Chapter 2

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Introduction

The use of wood for fuel is at least as old as civilization. Worldwide, wood is still a very important source of energy. The U.N. Food and Agricultural Organization estimates that the total annual world harvest of wood in 1975 was 90 billion ft^3 (about 25 Quads) of which nearly one-half was used directly for fuel. [1] Much of the wood that is processed into other products is available for fuel when the product is discarded from its original use, and indeed large but unknown quantities are used in this manner.

Wood has been a very important fuel in the United States, having been used for home heating and cooking, locomotive fuel, the generation of electricity for home, business, and industrial use, and for the generation of steam for industry. According to Reynolds and Pierson, more than half of the wood harvested from U.S. forests for the 300 years of American history preceding 1940 was used as fuel. [2] Consumption of wood fuel reached its peak in the United States in 1880 when 146 million cords (2.3 Quads) were used according to Panshin, et al.[3] The same authors report that per capita consumption of wood fuel peaked in 1860 at 4.5 cords/yr. During the past 100 years, the direct use of wood for fuel declined in the United States to about 30 million cords/yr (0.5 Quad/yr). It was used primarily as a fuel by the forest products industries, which used manufacturing residues, and for home fireplaces and outdoor cooking, which created demand for charcoal and hardwood roundwood.

There have, however, been periodic revivals of fuelwood use to replace conventional fuels in the United States. They have usually occurred during times of crises, such as World Wars I and 11, when conventional fuels became scarce. After the crises abated fuelwood use dwindled rapidly, even though the reemergence of the same conditions in the near future may have been expected.

During 1917-18, for example, the Eastern United States suffered a shortage of coal. Fuelwood was used whenever possible to replace coal, as were sawdust briquettes and other combustible biomass. Individual towns in New England organized "cutting bees" and "cut a cord" clubs for gathering wood fuel to offset the shortage of coal. Between 1916 and 1917 the price of fuelwood increased by about 20 to 30 percent.

The U.S. Forest Service prepared a publication explaining, among other things, how wood could be used as fuel to conserve coal.[4] It was thought at the time that coal reserves in the United States were dangerously low and that the war-induced shortage of 1917-18 had merely emphasized the inevitable need to conserve them. This publication advocated a broad Government policy for development of a fuelwood industry. The role that cutting fuelwood could play in forest management was considered, and an analysis of the economics of cutting and gathering, etc., was given. The report concluded that a fuelwood industry could be profitable and could benefit the forest in other ways as well. The document was published March 10, 1919, by which time the war had ended, and the Nation's fuel situation was already beginning to return to prewar conditions. There is no evidence that any of the recommendations were followed.

Since World War 11, the major emphasis on wood use has been for lumber and paper pulp. The annual harvest of commercial wood (wood appropriate for the forest products industry) grew by 22 percent between 1952 and 1976. During this same period, the net growth of

[1] *Yearbook of Forest Products 1%4-1975* (Rome: Food and Agriculture Organization of the United Nations, 1977)

[2] R V Reynolds and A. H. Pierson, "Fuelwood Used in the U.S. 16301930, " USDA Cir. 641, 1942

[3] A J Panshin, E. S H arrar, J S Bethel, and W. J. Baker, *Forest Products (New* York: McGraw-Hill, 1962)

[4] USDA Bulletin 753, Forest Service, Mar 10,1919

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commercial wood (total growth of commercial timber less mortality of commercial timber) increased by 56 percent. In only one region in the country, the Pacific Coast, did the inventory of live commercial wood on commercial forestlands decline. In the Pacific Coast region, however, the growth, as a percentage of the standing inventory, is the lowest in the country due to the old age of the timber. Nationwide the inventory of commercial timber increased by 20 percent from 1952 to 1976. Thus, increased harvests of wood do not necessarily imply that the forests are being depleted.

The growth of wood depends not only on the climate and soil type, but also on the type and age of trees and the way the forest is managed. In this chapter, the potential for fuelwood production from the Nation's forests is examined.

Present Forestland

Forestland is defined as land that is at least 10-percent stocked with forest trees or has been in the recent past and is not permanently converted to other uses. The forestlands are divided into two categories: commercial and noncommercial. Commercial forestland is defined as forestland that is capable of producing at least 20 ft^3/acre-yr (0.3 dry ton/acre-yr) of commercial timber in naturally stocked stands and is not withheld from timber production (e.g., parks or wilderness areas). The rest is termed noncommercial.

The forest regions of the United States and the percentage of the total land area of each State that is forestland are shown in figure 1. Currently, there are 740 million acres of forestland in the United States, with about half in the East (i.e., North plus South) and half in the West. About 490 million acres are classified as commercial forestland and nearly three-quarters of this are in the East. The productive potential of commercial forestlands is shown in figure 2.

In addition, there are 205 million acres of noncommercial forestland, which are classified this way because of their low productive potential (i. e., less than 20 ft^3/acre-yr). Practically all of the noncommercial forestland is in the West. Despite the low-productivity classification, however, timber is harvested from many areas of land in this category.

Most of the forestland in the East is privately owned, while about 70 percent of the western forestland is publicly owned and managed by the Federal Government or State and local authorities.

The U.S. Department of Agriculture (USDA) projects that the forestland area will decrease by 3 percent by the year 2030 (about 0.4 million acres/yr or a total of 20 million acres).[5] In the 1980's, a significant portion of the decline will result from conversion to cropland, particularly in the Southeast. USDA projects that in the 1990's, most of the conversion will be to reservoirs, urban areas, highway and airport construction, and surface mining sites.

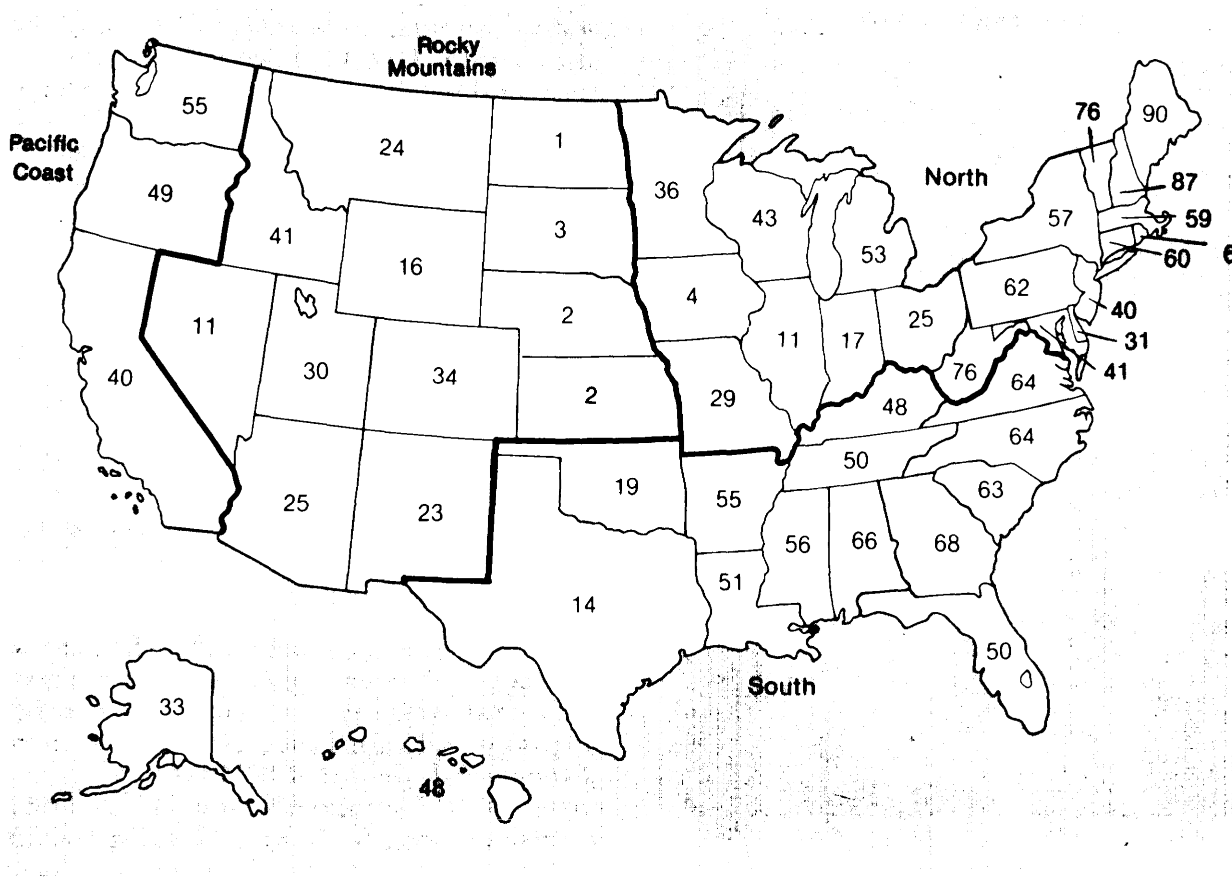
However, about 32 million acres of potential cropland are now classified as forestland (see ch. 3). Consequently, if a strong demand develops for cropland, then the decrease in forest area will be somewhat larger than USDA's projection.

[5] *An Assessment of the Forest and Range Land Situation in the United States,* review draft, USDA Forest Service, 1979

Present Cutting of Wood

Forest wood is currently being cut for four purposes: 1) production of forest products industry roundwood, 2) production of household fuelwood, 3) timber stand improvements, and

Figure 1.— Forestland as a Percentage of Total Land Area



SOURCE Forest Service u S Department of Agriculture

4) clearing of timberland for other uses. Each of these produces wood that can be or is used for energy.

Forest Products Industry Roundwood Harvesting

Currently, the forest products industry is harvesting 200 million dry ton/yr (3.1 Quads/yr) for lumber, plywood, pulp, round mine timber, etc.). During the processing of this wood, 90 million ton/yr of primary and secondary manufacturing wastes are produced. These wastes are discussed later under "Biomass Processing Wastes" in chapter 5.

In addition, the process of harvesting the wood generates considerable logging residue. The logging residue consists of the material left at the logging site after the commercial roundwood is removed. These residues are branches, small trees, rough and rotten wood, tops of harvested trees, etc.

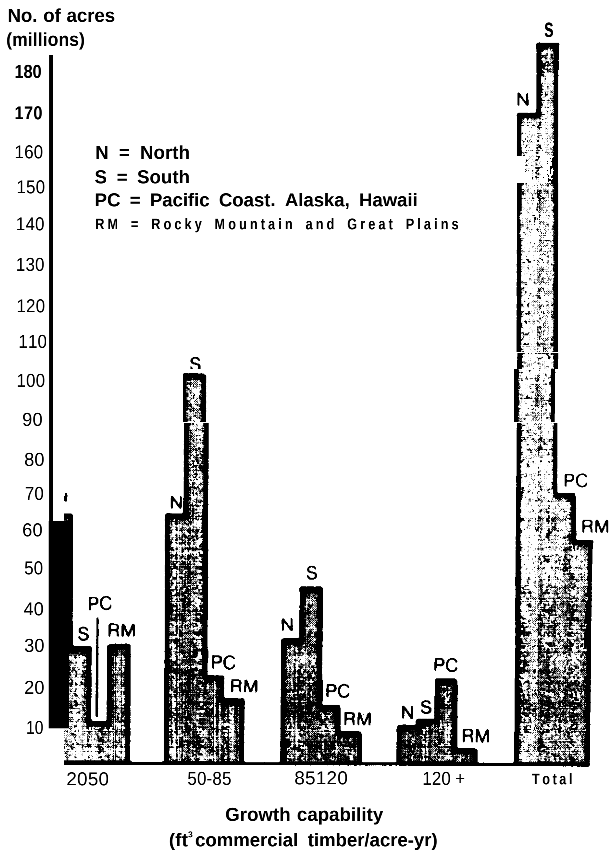
The statistics on logging residues reported for 1970 and 1976 by the Forest Service underestimate the total quantity of residues generated by harvesting activities. The Forest Service data only include wood logging residues from growing stock trees. *

Not reported are:

1. bark — most studies of logging residue present volumes without bark;
2. residues from:
   - nongrowing stock trees on logged-over areas,

'Commercial stock trees that are 1) at least 5-inch diameter at breast height (dbh) and 2) not classified as rough or rotten

Figure 2.—Area of Commercial Timberland by Region and Commercial Growth Capability as of January 1, 1977



SOURCE Data from *Forest Statistics*, 1977, Forest Service, U S Department of Agriculture, 1978

- trees of growing stock species and quality, but less than 5-inch diameter at breast height,
- trees that would be growing stock trees except that they are classified as rough or rotten, and
- trees of noncommercial species;

3. tops and branches; and
4. stumps.

All of these logging residue components, as well as the residue presented in the aforementioned reports, are potentially usable as fuel. *

From various sources' [7,8] and OTA estimates, the ratios of growing stock residues to total biomass residues were derived. [9] Using these ratios and the Forest Service data for growing stock residues, the quantity of logging residues was estimated to be about 84 million dry tons (1.3 Quads) in 1976. The regional breakdown is shown in table 1, and a more detailed breakdown is shown in table 2.

Table 1.–Logging Residues Estimate[a]–Summary
(in million dry tons)

Region	Softwood	Hardwood	Total[b]
North	2.9	13.2	16.0
South	17.6	15.2	32.8
Rocky Mountain	7.0	0.02	7.0
Pacific Coast	27.1	1.1	28.2
Total [b].	54.5	29.5	84.1

[a]From a 1976 harvest of 130 million dry tons of softwood and 54 million dry tons of hardwood
[b]Sums may not agree due to round off error

SOURCE J S Bethel, et al., "Energy From Wood, " College of Forest Resources, University of Washington, Seattle, contractor report to OTA, April 1979.

There is some uncertainty as to whether various logging residue studies are in agreement as to what constitutes nongrowing stock logging residue. Loggers may avoid cutting nongrowing stock trees that hold little or no economic value. This practice would be common in selective logging. In many logging residue studies, it is unclear whether or not such uncut trees were considered residue. Some of the differences observed in logging residue factors reported by various authors in the same region may be due largely to these methodological differences. There is a danger that if uncut nongrowing stock is counted as a logging residue, it might again be counted as part of the biomass that should be removed by various silvicultural stand improvements. Every effort was made to avoid this type of double counting.

*In this report, the stumpwood component is not considered

[6] J O Howard, "Forest Residues– Their Volume, Value and Use, " *Part 2: Volume of Residues From Logging Forest Industries, 98(1 2), 1971*

[7] R L Welch, "Predicting Logging Residues for the Southeast, " USDA Forest Service Research Note SE-263, 1978

[8] J. T Bones, "Residues for Energy in New England," *Northern Logger and Timer Processor* 25(1 2), 1977

[9] J S Bethel, et al , "Energy From Wood, " College of Forest Resources, University of Washington, Seattle, contractor report to OTA, Apni 1979

Table 2.–Logging **Residue Estimates** (thousand dry tons)

	Harvest in 1976	From growing stock: Wood	Bark	Total	From nongrowing stock: Wood	Bark	Total	Tops and branches incl. bark	Total
Softwoods									
North.	**7,448**	823		908	597	64	661	1,323	2,892'
South.	**63031**	3,756	393	4,149	2,697	314	2,993	10,415	17,557
W.Pine	**16,500**	1,548	181	1,729	2,022	236	2,258	*3,000*	6,987
Coast	**43,190**	7,496	876	8,372	8.117	949	9,066	*9,668*	27,106
Total.	130,169	13.623	1,535	15,158	13,433	1,563	14,978	*24,406*	54,542
Hardwoods									
North.	24,546	4,214	313	4,527	1,410	100	1,510	7,147	13,184
South.	27,974	4,984	381	5,275	1,637	123	1,760	8,185	15,220
W.Pine	34	3	—	3	2	—	2	11	16
Coast	1,094	345	36	381	255	27	282	458	1,121
Total	53,648	9,456	*730*	10,186	*3,304*	250	3,554	15,801	29,541

SOURCE J S Bethel, et al, "Energy From Wood, "College of Forest Resources, University of Washington, Seattle, contract or reporf to OTA, April 1979

Household Fuelwood

The harvest of roundwood for use as household fuel was estimated in 1976 to be 657 million ft^3, or approximately 10 million dry tons (0.16 Quad). These figures are similar to the results reported by Ellis, who found that 600 mill ion ft^3 of roundwood, excluding bark, were harvested for fuelwood. '" Allowing a IO-percent increase for bark, this becomes 660 million ft^3. The regional breakdown is shown in table 3. The quantity harvested in more recent years is considerably larger, however, space for the higher quality trees. These cutting activities are generally referred to as stand improvements, and include stand conversions* and thinning operations. Wood from these activities or sources is suitable for fuel.

Table 3.–Fuelwood Harvests in 1976 (in million dry tons)

Region	Softwood	Hardwood	Total[a]
North, ., ...	0.05	3.7	3.8
South	1.3	4.2	5.7
Rocky Mountains	0.43	0.01	0.44
Pacific Coast.	0.33	0.11	0.39
Total	2.3	8.2	10.2

[a]Sums may not agree due to round off errors

SOURCE J S Bethel et al Energy From Wood, ' College of Forest Resources, University of Washington Seattle contractor report toOTA April f979

Stand Improvements

In normal forestry operations, there may be several times during the growth of a stand of trees that malformed, rough, or otherwise undesirable trees are cut to make more growing

The data on the amount of current stand improvement activity are very limited and do not allow a detailed analysis. During the 1968-71 period, various practices, such as precommercial and commercial thinning, species conversion, weed control, and other stand improvements were carried out on a total of 1.4 million acres. This represents only 0.3 percent of the commercial timberland. Generally these practices are carried out irregularly, or on a when- and where-needed basis. Undoubtedly most of the activity is carried out on industry lands where intensive forest management is most advanced. A recent survey of forest industry firms that manage their own lands revealed the current level of these practices. ' These are summarized in table 4.

In addition, there are timber stand improvements (excluding thinnings), species conversion, and weed control items, on about 1.7 million acres of low-quality stands per year. Yields would vary tremendously among these prac-

[10]T H Ellis, "Fuelwood," unpublished manuscript, 1978

*Stand conversion is the practice of eliminating tree species currently occupying a stand and replacing them with other species.

[11]D S DeBell, A P Brunette, and D C Schweitzer, "Expectations From Intensive Culture on Industrial Forest Lands," *J.* For., January 1977

Table 4.–Current and Expected Annual Stand Improvements

Treatment	Percent of Industry lands treated	Estimated acres treated[a]	Percent of firms expecting to maintain or increase level of treatment
Precommercial thinning .,	0.2	135,000	53
Timber stand Improvement, . 1	8	1,212,000	69
Commercial throning ...	25	1,684,000	92
Species conversion	04	269,000	65
Weed control . . .,	0.3	202,000	50

[a]Percent of lands treated times total acreage owned by industry

SOURCE DS DeBell A P Brunette and O C Schweitzer Expectations From Intensive Culture on Industrial Forest Lands *J For* January 1977

tices, but assuming 17 dry ton/acre (as derived by Bethel for rough, rotten, and salvageable trees in the South), this amounts to 29 million dry ton/yr.

Thinnings were also carried out on 1.8 million acres, but there is little information regarding the amounts of residue produced. Yields have been reported of 2.2 dry ton/acre in 4-year-old loblolly pine thinning, [1]2 and 17 to 28 dry ton/acre in pole timber hardwoods in the North. " If a national average of 10 ton/acre is assumed, thinning would provide 18 million dry ton/yr of residue.

"*Si/vicu/ture Biomass Farms* (McLean, Va The MITRE Corp , 1977)

"F E Biltoner, W A Hillstrom, H M Steinhill, and R M Gadmar, USDA Forest Service Research Paper NC-1 37, 1976

Combining these two sources results in 47 million ton/yr (0.7 Quad/yr) of residues from stand improvements.

Clearing of Forestland

Clearing of forest land for other uses can provide a temporary, but potentially significant, local supply of wood. The yield per acre harvested varies widely with the locality. Assuming 30 ton/acre cleared, then USDA projections for forestland clearing would provide about 0.2 Quad/yr to 2030. If the forestland with a high and medium potential for conversion to cropland is all cleared over the next 15 years, then this would provide 1 Quad/yr of wood for these 15 years. Most of this would occur in the Southeast (see ch. 3).

Summary of Current Cutting of Wood

The forest products industry currently harvests about 200 million dry ton/yr (3.1 Quads/yr) of wood for lumber, plywood, paper pulp, and other products. The process generates an additional 84 million ton/yr (1.3 Quads/yr) of logging residues. Another 10 million dry tons (0.2 Quad/yr) are harvested for fuelwood, and about 47 dry ton/yr (0.7 Quad/yr) are cut during stand improvements. This results in a total harvest of about 340 million dry ton/yr or the eqiva lent of 5.3 Quads/yr. Another 0.2 Quad/yr is obtained from clearing and converting forestlands to other uses.

Present Inventory of Forest Biomass

It is not a simple matter to derive the total forest biomass inventory from the Forest Service surveys. As noted earlier, this lack of an adequate" census base stems from the traditional practice of evaluating the wood in a forest only in terms of what is assumed to be merchantable, rather than on a whole-tree or whole-biomass basis. Furthermore, the Forest Service does not survey noncommercial forestlands (about one-third of the total forest area). As a result of this inadequate information base, the present inventory of forest biomass can only be estimated.

Noncommercial Forestland

As mentioned above, of the one-quarter billion acres of noncommercial land, 24 million acres (about 10 percent) are so classified because they are recreation or wilderness areas, or are being studied for these uses. These lands are not included in the inventory of standing timber. Approximately 205 million acres are classified as noncommercial because they are considered incapable of producing as much as 20 ft^3 of commercial wood per acre-year. This criterion, is an arbitrary one, however, and timber is, in fact, harvested from many areas of land in this category. For this reason, the latter category of noncommercial forestlands is included in the inventory of standing timber.

Assuming that these 205 million acres produce an average of 10 ft^3/acre-yr of commercial wood, that they are mature stands (80 years old or more), and that the aboveground biomass is 1.5 times the amount of commercial timber, the inventory of these noncommercial lands is 3.7 billion dry tons (57 Quads).

In addition, 23 million acres, mostly in Alaska, were classified in 1978 as noncommercial because they were considered inaccessible. Assuming a production capability of 35 ft^3/acre-yr and the same assumptions as above, the inventory from these lands is 1.4 billion dry tons (22 Quads).

These two categories result in an inventory on 1978 noncommercial lands of about 5 billion dry tons (80 Quads).

Commercial Forestland

Approximately 488 million acres of forestland are classified by the Forest Service as commercial forestland for purposes of reporting a national forest survey. It is possible to estimate a fuel inventory from commercial forestland, using national forest survey data, with much more precision than was the case for noncommercial lands.

Two options were considered for developing estimates of total biomass on commercial forestland based on the national forest survey. One procedure involved the assumption of multipliers that would convert the basic product inventory data to whole-stem biomass estimates. A second method involved the use of stand tables from the national forest survey and allometric regression equations for estimating biomass for various tree components.[14]

[14]Bethel, op cit

For the purposes of this study, an estimate of total whole-stem biomass for the United States was developed, based on *Forest Statistics for the United States*, 1977.[15] Table 5 shows the result of this analysis for commercial forestland. The details of these computations and more extensive tables are given in OTA's contractor report "Energy From Wood."[16]

Table 5.-Estimated Above-ground Standing Biomass of Timber in U.S. Commercial Forestland
(excluding foliage and stumps, in billion dry tons[a])

Region	Hardwood	Softwood	Total
North .	5.2	1,3	6.5
South . . . : : : : : .,	4.6	2,3	6.9
Rocky Mountains .,	0.2	2 4	2.6
Pacific Coast, .,	06	4 2	4 8
Alaska, ., .,	0.08	1,3	1 4
Total ., . .	10.6	11 5	221

[a]Sums may not agree due to round off errors

SOURCE J S Bethel, et al Energy From Wood College of Forest Resources University of Washington Seattle contractor report to OTA April 1979

Adding commercial and noncommercial land inventories gives 27 billion tons (430 Quads), which is estimated to be the inventory of biomass in U.S. forests, excluding stumps, foliage, and roots and the biomass in parks and wilderness areas, or areas being considered for these uses. *

Quantity Suitable for Stand Improvement

Of the 27 billion tons of standing biomass, some of the wood is of the type that would be removed in stand improvements. This would include brush, rough, rotten, salvageable dead wood, and low-quality hardwood stands occupying former conifer sites. In Alaska, there are roughly 330 million tons of this type of wood.[17] In the rest of the Pacific Coast region, there are 565 million tons, and in the Rocky Mountain region, 324 million tons. The North and South have 822 million and 978 million tons, respec-

[15]*Forest Statistics of the U S . J 977*, USDA Forest Service, review draft

[16]Bethel, op cit

*For the purposes of this report, stumps, roots, and foliage are excluded from whole-stem biomass

[17]Ibid

tively.[18] The total is 3.1 billion tons (49 Quads) of wood that would be appropriate for removal in stand improvements on commercial forestlands. This figure does not include foliage or all of the cuttings that could be used to convert stands of one kind of trees to a more productive type. Consequently, this is a conservative estimate of the biomass available from stand improvements.

[18] Ibid

Present and Potential Growth of Biomass in U.S. Commercial Forests

Current gross annual biomass growth in commercial U.S. forests has been estimated from Forest Service data to be 570 million dry ton/yr, of which 120 million ton/yr are mortality, and 450 million ton/yr net growth. * The usual method of determining the productivity of a particular stand occupying a site is by reference to normal yield tables. These tables are models used to predict growth of active natural stands, and are based on stands of "full" or "normal " stock.

Because of the utilization assumptions built into normal yield tables, however, productivity may consistently be assigned a low, and misleading rating. For example, when the actual growth in 131 Douglas-fir plots scattered throughout western Washington and Oregon was compared with Forest Service Bulletin normal yield tables for Douglas fir, it was found that the yield tables consistently underestimated the actual growth. Actual growth in some age-site combinations was more than double the normal yield table value, and the overall average growth exceeded the yield table by nearly 40 percent.[20] Furthermore, in parts of the Rocky Mountains where Forest Service and industry lands are co-mingled, industry representatives report that measurements of actual growth are two to three times the productivity assigned by normal yield tables" Because of the errors associated with estimating tree types, their number, and their size from normal yield tables, OTA estimates that the actual current biomass growth on commercial forestland is one to two times the values derived from normal yield tables, or 570 million to 1,140 million dry ton/yr (9 to 18 Quads/y r). (See figure 3.)

These estimates do not take into account the productive potential of the forestland. Forest site productivity is estimated on the basis of the vegetation currently occupying the area at the time of the survey. But over 20 million acres of commercial forestland are unstocked, and much more land is stocked with species that are growing more slowly than could be achieved with species better suited to the site. The forest survey indicates that, due to these factors, current growth is about half the growth that could be achieved with full stocking of highly productive tree types (i. e., current growth is estimated by the Forest Service at 38 ft^3/acre-yr while the land capability is estimated by USDA at 74 ft^3/acre-yr). OTA therefore estimates the potential growth to be about two to four times that derived from normal yield tables, or 1.1 billion to 2.3 billion dry ton/yr (18 to 36 Quads/yr) with full stocking of productive tree species on commercial forestland. This corresponds to slightly more than 2 to 4 ton/acre-yr on the average.

Beyond the potential growth with unfertilized timber, studies in the Southeast indicate that fertilizers and genetic hybrids could increase the 'biomass growth by 30 percent.[22] However, not all of the potential growth is physically accessible or economically attractive as discussed below.

[19] H Wahlgren and T Ellis, "Potential Resource Availability With Whole Tree Utilization," *TAPPI*, vol 61, No 11, 1978

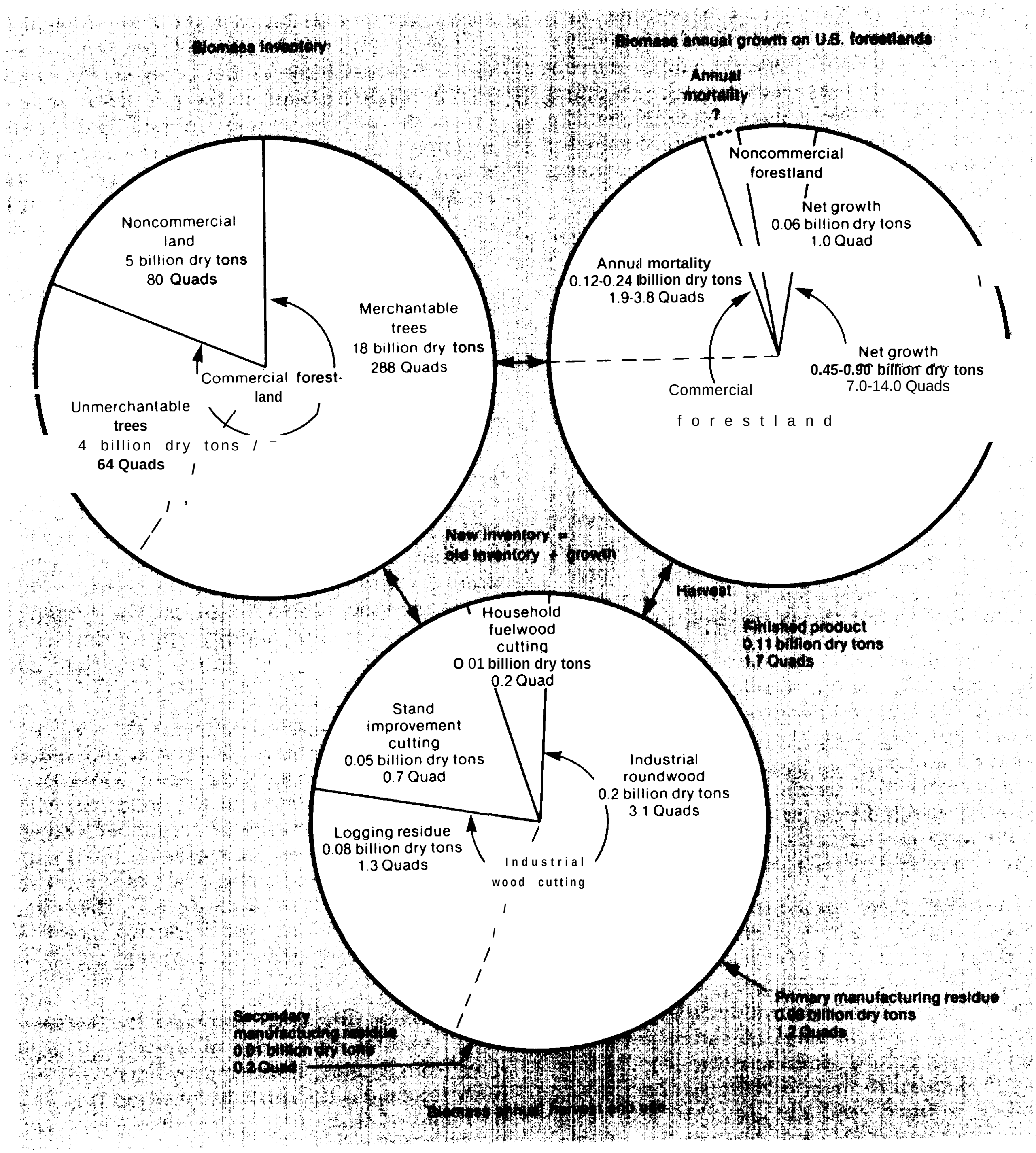
● The 120 million tons of annual mortality are from growing stock trees only Mortality from nongrowing stock trees is not known Under Intensive management, much of the mortality loss could potentially be captured for productive use

[20] Bethel, op cit

[21] Ibid

[22] Ibid

Figure 3.—Forest Biomass Inventory, Growth, and Use (billion dry tons with equivalent values in Quads)



SOURCE Office of Technology Assessment

Forest Biomass Harvesting

Variations on the current harvesting techniques (described below) are likely to be common with fuelwood harvests and stand improvement activities that produce residues suitable for fuel. Nevertheless development of new techniques and equipment designed for fuelwood harvests and stand improvements could lower the cost.

Intensive forest management might typically consist of the following: The stand would be clearcut, and the slash (or logging residue) removed. The stand would then be replanted with the desired trees. After 5 to 20 years the stand would be thinned so as to provide more space for the remaining trees. The stand would then continue to be thinned at about 10-year intervals, by removing diseased, rough, rotten, and otherwise undesirable trees and brush. In very intensively managed stands, the trees might also be pruned to avoid the formation of large knots in the stem of the tree (e.g., for veneer). These periodic thinnings and (possible) prunings would continue until the stand is again clearcut and the entire cycle repeated.

For each operation mentioned above (except the replanting), some woodchips suitable for energy could be made available. The method chosen for harvesting the fuelwood would depend on a number of site-specific factors. The primary objective would be to fell and transport the selected trees or to transport the slash in the most cost-effective manner, while doing a minimum of damage to the remaining stand.

Currently there are four basic methods of logging, each of which is designed to accommodate a number of physical and economic factors peculiar to the logging site. Once the tree is felled: 1) it can be skidded (dragged) to a roadside as a who/e tree, 2) it can be delimbed and the top cut off, and the entire stem or tree length skidded to the roadside, 3) it can be delimbed, topped, and cut (bucked) into long logs which are skidded, or 4) it can be cut into shorter logs or short wood which are skidded. The whole-tree skidding brings out the most biomass. However, if the limbs cannot be used they represent a disposal problem. Also the whole-tree and *tree length* methods tend to do more damage to the timber being skidded and to the residual stand. If there is thick underbrush, the *who/e-tree* method may be difficult or impossible. A weighing of the various factors appropriate to the site being logged results in the method used. If markets for the limbs develop, however, then more *who/e-tree* skidding may be used than is now the case.

Once the wood is at the roadside, it can be cut and loaded or loaded directly into trucks for transport to the mill or conversion site. Alternatively, the wood can be chipped at the roadside with the chips being blown into a van for transport.

Two large-scale harvesting systems considered here are whole-tree harvesting and cable logging. In the whole-tree chip system, the trees are felled by a vehicle called a feller-buncher, which grabs the tree and uses a hydraulic shear to cut the tree at its base. The tree is then lowered to the ground for skidding. This method is most appropriate for relatively flat land and smaller trees (i.e., less than 20-inch diameter).

In the cable logging method, cables are extended from a central tower and the felled trees are dragged to a central point, where they are sorted and skidded to the roadside. This method is used primarily on terrain with steep slopes and large trees. Estimates for the equipment and annual operating costs of these two systems are shown in tables 6 to 9. There are other logging systems, but these two methods are fairly representative of the range of existing systems.

The major difference between the harvesting of various categories of wood (e. g., residues from logging, stand improvements, or primary logging) is the quantity of wood that can be removed from a site per unit of time, i.e., the logging productivity. Several factors affect the logging productivity, and the most important of these are shown in table 10. The production of the logging operations discussed above might range from 15,000 to 75,000 green ton/yr, leading to harvesting costs from about $5 to $30/green ton. In addition, transportation, possible roadbuilding, and stumpage fees (fees paid to the landowner for the right to harvest the wood) must be included. Transportation ranges from $0.06 to $0.20/ton-mile, and where road building is necessary, the costs will be considerably higher. Stumpage fees for fuelwood have been estimated at $0.40 to $1 .00/green ton in New England, *J but these will change with the market.

The costs of whole-tree chipping 33 stands in northern Wisconsin and the Michigan peninsula have been modeled by computer simulation.[24] In each case, the center of the country was assumed to be the destination for the wood. The supply curve for these stands is shown in figure 4, exclusive of stumpage fees. The cost average varies from $6 to $1 5/green ton ($1 2 to $30/dry ton) in 1978 dollars. The range of delivered costs included relogging of logging residues ($16.50 to $20.30/green ton), thinning ($10.00 to $1 3.80/green ton), and integrated logging for lumber and residue chipping ($9.75 to $12.30/green ton). An equalizing factor in the delivered cost is the stumpage fee.

[23] C Hewett, School of Forestry, Yale University, private communication

[24] J A Mattson, D P Bradley, and E M Carpenter, "Harvesting Forest Residues for E nergy," Proceedings of *the* Second Annual *Fuels From Biomass Symposium* (Troy, N Y Rensselaer Polytechnic Institute, June 20-22, 1978)

Table 6.–Assumptions for Whole-Tree Harvesting Equipment

Equipment	Initial cost (dollars)	Salvage value (percent)	Life years	Labor[a] $/hour
Whole-tree chipper				
380 hp	$115,000	20	5	$4.62
600 hp	132,000	20	5	4.62
Feller-buncher	100,000	20	5	4.62
Skidder (each)	55,000	20	4	4.20
Used skidder	10,000	10	3	
Lowboy trailer.	10,000	10	10	
Used crawler	30,000	20	5	
Equipment moving truck	1,680/yr			
3/4-ton crew cab pickup . .	8,400/yr			
1/2-ton pickup .	7,862/yr			
Chain saws (3)	3,024/yr			
Other labor				
deck hands (2)				7.20
foreman				8.40
supervisor				2.81

[a] South, includes payroll benefits

SOURCE J S Bethel et al , Energy From Wood College of Forest Resources University of Washington, Seattle, contractor report to OTA April 1979

Where logging, transportation, and other costs are low, stumpage fees will be high and vice versa. The market will determine these fees, as well as the quantity and types of wood that can be economically harvested.

The 1979 delivered cost of fuel chips was about $12 to $18/green ton in New England. 25 A detailed national cost curve, however, would require a survey of all potential logging sites,

[25] Connecticut Valley Chipping, Plymouth, N H , L W Hawhensen, president, letter to Conservation Consultants of New England, Dec 20, 1979

Table 7.–Annual Whole-Tree Chipping System Costs

Annual costs to pay all expenses and earn 15% aftertax ROI, shown in thousands of dollars (values in columns are shown only when a change occurs).

Region	Annual capital cost	Maintenance	Fuel, lube, etc.	Local taxes and insurance	Labor[a]	Miscellaneous equipment[b]	Total
System based on 380-hp chipper Initial investment: $375,000							
North. ., ...	$221	$35	$44	$7	$83	$21	$442
South	221	—	—	—	62	—	390
West	221	—	—	—	104	—	432
System based on 600-hp chipper Initial investment $447,000							
North.	264	40	50	9	94	21	478
South . . . ., .	264	—	—	—	70	—	454
West ., ...	264	—	—	—	118	—	502

[a] Includes foreman and supervisor
[b] Pickup trucks chainsaws etc

SOURCE J S Bethel et al Energy From Wood College of Forest Resources University of Washington Seattle contractor report to OTA April 1979

Table 8.–Assumptions for Cable Yarding Equipment

Equipment	Initial cost (dollars)	Salvage value (percent)	Life years	Labor[a] $/hour
Yarder with 50-ft tower	$180,000	20	8	$10.29
Yarder with 90-ft tower	228,000	20	8	10.29
Radio and accessories . . .	11,386	0	4	—
Whole-tree chipper				
380 hp	115,000	20	5	7.76
600 hp . ., ., ...	132,000	20	5	7.76
Skidder (each) . . . .,	55,000	20	4	7.06
Hydraulic loader	207,000	20	6	10,64
Used skidder	10,000	10	3	
Lowboy trailer, ., .,	10,000	10	10	
Used crawler ., ., .,	30,000	20	5	
Equipment moving truck ., ., ...	1,680/yr			
3/4-ton crew cab pickup	8,400/Yr			
1/2-ton pickup	7,862/yr			
Chain saws (3)	3,024/yr			
Other labor				
yarding crew. . . .				47,84 (5 men)
foreman				14, 11
supervisor (1/3 time).				4.72

[a]West. includes payroll benefits

SOURCE Off Ice of Technology Assessment

which is not available. Nevertheless, some fuelwood can be had for as little as $10/green ton ($20/dry ton) plus stumpage fees.[26] In unfavorable circumstances, the wood could cost as much as $30/green ton ($60/dry ton for relogging of logging residues in the Northwest).[27] Thus, fuelwood chips may vary in price from about $20 to $60/dry ton which is in substantial agreement with the cost estimates based on harvesting costs.

In each category of wood there will be small businesses or individuals who are willing to work at lower rates, who are figuring only marginal costs, and/or who own the land and assign a zero stumpage fee. In other words, there will always be limited supplies of wood below the average market price.

[26]C Hewett, *The Availability of Wood for a 50 MW Wood Fired Power Plant in Northern Vermont*, report to Vermont State Energy Off Ice under grant No 01-6-01659

[27]Kip Hewlett, Georgia Pacific Corp , Atlanta, Ga , private communication, 1979

Table 9.-Cable Logging System Costs

Annual requirement to pay all expenses and earn 15% aftertax ROI (thousands of dollars)

Equipment	Annual capital cost	Maintenance	Fuel, lube, etc.	Local taxes and insurance	Labor[a]	Miscellaneous equipment	Total
50-ft tower/ 380-hp chipper investment: $466,000 ., ...	$200	$43	$44	$ 9	$158	$21	$475
90-ft tower/600-hp chipper $531,000	228	61	47	11	158	21	526

[a]Inlcudes foreman and Supervisor
[b]Pickup trucks chainsaws etc

SOURCE Office of Technology Assessment

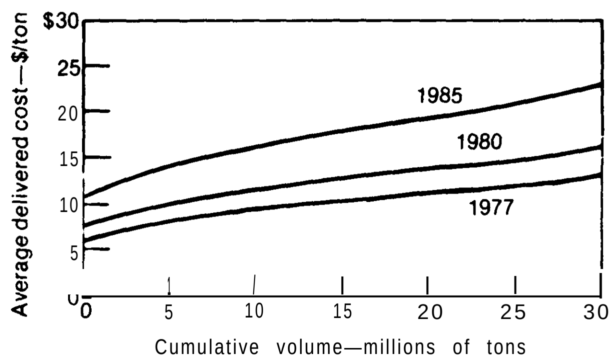
Table 10.–Factors Affecting Logging Productivity

Road space.
Slope and slope changes-slope steepness and whether logging is uphill or downhill.
Size and shape of landing.
Skidding distances–both loaded and return if different, affected by the tract shape and its relation to the road system
Skid trail preparation.
Timber character–
- Species–Especially hardwood v. softwood.
- Volume and number of trees per acre to be removed–The size of trees and logs is a very Important consideration.
- Quality– More defective timber is likely to result in more breakage, increasing materials handling problems
- Residual stand, if any, m terms of number of trees and volume per acre This is prescribed by the silvicultural method.

Cutting policy–appropriate for the stand
Felling and logging methods–whole tree, shortwood, tree length, etc.
Brush height and density.
Condition and number of windfalls, old stumps, and slash per acre.
Drainage and stream crossings.
Season.
Crew size and aggressiveness.
Wage plan.
Equipment types, functions, and balance–especially the number of places handled per cycle,
Maintenance policy.
Environmental regulations–may prescribe certain practices or preclude certain equipment from areas with sensitive mixes of soils, slopes, and/or drainage thereby reducing production or Increasing costs In the West these regulations have caused a shift in the mix of tractor v. cable logging as well as shifts within each of these general categories

SOURCE J S Bethel et al Energy From Wood College of Fores! Resources University of Washington Seattle contractor report 10 OTA April 1979

Figure 4.—Supply Curve for Forest Chip Residues for Northern Wisconsin and Upper Michigan



SOURCE: J. A. Mattson, D. P Bradley, and E M. Carpenter, "Harvesting Forest Residues for Energy," *Proceedings of the Second Annual Biomass Symposium* (Troy, N. Y.: Rensselaer Polytechnic Institute), June 20-22, 1978.

Factors Affecting Wood Availability

The presence of nearby roads, the concentration of wood on the logging site, and the terrain (steepness of the slope) are the most important physical factors affecting the economics, and thus the availability, of harvested wood, Nevertheless, landownership, alternate uses for the land, taxation, and some subsidiary benefits and constraints also play an important role in wood availability. These other factors are discussed below.

Landownership

One of the more important features distinguishing the various forest regions in the country is landownership. In New England 2 percent of the commercial forestland is federally owned, and public ownership accounts for only 6 percent. In the East as a whole, 14 percent of the commercial forestland is publicly owned, while 7 percent is federally owned. Ownership patterns in the West are reversed, with 68 percent of the commercial forestland being publicly owned (96 percent in Arizona) and 58 percent in Federal ownership.

Although patterns in the West permit logging firms to deal with a limited number of large landowners, other restrictions may be placed on the logging operations. One example is the Federal requirement that logging residues be removed from or otherwise disposed of on national forests in the West, to minimize the risks of forest fires.

Logging firms in the East must deal with a larger number of landowners, and in the Northeast, forestlands are often owned for recreational or investment purposes. It may be difficult to determine who owns the land, to contact the owner, or to interest the owner in using the land for logging. In the South this is less of a problem. Large areas of forestland owned by relatively small landowners are managed by the forest products industry and are available for logging.

Alternate Uses for the Land

The fact that a tract of land is forested and designated commercial does not necessarily mean that it can be logged. The owner may have esthetic objections to logging, may use the land for recreational purposes, or, in the case of an investor, may feel that it would be more difficult to sell the land after logging. in New Hampshire and Vermont, for example, a recent study concluded that only 6 percent of the owners of commercial forestland considered timber production as a reason for owning forestland, and only 1.3 percent listed it as the most important reason. [28] (This 6 percent owns 21 percent of the commercial forestland in the two States). Nevertheless, 10 percent of the private owners (representing 53 percent of the forestland) intended to harvest their timber within 10 years and over one-third of the owners (representing 87 percent of the land) intended to harvest "some day. " About half of the landowners (owning 9 percent of the land) indicated that they would not harvest the land because of its scenic value or because their tracts were too small.

Public Opinion

While proper management of a forest can improve the health and vitality of the trees, improper management can have severe environmental consequences. (See "Environmental Impacts".) In any event, an intensively managed forest will look like it is being managed. There will be fewer overmature trees, the trees will be more uniform in appearance and spacing, and the forest floor will have less debris and "extraneous" vegetation. The managed forest will not look like a natural forest, and the difference in appearance can be quite large.

This change in appearance, together with various environmental uncertainties (see "Environmental Impacts"), leads to widely varying opinions about the benefits of forest management. If the citizenry affected by increased management cannot effectively participate in the process of deciding where and how intensively the forests will be managed, and if business and Government officials are not sensitive to the concerns of the citizenry, then the political atmosphere surrounding forest management for energy could become polarized. Public opposition could then seriously restrict the use of forests for energy.

Forest management, however, is not an absolute. There are many ways to manage forestlands, from wood plantations to the occasional gathering of fallen trees and branches. The ability of political leaders to convey this fact to the public, and the ability of Government to aid in striking an equitable balance between environmental and esthetic concerns and the economics of wood harvesting, may prove to be one of the most significant factors affecting an increased availability of wood for energy outside of the forest products industry.

Alternate Uses for Wood

Much of the wood that will be used for energy in the near future is less suitable for materials (e. g., particle board or paper) than the wood currently used for these products. If there is a strong demand for wood products, however, some of this lower quality wood will be drawn into the materials market. Similarly, technical advances in wood chemistry may create an additional demand for wood to be processed into chemicals.

It must be remembered that a strong wood energy market would provide an incentive to

[28] N P Kingsley and T W Birch, "The Forest-Land Owners of New Hampshire and Vermont, " USDA Forest Service Resource Bulletin NE-51, 1977

increase the number of stand improvements. This will result in an increased supply of what is considered commercial-grade timber. Furthermore, some stands that cannot now be harvested economically for only lumber or pulpwood will become economically attractive for a combined harvest of lumber, pulpwood, and wood chips for energy.

In the very long term, competition for wood may develop between the energy and materials/chemicals markets. For the next 20 years, however, a wood energy market–properly managed—will increase the supply of wood for other uses over what would occur in its absence, and indeed this situation is likely to prevail for at least 50 to 60 years.

Other Factors and Constraints

As noted previously, the Forest Service requires that logging residues on national forests be disposed of to minimize the risks of forest fires. Stumpage fees for logging national forestlands are therefore lower than for comparable private lands in the region, in order to cover the cost of disposing of the residues. In the early 1970's, as a result of a strong demand for paper, some of these residues were collected and chipped for paper pulp. Currently, however, the residues (about 0.2 Quad/yr) are disposed of onsite by burning and other techniques. If a strong energy market existed, much of this could be chipped and used for energy.

It has been common practice in site preparation to use herbicides to kill unwanted plants so that preferred trees could regenerate either naturally or artificially. Increasingly, however, the use of herbicides for this purpose is being restricted and in some cases banned (e. g., 2, 4, 5-T). A strong energy market would provide an additional incentive to harvest the brush and other low-quality wood and thereby minimize the use of these controversial chemicals.

Net Resource Potential

There is no simple way to assess accurately the impacts of the various and sometimes contradictory factors affecting the availability of wood for energy. Many of the important factors, such as public opinion, the way the forests are managed, and the presence of roads, will depend on actions taken in the future. Assuming, however, that 40 percent of the growth potential of the U.S. commercial forestland is eventually accessible, 450 million to 900 million dry ton/yr (7.3 to 14.6 Quads/yr) could be available for harvest.

In terms of energy, the forest products industry currently cuts 5.1 Quads/yr of wood, including logging residues (1.3 Quads/yr) and stand improvement cutting (0.7 Quad/y r). Of this total, 1.7 Quads/yr are converted into products sold by primary or secondary manufacturers, and 1.2 Quads/yr, supplied by wood wastes, satisfies over 45 percent of the industries direct energy needs. This leaves about 2.2 Quads/yr of wood that are currently being cut but not used (see figure 5), and there is at least 40 Quads (total) of unmerchantable standing timber.

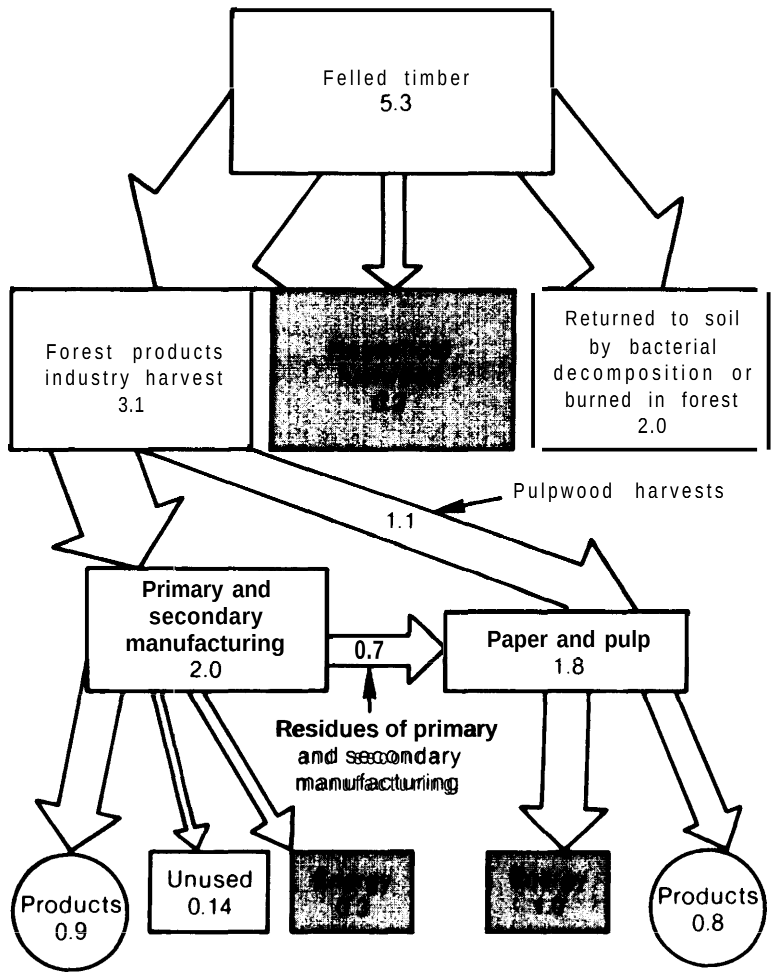
Assuming that the demand for traditional forest products doubles by 2000, then 3.4 Quads/yr will be needed for finished wood products, and 3.9 to 11.2 Quads/yr could be used for energy, provided increased forest management occurs. If, however, the forest products industry becomes energy self-sufficient by 2000, it could require as much energy as the lower limit of available wood energy, but three factors will probably alter this simple projection. First, the increased demand for wood products is likely to increase the number of stand improvements. Second, the energy efficiency of the forest products industry will probably increase as a result of higher energy prices and new processes (such as anthraquinone catalyzed paper pulping). Third, if the forest products industry requires most of the available output of 40 percent of the commer-

cial forestlands to supply its needs, then additional roads would be built to access more timberland. Additional wood that is not of high enough quality for lumber, veneer, paper pulp, etc., would therefore become available. In light of these factors, it is likely that significant quantities of wood will become available for energy uses outside of the forest products industry, but this industry could be the major user

These estimates are admittedly approximate, but a more precise estimate would require a survey of potential logging sites, land capability, road availability, and the costs of harvesting.

The results of such a survey could change these estimates, but 5 to 10 Quads/yr is OTA's best estimate of the energy potential from existing commercial forestland

Figure 5.—Materials Flow Diagram for Felled Timber During Late 1970's (Quads/yr)



Total left in forest	**2.0 Quads/yr**
Total used as energy	**1.5** Quads/yr
Unused residues	0.14 Quad/yr
Total products	1.7 Quads/yr

SOURCE Office of Technology Assessment

Environmental Impacts

Introduction

A forest may be perceived as:

- a natural ecosystem deserving protection;
- a source of materials — renewable or otherwise;
- a physical buffer to protect adjacent areas from erosion, flood, pollution, etc.;
- a source of esthetic beauty;
- a wildlife preserve;
- a source of recreation — hiking, hunting, etc.;
- a temporary land use;
- a place to retreat from civilization; or
- an obstacle to another desired land use such as mining or agriculture.

This range of perceptions is complicated by the fact that individuals do not perceive all forests to be alike, and few would attach the same perspective—or value— to all forests. Thus, the keenest environmentalist may comfortably accept a managed, single-aged pine forest in the same terms as he accepts a wheatfield, while a lumber company president may view a preserve of giant Sequoias with as much reverence as a Sierra Club conservationist.

These perceptual differences make an evaluation of the environmental effects of a wood-for-energy strategy difficult, because many of the effects may be valued by some groups as positive and by others as negative. In other words, although some potential effects of growing and harvesting operations (e.g., effects such as impaired future forest productivity or extensive soil erosion) are clearly negative or (in the case of restoration of lands damaged by mining) positive, other effects are more ambiguous. Changes in such forest characteristics as wildlife mix, physical appearance, accessibility to hikers, and water storage capabilities may be viewed as detrimental or beneficial depending on one's objectives or esthetic sense. For instance, measures that increase forest productivity by substituting softwood for hardwood production would be considered as strongly beneficial by those who value the forest mainly for its product output, but may be perceived as detrimental by those who cherish the same forest in its original state. Hence, it is likely that a wood-for-energy strategy that increases the areal extent or intensity of forestry management will promote a wide range of reactions . . . *even if the physical impacts are fully predictable and if forecasts of these physical changes are believed by all parties.*

Environmental evaluation is further complicated both by difficulties in predicting the physical impacts and by the strong possibility that even those predictions that *can* be accurately made will not be accepted as credible by all major interest groups.

The problem of credibility stems largely from the history of logging activities in the United States and the negative impact it has had on public perceptions of logging. The adaptation of the steam engine to logging around 1870 began an era (lasting into the 20th century) when America's forest resource was mined and devastated.[29] The dependence of logging on the railroads and on cumbersome steam engines— capital-intensive equipment that could not easily be moved from site to site–led to the cutting of vast contiguous areas. There was virtually no attention to reforestation. In fact, it was then thought that most of this land would be used for agriculture, and that clearcutting enhanced the value of the land. It also was thought that the timber resource was essentially unlimited and that it was unnecessary to worry about regeneration.

Massive cutting followed by repeated fires led to the destruction of tens of millions of acres of hardwood (in the South and East) and softwood (in the Lake States, Rockies, and part of the Northwest) forest and their replacement by far less valuable tree types or by grassland. This massive destruction led to a considerable public revulsion towards logging, much of which still survives. It also led to a revulsion

[29] M Smith, "Appendix L, Maintaining Timber Supply in a Sound Environment" in *Report of the Presidents Advisory Panel on Timber and the Environment* (Washington, D C Forest Service, U S Department of Agriculture, 1973)

67-968 0 - 80 - 3

against clearcutting and even-aged management within the forestry profession which lasted for 20 years;[30] although clearcutting (at least the very limited version used today, which involves very much smaller areas than were routinely cut in the past) is now an accepted and even popular practice in the profession, the attitudes formed by attempts at public education about forest values in the 1930's and 1940's linger on. Furthermore, there have been enough reports of unsound forest management and widely publicized environmental fights over such management in the intervening decades to create a sizable constituency that is generally very skeptical about logging practices. As a result, assessments that focus on the potential positive effects of increased forest management may be greeted with skepticism by large segments of the public.

The prediction of environmental changes that might occur in American forest areas if demand for wood energy grows is extremely difficult. The potential for wood energy identified previously is based on a "scenario"-a vision of a possible future—that assumes an increased collection of wood residues that are now left to rot in the forest as well as an assumed intensification of silvicultural management on *suitable land* that would increase growth rates and timber quality, increasing the supply of nonenergy wood products while providing a steady supply of wood fuel. This type of strategy could lessen harvesting pressures on wilderness areas and other vulnerable forestlands. It probably would be perceived by many groups as environmentally beneficial, although it would lead to esthetic and ecosystem changes on those lands where management was intensified. Given the present institutional arrangements, however, there is no guarantee that this assumed "scenario" will unfold as outlined. Instead, a combination of Federal, State, business, and other private interests will respond to a complex market amid a variety of institutional constraints. In order to predict the environmental outcome of such a response, the following factors must be understood:

1. The environmental effects that occur when different kinds of silvicultural operations (including different kinds and intensities of cuts, regeneration practices, roadbuilding methods, basic management practices, etc.) are practiced on different forest types and land conditions.
2. The kinds and amounts of land likely to be harvested and their physical-environmental condition.
3. The types of practices, controls, etc., likely to be adopted by those harvesting this land.

There is an extensive literature describing factor #1. However, the range of forest ecosystems and possible silvicultural practices is far greater than the range of existing research, and there are as well substantial gaps in the knowledge of some important cause-effect relationships such as the effect of whole-tree removal and short rotations on nutrient cycling, or, more generally, the ecosystem response to physical pollutants such as sediments and pesticides.

Identification and characterization of the land base most likely to be affected by increased wood demand (#2) are complicated by a lack of good land resource data, the lack of information on the precise nature of the future wood market, and the complexity of incentives that affect the decisionmaking of small woodland owners.

Predicting the types of practices and environmental controls likely to be adopted (#3) is difficult because State and local regulatory controls generally do not specify or effectively enforce "best management practices. " Thus, existing regulations cannot be used as a guide to actual practices. Also, although knowledge about the present environmental performance of the forest industry might provide a starting point for gaining an understanding of what to expect in the future (because most wood-for-energy operations are more intensive extensions of conventional forestry), it is surprisingly difficult to produce a clear picture of how well the forestry industry is performing. With the exception of a few isolated State surveys and a detailed survey of erosion parameters

[30] Ibid

(percentage of bare ground, compaction, etc.) in the Southeast,[31] there appears to be *a severe lack of* surveys or credible assessments of *actual forestry operations and their environmental impacts.* As a result, a critical part of the basis for an adequate environmental assessment is unavailable.

Because of these limitations, this discussion generally is limited to a description of *potential* impacts, although a few of the impacts described are inevitable. The economic and other incentives that influence the behavior of those engaging in forestry are examined to determine how probable some of these impacts are. The types of controls and practices available to moderate or eliminate the negative impacts also are described.

As discussed above, wood for energy may be obtained from several sources. With the growth of a wood-for-fuel market, the residue of slash from logging may be removed and chipped. Thinning operations may become more widespread because the wood obtained will have considerable value as fuel. Stand conversions— clearing of low-quality trees followed by controlled regeneration–as well as harvesting of low-quality wood on marginal lands may increase, also because of the increased value of the fuelwood gained. New harvesting practices such as whole-tree removal may become more common. Waste wood from milling and other wood-processing operations will certainly be more fully utilized. Finally, wood "crops" may be grown on large energy farms.

Many of these activities are similar to (though usually more intensive than) conventional logging. In addition, other activities associated with using wood as a long-term energy supply — including tree planting, pesticide and fertilizer application, etc. — are similar or even identical to "ordinary" silvicultural activities. This section, therefore, first discusses the general impacts of silviculture and then describes any changes or added effects associated with alternative wood-for-energy systems. In each case, the discussion will attempt to draw a distinction between clearly positive or negative pollution and land degradation and restoration impacts and the more ambiguous ecosystem and esthetic impacts. Because the environmental effects of silviculture are exceedingly varied and complex and because a number of good reviews are available, the discussion highlights only the major and most widespread impacts. It is stressed that few if any of the environmental relationships described in the discussion are applicable to all situations.

Environmental Effects of Conventional Silviculture

The practice of silviculture can have both positive and negative effects on the soils, wildlife, water quality, and other components of both the forest ecosystem and adjacent lands. Table 11 provides a partial list of the potential environmental effects of conventional silviculture. The magnitude of these impacts in any situation, however, depends almost entirely on management practices and on the physical characteristics of the site, i.e., type of trees and other vegetation, age of the forest, soil quality, rainfall, slope, etc. It is also important to remember that most of the negative impacts generally are short term and last only a few years (or less) over each rotational cycle.

Erosion has always been a concern in silviculture, especially in logging operations (and particularly in road construction). Undisturbed forests generally have extremely small erosion rates — often less than 75 lb of soil per acre per year[32] — and in fact tree planting is often used to protect erosion-prone land. * Increased erosion caused by logging, however, varies from negligible (light thinning and favorable condi-

"C Dissmeyer and K Stump, "Predicted Erosion Rates for Forest Management Activities and Conditions Sampled in the Southeast," USDA Forest Service, April 1978

[32] *Environmental Implications of Trends in Agriculture and Silviculture, Volume 1 Trend Identification and Evacuation* (Washington, D C Environmental Protection Agency, December 1978), E PA-600/3 -77-l 21

*However, from a historical perspective, all land forms go through natural erosional cycles that produce much higher rates of soil loss These rates are often driven by natural catastrophic events Including wildfire and storms

Table 11.-Potential Environmental Effects of Logging and Forestry

Water
- increased flow ***of sediments*** into surface waters from logging erosion (especially from roads and skid trails)
- ***clogging of sfreams*** from logging residue
- leaching of ***nutrients*** into surface and ground waters
- potential ***improvement of water quality and more even flow*** from forestation of depleted or mined lands
- ***herbicide-pesticide pollution*** from runoff and aerial application (from a small percentage of forested acreage)
- ***warming of streams*** from loss of shading when vegetation adjacent to streams is removed

Air
- fugitive dust, primarily from roads and skid trails
- ***emissions*** from harvesting and transport equipment
- effects on atmospheric CO_2 concentrations, especially if forested land is permanently converted to cropland or other (lower biomass) use or vice-versa
- ***airpollution*** from prescribed burning

Land
- ***compaction of soils*** from roads and heavy equipment (leading to following two impacts)
- ***surface erosion*** of forest soils from roads, skid trails, other disturbances
- loss ***of some long-term water storage capacity*** of forest, increased flooding potential (or increased water availability downstream) until revegetation occurs
- changes in ***fire hazard,*** especially from debris
- possible loss ***of forest*** to alternative use or to regenerative failure
- possible reduction in ***soil quality/nutrient and organic level*** from short rotations and/or residue removal (inadequately understood)
- ***positive effects of reforestation–reduced*** erosion, increase in water retention, rehabilitation of strip-mined land, drastically improved esthetic quality, etc.
- ***slumps*** and landslides from loss of root support or improper road design
- temporary degrading of ***esthetic quality***

Ecological
- changes in ***wildlife*** from transient effect of cutting and changes in forest type
- temporary degradation of ***aquatic ecosystems***
- ***change in forest type or improved forest*** from stand conversion

SOURCE Office of Technology Assessment

tions) to hundreds of tons per acre per year (poorly managed clearcuts on steep slopes in high rainfall areas).[33]

A recent Environmental Protection Agency (EPA) report suggests the loss of 7 or 8 tons of sediment per acre per year as a mean value for recently harvested forests, although the variation around this mean is very large. ” To place this rate in perspective, the *continuous* sheet and rill erosion rate on intensively managed agricultural land averages 6.3 ton/acre-yr.

Most forestland is harvested at most once every several decades and the increased erosion generally lasts only a year or two on the majority of the affected acreage. Increased erosion from poorly constructed roads, however, may last longer.

The processes involved in erosion of forestland are stream cutting, sheet and gully erosion, and mass movement of soil. Erosion danger increases sharply with the steepness of the landscape, and the most common form of this erosion is mass movement. Mass movement “includes abrupt or violent events such as landslides, slumps, flows and debris avalanches, as well as continuous, almost imperceptible creep phenomena."[35] Occurrence of mass movements is most often associated with steep slope conditions where the forest soil is underlaid with impermeable rock.[36] These movements are natural processes associated with the downwearing of these steep slopes, but they can be triggered by man’s activities. In contrast, sheet and gully erosion are rare in undisturbed forests, but they can be triggered by soil disturbances caused by careless road construction or logging practices.

The major causes of erosion problems in forestry operations are the construction and use of roads and other activities that may compact or expose soil or concentrate water.[37] The compaction caused by the operation of heavy machinery can reduce the porosity and waterholding capacity of the soil, encouraging erosion and restricting vegetation that eventually would reduce erosion. Roads and skid trails comprise up to 20 percent of the harvest area,[38] and the total area that may be compacted at a site may range up to 29 percent in

“*Environmental Readiness Document, Wood Commercialization*, draft (Washington, D.C.: Department of Energy, 1979).

[34]“*Environmental Implications of Trends in Agriculture and Silviculture, vol. 1*, op cit

“Earl Stone, “The Impact of Timber Harvest on Soils and Water, ” *Report of the President’s Advisory Panel on Timber and the Environment* (app M, Washington, D C Forest Service, U S Department of Agriculture, April 1973)

“Environmental Implications of Trends in Agriculture and Silviculture, vol. 1., op cit

“Stone, op cit

[38]*Draft 208 Preliminary Non-Point Source Assessment Report* (Augusta, Maine Land Use Regulatory Commission, State of Maine, 1978

some instances.[39] Although in most areas the thawing and freezing cycle allows compacted soil to recover in 3 to 10 years, recovery takes far longer when, as in parts of the Southeast, this cycle does not occur.[40] Also, when compaction is very severe, recovery may take considerably longer than 10 years; old logging roads are still visible in the Northeast, even with the frost cycle.

The vulnerability of logging roads to erosion is related to topography and soil type as well as to road design. Roads developed on gentle to moderate slopes in stable topography pose few problems with the exception of careless movements of soil during construction. Large areas of forestland served by such roads draw little attention or criticism.[41]

The great majority of difficulties and hazards arise, however, when roads are constructed on steep terrain, cut into erosive soils or unstable slopes, or encroach on stream channels. Steep land conditions present a dilemma for road development, and criteria for location, design, and construction that are satisfactory on even moderate slopes may lead to intolerable levels of disturbance on steep lands. Building a road on a slope involves cutting into the slope to provide a level surface. The soil removed from the cut is used as fill or dumped. The steeper the slope, the more soil that must be disposed of and the more difficult is the job of stabilizing this soil. In the absence of proper attention to soil and geology, road design (especially alinement and drainage), and other factors, surface erosion from road and fill surfaces can continue for years. Roadbuilding on steep slopes may also remove enough support from the higher elevations to cause mass failures; problems created by the road cut may be aggravated by inadequate drainage allowing further cutting away of supporting soil.

Aside from roads, the movement of logs from the harvest site to loading points may present considerable erosion potential. "Skidding" logs may expose the subsoil, or compact the soil. Exposing the surface is a problem when the soil is highly erosive or when water concentrates, but is usually not a major erosion problem. The deeper disturbances of compaction and of cutting into the soil create more significant erosion problems, especially when they occur parallel to the flow of water. Most surveys of logging have concluded that the hauling or skidding of logs "generally does not lead to appreciable soil erosion or impaired stream quality;"[42] however, the same surveys conclude that "exceptions are commen," and logging in vulnerable areas, under wet weather conditions, or with inappropriate equipment are thought to be important problems in the industry.

Erosion caused by the actual cutting of the trees generally is considered to be relatively unimportant. Vegetation usually regenerates quickly and reestablishes a protective cover on the land, preventing surface erosion except in areas where other components of the logging operation have damaged the soil. "Many observations and several studies on experimental watersheds demonstrate that sheet and gully erosion simply do not occur as a result of tree cutting alone, even on slopes as steep as 70 percent."[43]

However, land that is vulnerable to mass movements may be damaged by tree cutting. The decay of the old root systems will remove crucial support from a vulnerable slope faster than it can be replaced by the root systems of new growth; within 4 to 5 years after tree cutting (or fire), mass movement potential may increase dramatically. Forests in the Northwest United States and coastal Alaska are the main areas for this type of damage potential.[44]

The method of clearing for forest regeneration may also affect erosion potential. Intensive mechanical preparation of land before tree planting (i.e., use of rakes, blades, and other devices to reduce a forest to bare ground to favor reproduction of pine) can cause very

[39] *Environmental Implications of Trends in Agriculture and Silviculture*, vol 1, op cit
[40] Ibid
[41] Stone, op cit
[42] Ibid
[43] Ibid
[44] Ibid

serious erosion problems. This practice is occurring on hilly sites in the South that have been depleted by intensive cotton production in the past; it "may foster a dangerous cycle of topsoil and nutrient loss and increased sediment loading in streams. "[45] Poorly managed raking may have adverse effects on forest productility. " Area burning can also badly damage forest soils if managed improperly or if used on improper soils. Although suitable for highly porous, moist soils (where much of the surface cover is not consumed), poorly managed burning may consume most of the cover and leave the soil exposed to surface erosion. (However, area burning is considered to have a lesser potential to degrade productivity than raking.") Burning may also represent a significant local source of air pollution. On the other hand, "controlled" burning may reduce future fire hazard by reducing slash buildup and may favor regeneration on the site of fire-resistant trees.

The sediment resulting from the erosion described in this section is "the major cause of impaired water *quality* associated with logging."[48] These sediments are directly responsible for water turbidity, destruction of stream bottom organisms by scouring and suffocation, and the destruction of fish reproductive habitat. Sediments also carry nutrients from the soil. Nutrient pollution is further increased by increased leaching and runoff as increased solar radiation reaches the forest floor and warms it, microbial activity (which transforms nutrients to soluble forms) accelerates and nutrient availability increases (this soil heating effect also has been known to retard regeneration, especially on south-facing slopes, by killing off seedlings). The increased nutrient loading of streams may have a variety of effects, including accelerated eutrophication and oxygen depletion. Fortunately, the increased nutrient loading is usually short-lived, because revegetation of the site slows runoff and leaching, increases nutrient uptake, and, by shading and cooling the soil, slows the decomposition of organic material and consequent nutrient release.

The effects of nutrient enrichment are aggravated by the decomposition of organic matter from slash that is swept into streams, and by any water temperature increases caused by loss of streambank shading* (the temperature increases speed up eutrophication and further reduce oxygen content of the water). Temperature increases may also directly harm some freshwater ecosystems by affecting feeding behavior and disease incidence of cold water fish.

Logging operations affect *water supply* and may decrease a watershed's ability to absorb high-intensity storm waters without flooding (although this problem may have been exaggerated somewhat in the past).

The possibility of increased flooding stems from two causes. First, cutting the forest reduces the very substantial removal by transpiration of water from underground storage. During the period before substantial revegetation has taken place, the amount of this long-term "retention storage" capacity available to absorb floodwaters will be lessened and peak stream flows may rise. For example, increases in peak flows of 9 to 21 percent in the East and 30 percent in Oregon following clearcutting have been reported. These increases are usually observed only during or right after the growing season, where continual drawdown of storage would be occurring had the trees not been cut (floods occurring during the winter, as in the Northwest, may be unaffected or less affected because drawdown would not normally be occurring). This decrease in storage capacity apparently is not significant unless at least 20 percent of the canopy is removed.[49] Second,

[45] *Environmental Effects of Trends, vol.2* (Washington, D C Environmental Protection Agency, December 1978), E PA-600/3-77-121

"Stone, op cit

[47] Ibid

[48] *Silviculture Activities and Non-Point Pollution Abatement: A Cost-Effectiveness Analysis Procedure* (Washington, D C Forest Service, US Department of Agriculture, November 1977), E PA-600/8-77-Ol 8

*The extent of any Increases depends on stream volume, degree of removal of understory vegetation, and several other factors In many cases, no significant effects occur

"*An Assessment of the Forest and Range Land Situation in the United States* (Washington, D C Forest Service, U S Department of Agriculture, 1979), review draft damage to forest soil increases runoff and inhibits the action of even the temporary "detention storage" potential wherein water is temporarily stored in pores in the upper soil layers and can be delayed from reaching streams for anywhere from several minutes to several days. Although treecutting, even clearcutting, is not likely to affect this temporary storage capacity, compaction of the soil by roadbuilding, log skidding, and operation of heavy machinery may reduce the infiltration of water into the soil if the compaction occurs over a wide area[50] and thus drastically reduce storage. Area burning on coarse-textured soils can create a water-repellant layer that would also decrease this infiltration and thus reduce the soils' capacity for detention storage.[51]

The reduction of transpiration that is caused by timber harvest may be beneficial by increasing stream flow and groundwater supplies in water short areas. Also, carefully structured cuts can be used to trap and maintain snow accumulation, greatly reducing evaporation losses, It is claimed that by using such techniques, water yield from commercial forestland in the West could be increased, supplying millions of additional acre feet at a cost of a few dollars per acre foot. 52

Large-scale forestry operations often drastically alter local ecosystems, even for the long term. Wetlands in the South are being drained and pine forests are being created with the aid of substantial applications of phosphate fertilizers. In the process, aquatic ecosystems are being replaced by terrestrial ones and some critical wildlife habitats, especially for waterfowl, are being destroyed.[53] In the Pacific Northwest, old stands of Douglas fir are being replaced by single-aged plantings of the same species. Elsewhere, mixed hardwood forests are being replaced by plantations of conifers. In many cases, however, the ecosystems being replaced are themselves the result of past logging and agriculture as well as "unnatural" forest fire suppression that gradually replaced conifer forests with mixed hardwoods.

All types of replanting are accompanied by major changes in habitats available for wildlife. In the short term, any wood-harvesting operation, other than large area clearcutting, usually increases wildlife populations because mature forests normally do not support as great a total population of wildlife as do young growing forests. Many species require both cleared and forested area to survive, and thus, the "edges" created by logging operations are particularly attractive to deer and other species. Other species dependent on subclimax habitats (such as eastern cottontails) will also increase following logging, while species dependent on mature climax forests (e. g., wolverine, pileated woodpecker) will decline.[54]

Although the desirability of the ecosystem changes caused by logging may always be subject to one's point of view, different forestry practices tend to have varying effects that may be judged unambiguously from the standpoint of wildlife diversity and abundance:

> Forest management practices that reduce structural diversity of habitat, such as extensive old growth clearcutting, the removal of snags that provide wildlife food and nesting sites, and conversion to plantation management will generally reduce wildlife abundance and diversity by reducing habitat essential to many species. Conversely, animal diversity and wildlife abundance generally will be increased by opening up dense stands, making small patch cuts, or by conducting other timber management activities that increase structural diversity and provide a wide mix of habitat types. 55

Current pesticide *and fertilizer use* in U.S. forests is low, In 1972, insecticides were used on only 0.002 percent of commercial forestlands, and fertilizers were used on less than 500,000 acres. 5, Because long-rotation logging and removal of only boles generally do not

[50] Stone, op cit

[51] R M Rice, et al , "Erosional Consequences of Timber Harvesting An Appraisal, " *Watershed in Transition,* (Urbana, Ill American Water Res Assoc Proc Ser 14, 1972)

[52] *An Assessment* of the *Forest* and Range Land *Situation in the United States,* op cit

[53] Vol *II, Environmental* Effects *of Trends,* op cit

[54] *An Assessment of the Forest and Range* Land *Situation in the* United States, op cit

[55] Ibid

[56] *Vol* 1 *Environmental Implications* of *Trends in Agriculture* and *Silviculture,* op cit

deplete nutrients from forest soils, the most important use of fertilizers is on soils that are naturally deficient in nutrients or that have been depleted by past farming practices. For example, intensive cotton production in the Southeast seriously depleted soils and much of this land was abandoned long ago. Phosphate fertilization has allowed this land to become productive in the growth of softwood forests. Pesticides generally are used in forest management to control weed vegetation during reforestation or to combat serious outbreaks of insect pests. There is considerable controversy over aerial spraying of insecticides to control the gypsy moth and other damaging insects. Also, circumstantial evidence exists that certain herbicides in recent use may have caused outbreaks of birth defects and other damage when inadvertently sprayed over populated areas. Although the existence of these effects has been vigorously denied by the manufacturers, and although pesticide use in forests is a tiny fraction of the use in food production and is likely to remain so,[57] this use is likely to continue to be a source of disquiet accompanying intensive management of forests.

Silvicultural activities, and especially intensive harvesting operations, strongly affect the esthetic *appeal* of forests. The immediate aftermath of intensive logging is universally considered to be visually unattractive, especially where large amounts of slash are left on the site. Therefore, wood harvesting has a strong potential to conflict with other forest uses such as recreation or wilderness.

The significance of any negative effects depends on the nearness of logging sites to activity areas or to scenic vistas, the rapidity of revegetation, and the extensiveness of the operation. Therefore, the Forest Service seeks to route trails away from active harvesting sites, to avoid interrupting vistas, and to plan the extent and shape of the areas to minimize visual impacts.

The negative effect on the esthetic and recreational quality of forests caused by logging may be aggravated by a negative public perception of the environmental effects of clearcutting in particular and logging in general. As noted earlier, this perception has been exaggerated by a number of factors including the grim history (1870-1930) of forest exploitation in the United States, the former revulsion against clearcutting practices within the forestry profession itself during the 1930's and 1940's, and continued attacks against logging by the environmental community. Although a logged-over area may be no uglier, objectively speaking, than a harvested field, the public perception of the two vistas is vastly different.

All reviews of logging and general forestry impacts stress the importance of regional *differences* –as well as extensive site-specific differences – in determining the existence and magnitude of environmental effects. Figure 6 presents a summary of those characteristics of U.S. forest regions that are most relevant to potential silvicultural impacts. Because the descriptions in figure 6 are, of necessity, much oversimplified, they are meant to give some perspective of the general range of environmental conditions and problems in American forestlands and should not be considered as fully representing all of the major conditions and problems in these lands.

Potential Environmental Effects of Harvesting Wood for Energy

This section discusses the activities— harvesting logging residues, whole-tree removal, intensifying and expanding silvicultural management, and harvesting for the residential space-heating market — which are characteristic of an expansion in the use of wood as an energy source.

Harvesting Logging Residues and Whole-Tree Removal

The harvesting of logging residues for an energy feedstock has potential for both positive and negative environmental impacts depending on the nature of the forest ecosystem and the previous manner of handling these residues.

[57] Ibid

Figure 6.—Environmental Characteristics of Forest Regions

SOURCE: *Silviculture Activities and Nonpoint Pollution Abatement: A Cost-Effectiveness Analysis Procedure* (Washington, D.C.: Forest Service, U.S. Department of Agriculture, November 1977).

In forests where wood residues–tops, limbs, and possibly leaves and understory — are routinely gathered into piles for open burning (this is required in forest fire prone areas of the West), residue use for energy production is environmentally beneficial. It eliminates the air pollution caused by this burning and has essentially no additional adverse impacts except those incurred in physically moving the residue out of the forest (and burning it, with controls, in a boiler). In forests where residues would otherwise be broadcast burned, physical removal prevents some of the potential adverse effects of burning — especially destruction of a portion of the organic soil layer. The removal does, however, subject the soil to compaction or scraping damage by the mechanical removal process that would otherwise be avoided. Also, broadcast burning is, at times, used to control weed vegetation, and in some circumstances herbicide use may be substituted if burning cannot be practiced.

Where logging residues are normally left in the forest, institution of a residue removal program will have mixed environmental effects which are summarized in table 12.

A worrisome effect of residue removal is the increased potential for long-term depletion of nutrients from the forest soils and consequent declines in forest productivity. These effects are not well understood and although nutrient cycling in natural and managed forests has been extensively studied, few of these studies have included the effects of residue removal.[58] The existing studies indicate that short-rotation Southern forests may be more susceptible to depletion than longer rotation Northern forests, and that marginal sites suffer far more heavily than forests with fertile soils.[59 60 61 62]

[58] C. J. High and S E. Knight, "Environmental Impact of Harvesting Noncommercial Wood for Energy Research Problems, " Thayer School of Engineering, Dartmouth College paper DSD No. 101, October 1977.

[59] E H White, "Whole-Tree Harvesting Depletes Soil Nutrients, " *Can J. Forest. Res.* *4.530-535,1974*

[60] J R Jorgensen, et al., "The Nutrient Cycle: Key to Continuous Forest Production, " *J. Forestry 73.400-403, 1975.*

[61] J R Boyle, et al , "Whole-Tree Harvesting. Nutrient Budget Evaluation, " *J.* Forestry 71 760-762

[62] G F Weetman and B Webber, "The Influence of Wood Harvesting on the Nutrient Status of Two Spruce Stands, " *Can. J. Forest. Res.* 2 351-69, 1972

Table 12.-Environmental Impacts of Harvesting Forest Residues

Water
- ***decrease in clogging*** of streams caused by entry of slash
- increased short-term flow of ***sediments*** into streams because of loss of erosion control provided by residues, soil damage caused by removal operations; somewhat counteracted by decline in broadcast burning, which at times destroys surface cover and causes erosion potential to increase
- possible changes in long-term flow of sediments where residue removal affects revegetation; this effect is mixed
- ***changes in herbicide*** usage–on the one hand, chemical destruction of growing residues (valueless trees) will cease; on the other, broadcast burning no longer effective in retarding vegetative competition to new tree growth, herbicide use may increase
- increased short-term ***nutrient leaching*** because of increased soil temperatures, accelerated decomposition

Air
- ***reduction in air pollution*** from ***forest fires***
- ***reduction in air pollution*** from ***open burning*** of residues (if the residues normally are broadcast burned or burned after collection)
- ***dust*** from decreased land cover, harvesting operations

Land
- ***potential depletion of nutrients and organic matter from*** forest soils and possible long-term loss of productivity (inadequately understood)
- ***short-term increase in erosion and loss of topsoil,*** possible long-term decrease or increase
- ***reduction in forest fire hazard***
- ***short-term decreased water retention,*** increased runoff (and flooding hazard) until revegetation takes place; aggravated by any soil compaction caused by removal operation

Other
- change in ***wildlife*** habitat—bad for small animals and birds, good for large animals unless serious erosion results
- changes in tree species that can regrow
- ***esthetic change,*** usually considered beneficial when slash is heavy
- ***reduction*** in ***bark beef/es*** and other pathogens that are harbored by residues

SOURCE Office of Technology Assessment.

Further study and careful soil monitoring would allow the use of fertilizers to compensate for nutrient depletion, but fertilizer application is energy intensive; it may increase the flow of nutrients to neighboring streams, and its correct use may be difficult to administer for smaller stands. Also, successful application may be difficult unless the nutrient depletion is a simple one involving only one or a few nutrient types.

Residues serve a number of ecological functions in addition to nutrient replenishment, and their removal will eliminate or alter these functions. They provide shelter and food to small mammals and birds, provide a temporary food supply for deer and other larger mammals, moderate soil temperature increases that normally occur after logging, provide some protection to the forest floor against erosion, and are a source of organic matter for forest soils. Thus, removal of residues will reduce certain wildlife habitats and may expose the forest floor to some additional erosion above and beyond that caused by conventional logging. Higher soil temperatures resulting from loss of the shade provided by residue cover will accelerate organic decomposition activity and may lead to a period of increased nutrient leaching before revegetation commences. Also, the increased rate of organic decomposition coupled with the removal of a primary source of organic matter may lower the organic content of forest soils. Declines in soil organic matter are expected to be accompanied by declines in nitrogen-fixing capacity, soil microbial activity rates, and cation exchange capacity, all considered to be important determinants of long-term forest health.[63 64] The present scientific understanding of organic matter removal is, however, insufficient to allow a determination of the significance of these possible effects.

The extensive residue left on the forest floor after cutting dense stands can inhibit revegetation, especially in softwood forests. To the extent that residue removal may promote new vegetation, this will counteract the removal's short-term negative erosion and nutrient-leaching effect (as long as removal is not so complete as to eliminate the light mulch necessary to shade the surface and maintain soil moisture).

Residues also provide a habitat for disease and pest organisms such as the bark beetle and, when washed into neighboring streams, may clog their channels and degrade water quality. They add considerably to the incidence and intensity of forest fires, especially in the West. Also, the esthetic impact of residues is generally considered to be negative when they are left at the logging site; when densely forested areas are cut, residues will completely cover the ground with several feet of unsightly slash. Therefore, removal of residue will, in a positive sense, reduce the number and severity of forest fires and pest infestations, improve esthetics, and reduce the potential for stream clogging.

"Whole-tree harvesting" is really a variation of residue removal with the bole and "residue"- branches, leaves, twigs– removed in one integrated operation. It is most likely to occur when the entire tree is to be chipped for fuel or some other use.

The problems of long-term nutrient and organic matter depletion from whole-tree harvesting are basically the same as those of residue removal, and whole-tree logging similarly removes far greater nutrients and organic matter from forest soils than do other conventional methods. Whole-tree removal of Norway spruce, for example, results in a loss of 2 to 4 times more nitrogen, 2 to 5 times more phosphorus, 1.5 to 3.5 times more potassium, and 1.5 to 2.5 times more calcium than conventional logging.[65] In addition, ground disturbance from the actual tree removal is likely to be worse with whole-tree harvesting when the fully branched trees are dragged off the logging site, eradicating understory vegetation in the process. This disturbance, besides promoting erosion, will accelerate organic matter decomposition. As noted previously, however, the effects of these organic matter and nutrient removals on long-term forest productivity are poorly understood.

Intensifying and Expanding Silvicultural Activities

The creation of new energy markets for wood will have a significant effect on the economics of managing forested land, including land not currently considered to be high-grade

[63] E L Stone, "Nutrient Removals by Intensive Harvest— Some Research Gaps and Opportunities," *Proceedings Impact of Harvesting on Forest Nutrient Cycle* (Syracuse, N Y State University of New York, College of Environmental Science and Forestry, 1 979)

[64] E H White and A E Harvey, "Modification of Intensive Management Practices to Protect Forest Nutrient Cycles," *Proceedings Impact of Harvesting on Forest Nutrient Cycle* [Syracuse, N Y State University of New York, College of Environmental Science and Forestry, 1979)

[65] E Malkonen, "The Effects of Fuller Biomass Harvesting on Soil Fertility," *Symposium on the Harvesting of a Larger Part of the Forest Biomass* (Hyvinkaa, Finland E conomic Commission for Europe, Food and Agriculture Organization, 1976)

forest. New lands will be harvested and silvicultural practices will intensify.

One effect will be the expansion of logging onto lands that are not now in the wood marketplace. The operational costs of logging some of these lands cannot, at present, be recouped through increased property values, the sale of the harvested wood, or the value of future growth of a regenerated forest. Additional lands that currently *are* economically attractive targets for logging activities (stand conversion, clearing for nonforest use, etc.) are withheld by their owners for a variety of reasons (their higher valuation of the land's recreational potential, fear of environmental damage, etc.). As an energy market for wood develops, however, harvesting part or all of the wood resource on these lands will become increasingly attractive.

The logging of some forests that would otherwise be untouched (or, perhaps more realistically, that would only be logged at some later time) may be viewed as beneficial by some groups. Most reviews depict American forests as being characterized by "overmature stands of old-growth timber, especially in the West, and . . . many stands, mainly in the East and South, that were repeatedly mined of good trees in earlier, more reckless times. "[66] Conversion of such stands is often characterized as a step towards a healthier forest, because tree growth generally is enhanced and more "desirable" tree species are introduced. Where whole-tree harvesting or residue removal is practiced, the forest may become more accessible to hikers and may be more esthetically appealing. The extent to which all this is considered a benefit depends heavily on one's perspective, however, and optimizing commercial value is not necessarily synonymous with optimizing other values such as ecosystem maintenance or wildlife diversity.

As discussed later, expansion of silvicultural management onto suitable lands, combined with an increase in the intensity of management on existing commercially managed lands, may provide important environmental benefits in the form of decreasing logging pressures on lands that combine high-quality timber with competing values that would be compromised by logging. Unfortunately, a decrease in logging pressures on one segment of America's forests may be coupled with an undesirable increased pressure on another segment.

A particular fear associated with the rise in demand for "low quality" wood is that marginal, environmentally vulnerable lands with stands of such wood may become targets for logging. Much of this land that may be vulnerable to logging for energy, although "poor" from the standpoint of commercial productivity, is valuable for esthetic, recreational, watershed protection, and other alternative forest uses. These forest values may be lost or compromised by permanent clearing or by harvesting on sites where regeneration may be a problem. For example, forests in areas with marginal rainfall —e. g., in the Southwest— may be particularly vulnerable to regeneration failures and thus may be endangered by a growth in wood demand. On lands with poor soils and steep slopes, clearcutting and other intensive forms of harvesting create a high potential for nutrient depletion, mass movement, and other problems as described earlier. Because, as discussed later, the Federal Government maintains supervisory control over forest operations on federally owned lands, this potential problem is likely to be concentrated on private lands. The overall danger is somewhat mitigated, therefore, by the Federal Government's ownership of a significant percentage of the most vulnerable land.

It is difficult to predict whether wood-for-energy operations will tend to gravitate to the poorer quality and more vulnerable lands. The several factors that will determine the tendency of wood-for-energy harvesting to gravitate to vulnerable lands include:

1. *The direct cost of wood harvesting, –* Development of more versatile harvesting equipment can lower the cost of operating on steep slopes and promote harvesting on vulnerable lands.

"Smith, op. cit

2. The stringency and *enforcement of environmental standards.* –The stronger the controls, the more likely it is that loggers will avoid the more vulnerable stands.
3. The price *of woodchips for energy.* –At a high enough price, the "value-added" to the land by clearing will become less important, and poorer quality lands will become more attractive targets for harvesting.
4. *The price of agricultural land and "high value" forestland.* –At high prices, wood harvesting for energy would tend to gravitate to higher quality, less erosion-prone/depletion-prone lands because clearing for agriculture or stand conversion will be more profitable.
5. The *distribution* of different soil/slope/rainfall conditions in forestland potentially available for cutting.
6. *The attitude of private landowners,* who currently own much of the land available for clearing but who often are reluctant to allow harvesting.
7. The *cost of transporting wood.* – Because the higher this cost, the more likely it is that local shortages could force harvesting onto vulnerable lands.

Except for (1) and (5), these factors may be extremely volatile and will themselves depend on the availability of alternate fuels, the state of the economy, etc. Except for forestland in the Southeast, the data necessary to define (5) are not available.

The Department of Energy, in its draft "Wood Commercialization Environmental Readiness Document,"[67] asserts that the sites with "nutrient deficiencies and delicate nutrient balances, and subsequently low productivity . . . are the non-commercial forests that often are considered available for whole-tree harvest for energy." And a recent EPA report asserts that "areas previously left unlogged . . . are most often increasingly steep with difficult terrain."[68] Both of these statements imply that an areal expansion of logging to satisfy energy demands could be expected to lead to exploitation of lands particularly vulnerable to environmental damage.

These references may have overlooked several factors, however:

1. As noted previously, there is considerable forest acreage of high quality— low slopes, rich and nonerosive soils, adequate rainfall —with low-quality timber growing on it. This is especially true in the East.
2. The cost of harvesting timber on flatter— and thus less erosive —slopes is considerably less than on steep-sloped lands. These flatter lands presumably would be the first choice for harvesting.
3. The higher quality, less vulnerable sites offer the landowner the economic incentive of an added return from regrowth of high-quality timber or else alternative land uses such as farming.
4. Increases in land prices for rural acreage with high recreational and esthetic value have increased the economic incentive to guard against environmental damage that would compromise these values.

On balance, it would appear that market pressures would tend to favor the harvesting of the less environmentally vulnerable lands. However, variations of land availability from region to region, landowner decisions based on other than land suitability grounds, and other factors are likely to lead to some level of inappropriate harvesting — especially if the current state of regulatory "laissez-faire" continues (see discussion on "The Institutional Climate for Environmental Control").

A second effect of new energy markets for wood will be an *intensification* of forest management—especially of thinning— because part or all of its cost will be recouped through use or sale of the collected wood. Residue removal or whole-tree harvesting, discussed previously, are likely to be another facet of this management intensification.

The process of removing trees that are dead or diseased, stunted, poorly shaped, or of "undesirable" species is considered by foresters to

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[67] *Environmental Readiness Document, Wood Commercialization,* op cit
[68] *Vol II, Environmental Effects of Trends,* op cit

be beneficial to the forest. Thinning allows increased growth in the remaining trees, esthetically and physically "opens up" the forest, and may allow some additional growth of understory vegetation if the thinning is extensive enough. If heavy machinery is used, however, resulting soil compaction can cause adverse impacts, and care must be taken during the thinning operation to avoid damaging the trees that remain.

A critical argument in favor of thinning and other logging operations is that these activities result in increased wildlife populations and diversity. The definition of "diversity" is critical to this argument. There is a substantial difference between maximizing diversity in a single *forest stand* and maximizing it in the *forest system* composed of many forest stands in a region. The first definition may be well served by more intensive management because such management provides more "edges" and understory vegetation for browse. On the other hand, many species will suffer from such management. A great many species depend for their food and shelter on "unhealthy" –dead, dying, rotten —trees that would be removed in a managed forest, and other species cannot tolerate the level of disturbance that would be caused by thinning operations. Maintaining diversity in a forest system must include protecting these species by deliberately leaving unmanaged substantial portions of the forest or a percentage of the individual stands within the entire system. in regions where officially designated wilderness areas or other protective measures are adequate, intensive management on the remaining stands may be considered (even by environmental groups) as benign or beneficial if good management practices are carefully followed. In other regions, especially in the East, intensive management may conceivably work to the detriment of species diversity although it may increase the total wildlife population. Even in these regions, however, there is a possibility that large numbers of property owners may choose to leave their lands unmanaged because of personal preferences. This would serve to protect diversity.

The potential for added growth of high-quality timber from stand conversions of low-quality forest and the increased use of thinning on commercial forestlands may have, as its most important effect, a decrease in the pressures to log forests that have both high-value timber and strong nontimber values —recreation, esthetic, watershed protection, etc. — and that may be quite vulnerable to environmental damage. Analysts such as Marion Clawson of Resources for the Future have long argued that the management of American forestland is extremely inefficient, that by concentrating intensive management practices on the most , productive lands we could increase harvest yields while withdrawing from silviculture less productive or more environmentally vulnerable lands.[69 70] An expansion of wood use for energy and the consequent creation of a strong market for "low quality" wood may have this beneficial effect.

OTA estimates that placing 200 million acres of commercial forestland into intensive management (full stocking, thinnings every 10 years, 30- to 40-year rotations) could allow wood energy use to reach 10 Quads annually while the availability of wood for nonenergy products might double its 1979 value. Alternatively, the same result might be achieved by using less intensive management on a larger acreage. The nature of any actual benefits, however, are dependent on the following considerations:

- Major effects on the availability of high-quality timber probably would not occur for a number of years. Some additional high-quality wood might be available immediately from stand conversions and harvest of noncommercial timber, and some in about 20 years from timber growth in stands that required only thinning for stand improvement. The quantities would not peak, however, before about 30 to 40 years as stands that had been cleared and replanted began to reach harvesting age, By this time, most of the old-growth stands accessible to logging already may have been harvested, al-

"M. Clawson, "The National Forests, " Science, vol 20, February 1976

[70]M Clawson, "Forests in the Long Sweep of American History, " *Science*, vol 204, June 15, 1979

though significant benefits from reducing logging pressures on other valuable or fragile lands would still be available.

- Although the increased availability of high-quality timber might negate arguments that these valuable or fragile stands *must* be cut to provide sufficient wood to meet demand, there is no guarantee that the wood made available from intensified management will be less expensive than that obtainable from these stands, and economic pressure to harvest them might continue.

Although the long-range economic goals of intensive management provide an incentive against poor environmental practices, careless logging and regeneration practices will still occur on a portion of the managed sites. Poor management may be practiced on a smaller proportion of sites than would have been the case without an expansion of wood for energy, but the effects of such management may be aggravated with such an expansion because:

- more acreage will be logged each year,
- most affected sites will have fewer years to recover before they are logged again, and
- the removal of maximum biomass and subsequent soil depletion may reduce the sites' ability to recover.

Thus, the impacts associated with conventional logging— including erosion and soil degradation, damage to water quality, esthetic damage, and other impacts–are likely to occur with even greater severity on a portion of those lands devoted to wood production for energy. Unfortunately, because of the lack of data on logging practices and the very mixed nature of the incentives for good management, it is impossible to make a good quantitative prediction of the size of this portion.

A basic— and difficult to resolve— issue concerning the wisdom of moving to a very high level of intensive management of U.S. forestland is the possibility that the long-term viability of these forests may be harmed. The possibility of soil depletion is only one aspect of this. The cycles of natural succession occurring in an unmanaged forest give that forest substantial resilience, because the diversity of vegetation and wildlife of the more mature states of the forest cycle as well as the diversity created by the heterogeneous mix of stages tend "to buffer the system against drastic change as by diluting the effects of pests on single species."" Ecologists often have argued that man pays a significant price in moving too far from this natural state:

> The whole history of agriculture, and later, forestry, is basically a continuous effort to create simplifed ecosystems in which specialized crops are kept free of other species which interfere with the harvest through competition . . . diversified systems have built-in insurances against major failures, while the simplified systems need constant care. 'z

> In relation to human needs, the human strategy can be viewed as a reversal of the successional sequence, creating and maintaining early successional types of ecosystem where gross production exceeds community respiration. Such . . . ecosystems, despite their high yield to mankind, carry with them the disadvantages of all immature ecosystems, in particular they lack the ability to perform essentially protective functions in terms of nutrient cycling, soil conservation and population regulation. The functioning of the system is thus dependent upon continued human intervention. 73

There are, of course, counterarguments to the thesis that this simplification of ecosystems places these systems under significant risk. One argument is that much of silviculture duplicates natural events, and purposely so; for example, clearcutting, sometimes followed by broadcast burning, is said to duplicate the effects of severe storms or catastrophic fires. 74 Another is that professional silviculturalists can compensate for any tendency towards a

"Smith, op cit

[72]A H Hoffman, "Comprehensive Planning and Management of the Countryside A Step Towards Perpetuation of an Ecological Balance, " *Global Perspectives on Ecology,* Thomas C Emmel, ed (May field Publishing Co , 1977)

"R Manners, "The Environmental Impacts of Modern Agricultural Technologies, " *Perspectives on Environment,* I R Manners and M W Mikesell, eds (Association of American Geographers, 1974), publication No 13

[74]Smith, op cit

decline in resiliency. In its extreme, this argument is particularly unacceptable to those who are skeptical of placing too great a faith in science:

> We ought to believe that we can excel over nature; and if we do, we should not be restricted to blind imitation of her methods . . . we have the chance to sift nature's truths, and recombine them into a new order in which not only survival, but enhanced productivity are the ruling criteria . . . (we) must look to near-domestication of our forests . . . we must move forestry close to agriculture.[75]

The strongest argument that can be made, however, is that past forestry experience has demonstrated that temperate forests can absorb an unusual amount of stress without suffering long-term damage. For example, large acreages in Europe as well as the United States that today are densely forested were intensely exploited as agricultural land in the past. In many instances, foresters can point to intensive management practices in European forests that have continued to provide high productivity of lumber for a hundred or more years. In counterpoint to these arguments, some environmentalists are worried about the future of Europe's forests and point to increasingly high external costs in terms of polluted water and increasing incidence of disease epidemics.[76] Also, insufficient data is available to indicate whether or not small but significant drops in long-term productivity may have occurred because of such past practices.

A similar argument rages about high-yield agriculture: yield levels in the Western countries have climbed steadily over the past century, with temporary setbacks that have thus far been dealt with by further adjusting the system, but environmentalists as well as many agronomists are worried about increasing numbers of pesticide-resistant insects and rising environmental costs.

Pursuit of the evidence on both sides of this argument may be worthwhile, but it is beyond the resources of this assessment. Also, the high level of emotional commitment that is attached to the alternative views of how far nature can be safely manipulated makes it unlikely that such a gathering of evidence will change many minds. However, it is at least clear that a substantial increase in intensive management must be accompanied by a thorough research program stressing examination of such critical factors as nutrient cycling, the role of soil organic material vis-a-vis resistance to tree disease, and other factors affecting system resiliency. The possibility that forest viability might be at excessive risk if hundreds of millions of acres in the United States were placed in intensive management should not be automatically rejected, even though some degree of success in such management apparently has been achieved elsewhere.

Harvesting for the Residential Market

The rapidly expanding demand for wood fuel for residential use currently is satisfied largely by harvesting of wood by homeowners and by local entrepreneurs. The high price of wood for residential use is an incentive for larger scale loggers to enter the market, and a trend in this direction probably should be expected in the future. The identity of the supplier may be an important component in determining the environmental effects of satisfying a high residential demand for wood fuel.

An expansion of the residential wood market represents an opportunity for improved forest management because of the value it places on lower quality wood, which in turn should stimulate an increase in thinning activities. The potential benefits are the same as those described for the increase in intensive management: an increase in productivity and timber value on the affected lands. This opportunity exists on woodlands ranging from small private woodlots to federally- and State-managed forests. The latter could use homeowners as a "free" work force to harvest selected trees, a practice that is already in operation in many areas.

Unfortunately, a rising demand for wood will bring with it a potential for significant

[75]G Staebler, "The Forest and the Railroad, " brochure published by Weyerhaeuser Co , December 1975

[76]Goldsmith, "The Future of Tree Diseases, " *The Ecologist*, No 4[5, July-August 1979

negative effects on woodlands. High prices for wood fuels are likely to stimulate an increased incidence of illegal cutting of wood. "Timber rustling" apparently is frequently encountered in stands of very high-quality timber such as redwood and walnut. More substantial cutting involving multiple acres at a time must be expected as wood demand grows and prices increase; remote areas, or areas where property boundaries are not well marked should be particularly vulnerable. (Illegal mining of coal may be an analogous and somewhat prophetic example. Although it takes considerable time and effort to expose and mine a coal seam, coal poaching is not at all unusual in Appalachia, and some examples involving millions of dollars worth of coal have been reported recently. Poaching timber is going to be a lot easier than poaching coal.) In areas where wood stoves are oversold or where forest products companies occasionally enter the (lower quality) wood market, temporary fuelwood shortages or price escalation may further stimulate illegal cutting, especially among poorer homeowners or those who cannot shift to an alternative fuel for space heating.

The same forces that stimulate illegal cutting, especially where coupled with ignorance of forest management, are likely to result in a variety of poor practices: improper harvesting techniques leading to damage to adjacent trees or to forest soils, incorrect tree selection, overcutting, etc.

The balance between beneficial and adverse effects of a rising demand for wood as a residential fuel is uncertain. Positive measures such as an increased availability of trained foresters to provide assistance to small woodJot owners, better dissemination of information on woodlot management, and the organization of efficent and competitive retail suppliers would help to limit adverse impacts. On the other hand, the combination of a sharply increased demand for wood coupled with a resource base that is accessible and vulnerable to illegal or poorly managed cutting appears to be virtually a guaranteed source of trouble.

Tree Plantations

The concept of an energy farm or plantation where trees are grown and harvested on short rotations like agricultural crops is a logical extension of current intensive single-aged management of forests. In fact, the growing of Christmas trees on plantations is a more intensively managed activity than an energy farm is likely to be, because the level of "management" — including pesticide and fertilizer use —will tend to increase with the unit value of the crop. In addition, a Christmas tree farmer cannot tolerate relatively minor levels of pest or drought damage because his crop value is strongly dependent on appearance, and thus he must apply pesticides or irrigation water during episodes that the energy "farmer" may be able to ignore.

The land requirements, growing needs and harvesting techniques associated with energy farms appear to be very similar to those of a large agricultural enterprise growing perennial food crops. Because of this resemblance, the environmental impacts are not treated in this section. The chapter on agricultural biomass production should provide sufficient information about these impacts.

Controlling Negative Impacts

A common theme running through reviews of silvicultural practices by the forestry establishment—the wood products industry, schools of forestry, and the Forest Service— is that these practices may have negative environmental consequences but that the consequences are readily controlled, that significant environmental damages today are the exception rather than the rule, and that in those cases where damages occur they are almost always short lived, i.e., the forest quickly recovers and normal forest dynamics are restored.

The President's Advisory Panel on Timber and the Environment reported that: 77

"Fred A Seaton, et al , Report of *the President's Advisory Panel on Timber and the Environment* (Washington, D C President's Advisory Panel, April 1973)

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> A careful review . . . revealed that most of . . . (the environmental) damage caused by logging can be avoided or minimized. Many of the fears that have been expressed are unfounded, misleading, or exaggerated, often due to extrapolation from an isolated case to forest lands in general.
>
> Properly *executed* timber harvesting and other silvicultural procedures need not result in important long-term losses of soil nutrients, deterioration of the soil, nor cause other physical environmental damage. Damage that has occurred resulted primarily from erosion associated with logging road construction and use, skidding of logs downhill or across streams, or harvesting on steep slopes where removal of vegetative cover caused slides. *With updated methods, such difficulties will become rare exceptions. Such damage as has occurred will be corrected through natural processes as the* forest grows *back.* (Emphasis added.)

The problem with statements such as these is that they do not acknowledge the current paucity of information on actual logging practices and effects. As noted in the introduction to this section, there are few credible assessments of forestry operations on a statewide or regional basis, The few that have been attempted are limited in scope; for instance, a survey of practices in Maine in support of the 208 program (sec. 208, Public Law 92-500/ Federal Clean Water Act) is limited to recording the occurrence of gullying and the use or nonuse of simple erosion controls. 78

The limited information that is available seems to indicate that the generally optimistic tone of most reviews of forestry impacts should be viewed with caution. An interesting conclusion of the Maine study was that "the area wide magnitude of the (erosion and sedimentation) problem is somewhere between the positions espoused by the industry representatives on the one hand, and groups and agencies concerned with maintaining environmental quality on the other hand. 79 The survey found that simple — and supposedly standard — erosion control techniques such as using water bars and artificially seeding erodible areas "are (done) so infrequently that the role of these convenient erosion control devices in preventing postlogging degradation of water quality is minimal at present. " [80]

Given the lack of knowledge of current forest practices and the hints of environmental problems provided by the limited data, Congress should consider both the availability of control measures and the institutional climate for putting these measures into practice *before* attempting to stimulate the increased use of wood for energy.

Control Capability

The technical capability exists to control or reduce the negative effects of logging and, more generally, of all silvicultural activities. Table 13 presents a partial list of the control methods available to the forester. Some of the more critical are:

- Site *selection/identification and possibly avoidance of problem areas.* — Because many of the environmental problems of logging are strongly site-dependent, identification of problem areas followed by revision or abandonment of logging plans is a critical environmental control strategy. Avoidance of steeply sloped sites with unstable soils is important for minimizing erosion. This often coincides with economic incentives, because the more efficient heavy equipment cannot operate on steep slopes. Geologic surveying of the site can often detect vulnerable soil/rock/ slope formations, although this capability is not fully developed. Temporary avoidance of some areas, for example, during rainy conditions, can avoid major problems of soil compaction and destruction of soil structure. Other site conditions that must be treated with special care or avoided include nutrient-deficient and thin soils, and sites in immediate proximity to lakes and streams. In the latter case, a buffer strip of smaller trees and shrubs

[78] "A Survey of Erosion and Sedimentation Problems Associated With Logging in Maine, " Land Use Regulation Commission, State of Maine, for the Maine Department of Environmental Protection, May 1979

[79] Ibid

[80] Ibid

Table 13.–Control Methods

Mitiaative[a]	Preventive
Surface protection:	***System design and maintenance:***
• Access: seeding, mulching, riprap, or mat on cut-and-fill slopes	• Access: minimize cuts and fills, roadway widths and slopes; control road density
• Timber harvest: maintenance of vegetative cover; distribution of slash	• Timber harvest: minimize soil compaction from equipment operation; use site-compatible log removal system; control harvested volume within a watershed; limit harvest on unstable slopes; shape openings for minimum esthetic impact, avoid cutting next to recreational activity areas
• Cultural treatments: seeding; planting; fertilization	• Cultural treatments: minimize reentry disturbances; fire control
Flow diversion and energy:	***Timing:***
• Access: berms above cut slopes; benches on cut slopes; checkdams in ditches; drop structure at culvert ends; water bars on road surface; flow diversion from potential mass failures or at mid-slope	• Access: closure of temporary roads; limited access; closure during adverse conditions
• Timber harvest: buffer strips; water bars on skid trails	• Timber harvest: limit operation during adverse climatic conditions; site preparations during favorable conditions
• Cultural practices: plowing, furrowing, bedding	• Cultural treatments: intensity and number of thinnings
Access design modification	

[a]Controls can be described as preventive' or "mltlgal[ve" according to the mode of applications *Preventive controls* apply to the preimplementation phase of an operation These controls involve stopping or changing the activity *before* the soil-disturbing activity has a chance to occur *Mitigative controls* include vegetative or chemical measures or physical structures which alter the response of the soil disturbing activity *after* it has occurred

SOURCE *Silviculture Activities and Nonpoint Pollution Abatement A Cost-Effectiveness Analysis Procedure* (Washington, D C Forest Service, USDA, November 1977)

along the shoreline may be sufficient to provide shading and some sediment protection to the body of water.

- Selection of harvesting system. — Control of erosion, esthetic, and other impacts can be achieved by matching the harvesting system to the site conditions. For example, the type of forest regenerated at the site can be controlled by the harvest system, because different degrees of disturbance favor different tree species. Clearcutting and residue removal favor species that need maximum disturbance to grow (e. g., Douglas fir, jack and lodgepole pine, paper birch, red alder, and cottonwood[81]) and shelterwood cutting (which leaves residual trees in sufficient numbers to shade new seedlings) favors species (such as true firs, spruces, and maples) that require light shade to thrive. The harvesting system may also be used to avoid some of the negative effects to which the site is particularly vulnerable. Clearcutting, for example, would be indicated for old, decrepit stands in which residual trees would be likely to blow down in the first severe storm following harvest. Shelterwood cutting would be appropriate for stands important to scenic views. A light selection cut may be the only harvesting allowed on soils subject to mass movement.
- *Erosion/sediment control measures.* — Although a certain amount of erosion from soil compaction and mineral soil exposure is inevitable in logging operations, it can be reduced by using lighter equipment to avoid compaction, by using overhead or *even* aerial (balloon or helicopter) log collection methods (although these methods are economically feasible only for very high-quality timber), by properly designing roads and minimizing their overall length, by mulching the site, and by a variety of other methods. Furthermore, the erosion that cannot be controlled can be prevented from damaging water quality by using buffer strips, sediment traps, and other means.

The Institutional Climate for Environmental Control

Despite the generally resilient nature of the forests and considerable scientific knowledge of forest ecology and regeneration, forest environments may be threatened in the future because certain market forces or institutional constraints discourage adequate environmental protection. These problems include a lack of expertise in the logging community, a volatile market that hinders adequate planning in

"Smith, op cit

certain segments of the industry, and a lack of sufficient incentives to practice environmentally sound management.

1. *Lack of expertise.* –Although the majority of negative impacts may occur because of failure to follow well-recognized guidelines, others occur because of failures of judgment; forest environments are extremely complex and often require expert judgment about site conditions to select correct harvesting strategies. Some important impacts can be avoided only if the logger can recognize subtle clues to the existence of vulnerable conditions. For example, many unstable soil conditions may be recognizable only to a soils expert. This type of expertise usually is not available to the small operator, except possibly where local and State governments offer preoperation inspections and guidance (e. g., in Oregon]. This poses a special problem if the residential market for wood expands considerably, because small operators may be expected to satisfy much of this new demand.
2. *Insufficient time for proper planning.* – In current mill operations in Maine, many "mill managers commonly call on short notice for a certain volume of a given type of product from the firms' logging division . . . A common result is that a considerable amount of the haul road construction is done on short notice . . . (without) . . . proper planning and correctly installed and maintained drainage structures. "[82] It is not clear that problems of this nature will be as severe for wood harvesting for energy, because demand for the wood as a feedstock may be more uniform and predictable than the demand for traditional forest products (it also is not certain that the Maine experience is widely applicable). Nonetheless, most operations will combine lumber and energy feedstock operations— removing the high-quality wood, and then clearing to harvest the remainder of the biomass for energy users. To the extent that the timing of these operations depends on the demand for the (higher value) lumber, this problem may remain.
3. *Lack of incentive.* —These are four reasons why a logger would pay strict attention to minimizing environmental damages:
   - personal environmental or esthetic idealism,
   - economic incentive,
   - regulatory controls, or
   - public relations

Idealism–and the role of education in fostering it—should not be ignored in predicting impacts and attempting to mitigate them. The strengthening of existing programs to educate potential wood harvesters about the adverse environmental effects of careless harvesting may be useful in tapping the vein of environmental idealism in the United States. Idealism is clearly insufficient to assure environmental protection, however, and more selfish incentives are needed.

The long time period needed to recoup the benefits of protective measures and the tendency of many of the benefits to accrue to adjacent landowners or the general public reduce the *economic incentive* of environmental protection. The shorter rotation periods that may be used for obtaining wood for energy may enhance the economic incentive, especially for owners of large tracts of land (because they are the "adjacent landowners"). Also, some "best management" measures do yield immediate returns to loggers, for example, measures that minimize road length or that prevent roadbeds from washing away.

Finally, to the extent that poor management of logging does long-term physical and esthetic damage to the forest, the value of forested land as a recreational and esthetic asset offers a strong incentive to the landowner to insist on sound practices. This incentive will be particularly strong in areas that have seen recent increases in market value because of their environmental value. This incentive will be effective, however, only where the landowner maintains close supervisory control over the logger.

Regulatory control of wood harvesting operations in the United States is very uneven. Although the Forest Service can exert considerable control of logging operations on Federal

[82] "A Survey of Erosion and Sedimentation Problems Associated With Logging in Maine, " op cit

lands, logging on private lands is largely uncontrolled or very loosely controlled.

The 1976 National Forest Management Act includes requirements that federally owned timber "be harvested only where soil or . . . water conditions will not be irreversibly damaged, that harvests be on a sustained yield basis, that silvicultural prescriptions be written to ensure that stands of trees will generally not be harvested until they are mature (although thinning and other stand improvement work is permitted), that clearcutting meet certain standards, and that land management plans be written with public participation."[83] The Multiple Use Act of 1960, by defining environmentally oriented uses (such as wildlife protection) as legislated uses of the national forests, requires management practices in these forests to consider environmental protection as a direct requirement. In response to these mandates, the Forest Service enforces strict standards for harvesting lumber on Federal lands.

The degree of control exerted on non-Federal forests — especially privately owned forests — is noticeably weaker. Water quality impacts from wood harvesting theoretically should be regulated through the development of nonpoint source control plans under section 208 of the Federal Water Pollution Control Act. As discussed in volume 1, however, implementation of section 208 generally has been disappointingly slow, and the eventual effectiveness of the 208 plans is highly uncertain. Also, few States have comprehensive forest practices legislation or the manpower to enforce such legislation. A major problem facing States wishing to control forest practices is the complexity and site-specific nature of the environmental impacts, forcing the difficult choice of using either a substantial force of highly trained foresters enforcing loosely written performance guidelines or else a more (economically) manageable agency enforcing rigid — and perhaps impractical — rules. This problem is discussed with insight in Brown 1976:[84]

> The difficulty is that rules specific to the wide variety of situations encountered would often be difficult to write and cumbersome to enforce for a great many problem areas, particularly within the context of our present state of technology. Field personnel recognize the dilemma of rules so vaguely written that they provide no control versus rules so specific that they prohibit flexibility and prevent forest practice officers and operators from adjusting methods to meet complex or highly varying situations. Given the option, most field people prefer to have flexibility at the risk of losing some control.

Finally, many State forestry agencies have concentrated their attention on forest fire prevention and control and not on forest management. Hence, the experience, interest, and expertise of present State forestry personnel may not provide a good base on which to build a strong management-oriented program.

The public's increasing awareness of environmental problems and willingness to act may serve as a strong incentive for the larger forest products companies to consider the public *relations implications* of their decisions. Companies like Weyerhaeuser spend large sums of money explaining their activities in sophisticated advertisements; presumably, this awareness of the importance of public approval affects their decision making and operations.

Potential Environmental Effects—Summary

The use of wood as an energy feedstock holds considerable potential for reducing the adverse impacts associated with fossil fuel use. It also offers the potential for some important environmental benefits to forests, including:

- decreased logging pressures on some environmentally valuable forests;

[83] *Environmental Readiness Document, Wood Commercialization*, op cit.

[84] Brown, et al, *Meeting Water Quality Objectives Through the Oregon Forest Practices Act*, (Oregon State Department of Forestry, 1976)

- improved management of forests that have been mismanaged in the past, with consequent improvements in productivity, esthetics, and other values; and
- reduced incidence of forest fires.

There is considerable uncertainty, however, about the extent to which a significant increase in the use of wood for energy will actually result in these benefits and avoid the negative impacts that could also accompany such an increase. There are important economic incentives for good management, including increased production of high-value timber and avoidance of losses in land values. There are a number of factors, on the other hand, that must be interpreted as warning signals:

1. Environmental regulation of forestry operations, especially on private lands, generally is weak or nonexistent.
2. Some of the existing economic incentives may induce cutting of vulnerable lands or neglect of best management practices.
3. Important gaps in the knowledge of the effects of intensive silvicultural activity— for example, of the nutrient and organic matter changes in the soil caused by whole-tree logging — may deter environmentally sound choices from being made.
4. The complexity and site-specificity of the harvesting choices that "must be made may complicate adoption of environ mentally sound harvesting plans, especially by small operators.

If careful environmental management is not practiced, the result might be:

- increased erosion of forest soils and consequent degradation of water quality,
- significant losses in esthetic and recreational values in forested areas,
- possible long-term drop in forest productivity,
- decline in forested area, and
- reduction of forest ecosystem diversity and loss of valued ecosystems and their wildlife.

Because the quality of forest management and the capacity for environmental regulation currently span the entire range from very low (or nonexistent) to high, the expected result of a "business as usual" approach to wood-for-energy environmental management would undoubtedly be a complex mix of the above impacts and benefits —with the marketplace determining the balance between positive and negative effects. Government action — including improved programs for local management assistance, increased research on the effects of intensive management, and increased incentives (economic or regulatory) for good management — may be capable of shifting this balance more towards the positive.

R&D Needs

The primary R&D needs in the area of wood supplies from forests fall into the categories of harvesting technology, growth potential, environmental impacts, and surveys. Traditional harvesting technologies are geared toward removing large pieces of wood in a way that is appropriate for lumber or paper pulp production. The wood that can be harvested for fuel, however, is considerably more varied, involving brush, rough and rotten timber, and the smaller pieces associated with logging residues. Although the whole-tree chip method seems to work well on relatively flat land, there is a need to develop low-cost techniques and equipment for harvesting smaller pieces of wood and brush on more varied terrains and at greater distances from roads.

Most research into forest growth potential is aimed at producing large straight trees suitable for the traditional forest products industry. Although some of this is research applicable to the production of wood for energy, the conditions and techniques for enhancing commercial timber growth are not the same as those for enhancing total biomass growth. As an example, thinning of tree stands reduces the total leaf surface and, with it, the amount of sunlight that is being captured by plants. This reduces the total biomass growth on the stand, although it tends to increase the growth of commercial timber. If a strong wood energy market develops, the ideal forest composition could involve a mix of tree types, sizes, and qualities. Various strategies for achieving integrated and economical energy-commercial timber operations need to be investigated. Tree hybrids, for example, should be developed with both commercial timber production and biomass production as dual goals.

There are a number of uncertainties regarding the environmental impacts of increased logging for energy. The nutrient balance in forests, as noted, needs to be better understood in order to better define the types and quantities of wood that can be removed without depleting the soil's nutrients. The effects of high biomass removal on soil carbon content and any subsequent long-term impacts on productivity or on forest viability require considerable research. The relationship between the diversity of tree and understory species in a forest and the forest's resilience to environmental stresses must be better understood before highly intensive management is allowed to expand to a majority of the commercial forest acreage. Alternative harvesting techniques such as strip cutting (or the cutting of strips of trees through the forest rather than clearcutting a large area) should be pursued in order to provide a repertoire of techniques that can be used where soil erosion may be a problem, such as in steeper slope terrains. Harvesting techniques that decrease the degree of soil compaction should also be developed. Furthermore, the entire forest ecosystem needs to be better understood if the environmental impacts of various types of forest activities are to be appropriately managed.

The national forest survey is primarily intended as a survey of commercial timber. The assumptions as to what is commercial should be separated from the survey of the biomass inventory and growth potential, in order to have an accurate assessment of the quantities available for all uses. The survey should incorporate noncommercial forest lands which are classified that way because of low growth potential.

A thorough assessment of the energy potential of the forests should also include a qualitative assessment of the conditions of the stocking on forestlands and the silvicultural activities (e. g., stand improvements) that could be carried out to increase the yield. The survey data should include environmental conditions such as soil types, rainfall, and other parameters. Finally, the size of tract is an important factor affecting the availability of the wood. Consequently, the farm and miscellaneous forest landowner classifications in forest surveys should be subdivided according to tract size and ownership.