compute a Leontief inverse matrix; industrial multipliers are estimated from A matrix coefficients with regression equations.¹ The disadvantage of the original RIMS multipliers is that they are not broken down by affected industry; the user knows only that k dollars of output from industry j leads to a total increase in regional industrial output of $k \times m_j$ dollars but cannot tell how much of this output increase occurs in any one industry, something that could be calculated with a complete Leontief inverse matrix.

In 1977, the READ developed a method for disaggregating its RIMS multipliers by affected industry. One such disaggregated multiplier is the equivalent of a single column of a Leontief inverse matrix: the user knows that k dollars of output from industry j lead to an increase of $k \times m_{1j}$ dollars in the output of industry 1, an increase of $k \times m_{2j}$ dollars in the output of industry 2, and so on for each industry in the region. The m_{ij} here represent the coefficients of the disaggregated multiplier for industry j. Obviously, with a complete set of such disaggregated RIMS multipliers, a user can make any calculations that could be made with a Leontief inverse matrix.

In the process of constructing these disaggregated industrial multipliers, or $(1 - A)^{-1}$ matrix columns, the READ also constructed direct requirements multipliers, or A matrix columns. Currently, the READ is equipped to supply for any county or collection of counties in the United States the following sets of data:

- 1) A disaggregated direct requirements multiplier vector for each industry (according to the RIMS four-digit industry classification scheme) of the region.² Each multiplier is then disaggregated into up to 57 coefficients, one for each industry (according to the RIMS alternative two-digit scheme) of the region. Each multiplier is the equivalent of one column of a direct requirements (or A) matrix; taken together, the multipliers form the equivalent of an A matrix of order $(m \times n)$, where m is the number of separate industries in the region according to the RIMS two-digit classification scheme, and n is the number of industries in the region according to the RIMS four-digit classification scheme.
- 2) A disaggregated industrial multiplier for each (four-digit) industry of the region. Each multiplier is then disaggregated into up to 57 coefficients, one for each industry of the RIMS two-digit scheme. Each multiplier is the equivalent of one column of a Leontief inverse $[(1 - A)^{-1}]$ matrix; taken together, the multipliers form the equivalent of a $(1 - A)^{-1}$ matrix of order $(m \times n)$, where m and n are as described above.
- 3) An employment-earnings ratio for each of the 57 industries of the RIMS two-digit classification scheme. Used together selected coefficients of the direct requirements

multipliers described in 1) above, an employment multiplier for each of the 57 industries can be calculated (see Section 5).

3. Location Quotients

To construct its direct requirements and disaggregated industrial multipliers (see Section 4), the READ must calculate a set of location quotients for the study region. The standard READ I-O data include no location quotients explicitly; location quotients are explained here as background for Section 4.

Location quotients are measures of the degree to which a region produces the industrial output it needs. A single location quotient is calculated for a single industry within a specific region. The general formula for the location quotient of industry i in region j is:

$$LQ_{ij} = \frac{Q_{ij} \sum_{k=1}^n Q_{kj}}{Q_{ic} \sum_{k=1}^m Q_{kc}}$$

Q_{ij} is the total dollar output of all firms within industry i located in region j .

$\sum_{k=1}^n Q_{kj}$ is the sum of the dollar outputs of all industries in region j , or the total industrial output of region j .

Q_{ic} is the total dollar output of all firms within industry i located in the country that contains region j .

$\sum_{k=1}^m Q_{kc}$ is the total industrial output of the country that contains region j .

The numerator of the location quotient is the fraction of regional output produced by industry i ; the denominator is the fraction of national output produced by industry i .

Location quotients are often used in problems for which it is necessary to estimate the self-sufficiency of a region. If $LQ_{ij} \geq 1$, the output of industry i comprises a larger share of the total industrial output of region j than of the total national output. It is therefore assumed that region j produces at least as much of the output of industry i as it requires. The fraction of national output produced by industry i ($Q_{ic} / \sum_{k=1}^m Q_{kc}$) is thus interpreted as the fraction of total output that industry i must produce in a region to supply 100% of the regional demand for its output. If $LQ_{ij} < 1$, it is assumed that the firms of industry i in region j supply only the fraction LQ_{ij} of the output of the industry i that the consumers and firms of region j need; the remaining $(1 - LQ_{ij})$ of it is assumed to be imported from outside the region.

It is often too difficult to get the output data necessary to calculate location quotients, so some substitute for output must be used. The substitute is another quantity that is almost directly proportional to output, such as employment or earnings. Earnings is defined as total payments to labor, including employees and proprietors. It is used to calculate a location quotient as follows³:

$$\frac{E_{ij} \sum_{k=1}^n E_{kj}}{E_{ic} \sum_{k=1}^n E_{kc}} .$$

E_{ij} is the total earnings of all firms within industry i located in region j .

$\sum_{k=1}^n E_{kj}$ is the sum of the earnings of all industries in region j , or the total industrial earnings of region j .

E_{ic} is the total earnings of all firms within industry i located in the country that contains region j .

$\sum_{k=1}^m E_{kc}$ is the total industrial earnings of the country that contains region j .

4. Expenditure Multipliers

The final output of the READ matrix calculations is not in the form of matrices, though it is the equivalent of two input-output matrices. It is a set of direct requirements and industrial multipliers disaggregated by receiving industry. The multipliers for each separate industry in the study region are listed on a separate page of computer output. One page of output, that for the construction industry in the three-county Vermont region I used as a study area in this report, is reproduced in Table 37. The label at the top shows that the construction industry is 1500 in the RIMS four-digit classification scheme. The affected industries, with their two-digit labels, are in the left-hand column.

The column labeled "Direct Component" is the direct requirements multiplier of the construction industry in this region; the column labeled "Total Multiplier" is the corresponding industrial multiplier. The middle column, labeled "Indirect-Induced Component," is, with the exception of the row labeled "Contract Construction," the difference between the other two columns. The i th entry of this column is meant to be interpreted as the indirect dollar increases in the output of industry i that result from a one-dollar increase in the output of the contract construction industry; it does not include the value of the industry i output purchased by the contract construction industry to produce the extra dollar's worth of its own output (the corresponding entry of the "Direct Component" column), which is considered "direct." The "Indirect-Induced" coefficients are not necessary for an I-O analysis.

As mentioned previously, the direct requirements and industrial multipliers can be viewed either as disaggregated multipliers or as columns of the

TABLE 37

READ OUTPUT FOR CONSTRUCTION INDUSTRY IN THREE NORTHERN VERMONT COUNTIES

Regional Industrial Multiplier System--Lamoille, Caledonia, Washington County,
1500-construction.

SIC	Industry Name	Elements of		
		Direct Component	Indirect- Induced Component	Total Multiplier
01	Farms	0.0008	0.0132	0.0140
07	Agricultural services	0.0016	0.0010	0.0026
14	Nonmetallic mineral mining and quarrying	0.0092	0.0028	0.0120
15-17	Contract construction	0.0003	0.0030	1.0041
20	Food and kindred products	0.0000	0.0212	0.0212
22	Textile mill products	0.0002	0.0069	0.0071
23	Apparel and other fabricated textile products	0.0005	0.0129	0.0134
24	Lumber and wood products, exc furniture	0.0320	0.0121	0.0441
25	Furniture and fixtures	0.0028	0.0011	0.0038
27	Printing, publishing and allied products	0.0000	0.0020	0.0020
28	Chemicals and allied products	0.0000	0.0033	0.0033
30	Rubber and miscellaneous plastic products	0.0056	0.0013	0.0069
32	Stone, clay and glass products	0.0385	0.0018	0.0403
34	Fabricated metals products	0.0109	0.0007	0.0116
35	Machinery except electrical	0.0000	0.0004	0.0004
36	Electrical machinery	0.0011	0.0004	0.0015
39	Miscellaneous manufacturing	0.0004	0.0016	0.0020
42	Motor freight transportation and warehousing	0.0151	0.0083	0.0234
45	Air transportation	0.0000	0.0002	0.0002
47	Transportation services, incl. carrier affiliates	0.0000	0.0000	0.0000
48	Communications	0.0033	0.0092	0.0125
49	Public utilities	0.0006	0.0146	0.0153
50	Wholesale trade	0.0290	0.0225	0.0515
52-59	Retail trade	0.0416	0.0654	0.1069
60	Banking	0.0023	0.0056	0.0079
61+67	Credit agencies and holding and investment companies	0.0000	0.0004	0.0004
62	Security and commodity brokers, dealers and services	0.0000	0.0003	0.0004
63	Insurance carriers, incl. solicitors	0.0039	0.0109	0.0149
64	Insurance agents, brokers and services	0.0000	0.0042	0.0042

TABLE 37 (Continued)

SIC	Industry Name	Elements of		
		Direct Component	Indirect-Induced Component	Total Multiplier
65+66	Real estate and combinations	0.0032	0.0156	0.0187
70	Lodging places	0.0000	0.0016	0.0016
72+76	Personal and miscellaneous repair services	0.0000	0.0076	0.0076
73	Miscellaneous business services	0.0051	0.0020	0.0071
75	Auto repair and services	0.0041	0.0089	0.0130
78	Motion pictures	0.0000	0.0004	0.0004
79	Amusement and recreation services, excl motion picts	0.0000	0.0009	0.0009
80	Medical and other health services	0.0000	0.0152	0.0152
81+89	Legal and miscellaneous professional services	0.0283	0.0057	0.0340
82	Private educational services	0.0000	0.0075	0.0075
	Households	0.2790	0.1803	0.4593
	TOTAL	0.5195	0.4741	1.9936

Source: Regional Economic Analysis Division, Bureau of Economic Analysis, U.S. Department of Commerce.

A and $(1 - A)^{-1}$ matrices, respectively. The READ actually calculates them by first constructing complete A and $(1 - A)^{-1}$ matrices for the relevant region, then adjusting the coefficients of each column of the $(1 - A)^{-1}$ matrix with the traditional RIMS multiplier (see Section 2) for the industry corresponding to that column. These adjusted columns are the disaggregated industrial multipliers supplied by the READ to clients.

The purpose of adjusting the matrix columns rather than using them directly is accuracy. READ statisticians believe that, as a measure of total regional multiplier effects, the RIMS multipliers are more accurate than the sum of the entries of a column of their regional Leontief inverse matrices. However, as a measure of the distribution of these effects among industries, the Leontief inverse is as accurate as possible with limited resources. By rescaling the Leontief inverse coefficients, statisticians hope to derive a set of industrial multipliers that have the best features of both data sources. After the adjustment process is complete, the aggregate multiplier effect implicit in each multiplier, i.e., the sum of its coefficients, is equal to the RIMS multiplier for the same industry. But rather than being simply aggregate industrial multipliers, the final READ multipliers are broken down by receiving industry so that the coefficients are in the same proportion to one another as are the entries of the corresponding column in the Leontief inverse matrix. An understanding of the exact methods of calculation of the READ multipliers clarifies these properties.

The calculation of the READ multipliers can be divided into 13 distinct steps. These are explained in detail below, and are summarized at the end of this section for reference.

Step 1: Rather than construct regional output tables from primary data, the READ begins with the Bureau of Economic Analysis' (BEA) national input-output table and adjusts it according to regional data, as outlined in later steps. The BEA national input-output table used is a 478 x 478 direct requirements (or A) matrix for the region of the entire United States developed with 1967 data. The industrial classification scheme used in the matrix is identical to what is called the RIMS four-digit scheme in this appendix.

Step 2: The rows and columns of industries that do not exist in the study region are deleted. If no firms of a particular industry exist in the study region, there are no regional firms that produce and sell the output of that industry or buy the goods and services necessary to produce such output. Therefore, the regional sales of such an industry (its row in the matrix) and its regional purchases (its column in the matrix) must be removed from the national A matrix.

Step 3: For each remaining industry in the matrix, each entry of the matrix row corresponding to that industry is multiplied by the location quotient for that industry in the study region if this location quotient is less than one. The location quotients are calculated with the earnings data collected for each county in the United States by the Social Security Administration. These data are collected for each industry only according to the RIMS two-digit classification scheme. Therefore, different rows must be multiplied by the same location quotient: if industries i, j, and k are distinct according to the four-digit scheme but grouped together within the same two-digit industry, the entries of rows i, j, and k are each multiplied by the location quotient for the two-digit industry, assuming that the location quotient is less than one.

The rationale behind rescaling rows of the matrix with location quotients is as follows. Entry a_{ij} is supposed to be the dollar sales of the regional firms within industry i to the regional firms within industry j for each dollar's worth of output of the regional firms of industry j. But, before adjustment, it shows this quantity for national firms within the respective industries. In reality, the regional i-firms may not be able to supply the region with as much i-type output as it needs: the location quotient, LQ_i , of industry i in the region may be less than one. If this is the case, it is assumed that only the fraction LQ_i of the output that regional j-firms need comes from regional i-firms, and so the ij th entry of the matrix should be changed to $LQ_i \times a_{ij}$. If LQ_i is greater than or equal to one, no adjustment of the entries of row i is made.

At this point, the READ has an acceptable regional A matrix. However, it is extremely large; of the 478 industries in the original U.S. matrix, 200 or more may be left. To calculate $(1 - A)^{-1}$ with an A matrix this large is expensive and time-consuming with the best of computer techniques. Therefore, the READ uses a method of calculating the columns of the $(1 - A)^{-1}$ matrix about 50 at a time in a much smaller A matrix. This method is outlined in Steps 4 through 9. As noted in Step 11, the process is repeated for sets of

about 50 industries until all of the (four-digit) industries in the regional matrix as it stands at this point have had $(1 - A)^{-1}$ columns calculated for them. The final $(1 - A)^{-1}$ columns have only one entry for each two-digit industry in the region, not each four-digit industry.

Step 4: Approximately 50 industries in the A matrix are selected, and their rows and columns are removed from the matrix. These are the industries whose $(1 - A)^{-1}$ columns will be calculated first. For reference, assume that exactly 50 industries are selected.

Step 5: In the remaining A matrix, the rows of four-digit industries within the same two-digit industry are added together. If industries i, j, and k are all in the same industry according to the two-digit scheme, entries a_{i1} , a_{j1} , and a_{k1} are replaced by the single entry $(a_{i1} + a_{j1} + a_{k1})$. The same goes for a_{i2} , a_{j2} , and a_{k2} , and so on across the rows. This collapses the matrix into a rectangular shape, with more columns than rows. The significance of any entry is still the same; if the ijth entry is a_{ij} , the regional firms of (four-digit) industry j use, for each dollar's worth of their output, a_{ij} dollars' worth of the output of regional firms of (two-digit) industry i.

Assume for reference that the deletions of four-digit industries in Steps 2 and 4 leave at least one four-digit industry within each of the 57 two-digit industries of the RIMS classification scheme. This means that the A matrix at this point is $57 \times n$, where n is the number of four-digit industries in the region minus the 50 removed from the matrix in Step 4:

$$\begin{array}{c} 57 \boxed{\text{A matrix}} \\ n \end{array}$$

Step 6: The n columns of the matrix are aggregated into 57 columns to make the matrix square:

$$\begin{array}{c} \boxed{\text{A matrix}} \\ 57 \end{array}$$

It would be theoretically incorrect to add the columns as the rows were added; a weighted average of the columns must be taken. If industries i, j, and k are within the same two-digit industry, their pth row entries are replaced by the single number given by the expression:

$$a_{pi} \frac{e_i}{e_i + e_j + e_k} + a_{pj} \frac{e_j}{e_i + e_j + e_k} + a_{pk} \frac{e_k}{e_i + e_j + e_k}$$

where e_i , e_j , and e_k are the employment of i-firms, j-firms, and k-firms, respectively, within the study region, as measured by the Department of Commerce in County Business Patterns. Employment serves in a proxy for output this expression as.

The significance of the ij th entry of the new matrix is still the same: for each dollar of their output, the regional firms of (two-digit) industry i use, on the average, a_{ij} dollars' worth of the output of the regional firms of (two-digit) industry j .

Step 7: The current 57×57 A matrix is combined with the columns and rows of the 50 industries removed from the matrix in Step 4 to form a 107×107 A matrix:

	57	50
57	I	III
50	IV	II

The upper left of the new matrix, labeled I in the diagram above, is the 57×57 A matrix completed in Step 6. Section II, in the lower right, is made up of the coefficients representing sales between the 50 four-digit industries as they were at the end of Step 3. Section III is made up of the coefficients representing sales to the 50 four-digit industries as they were at the end of Step 3, summed up by row as in Step 5. Section IV is made up of the coefficients representing sales to the 50 four-digit industries to the remaining regional four-digit industries as they were at the end of Step 3, averaged by column as in Step 6. This new matrix -- call it A_1 -- is a direct requirements (A) matrix for the 107 industries of the region, 57 of which are classified according to a very aggregated scheme, and 50 according to a finer scheme.

Step 8: The upper right-hand section of the A_1 matrix is copied as the final set of direct requirements multipliers. For each of the 50 four-digit industries in the matrix as it now stands, one column of Section III tells how much the industry buys from each two-digit industry in the region for one dollar of its own output. These columns are then the desired direct requirements multipliers for the 50 four-digit industries. They are ready to be printed out as "Direct Component" columns on the data pages of the 50 four-digit industries, one of which is shown in Table 37.

Step 9: The Leontief inverse of the A_1 matrix is calculated. A computer is used to calculate $(1 - A)^{-1}$.

Step 10: The upper right-hand section of the $(1 - A_1)^{-1}$ matrix is saved as the final set of Leontief inverse columns. The $(1 - A_1)^{-1}$ matrix has the same shape as the A_1 matrix:

$$(1 - A_1)^{-1} = \begin{array}{|c|c|} \hline \text{I} & \text{III} \\ \hline \text{IV} & \text{II} \\ \hline \end{array}$$

The columns of Section III are saved. After adjustment (see Step 12), they will be the industrial multipliers, or "Total Component" columns in the data printouts, for the 50 four-digit industries.

Step 11: Steps 4 through 10 are repeated with a different set of selected industries (see Step 4) until each industry has been selected exactly once.

At this point, there is one direct requirements multiplier, or direct requirements matrix, column and one industrial multiplier, or Leontief inverse column for each four-digit industry in the study region. Each column has 57 coefficients, one for each of the 57 two-digit industries in the region.

Step 12: Each industrial multiplier is rescaled with a RIMS multiplier. The i th coefficient of the multiplier for industry j is recalculated as follows.

$$a'_{ij} = m_j \frac{a_{ij}}{\sum_{k=1}^{57} a_{kj}} \quad (1)$$

a'_{ij} is the new value of the i th coefficient of the multiplier for industry j .

a_{ij} is the old value of the i th coefficient of the multiplier for industry j .

m_j is the RIMS multiplier for industry j in the study region.

$\sum_{k=1}^{57} a_{kj}$ is the sum of the coefficients of the old industrial multiplier for industry j .

Obviously, the new entries of a disaggregated multiplier must total the corresponding RIMS multiplier:

$$\sum_{k=1}^{57} a'_{kj} = \sum_{i=1}^{57} m_j \frac{a_{ij}}{\sum_{k=1}^{57} a_{kj}} = m_j \frac{\sum_{i=1}^{57} a_{ij}}{\sum_{k=1}^{57} a_{kj}} = m_j \quad (2)$$

But also, any one coefficient of the new multiplier will be the same fraction of the sum of the coefficients of the new multiplier as its old counterpart was of the sum of the old multiplier coefficients:

$$\frac{a'_{ij}}{\sum_{k=1}^{57} a'_{kj}} = \frac{m_j \frac{a_{ij}}{\sum_{k=1}^{57} a_{kj}}}{\sum_{i=1}^{57} m_j \frac{a_{ij}}{\sum_{k=1}^{57} a_{kj}}} = \frac{\frac{m_j}{\sum_{k=1}^{57} a_{kj}} a_{ij}}{\left(\sum_{i=1}^{57} a_{ij} \right) \left(\frac{m_j}{\sum_{k=1}^{57} a_{kj}} \right)} = \frac{a_{ij}}{\sum_{i=1}^{57} a_{ij}} \quad (1)$$

$$\frac{a_{ij}}{\sum_{k=1}^{57} a_{kj}} = \frac{m_j \frac{a_{ij}}{\sum_{k=1}^{57} a_{kj}}}{\sum_{i=1}^{57} m_j \frac{a_{ij}}{\sum_{k=1}^{57} a_{kj}}} = \frac{\frac{m_j}{\sum_{k=1}^{57} a_{kj}} a_{ij}}{\left(\sum_{i=1}^{57} a_{ij} \right) \left(\frac{m_j}{\sum_{k=1}^{57} a_{kj}} \right)} = \frac{a_{ij}}{\sum_{i=1}^{57} a_{ij}} \quad (2)$$

Step 13: The "Indirect Component" column for each four-digit industry is calculated. The i th coefficient of the column for industry j is calculated as follows:

$$c_{ij} = n_{ij} - d_{ij} .$$

c_{ij} is the i th "Indirect Component" coefficient of industry j .

n_{ij} is the i th industrial multiplier ("Total Component") coefficient of industry j .

d_{ij} is the i th direct requirements ("Direct Component") coefficient of industry j .

The one exception to this formula in each "Indirect Component" column is the coefficient that corresponds to industry j itself -- the coefficient c_{kj} , where k is the number of the two-digit industry that contains the four-digit industry j . The coefficient is calculated as follows.

$$c_{kj} = n_{kj} - 1 - d_{kj} .$$

The extra 1 subtracted out represents the original dollar increase in the output of industry j , the dollar increase whose effects the coefficients of column j measure. That dollar is included in the industrial multiplier coefficient because it represents an increase in the sales of industry j ; it is not included in the direct requirements coefficient because it does not come from a purchase made by industry j , nor in the "Indirect Component" coefficient because it does not come to industry j through indirect channels of spending.

This completes the calculation of READ expenditure multipliers, such as those shown in Table 37. The "Direct Component" column is the disaggregated direct requirements multiplier (saved in Step 8); the "Total Multiplier" column is the final version of the disaggregated industrial multiplier (completed at the end of Step 12). There are only 40 rows of coefficients because the study region for which they were calculated lacks any firms in 17 two-digit industries. The coefficients of these industries were therefore removed from the A matrix in Step 2.

In summary, the expenditure multipliers are constructed in the following sequence of steps:

Step 1: The BEA national A matrix is taken.

Step 2: The rows and columns of industries that do not exist in the study region are deleted.

Step 3: The coefficients of each remaining row of the matrix are multiplied by the location quotient of the industry corresponding to that row whenever the location quotient is less than one.

Step 4: The rows and columns of about 50 industries are removed from the matrix.

Step 5: Rows of the matrix that correspond to industries within the same two-digit classification are added together. At this point, the matrix has a maximum of 57 rows (fewer if the study region lacks firms within any of the 57 two-digit industries).

Step 6: Columns of the matrix that correspond to industries within the same two-digit classification are combined according to a weighted average. At this point the matrix is square.

Step 7: The 50 or so industries removed in Step 4 are replaced into the matrix, with rows added and columns averaged as necessary.

Step 8: The columns of the matrix for the 50 or so four-digit industries are copied as the industries' direct requirements ("Direct Component") multipliers.

Step 9: The Leontief inverse of the matrix is taken.

Step 10: The columns of the Leontief inverse matrix for the 50 or so four-digit industries are saved.

Step 11: Steps 4 through 10 are repeated until a Leontief inverse column is obtained (Step 10) for each four-digit industry in the study region.

Step 12: The coefficients of the Leontief inverse column of each industry are rescaled to total the RIMS multiplier for that industry in the study region. These adjusted columns are the industries' final industrial ("Total Component") multipliers.

Step 13: The difference between each four-digit industry's industrial multiplier and direct requirements multiplier is calculated to obtain its "Indirect Component" coefficients.

5. Employment Multipliers

The employment multiplier of the type that is useful in input-output analysis is defined by the following equation:

$$em_{ij} = \frac{e_{ij}}{i_{ij}} .$$

em_{ij} is the employment multiplier for industry i in region j .

e_{ij} is the total employment of the firms within industry i in region j .

i_{ij} is the total income (dollar value of the output) of the firms within Industry i in region j .

Ideally, the region j for which the employment multipliers are calculated coincides with the study region of the input-output study that uses them.

With its standard set of I-O data for a region, the READ includes enough information to calculate an employment multiplier for each two-digit industry in the region. This information includes: 1) one employment/earnings ratio

for each two-digit industry; 2) a single inflation correction coefficient to adjust the employment-earnings ratios to reflect 1976 wage levels, and 3) a method for calculating one earnings/income ratio for each two-digit industry in the study region from select coefficients of the direct requirements multipliers. These three items can be used to calculate a set of employment multipliers as follows:

$$em_i = \frac{m_i}{1000} \times c \times a_i$$

- em_i is the employment multiplier for industry i .
- m_i is the employment/earnings ratio supplied by the READ; it is the number of employees per \$1000 of earnings in industry i .
- c is the deflator to adjust 1967 data to 1976 wage levels.
- a_i is the earnings/income ratio; it is the dollars of earnings per one dollar of income in industry i .

The employment/earnings ratios used in the analysis of this report, as received from the READ, are listed in Table 38. They are Office of Business Economics-Economics Research Service (OBERS) estimates from state data, in this case, Vermont.⁴ At the discretion of the READ and its client, the employment/earnings ratios it supplies from OBERS data may be estimated from BEA economic area data rather than state data. The inflation correction coefficient is necessary because the OBERS employment/earnings ratios were estimated with 1967 data. Since then these ratios have fallen because salaries have risen (with the same amount of earnings industry will hire fewer workers now than it would have in 1967). According to the READ, industry hired only about 0.62148 as many employees per dollar of earnings in 1976 than it did in 1967. Therefore, to convert the READ employment/earnings ratio to correct 1976 values, they must be multiplied by 0.62148, the inflation correction coefficient.

Earnings/income ratios for each two-digit industry in the study region can be calculated from the direct requirements multipliers supplied by the READ. The household coefficient of an industry's direct requirements multiplier is the dollar amount that the industry pays to households (i.e., employees) for each dollar's worth of output (i.e., industrial income). This number is, therefore, the earnings/income ratio for the industry. However, the household coefficients from the direct requirements multipliers cannot be used directly because of the differences between the classification schemes of the multipliers (four-digit) and the industries to which the employment multipliers are applied (two-digit). One employment/income ratio, and hence one earnings/income ratio, is needed for each two-digit industry. Because there is a direct coefficient multiplier for each four-digit industry, in many cases there are two or more household coefficients applicable to the same two-digit industry. In these cases, the READ recommends taking the simple average of the direct requirements multiplier household coefficients of the four-digit industries classified within the same two-digit industry. These averages serve as the earnings/income ratios of their respective two-digit industries. The earnings/income ratios so calculated in this study are listed in Table 38.

TABLE 38
READ RATIOS USED IN REPORT ANALYSIS

Industry	Employment/ Earnings Ratio ^a (Employees per Thou. Dollars)	Earnings/ Income Ratio ^b (Dollars per Dollar)
Farms	0.1569	0.4415
Agricultural services	0.1569	0.4415
Nonmetallic mineral mining & quarrying	0.1451	0.3112
Contract construction	0.1542	0.279
Food & kindred products	0.1471	0.225
Textile mill products	0.1922	0.2467
Apparel & fabricated textile products	0.2553	0.1226
Lumber & wood products, exc furniture	0.1523	0.2395
Furniture & fixtures	0.1523	0.3471
Printing, publishing, & allied products	0.1408	0.4826
Chemicals and allied products	0.1079	0.2987
Rubber and misc. plastic products	0.1079 ^c	0.1314
Stone, clay & glass products	0.1458 ^c	0.3353
Fabricated metals products	0.1183	0.2807
Machinery exc electrical	0.0976	0.3443
Electrical machinery	0.101	0.4025
Misc. manufacturing	0.1458	0.2975
Motor freight trans. & warehousing	0.1134	0.4523
Air transportation	0.15 ^c	0.3543
Trans. services, incl. carrier affiliates	0.1476	0.6881
Communications	0.1131	0.3346
Public utilities	0.1149	0.2013
Wholesale trade	0.1976	0.4627
Retail trade	0.1976	0.5466
Banking	0.187	0.3854
Credit agencies & holding & invest. co.	0.187	0.8464
Security & commodity brokers	0.187	0.5402
Insurance carriers, incl. solicitors	0.187	0.3471
Insurance carriers, brokers, and services	0.187	0.4653
Real estate and combinations	0.187	0.0166
Lodging places	0.2127	0.5021
Personal & misc. repair services	0.2063	0.4215
Misc. business services	0.1998	0.675
Auto repair & services	0.1998	0.2565
Motion pictures	0.2846	0.2834
Amusement & recreation services	0.2846	0.4066
Medical & other health services	0.181	0.6679
Legal and misc. professional services	0.181	0.65
Private educational services	0.181	0.6398
Households	0.18	0.0061

^aSupplied by READ.

^bCalculated from READ direct requirements multipliers.

^cThe READ employment/earnings ratios list included no ratios for these industries. These estimates are supplied by the author.

NOTES TO APPENDIX C

1. For a full technical discussion, see R. L. Drake, "A Short-Cut to Estimates of Regional Input-Output Multipliers: Methodology and Evaluation," International Regional Science Review 1 (1976), pp. 1-17.
2. The RIMS industry classification scheme, with a few exceptions, is identical to the Department of Commerce SIC code.
3. For a complete discussion, see A. M. Isserman, "The Location Quotient Approach to Estimating Regional Economic Impacts," American Institute of Planning Journal (January 1977), pp. 33-41.
4. OBERS stands for Office of Business Economics-Economic Research Service. The OBE is within the Department of Commerce and the ERS within the Department of Agriculture. Jointly these two offices have made a set of economic and demographic forecasts and estimates published under the name OBERS.