take that is not being made by the other major industrial countries, whether exporters or importers. While most bilateral research, development, and education programs have as their central purpose the advancement of the recipient country, many of the best of these foster the mutual interests of the two countries involved.

Summary

The United States has a large potential capacity for increasing the supply of renewable materials that could substitute for scarce nonrenewables or for renewables in foreign jurisdictions. It has not elected to give high priority to this development. If such a goal were viewed as a desirable national policy, several actions would be indicated. The national forest survey could be improved to provide a better basis for assessment of current reserves and long-term production capacity. Federal and state land use policies could emphasize the importance of encouraging materials production on the most productive forest sites. The research needed to improve product yields from renewable raw materials and to advance cost-effective technologies could be encouraged at government laboratories and in the universities pursuing these lines of research.

Given the possibilities of sudden change in resource price and availability on the world market, it would be prudent for the nation to improve its options for substitution of domestic renewable materials for foreign nonrenewable materials. Rapid substitution is not feasible if the essential foundation in science and technology has not been fostered in advance.

References and Notes

1. E. P. Cliff, *Timber the Renewable Material*, report to the National Commission on Materials Policy. (National Commission on Materials Policy, Washington, D.C., 1973).
2. Committee on the Survey of Materials Science and Engineering, *Materials and Man's Needs* (National Academy of Sciences, Washington, D.C., 1974).
3. *Materials Needs and the Environment Today and Tomorrow* (National Commission on Materials Policy, Washington, D.C., 1973).
4. *The Principal Laws Relating to the Establishment and Administration of the National Forests and to Other Forest Service Activities* (Handbook No. 20, Department of Agriculture, Washington, D.C., 1964).
5. U.S. Forest Service, *The Outlook for Timber in the United States* (Department of Agriculture, Washington, D.C., 1973).
6. *Report of The President's Advisory Panel on Timber and the Environment* (Government Printing Office, Washington, D.C., 1973).
7. J. S. D. Richardson, *Aust. For.* **37** (1974).
8. Public Land Law Review Commission, *One Third of the Nation's Land* (Government Printing Office, Washington, D.C., 1970).
9. *1971 Yearbook of Forest Products* (U.N. Food and Agricultural Organization, Rome, 1973).
10. G. S. Nagle, paper presented at the 66th Western Forestry Conference, Vancouver, 1975.
11. J. J. Solecki, paper presented at the 66th Western Forestry Conference, Vancouver, 1975.

Timber: Biological and Economic Potential

Stephen H. Spurr and Henry J. Vaux

Forests are estimated to cover 33 percent of the land surface and 10 percent of the total surface of the earth. In terms of the world net primary production, they account for 67 percent of all dry matter production on land and 45 percent of the total produced on both land and water (*1*).

If we define as timber the merchantable stems or boles of trees in the forest at least 5 inches (12.7 centimeters) in diameter at breast height, including all the wood above a 1-foot stump and extending up to a 4-inch top (this is the definition of roundwood used in the forest survey of the U.S. Forest Service) it would appear that approximately half of the total biomass produced by the forest is timber (*2*). Roughly 20 to 25 percent of all photosynthetic matter produced on earth is accounted for by this one product.

From a biological point of view, timber (or more strictly speaking, wood) as a renewable natural resource has great potential. From an economic point of view, however, many factors operate to reduce the use of wood and indeed the use of forested land to produce wood under intensive management. These are the subjects of this article.

The overall biological potential of the forests of the United States can be most simply expressed in terms of the area of land devoted to the growing of trees to be utilized as wood or timber and the average growth of wood per unit area under different intensities of management. The total productive potential is the product of the two. Economic and institutional considerations will determine in large part that portion of the potential forest acreage that will actually be utilized and the degree of management intensity that will in fact be practiced.

Area of U.S. Commercial Forest

One-third of the land area of the United States or 754 million acres (305×10^6 ha) was classified as forest land in 1970 (*3*), of which two-thirds or 500 million acres (202×10^6 ha) is commercial timberland according to the definition established by the U.S. Forest Service. This provides that such lands are capable of growing at least 20 cubic feet of timber per acre per year (1.4 m^3 per hectare per year) and are not legally withdrawn from the possibility of timber harvesting (such as wilderness area) (*4*). The definition is thus in part biological in that it is based upon potential growth per unit area and in part legal in that it excludes productive land legally withdrawn from use. It is in no sense economic, and thus the term "commercial" is a misnomer.

The commercial forest base of 500 million acres will change as a result of additional withdrawals of forest land, clearing of forests to convert land to agricultural use, abandonment of agricultural land to forest use, and clearing of forests to convert land to urban or industrial use.

Some 20 million acres (8×10^6 ha) of productive timberland is currently used for parks, wilderness, and other purposes not compatible with the harvesting of trees for timber. Substantial political pressures currently exist to withdraw additional forested lands from timber production. At present there are some 12.3 million acres (5×10^6 ha) in the National Wilderness Preservation System, 93 percent of which is in the national forests and much of which would not be classified as commercial forest because of the slowness of growth.

The area of formally designated wilder-

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ness will undoubtedly increase. As of July 1975, 112 proposals for additional wilderness covering 26 million acres (10.5×10^6 ha) were before Congress, while 316 other areas totaling in excess of 13 million acres (5×10^6 ha) were under study by the National Park Service and the Forest Service (*4*). Alternative goals being considered for Forest Service's Renewable Resource Program range from a total National Forest Wilderness target of 17.3 to 41.0 million acres (7×10^6 to 17×10^6 ha). If this system were expanded to 28.5 million acres (11.5×10^6 ha), and if half of the withdrawals were from commercial forest land, somewhere in the neighborhood of 8 to 9 million acres (3 to 4 million ha) would be withdrawn from our commercial forest land base. Wilderness designations within the national parks would not affect this base because these lands had already been classified as nonavailable for timber harvesting. On the other hand, there are very real possibilities that additional lands will be purchased by the federal government in the eastern United States for use as national wilderness, adding up to a loss of perhaps 10 million acres. This, added to the 5 million acres in the Rocky Mountains discounted because of inaccessibility (*3*), reduces the effective commercial base forest to 485 million acres (196×10^6 ha).

Marginal lands continue to move from forest to agriculture and vice versa. The Forest Service (*5*) estimates that from 1962 to 1970, 3 million acres (1.2×10^6 ha) of former agricultural land was converted to forest in the mid-Atlantic states while 7 million acres (3×10^6 ha) of forest was cleared, largely for farming, in the South. There, much clearing of commercial timberland for soybean and other crop production has taken place in recent years on the floodplains of the Mississippi and other rivers. In addition, extensive areas of forest uplands were converted into pasture. If the net loss of timberland to farming has been approximately 4 million acres in 8 years, we project, over the next five decades, a loss of 20 million acres (8×10^6 ha) of forest, presumably all of it classified currently as commercial timberland.

Finally, in all regions of the United States, sizable areas of forest lands have been lost to suburban development, highways, rights-of-way, reservoirs, and other nontimber uses. We estimate a total loss of 10 million acres from these sources over the next 50 years.

Add these two sources together and we project that the commercial timberland base would be further reduced to 455 million acres (184×10^6 ha) by approximately the year 2020. The comparable U.S. Forest Service projection is 475 million acres by 2020 (*3*). In addition, as discussed below, substantial acreages classified as commercial forest land will not in fact be used to grow timber for commercial use because the owner either does not wish to or cannot profitably manage his land for that purpose.

Expected Changes in Forest Productive Potential

Since the future productivity of the forests of the United States is estimated by multiplying the area of commercial forest land by the expected mean growth or increment per unit of area, the question naturally arises as to the effect that the reduction of the commercial forest area from 495 million acres to 455 million acres will have on the mean productivity of these lands. In its national forest survey (*3*), the U.S. Forest Service recognizes five site classes or productivity classes of land according to the potential mean annual increment of the native forests if they fully occupied the site. More precisely, site is categorized by the mean growth in cubic feet per acre per year at culmination of mean annual increment. Site class I consists of land capable of growing, per year, 165 cubic feet per acre (11.6 m^3/ha) or more; site II, 120 to 165 cubic feet per acre (8.4 to 11.6 m^3/ha); site III, 85 to 120 cubic feet per acre (6.0 to 8.4 m^3/ha); site IV, 50 to 85 cubic feet per acre (3.5 to 6.0 m^3/ha); and site V, 20 to 50 cubic feet per acre (1.4 to 3.5 m^3/ha). Since there is much more poor than good site land, the average potential productivity of the current commercial forest land base is estimated to be 74 cubic feet per acre per year (5.2 m^3 per hectare per year), a figure well within site IV.

Of the 40 million acres estimated to be withdrawn from the commercial forest land base, the 10 million acres withdrawn for wilderness and similar purposes will be predominantly from the lower sites, since the terrain desired for this use, picturesque unroaded land in mountainous and hilly country, generally has relatively low timber growth potential. On the other hand, the 20 million acres estimated to be withdrawn from the commercial forest land base for agricultural purposes will be predominantly from the better sites. They will not be from site I forest lands, for these are primarily located in the Pacific Northwest and are under relatively little pressure for conversion to agricultural land, but they will be from site II and III forest lands in the southern states, much of which are presently covered by bottomland hardwood forest. Withdrawals for nonagricultural use such as for suburban development and rights-of-way will be generally unrelated to site quality. These lands thus are presumed to average near the present mean in terms of forest productivity. The net result of these withdrawals for wilderness and recreation, agriculture, and development thus may be a slight reduction in average productivity of the lands classified as commercial forest in 2020. In our rough model, we assume an average growth in 2020 of 71 cubic feet per acre per year (5.0 m^3 per hectare per year).

Yield of U.S. Commercial Forest

The current net annual growth of the 495 million acres presently classified as commercial forest in the United States is estimated by the U.S. Forest Service (*3*) to be 38 cubic feet per acre (2.7 m^3/ha). Multiplying the mean annual increment by the area to which it applies gives a current estimate of net growth of 18.6 billion cubic feet per year (530×10^6 m^3/year) for the United States as a whole.

Volume data can be approximately converted into dry weight equivalents on the basis of 27.4 pounds per cubic foot (438 kg/m^3) for softwoods (gymnosperms such as pine, spruce, and fir) and 32.8 pounds per cubic foot (525 kg/m^3) for hardwoods (angiosperms such as oak, maple, birch, and aspen). The conversions are based on green volume and oven-dry weight. On the basis of the present mix between hardwoods and softwoods, the conversion factor is 29 pounds per cubic foot (467 kg/m^3) for all species.

In its recent study (*3*), the U.S. Forest Service has projected the growth of forests at 10-year intervals to the year 2020 by assuming a continuation of 1970 levels of forest management (*3*)—that is, that silvicultural treatments of the forest will maintain the levels of the late 1960's in terms of acreage treated and dollars expended. The cultural practices include forest fire control, insect and disease control, planting and natural reforestation, timber stand improvement, fertilization, assistance to private landowners, research, and road construction.

Under these assumptions, the acreage of commercial forest land is projected to drop from 500 million acres (202×10^6 ha) in 1970 to 485 million acres (196×10^6 ha) in 2000. Net growth per acre per year is expected to increase from a present 38 cubic feet per acre (2.7 m^3/ha) to 41 cubic feet per acre (2.9 m^3/ha) by 2000, an increase of 8 percent. The total net growth of the U.S. forests would then rise from a present 18.6 billion cubic feet (530×10^6 m^3) to 19.6 billion cubic feet (555×10^6 m^3) by 2000, an increase of about 5 percent.

Since these projections assume a continuation of 1970 levels of management, it follows that the increased production per acre is presumed to arise from such factors as the conversion of slow-growing old-growth timber to faster-growing young-growth, and from improvement of stocking from continued planting and natural regeneration.

The U.S. Forest Service estimates potential productivity of forest lands through the use of normal yield tables which give the estimated volume of even-aged forest stands that fully occupy the ground at a given age and on a given site quality. On this basis, the potential growth of U.S. commercial forest lands is 74 cubic feet per acre (5.2 m^3/ha), or 95 percent greater than the present average net annual growth.

The normal yield table approach, however, has distinct shortcomings. First, it assumes that forests are managed as even-aged stands and does not adequately assess potential growth of stands managed on an uneven-aged basis. Second, yield tables are often developed from measurements of temporary sample plots which are subjectively chosen as appearing as fully stocked as possible; this introduces an element of bias as well as the possibility that a younger stand so chosen will not necessarily develop into the same dimensions as an older stand. Yield tables do not predict adequately the growth of stands that are stocked less or more than the "normal" plots. Most American normal yield tables do not provide an adequate basis for estimating the growth of managed stands. Managed stand yield tables derived from the repeated measurement of permanent sample plots, are greatly needed to supplant the current yield tables for unmanaged stands derived from data on subjectively chosen temporary sample plots.

The Forest Service estimate that the potential growth of U.S. forests is 95 percent greater than the current growth is also suspect because of the estimation method. Current growth is estimated by stand-table projection methods involving the measurement of the width of growth rings taken through increment cores and correction of gross growth estimates thus obtained to net growth through estimates of future mortality, the latter being a low precision procedure at best. Differences between the growth estimates thus derived and estimates of forest productivity obtained through the use of yield tables may be due in part to differences in methodology.

Nonetheless, we know that potential growth is much greater than current growth. Much of the western commercial forest land is still covered with old-growth forests for which net growth is negligible because the rate of mortality approximates the rate of wood growth in the surviving trees. In addition, over 20 million acres (8×10^6 ha) of our commercial forest lands are currently without trees, and much of the remainder is only partially stocked with trees.

Actual yields over large areas will never reach the level predicted from carefully selected sample plots. Inevitably, holes in the forest canopy will be created by rocky or wet spots on the ground, by the death of occasional trees that cannot be harvested, by the random presence of slow-growing species, and by human occupancy and use. In Sweden, actual yield under intensive management has been estimated at 90 percent of that estimated from yield tables (*5*). Lacking similar data in the United States, we may use this figure for an approximation.

Bearing these limitations in mind, we take 90 percent of our 2020 estimate of 71 cubic feet per acre as our first estimate of the potential net productivity of U.S. forests. For a forest land base of 455 million acres, a growth of 64 cubic feet per acre will yield an annual biological production of 29.1 billion cubic feet per year (820×10^6 m^3/year). This is the estimated growth of stem wood merchantable by current standards if all commercial forest land were fully stocked with an even distribution of age classes, these stands were harvested at the culmination of mean annual increment, and there were no thinning or other cutting in the forest before the final clear-cutting of the even-aged stands. In short, it is a rough estimate of the maximum net growth possible from American forests if they were managed only to be as fully stocked as possible.

Obviously, we have the capability of applying known silvicultural techniques to substantially increase the harvestable growth of our forests. The potential biological productivity of U.S. forests under intensive management has been assessed in broad terms on a countrywide basis (*6*). In this recent study, it was assumed that intensive management would involve practicable but not necessarily economically profitable programs for (i) site improvement through fertilization, drainage, and irrigation; (ii) conversion of existing slow-growing inferior forests to faster-growing forest types; (iii) improvement of stocking through reforestation; (iv) introduction through planting of genetically faster-growing trees; (v) stimulation of growth of desired species through weeding back of competing trees; (vi) recovery of a larger share of the gross growth through thinnings to salvage trees before they die; and (vii) reduction of losses from fire, insects, and diseases through better forest protection.

The gains in forest productivity through the widespread application of the above silvicultural practices are substantial. In terms of percentage increment nationwide, they are summarized as follows.

The practicability of applying nitrogen fertilizers in the Pacific Northwest and of coupling potash fertilization with drainage of wet pinelands in the South has been amply demonstrated. If 10 percent or 50 million acres of commercial forest land can be similarly treated to increase growth by 15 percent, the average growth on all forest lands would be increased by 1.5 percent.

Conversion of existing forests to suitable faster-growing types also would result in increased forest productivity. If we assume that 30 million acres of slower-growing hardwoods were to be converted by clear-cutting and planting with faster-growing southern pines, Douglas fir, and other conifers, and predict an increased yield of 50 percent in such cases, the average net gain would be 3 percent for the commercial forests as a whole.

Major gains from improved genetic selection apply only to species, primarily conifers, that are managed by clear-cutting and planting. If we project that 30 million acres will be converted from hardwoods to softwoods, 20 million acres of nonstocked land will be afforested, growth of Douglas fir and other conifers will continue on 30 million acres in the Pacific Northwest, and growth of southern and eastern pines will continue on 70 million acres, 150 million acres would be available for planting with genetically improved stock. If this conversion were scheduled over a 50-year period, 3 million acres could be so forested each year. With a postulated growth gain of 1 percent per year, the net growth improvement would be 7.5 percent for U.S. forests as a whole.

Intermediate treatments such as weeding to provide adequate growing space for the desired tree species and thinning to salvage trees that would die so as to concentrate the growth on the most desirable stems can be expected to produce harvestable yield increases of 25 percent.

In 1970, the net annual growth of our commercial forests was 18.6 billion cubic feet, or 80 percent of what it would have been were it not for an estimated mortality in the same year of 4.5 billion cubic feet. In its recent report (*3*), the Forest Service projects a continued 20 percent loss from mortality. It seems reasonable that this loss could be reduced to 15 percent with more intensive protection against losses from fire, insects, and disease.

A realistic level of forest productivity under widespread intensive management can be estimated by beginning with the Forest Service projection for potential growth computed from yield tables and adding or subtracting the following:

Holes in the forest canopy	−10 percent
Fertilization and drainage	+ 1.5 percent
Conversion of forest type	+ 3 percent
Genetic improvement	+ 7.5 percent
Weeding and thinning	+25 percent
Mortality losses	−15 percent

The potential growth for 2020 of 71 cubic feet per acre per year would thus be adjusted upward by 7.5 percent ($0.90 \times 1.015 \times 1.03 \times 1.075 \times 1.25 \times 0.85$) to 76 cubic feet per acre per year (5.3 m^3 per hectare per year).

For a commercial forest land base of 455 million acres, therefore, the potential productivity of U.S. forests would be 34.6 billion cubic feet per year (980×10^6 m^3/year). This would be approximately twice the present net growth and two and one-half times the current (1970) net removals of 14 billion cubic feet. This estimate represents the maximum biological productivity of American forests if present levels of silvicultural technology were widely practiced. It could not be attained until approximately 50 years after the initiation of such practices at the levels indicated. Policy and economic considerations to be discussed below will inevitably limit the attainment of this biologically feasible potential.

The estimated nationwide potential net growth of 80 cubic feet per acre of commercial forest land per year is for the merchantable portion of the stem only. Were the stump, top, bark, and branches of the trees in the forest to be utilized at time of harvest as well, the yield of forest products would be increased by approximately 40 percent. Thus the potential yield would be approximately 110 cubic feet per acre per year (8 m^3 per hectare per year), a volume that would produce about 3200 pounds (1450 kg) of biomass dry weight per acre per year.

Restraints on Use of Commercial Forest

We noted above that some forest covered land is excluded from classification as commercial forest either because of low natural productivity or by legal withdrawal. Now some additional economic and institutional restraints on attaining full biological potential must be noted.

The *economic* potential for timber growing is limited by the fact that on sites of lesser productivity the real cost of growing wood may exceed the real value of the wood produced. Where this is the case, whether on public or private land, any expenditure to grow trees will be socially wasteful. Thus, some areas which have significant biological potential for wood production are economically submarginal for such production in the light of prospective conditions of wood demand and supply. Precise identification of the economic margin for timber growing is surrounded by a great deal of uncertainty. Since marginality depends on the market value of an output which will only be marketable after several decades, identification of the margin depends on an estimate of what demand for timber will be a great many years in the future—an estimate beset with uncertainty about future levels of population and income, long-term changes in tastes, technology, the availability of substitutes, and a wide array of other factors.

Despite these uncertainties, both the logic of determining the nation's economic potential for timber growing and the practical necessity of deciding where and when to grow wood requires that future wood markets with all their uncertainties be assessed, albeit with caution. Under congressional directive, the U.S. Forest Service has conducted repeated studies of the outlook [for example, (*3, 7*)]. In general, these timber-demand projections have stood up well both in comparison with independent analyses of others and, in the case of some of the older efforts, with actual realizations at termination of the forecast period. Thus, use of such projections as a basis for estimating economic potential is warranted, provided one recognizes the uncertainty inherent in them.

The most recent Forest Service study estimates a market for industrial roundwood in the United States in the year 2020 of about 28 billion cubic feet (790×10^6 m^3) if 1970 prices were still to obtain (*5*). This represents a little more than a doubling of demand for wood over the next 50 years. (Since this is a projection of ***demand*** and since prices of wood are generally expected to rise significantly, it should not be inferred that *consumption* of wood is likely to double.) The price elasticity of long-run demand for wood products has been little studied but seems likely to lie in the range −0.5 to −0.75 (*8*). Using assumptions consistent with this view of the demand outlook, three recent studies have explored the economic potential in various forest situations. Vaux (*9*) found that, with some variations due to species, site productivity class V was submarginal in California, as were the more costly portions of class IV. A comparable conclusion would follow from Clawson's work on the Pacific Northwest and the South (*10*). Similarly, Montgomery *et al.* (*11*) found that with relatively intensive forest plantation management in Georgia, timber-growing investments on site V land would, in most cases, be unlikely to yield returns sufficient to cover costs.

In light of these evaluations, perhaps 15 percent of the aggregate biological potential for wood production (that on site V and low site IV land) is submarginal for economic production at least in relation to a 50-year future time horizon. (This may not mean, however, that all of this 15 percent is lost to society. Most forest land, even if it is of the poorest productivity, and is not under any form of economic timber management, will produce some wood provided only that it receives effective protection against wildfires and pest epidemics. Since such land is likely to receive this kind of protection in order to maintain its nontimber values, a modest fraction of the wood potential from submarginal timber growing land may well be available.) We conclude that the economic potential for wood growth under the management regimes outlined earlier is 29.4 billion cubic feet per year (830×10^6 m^3).

The extent to which this economic potential will be realized depends on the attitudes and intentions of the forest owners and on the institutional environment in which they make their management decisions. There are more than 4 million such owners in the United States (*7*), with widely divergent ownership objectives and substantially differing degrees of managerial effectiveness. Full economic potential is most likely to be realized on lands owned by forest products industries. Land in industry holdings comprises 17 percent of such potential. An additional 25 percent is in various forms of public ownership, two-thirds of which is in the National Forest System. Most public forest land having economic potential for wood production is managed under the multiple use policy, which means that realization of portions of the wood-growing possibilities may be deliberately foregone in order to maintain alternative forest values such as recreation. Any present judgment as to the magnitude of this impact is highly speculative. On a number of western national forests, 40 to 55 percent of the commercial forest land currently is managed for objectives which limit full realization of the economic potential for timber. Due to these constraints from competing land uses, perhaps 75 percent of that potential might be attainable in the future on the public forests.

The bulk of the economic wood-growing potential (58 percent) is on private nonindustrial ownerships. Such ownerships defy generalized description because of wide variations in ownership intents, size of holding, and managerial skill (*12*). Forest Service estimates in 1973 indicate that only about 5 percent of these ownerships are intensively managed for timber growing, that about 15 percent are held for purposes generally incompatible with timber growing, and that on the remaining 80 percent wood-growing potential is at present being only partly utilized. The extent to which such utilization may improve in the future will depend largely on economic and institutional factors to be mentioned below. Without future improvement in these factors we would expect farm and miscellaneous ownerships actually to realize little more than the 49 percent of total potential they were achieving in 1970. In the absence, then, of substantial economic and institutional change, practically realizable yields within the 50-year time horizon appear to be constrained to 19.0 billion cubic feet (540×10^6 m^3). Although this figure is more than a third higher than the 1970 levels of removals, it is only two-thirds of the level of consumption to be expected if real prices of wood remain constant. Hence, future continuation of the historic rising trend of real prices of wood is generally expected.

The prospect of such price rises could conceivably lead to fuller realization of economic potential on farm and miscellaneous ownerships, to significant further intensification of management on industrial forests, and to some shift in public forest management objectives toward greater emphasis on timber growing, at least on the better sites. As we have seen, there is room within the constraint of economic marginality to meet the prospective 50-year demand expansion fully, provided price prospects stimulate the necessary timber-growing response. If they do not, actual realization of substantially higher prices will serve to constrain consumption and hold it close to the level of 19 billion cubic feet (540×10^6 m^3). Which of these outcomes is realized will depend largely on what public forest policies are pursued during the next two or three decades and how those policies influence the long-term timber-growing efforts of various classes of forest owners. The possibilities may be suggested by outlining two alternative scenarios from among the innumerable possible ones.

A scenario which assumes continuation of present forest policies would lead to levels of wood consumption at the end of 50 years on the order of 19 billion cubic feet, accompanied by real prices for industrial roundwood at perhaps twice present levels. The social costs of such an outcome would have to be measured both in terms of the resultant higher costs for wood-based consumer goods and in terms of expanded use of wood substitutes. Such substitutes are derived mainly from nonrenewable resources, chiefly metals and plastics. There is at least some evidence that many such substitute materials may have higher energy requirements and have more serious environmental impacts associated with production of a given utility than those associated with production of the same utility from wood. These considerations suggest the wisdom of a forest policy looking toward fuller utilization of the economic wood potential.

A second scenario could result from public policy changes designed to stimulate fuller utilization of existing economic potential for timber growing. More intensive timber management will require large amounts of capital. Forest Service preliminary studies have identified capital investments needed for such intensification ranging from \$40 to \$80 per acre, with associated increases in yield of 75 to 125 cubic feet per acre treated. Thus, to raise output 50 years hence by 1 billion cubic feet (28×10^6 m^3) would require new timber-growing investment in the near future on the order of \$600 million. A major source of underutilization of productive potential on both national forests and farm and miscellaneous ownerships has been lack of an adequate level of capital investment. In the national forest case, the needed appropriations of federal funds simply have not been made. Inefficient size of ownership, meager access to capital, uninsurable risks, and adverse local tax systems are among the significant deterrents to forestry investments on nonindustrial private ownerships. Policy changes in these areas leading to expansion of forestry investment by \$2 billion to \$3 billion over the next two decades would increase wood yields 50 years hence by 3 billion to 5 billion cubic feet. This would moderate the expected wood price rise to perhaps a 50 percent increase. The social costs of this alternative would be in the form of alternative investment opportunities foregone from commitment of the additional \$2 billion to \$3 billion to forestry and probably some modest reduction of recreational and amenity values on public lands.

Conclusion

The preceding assessment may be recapitulated in terms of the following estimates:

Biological potential from fully stocked stands, 29.1 billion cubic feet per year (820×10^6m^3/year).

Biological potential with more intensive management, 34.6 billion cubic feet per year (980×10^6 m^3/year).

Economic potential under more intensive management, 29.4 billion cubic feet per year (830×10^6 m^3/year).

Economic potential under existing institutional constraints, 19.0 billion cubic feet per year (540×10^6 m^3/year).

Future domestic demand for wood falls somewhere between the last two of these estimates. Whether consumption 50 years hence will be close to the higher or to the lower estimate will depend on what forest policies are pursued, particularly over the next two or three decades. Prompt adoption of policies designed to stimulate timber-growing investment on a very substantial scale could result in more moderate increases in wood prices accompanied by future consumption levels in the neighborhood of 28 billion cubic feet (790×10^6 m^3). In the absence of such a stimulus to investment, future consumption is unlikely to exceed 19 billion cubic feet (540×10^6 m^3) with real wood prices double their present level. Achieving the higher of these two levels will involve large capital investments and consequent costs in terms of the other programs foregone plus at least a modest sacrifice of some recreational and amenity values. The lower alternative involves significant social costs in terms of higher prices of wood products to consumers, lower levels of product consumption, and significant substitution of nonrenewable materials (with potentially higher energy requirements) to provide consumer utilities which could, under the alternative policy, be readily supplied by wood.

References and Notes

1. R. H. Whittaker and G. M. Woodwell, in *Productivity of Forest Ecosystems* (Unesco, Paris, 1971), pp. 169–175.
2. S. H. Spurr, Geo. S. Long Lecture delivered at the University of Washington, 1975.
3. U.S. Forest Service, *The Outlook for Timber in the United States* (Department of Agriculture, Washington, D.C., 1973).
4. Excludes all forest land in the interior of Alaska as well.
5. U.S. Forest Service, *The Nation's Renewable Resources—An Assessment* (Department of Agriculture, Washington, D.C., 1975).
6. Unpublished report of panel I, Committee on Renewable Resources for Industrial Materials, National Research Council.
7. U.S. Forest Service, *Timber Resources for America's Future* (Department of Agriculture, Washington, D.C., 1958).
8. R. J. Marty, in *Report of the President's Advisory Panel on Timber and the Environment* (Government Printing Office, Washington, D.C., 1973), pp. 129–140.
9. H. J. Vaux, *J. For.* **71**, 399 (1973).
10. M. L. Clawson, *Forest Policy for the Future* (Resources for the Future, Washington, D.C., 1974).
11. A. A. Montgomery, V. L. Robinson, J. D. Strange, *Georgia's Forest: An Economic Outlook* (Georgia State University, Atlanta, 1974).
12. J. A. Zivnuska and H. J. Vaux, in *Perspectives on Prime Lands* (Committee on Land Use, Department of Agriculture, Washington, D.C., 1975).
13. The views on potential biological productivity of U.S. forests are those of S.H.S., but helpful input is acknowledged from G. R. Staebler, Weyerhaeuser Company; R. E. Buckman, U.S. Forest Service; and others who collaborated in the NAS-NRC CORRIM panel I study.