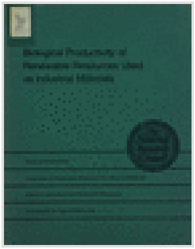

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RENEWABLE RESOURCES FOR INDUSTRIAL MATERIALS

Biological Productivity of Renewable Resources Used as Industrial Materials

A Panel Report for

the Committee on Renewable Resources for Industrial Materials
Board on Agriculture and Renewable Resources
Commission on Natural Resources
National Research Council

National Academy of Sciences
Washington, D.C. 1976

NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard to appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This report has been prepared by an ad hoc advisory panel of the Committee on Renewable Resources for Industrial Materials, Board on Agriculture and Renewable Resources, Commission on Natural Resources, National Research Council.

This study was supported by the National Science Foundation.

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FOREWORD

Potential problems from changes in patterns of materials supply or use are causing concern: the current emphasis is on mineral or nonrenewable resources. The Science and Technology Policy Office (STPO), in support of Dr. H. Guyford Stever, the Science Advisor to the President, requested the National Academy of Sciences (NAS) to reexamine the role of renewable resources, as the other major component of natural resources, in helping to better meet needs for materials in the future. Important factors to be taken into account in assessing the desirable balance between these different classes of resources for materials are 1) the increasing variety of technological options available for choice of material for a required performance in a given application, and 2) the increasing concern to minimize both consumption of energy and environmental impact. In addition, the usual economic factors apply in the use of materials.

While the concept of renewable resources is useful, it lacks the coherence of statistical information on resources and use, and the scientific perspective that has developed for "materials from minerals" (including metals, ceramics, electronic solids, and synthetic organic polymers derived from fossil fuels). Strong specialization exists in forest sciences and wood products on the one hand, and agricultural sciences and associated natural materials (such as fibers and leathers) on the other. We require both a broader view of the science and technology of natural products and, correspondingly, more integrated statistical information on resources, and on materials flows and use (including aspects associated with energy and the environment).

The above considerations led to this analysis of renewable materials in the United States economy as a basis for identifying both the optimum use of such resources and the role of science and technology in helping overcome barriers to their use. The following are the principal items addressed in the study at the request of STPO:

1. Quantitative analysis of current materials flows for renewable resources as the basis for assessing the impact of potential future changes (compared with nonrenewable flows). Definition of the

limitations (cost and technical) of renewable resources for meeting expanded demands for materials based on them. Delineation of the energy, environmental, and social consequences of such increases. International aspects.

2. Interchangeability of renewable and nonrenewable resources as the basis for materials.

3. Assessment (stocktaking) of quantity and quality of R&D currently supported in the area of renewable resources by (a) the Federal Government and (b) industry. Evaluation of the relationship of these activities to the size of the industry and its role in the economy. Assessment of changes in scale and emphasis needed to meet future changes.

4. An evaluation of relevant federal, state, and local legislation and regulations that influence the effectiveness of the development and use of renewable resources.

5. Improvement in materials properties and performance.

6. Improvement in the yield of raw materials and in the efficiency of processing.

7. The potential of renewable resources as "feedstock" for synthetic materials, (a) cellulose based and (b) converted to products (such as ethylene), that can be used to supplement or replace the petrochemical supply used currently for synthetic polymer production.

8. Consideration of the energy requirements and environmental impacts associated with the implementation of the recommendations.

A Committee on Renewable Resources for Industrial Materials (CORRIM) was established by the Board on Agriculture and Renewable Resources (BARR), under the Commission on Natural Resources of the National Research Council, to undertake an analysis of renewable resources in the United States, identify the optimum production and use of such resources, and look at the role of science and technology in increasing their production and use. The training of manpower in renewable resource fields was not addressed in this study, since other specific studies in education had been proposed by the BARR.

This report on Biological Productivity of Renewable Resources Used as Industrial Materials was prepared by an ad hoc advisory panel of the Committee on Renewable Resources for Industrial Materials, as background material for the preparation of the main report.

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CHAPTER I

INTRODUCTION

A wide range of plant and animal products is used as industrial materials. In the United States, however, only a few products account for any appreciable portion of the total. Wood is the most important, accounting for more than a quarter-million tons per year (Table 1) and over $6 billion in value at local delivery points in 1974. In addition to wood, trees produce extractives such as resin and tannin that have important industrial uses.

Of the vegetable fibers, cotton is the most important with an annual production of nearly 3 million tons. The value of cotton at local delivery points is over $2 billion per year for the fiber alone in 1974. Wool is the other important natural fiber produced in the United States: more than half of United States needs or 88,000 tons are produced annually at home. Vegetable fibers other than cotton are used in small amounts only and are almost entirely imported into the United States. These include coir, kapok, jute, kenaf, ramie, hemp, sunn, abaca, sisal, and henequen.

The principal vegetable oils, except for linseed oil, are used largely for food and only to a minor degree for industrial purposes. The total amount of fats and oils used for civilian consumption in the United States in 1970 for soap, drying-oil products, and other industrial products was 2.636 million pounds. Of this, approximately half was industrial uses of cottonseed oil, peanut oil, soybean oil, and imported vegetable oils; one-half was animal and fish fats and oils. Animal hides, especially from cattle constitute another important by-product that finds industrial use.

If we take into account all natural materials grown for industrial use and the principal by-products of food crops, but exclude agricultural residues, it becomes evident that more than 95 percent of the renewable resources used for industrial materials is accounted for by wood. Of total value, wood probably represents approximately one-half.

Table 1

Renewable Resources Produced in the United States
Primarily for Industrial Materials - 1970

	Produced	Imported	Exported	Apparent Net Consumption
		thousand tons		
Wood (including bark)				
Hardwood	79,538	6,043	3,698	81,883
Softwood	145,018	31,496	17,330	159,184
Total	224,556	37,539	21,028	241,067
Cotton				
Lint	2,541	9	966	1,584
Linters	344	17	47	314
Total	2,885	26	1,013	1,898
Wool (grease basis)	88	77	>1	165
Linseed Oil	191	>1	26	165
Animal Hides*	1,500	365	440	1425

*Figures for 1972.

Source: The Outlook for Timber in the United States, U.S. Department of Agriculture Forest Service (1974).

Agricultural Statistics, U.S. Department of Agriculture (1974).

In addition, a wide range of organic wastes is potentially available for industrial application. Anderson (1972) conservatively estimates that 136 million tons dry weight out of a total of 880 million tons annually produced in the United States could be used. Much of the plant material produced by agricultural crops is unused. For such materials as wheat chaff or corn stalks which are left in the fields, the potential for use is low. For bagasse, however, which is the residue from processing sugar cane at the mill, industrial usage is more feasible. The volume of bagasse available in the United States is estimated at 5 million tons dry weight annually. Manure is another residue with industrial-use potential to the extent that it is naturally concentrated in feedlots. At the present time, some 26 million tons dry weight are produced annually in such locations.

The United States already produces a great deal of plant and animal materials for industrial use, but we have the biological capacity to produce a great deal more. We have highly developed industrial uses, but we have the technology to use renewable resources to a much greater extent to derive a much wider range of products. It is the function of the Committee on Renewable Resources for Industrial Materials (CORRIM) of the National Research Council's Board on Agriculture and Renewable Resources to sketch out this potential and these possibilities.

The assessment of the biological productivity of renewable resources used for industrial materials is rendered difficult because of insufficient data and because our potential biological productivity will depend in large part upon future governmental subsidy, governmental regulatory practices, and economic conditions that cannot be readily predicted.

Fortunately, existing data are adequate to chart past trends, to assess current production levels, and to make overall predictions of biological productivity of the major industrial renewable resources as of 1985 and 2000.

For the duration of the present century, the productivity of the United States with regard to renewable resources used for industrial materials will be a function derived from present circumstances modified by projected changes in the availability of resources, the level of technology, and the nature of the economic and political situation. The obvious approach to forecasting biological potential is to: (1) project the yield per unit area of a crop, (2) estimate the land area available to that crop, and (3) multiply the two to provide the estimate. We have used this technique in our report.

It should always be remembered, though, that the area and the production per unit area are inversely related. As the acreage devoted to a given crop is increased, marginal areas are brought into production, and the yield per unit area is decreased. Conversely, as high yields are demonstrated to be both biologically possible and technologically and economically feasible, crop production is concentrated upon the best sites, and marginal producing areas are apt to be taken out of production. High yields over large areas may be theoretically possible from a biological viewpoint: they will seldom if ever be achieved because of limiting economic conditions and practical considerations of management.

Our report, therefore, estimates the biological productivity of industrial renewable resources in terms of current yields, existing land bases, and increments to these bases that may reasonably be forecast by 1985 and 2000.

The forecast divides naturally into two parts: the silvicultural product of wood, and products for industry from agriculture consisting chiefly of vegetable fibers, oil seeds, wool, animal fats, tallows, and hides.

Wood is not only by far the most important renewable resource used for industrial materials, but also one whose production can be greatly increased if needed. Because of the many years needed to grow a tree and because of the different statistical base and differing technologies involved, wood is treated separately from other materials.

Agricultural products include cotton and other vegetable fibers; soybean, cottonseed, peanut and linseed and other vegetable oils; wool; and hides, fats, and tallows. Many of the vegetable oil crops are used primarily for food or feed and only secondarily for industrial materials. Flax (linseed oil) is the major exception. Other crops have use for industrial purposes, but their contribution to the whole is so limited that they merit only brief treatment in our quick appraisal of major industrial materials.

With the major exception of soybeans, the market for--and, consequently the production of--industrial agricultural crops has been declining in recent years. For these crops, therefore, demand is substantially less than productive capacity at current levels of agricultural technology and economic restraint. Furthermore, there is little reason to believe that market demand will strain biological potential by 1985 or 2000. Under these conditions, long-term estimates of productivity become a mere exercise in imagination.

Both natural fibers and natural oils have lost markets to the petrochemical industry in recent years. Of the total United States domestic demand for petroleum products of over 6.3 billion barrels (1973), only 330 million barrels or about 5 percent went into petrochemical feedstocks. A comparable amount was used in addition as energy by the petrochemical industry. Even a majcr come-back in demand for natural fibers and natural oils for industrial materials would have little effect upon total United States consumption of petroleum.

REFERENCE

Anderson, L. (1972) Energy potential from organic wastes: a review of the quantities and sources. U.S. Department of the Interior, Bureau of Mines Information Circular 8549, 16 pp.

PART I

WOOD PRODUCTION FOR INDUSTRIAL MATERIAL

CHAPTER 2

UNITED STATES TIMBER SUPPLY

INTRODUCTION

The forests of the United States are biologically diverse. More than 40 major forest types include some 120 commercially important tree species. Each has its distinctive range, its particular site requirements, its unique physical and chemical properties, and its own set of commercial uses. The conifers or softwoods are the most fully used--for structural lumber, plywood and veneer, and paper pulp. Resinous pines produce naval stores as important extractives. Broad-leaved trees or hardwoods are used for specialty products as solid wood or as plywoods and veneers for furniture, pallets, flooring, and many other uses, including paper and paper board. Hardwoods vary more than softwoods in their physical properties and have more specific uses. In short, wood comes from many different trees, has a wide range of characteristics, and finds many different uses. Although we deal with it in the generic sense in this report, the resulting simplicity is apt to be misleading unless the actual complexities are kept in mind.

A total of 754 million acres, one-third of all land in the United States, is classified as forest land. This land ranges in elevation from sea level to 12,000 feet and includes extremely diverse soils, climates, and topography. Forest management must be geared to maintain diverse plant communities in all regions of the country to permit future options for changing forest products and to provide a broad range of environments for varying levels of recreation, wildlife, water, and other forest-related uses.

The status of the forests of the United States with regard to acreage of commercial forest land, forest yield, growth and harvest is under continual study by the Forest Service, United States Department of Agriculture, and is summarized by this agency at intervals of approximately 10 years. The most recent updating of forest statistics is contained in "The Outlook for Timber in the United States" (USDA 1974) which we will refer to throughout this report as the "Outlook Study". The study summarizes recent trends in forest land and timber resources in the United States. It also projects future trends in timber supplies through intensified management and use at home, and through greater reliance upon world timber resources abroad. Finally, both the Outlook Study, and the Report of the President's Advisory Panel on Timber and the Environment (PAPTE 1973) project future demand for timber products as well, and deal with timber demand-supply relationships.

The Outlook Study thus provides a base for a critical evaluation of the biological potential of the commercial forest lands of the United States. Such an evaluation is possible, however, only so long as we use the same parameters defined in the same way as in the Outlook Study. For this reason, we have adopted the same definitions in our evaluation. Thus, we have considered the area devoted to the production of forest products in terms of commercial forest land as defined in the Outlook Study and have dealt with forest products in terms of the cubic-foot volume of the boles (i.e., trunks) of standing trees above a one-foot stump to a four-inch top diameter outside bark. Total bole value, including stump and tip will range slightly higher. For a 12-inch spruce tree 60 feet high, the stump volume is 6 percent of that of the merchantable bole while the top adds another 2 percent. For a larger spruce 24 inches in diameter and 90 feet high, the stump adds only 4 percent to the merchantable volume while the top adds less than 1 percent (Spurr 1952).

At the same time, we are aware of the potential importance of the total biomass production of the forest, both in the complete tree and in other biota. Although insufficient data are currently available to permit accurate projections of total productive capacity of the forests of the United States, it is nonetheless useful to summarize the work on this subject.

CONSUMPTION OF TIMBER IN 1970

The Outlook Study provides data on United States timber as of 1970. The apparent consumption is derived by taking the annual removals from United States forests, adding timber imports and subtracting timber exports. The overall estimates are summarized in Table 2. The cubic-foot estimates are derived from the Outlook Study. The weight estimates are obtained by multiplying the volumes by a conversion factor of 27.4 pounds per cubic foot for softwoods and 32.8 pounds per cubic foot for hardwoods. These conversion factors were obtained by weighting the average oven-dry weight per green cubic-foot for a given species, as given in the Wood Handbook, by the total volume of that species in the United States removed in 1970, as given in the Outlook Study. Whereas volume data are for wood content of the merchantable bole only, weight data include a 10 percent increase to estimate combined wood and bark mass of the bole.

Table 2

Consumption of Timber in the U.S., 1970
(roundwood equivalent)

	Softwood	Hardwood	Total
		billion cubic feet (wood only)	
Removals, U.S.	9.623	4.409	14.032
Import	2.090	0.335	2.425
Export	1.150	0.205	1.355
Consumption	10.563	4.539	15.102
		thousand tons (including bark)	
Removals, U.S.	145,018	79,538	224,556
Import	31,496	6,043	37,539
Export	17,330	3,698	21,028
Consumption	159,184	81,883	241,067

Source: The Outlook for Timber in the United States, U.S. Department of Agriculture Forest Service (1974)

The projections of the Outlook Study are presented in terms of two different concepts: removals and supplies. Both include the total cubic-foot volume of trees that are harvested from the growing stock and used. The removals value includes also the volume of logging residues left in the woods and the volume of timber on land cleared for non-timber uses or on land withdrawn for parks, wilderness areas, or other purposes. The supplies value consists primarily of trees harvested from the growing stock and includes logging residues and trees on non-commercial forest land only to the extent they are used. The data summarized in this report are based on removals, which characteristically run higher than comparable supply statistics.

It will be seen that the United States is a net importer of timber products both for hardwoods and for softwoods. The total consumption of timber in the United States in 1970 was over 15 billion cubic feet or more than a billion cubic feet higher than actual removals from American forests in that year.

The annual growth in 1970 exceeded annual harvest. While the growth of sawtimber expressed in board feet was only 95 percent of removals in 1970, the growth of total growing stock expressed in cubic feet was 133 percent of removals in the same year. For softwoods as a group, sawtimber growth was 84 percent of removals, while growing stock growth was 111 percent. Hardwoods, on the other hand, were being cut at a much lower rate than growth. Sawtimber growth was 131 percent of removals of hardwoods, while growing stock growth was 179 percent of removals.

In 1970, the current annual growth of the commercial forest lands of the United States was estimated at 38 cubic feet per acre per year. The mean growth varied from 65 cubic feet per acre on forest industry lands on the Pacific Coast to 23 cubic feet on public lands in the Rocky Mountains (Table 3).

Had all the commercial forest areas been fully stocked in 1970 and had a normal distribution of age classes existed at that time, the potential annual growth of the commercial forests of the United States estimated from normal yield tables would have been 74 cubic feet per acre per year, or almost twice the estimated net annual growth. considerable gain would be achieved through harvesting old-growth stands on the Pacific Coast and in the Rocky Mountains, stands where current growth is negligible, and replacing them with faster growing second-growth forests.

Table 3

Average Net Annual and Potential Growth per Acre by Owner, Class and Section 1970[1]

(Cubic feet)

Section	All Owners	National Forest	Other Public	Forest Industry	Farm and miscellaneous private
North:					
Current	31	38	33	40	29
Potential	68	66	59	72	69
South:					
Current	45	55	45	53	42
Potential	76	70	71	81	75
Rocky Mountains:					
Current	24	23	23	47	25
Potential	60	65	54	70	50
Pacific Coast:					
Current	45	27	60	65	58
Potential	95	88	100	107	96
Total:					
Current	38	30	39	52	36
Potential	74	73	68	83	72

[1] Potential growth is defined as the average net growth attainable in fully stocked natural stands. Higher growth rates can be attained in intensively managed stands.

Source: The Outlook for Timber in the United States, U.S. Department of Agriculture Forest Service (1974)

PROJECTED SUPPLY IN 1985 AND 2000

In the Outlook Study, the Forest Service projected future timber supplies of the United States from 1970 through 2020 at 10-year intervals. These projections are stratified by geographic section of the country, species group (softwoods and hardwoods), and ownership class (national forest, other public, forest industry, other private). The projected supplies are given both in terms of cubic feet (roundwood products) and board feet (sawtimber products).

The base-line projection in the Outlook Study is based on the assumption of a continuation of the 1970 level of management. This level is defined as the average amount of forest management activities prevailing throughout the 1960s. Specifically, it was assumed that current levels would be maintained in such matters as expenditures for fire control and area burned, expenditures for pest control and level of damage, expenditures for reforestation and area planted, expenditures for forest fertilization and area treated, assistance to private forest landowners, support of forestry research, expenditures for forest roads and mileage developed, and the like.

The average investment in constant 1967 dollars during the 1960s was $148 million for forest fire protection (annual burn 3.9 million acres), and $13 million for forest pest control. During the decade, an average of 1,477,000 acres was planted annually at an estimated cost of roughly $85 million. For the period 1968-70, an estimated 1,413,000 acres were treated annually to improve the timber stand at an estimated cost of $25 million per year. By 1971, forest industries were reported to be applying fertilizer to nearly 150,000 acres annually, almost entirely on the Pacific Coast and in the South. Road construction for forestry purposes totaled $180 million in 1970 for National Forests alone.

The Outlook Study's projection of future timber production is based upon a continuation of these "1970" levels of management. In actual fact, the intensity of timber management has increased over the years. While it would be entirely appropriate to base estimates of future production on a trend line of increasing intensity of management, the baseline of a continuing of 1970 levels of management adopted by the Forest Service is acceptable for a conservative projection.

If we assume the continuance of these expenditures and forest management achievements, the trends in productive potential of the United States forests can be highlighted as in Table 4. The data for 1985 are interpolated from the Outlook Study. Compared with total removals in 1970 of 14 billion cubic feet, those for the year 2000 are estimated to be 20.3 billion or an increase of 45 percent. In addition, the ultimate productive potential of the United States forests, as estimated from normal yield tables, is appended in the bottom line. As can be seen, the potential productivity of our forests as defined by this measure is over twice as great as the 1970 harvest for softwoods and nearly four times as great for hardwoods.

The productive potential as defined by yield tables is, however, only a rough measure, and it should be taken as such. In the first place, it is totally unrealistic to assume that all the commercial forest land could be brought to a fully stocked condition with a balanced distribution of age classes created within each working circle. Inevitably, average volumes over large areas of forest are less than those measured on selected sample plots. Ostrom and Gibbs (1973) cite a Swedish study by Eriksson (1967) over a 30-year period. Comparing yield data from permanent sample plots averaging 1/4 hectare with the yield of surrounding stands averaging eight hectares in area that were periodically thinned, Eriksson found that the yield of entire stands was only 90 percent of the yield measured on the growth plots. He attributed the difference to unproductive spots caused by rocks, blanks resulting from windfall, the occurrence of other species, irregularity in spacing, edge effects, log landings, logging damage, and greater care in management within the plot boundaries.

In the United States, shallowness of soils and dry climatic conditions often result in stands less than fully stocked in terms of crown closure. Particularly in the ponderosa pine type in the interior of the western United States, actual yields will often be substantially under those indicated by normal yield tables (MacLean and Bolsinger 1973).

While the estimates of future timber supplies based upon yield tables are unrealistic, the estimates in Table 4 of the productive potential of timber based upon the continuation of 1970 levels of management for 1985 and 2000 appear to be fully attainable.

From the Outlook Study projections of the United States Forest Service, it is clear that harvests from United States forests could be increased by approximately 25 percent over 1970 levels by the year 1985 and by as much as 50 percent by the year 2000, by continuing at 1970 levels of forest management. Much of this increase, however, would come from hardwoods, a category which is currently being underused. The projected increase in softwood timber supplies would be only 14 percent by 1985 and 25 percent by 2000.

Table 4

Past Production and Future Productive
Potential for U. S. Forests

	Softwoods		Hardwoods		Total	
	billion cu.ft.	million tons	billion cu.ft.	million tons	billion cu.ft.	million tons
1952	7.8	118	4.1	74	11.9	192
1962	7.6	115	4.2	76	11.8	191
1970	9.6	145	4.4	80	14.0	225
1985	11.0	166	6.5	117	17.5	283
2000	12.1	182	8.2	148	20.3	330
Potential (Yield table)	20.5	309	17.5	316	38.0	625

Source: The Outlook for Timber in the United States, U.S. Department of Agriculture Forest Service (1974)

PROBLEMS OF ESTIMATING CURRENT AND FUTURE RAW MATERIAL SUPPLY

Among the renewable resources, forests differ from agricultural crops, both animal and plant, in ways that make the problem of estimating current and future supplies unique, not well understood, and vastly more difficult.

The forest is both the product and the means of production; when we harvest the trees, the capacity of the land to produce more wood in the immediate future is largely dissipated. And when we reforest the land, no products are available for long periods. Even after products are initially available, they must be allowed to accumulate in the forest factory to insure maximum future and average production. Even if we exclude social, political, and environmental factors to which forests are peculiarly subject, the uniqueness of the forest makes economic rationalization of forestry extremely complicated as an enterprise.

Data on current and future raw materials supply must be collected in a way that makes the economic analyses possible. It is apparent from the above that the task is a difficult one.

CHAPTER 3

UNITED STATES TIMBER INVENTORY

INVENTORY MEASURES

Units of forest measurement were developed at a time when there was only one product: lumber. The board-foot is still used today. It is as though we were to measure what is in a granary in terms of loaves of bread. The farmer would then have to think of his crop as consisting of so many loaves of bread rather than bushels of grain. So would the buyer, regardless of how he intended to use the produce. A feedlot owner buying wheat for stock food would have to use one conversion, and a baker another. The baker would be no better off, because he might be making 14-ounce loaves of whole wheat bread when he had bought wheat in terms of one-pound loaves of white bread.

Board Foot Measure

One board-foot is theoretically a piece of lumber one-foot square and one-inch thick. In practice, however, this is never the case. The variations arise from many causes, but the result is that the board-foot is a highly inaccurate measure even of sawn lumber.

Lumber is often cut from a green log. It shrinks as its moisture content is reduced below the fiber saturation point. Some lumber is used rough from the saw, and some is surfaced. Lumber widths and thicknesses are specified in terms of their nominal dimensions though their actual dimensions may be quite different. These varying dimensions are catalogued in the "American Lumber Standards," an industrially accepted specification originally promulgated some 50 years ago and changed only moderately since. Under these lumber standards a nominal 2" by 8" dry, surfaced board must have a minimum dimension of 1-1/2" by 7-1/2". Thus a board of minimum dimensions in this nominal size would have a cross section slightly more than 82 percent of the nominal cross section area. The average dimension in thickness and width of lumber from any particular mill is likely to be a function of the manufacturing precision of that mill. Those that are precise are set nearer the minimum than those that are less precise.

The American Lumber Standards for variation in sawing (miscutting) of softwood lumber are also archaic. Variation in sawing is defined as deviation from the line of cut. The standards prescribe that slight variation is not over 1/16 inch scant in 1 inch lumber, 1/8 inch in 2 inch, 3/16 inch in 3 inch to 7 inch, and 1/4 inch in 8 inch or more. These are precisely the same standards for miscutting that were contained in the original American Lumber Standards promulgated in 1925. The situation has now remained static for 50 years. There have been improvements in equipment and manufacturing procedures, but they have not been reflected in the American Lumber Standards. These standards protect the worst practices in the industry and fail to reflect the best available technology.

The situation with respect to precision in the manufacture of hardwood lumber is even worse. Current standards for miscutting of hardwood lumber are more relaxed in 1975 than they were in 1945. These lax standards might be tolerated in a situation where the basic resource is available in excess of need, but they are not acceptable when applied to a commodity whose raw material base is in short supply.

Crude specifications and standards for measurement foster large-scale material waste and make it difficult to estimate available supplies with any precision.

Log Rules

Even greater inaccuracies in estimating the volume of wood result from the crude but persistent methods by which the number of board feet in logs is estimated. Logs are bought and sold for the most part on the basis of log rules, devices that evaluate the useful content of a log in terms of an estimated recovery of mill-run ungraded lumber. A number of log rules of this type are used by the American lumber industry. Given the lack of precision in measuring lumber and timbers and the lax manufacturing procedures reflected in lumber standards, the task of attempting to estimate recovery of these materials from round logs of various sizes is a difficult one. Two general types of log rules have been widely adopted by industry and government, and several of them are in current use.

One type of log rule is that developed by graphically diagramming circular cross sections of various diameters to project the reduction of a log to boards and timbers. The Scribner log rule is such a diagram rule. It was devised over 100 years ago and is still widely used in the United States. It is the only diagram rule still in extensive use.

A second type of log rule is the formula log rule, which attempts to express lumber recovery from a log through the use of an algebraic formula. Two such log rules are still commonly used in the United States. The Doyle rule, the oldest of the formula rules still commonly used, is crude and highly inaccurate. The International rule, which uses an algebraic formula that is more complex and sophisticated, is the most widely used of the formula log rules. While it is of more recent vintage than the Scribner and Doyle rules, it is still a very old one. Unlike the Scribner and Doyle rules, the International rule recognizes taper in a log.

The nature of all log rules requires that they be based upon at least implicit assumptions regarding the lumber manufacturing process. These assumptions include the mix of board sizes to be produced, the width of the saw kerf and the slabbing and edging practices to be employed. Regardless of the general validity of the geometrical and algebraic procedures used in devising a log rule, it is obvious that assumptions based upon manufacturing practices of a century ago bear little relationship to modern technology. Manufacturers have, of course, accommodated to the inaccuracies and imprecision of log rules, and such criteria as "overrun" and "board foot-cubic foot ratio" represent efforts to estimate true volume from the inaccurate estimates in board-foot volume provided by the log rule.

Log rules are commonly used in the timber trade as a basis for log and tree marketing even in situations where the use is for veneer rather than lumber. Here the log rules, based as they are upon estimated lumber recovery, make no technological sense at all.

With the advent of large-scale electronic computers, the possibility has been explored of using simulation models to predict product recovery under the manufacturing conditions actually projected for use. A large number of such computerized models have been constructed and are in use. Evaluation of logs in terms of actual solid volume or weight can be accomplished with much greater precision than can be achieved in attempting to predict actual product recovery through the use of log rules.

Evaluation of log content in terms of cubic volume or weight has the advantage of permitting more meaningful comparisons among alternative uses for the same log and perhaps more importantly for evaluating multiple uses of the same log. There has been some progress in substituting the cubic-foot measure or weight for the board-foot measure, although the use of old log rules is still a common practice fostered by tradition, archaic laws, and government practices at national and state levels.

Volume Tables

The measurement of tree volumes presents many of the same problems that are associated with the assessment of log volumes. Tree volumes are customarily estimated through the use of volume tables which estimate the merchantable volume of a tree in terms of its diameter 4.5 feet above the ground and its height. Most volume tables are developed by making assumptions concerning the choice of a geometric solid configuration that approximates the shape of the tree bole, the probable stump height and minimum usable top diameter, and, sometimes, the mixture of logs that are potentially recoverable. In some cases, the volume estimate by volume tables is the cubic volume of the whole stem, but most volume tables have concentrated upon estimation of the volume of the so-called merchantable bole. This is defined as either the number of 16-foot logs or the portion of the stem between the top of the stump and the point of minimum merchantable diameter. When volume tables are based upon estimates of product recovery, they must include assumptions concerning the nature of the product conversion process. Commonly, the log rules previously discussed are used as the basis for the conversion assumptions. When this is done, the merchantable quantities estimated are obviously no better than the conversion assumptions built into the log rules.

The geometric solid configurations most commonly used are designed to give good estimates of total cubic volume in the middle portion of the bole--the so-called merchantable portion of the stem. They are less precise when used to estimate those portions of the bole that are traditionally non-merchantable; i.e., the stump, top and large branches. As use of the full tree becomes more widely practiced, failure to estimate accurately the volumes in the "non-merchantable" fraction of the tree is an important mensurational deficiency.

Similarly, volume tables based upon single product use will be of limited value in estimating product recovery potential when the trees are used for products other than those anticipated, or when they are used for multiple product recovery. As larger components of the tree are used for fiber products and chemical feed stocks, it becomes increasingly important to be able to assess raw material in trees in terms of weight rather than volume, the conventional basis for forest resource inventory.

INVENTORY OF PRESENT STANDS

An inventory is essential for adequate appraisal of the current resource: the standing volume; current annual increment; and, for stands still in the developmental stages, mean annual increment, or the average growth per year from the year of establishment to the present time.

Standing volume is measured in a number of ways. The basic unit of measure may be board feet, cubic volume, or weight. The volume of the total tree bole or only a part of the tree bole may be estimated. Only trees above some arbitrary size limit may be counted, and even then, large trees with varying amounts of defect or deformity may be omitted. The user who makes chips from any size or species of tree, the sawmiller who wants a specific size or species, and the user with fully integrated manufacturing facilities must appraise the value of the resource from the same inventory.

Adequate sampling of extensive forest areas through the management of sample plots in the field is time consuming and expensive. Even the best designed forest surveys are of questionable accuracy because of the problems already described with the basic units of measuring, the difficulty of making accurate measurements of basic parameters in the field, and the high cost of adequately sampling highly variable forests. The result is that the forest manager is typically confronted with an absence of needed inventory data.

Even when forest inventories provide good estimates of the cubic-foot volume of tree boles, such data do not include the stump, top of the bole, root system, large branches, and foliage. Botanists studying total forest biomass have been restricted by cost and basic-science-directed personal decisions to small and arbitrarily chosen samples. The nature of these samples does not permit generalization of the results to large forest areas. Botanists and foresters are both concerned with forest biomass, but the two groups work independently by and large with little or no joint efforts to use and interprete data.

ESTIMATING GROWTH

The measurement of growth is subject to the same problems inherent in the measurement of current forest volume or weight. The larger amount of effort required to estimate growth, however, renders adequate sampling of the forest more expensive and therefore more unlikely. Furthermore, growth, involving as it does a projection over time, is inherently less easy to assess than current volume or mass.

Current growth or annual increment is measured either by successive measurements of sample plots or by reconstruction of the stand at an earlier time through the extraction of increment cores from the tree to count and measure growth rings. The first technique is better, but the number of plots remeasured in practice is seldom enough to permit adequate sampling, and the precision of the repeated measurements is seldom good enough to provide accurate measurements of the differences that constitute growth. The use of increment cores in the stand-table projection method is adequate to provide data on the gross growth of individual forest stands, but may not provide accurate estimates of net growth because of the difficulty of measuring tree mortality over a specific period of time. In addition, tree mortality tends to be episodic rather than continual, thus leading to even greater errors in prediction. Stand table projection is much less satisfactory when applied to an entire forest or region than when used on a stand-by-stand basis.

In the absence of actual growth studies, increment must be measured by growth or yield tables that generalize expected growth in such terms as site, age, and degree of stocking. Conventional yield tables based on age are applicable to even-aged stands only. In irregular, mixed, and uneven-aged stands, adequate growth tables based on variables other than age are generally not available.

A considerable expertise exists about how to measure current volume or mass and its increment over time. Inadequate funds have been allotted, however, to applying this knowledge to our present forest resources. In view of the critical nature of growth data in the forecasting of future supply and the time periods necessary to obtain such data, we cannot overemphasize the importance of an immediate remedy to this situation.

POTENTIAL PRODUCTIVITY

In taking a long look into the future, we need to know what a new forest under man's management will produce using current and projected technology.

Forest development in volume follows the familiar S-shaped growth curve, with the X-axis in years or decades. The grand period of growth is followed by a leveling off. If the forest type is one of the early successional stages, the volume will decline substantially as it progresses to the climax forest and will eventually level off at a lower level of volume with no growth. Even if current annual growth could be accurately determined, its significance can only be judged if the observer knows where the forest is on the growth curve.

If the development curve is described in terms of biomass, it is quite different from one described in board foot volume of merchantable trees only.

Furthermore we must still predict the growth of managed forests from observations of natural untended stands. Consequently, we are underestimating biological potential because managed stands can produce more than unmanaged.

Data on the response of forests to intensive management practices are generally restricted to periods of only a few decades. Few studies cover longer segments of the life of the forest. We need to develop data collection techniques and analytical procedures to predict long-term responses of forests to silvicultural treatment based upon short-term monitoring of the forest.

We need yield tables for managed stands showing the production expected using various silviculture and management options. The development of definitive predictions requires watching and measuring a managed stand throughout an entire rotation. The obvious necessity, as pointed out in this report, for exploiting today the potential productivity of the forest cannot wait for the development of such yield tables. Interim prediction techniques are needed to guide investments in improved technology that must be made today to insure healthy, productive forests for the future.

A CONTINUOUS FOREST INVENTORY

The United States forest resource is on the one hand extensive and valuable, and on the other remarkably poorly defined as to extent, content, and current and potential growth. This is not to say that large efforts by competent professional foresters have not been productive. The primary limitations are three: (1) most inventories contain a mixture of biological and physical data and local management data, the latter often playing a dominant role in setting procedure and pace; (2) inventories have most often been designed to produce data for the moment, with no deliberate intention of keeping current; and (3) the onset of the quickening pace of operations due both to demands of intensive management and the pressure of conflicting interest groups is rendering much of forest inventory practice obsolete.

Procedures for forest inventory, even of total occupied land, are so tedious and time consuming that it can take 10 years to complete the cycle of a national inventory. Rapid methods such as use of satellite imagery must be developed and adopted so that planning can proceed based upon data that are current. (At present many industrial and national forests have no inventories more recent than 1955.) Even where more appropriate inventory techniques are available, forest surveys have tended to become limited or delayed because of lack of funds, disagreement between interested parties as to objectives, and restraints imposed by management. The Forest Survey, an on-going project of the United States Forest Service, has provided invaluable data, but it is so underfinanced and understaffed that the statistical base of the 1974 Outlook Study is often necessarily scanty and out of date. The principles and programs it stands for, however, are important and need immediate further development, expansion, and application.

If forest policy planning is to be based on adequate data, a continuous nationwide inventory of forests should be reinstituted and maintained. Instead of using the board-foot or the merchantable cubic-foot as the unit of measure, we should express forest inventories in the dry-weights and volumes of their component parts. The objective should be to provide biological and physical data that can be interpreted over a range of terms from total biomass at one extreme to current merchantable harvest at the other.

The reinstituted continuous forest inventory should make full use of remote sensing and modern sampling techniques. It should be based upon sufficient actual measurements in the field that current inventory and growth data can be provided on a unit-area basis for the important (both biologically and economically) forest types, forest site classes, forest age and size classes, major ownership classes, geographical regions, and other stratifications needed to form the basis of public management and policy decisions.

The time is past when we can afford to plan without facts. The potential of forests as a renewable resource is more than great enough to justify the effort and cost of creating and maintaining a nationwide continuous forest inventory.

CHAPTER 4

UNITED STATES TIMBER POTENTIAL

TIMBER PRODUCTION UNDER INTENSIVE MANAGEMENT

A wide variety of opportunities exists for increasing timber production through intensive management (Ostrom and Gibbs 1973). The principal approaches include: (1) improving the site through cultivation, fertilization, drainage, and irrigation; (2) conversion of forest areas to faster-growing species; (3) improving stocking through reforestation; (4) introduction of genetically faster-growing genotypes within a given species; (5) stimulating the growth of faster-growing trees through weeding; (6) recovering a larger share of the gross growth through thinnings; (7) reducing losses from fire, insects, and diseases through better forest protection; and (8) increasing the allowable cut as a result of management decisions.

We will consider each of these approaches in turn. But before we do so, it may be instructive to review some earlier efforts to estimate the increased production of timber that could be achieved under intensive management. Staebler (1972) presented both the potential gains from intensive forest management and its effect upon the distribution of management effort within the forest, using the generalized example of a tree farm in the Douglas-fir region of the Pacific Northwest. Based upon existing research, he suggested an increase in production of about 140 percent over average management on median quality (Site III) Douglas-fir lands if high-order management is applied, including fertilization, thinning, and genetic improvement of tree species. He concluded that one acre of the highest quality (Site I) land so intensively managed would produce as much wood annually as eight or nine acres of the lowest quality (Site V) given average management, so that the intensive management of low-elevation, high-site land could compensate if necessary for the withdrawal of high-elevation, low-site land from timber production.

In his consultant's report to the President's Advisory Panel on Timber and the Environment (PAPTE 1973), Marty assayed some generalized estimates of the net mean annual growth that might be anticipated for various softwood timber types, and multiplied these values by the area in each site class for each softwood forest type. By this simple method, he estimated that the United States could grow 17 billion cubic feet of softwoods per year, 77 percent more than the 1970 supply of 10.7 billion cubic feet, but less than the

20.5 billion cubic feet indicated by the use of normal yield tables.

In the southern United States, Boyce (1974) initiated a series of attempts to estimate the biological potential of pine ecosystems through a refinement of the yield table approach. For loblolly pine in the southeastern states he estimated a mean annual growth of 98 cubic feet per acre per year in total stem volume. Boyce's analysis confirmed the estimates made in The South's Third Forest (Southern Forest Resources Analysis Committee 1969) that the potential growth of softwood in that region could be doubled with intensive management.

In the Outlook Study, preliminary analyses are included of the increased timber production possible through intensive management of: (1) National Forests, and (2) miscellaneous private holdings, which are the two ownership classes where the greatest gains were thought to be possible. The management practices considered were reforestation, stand release, thinning, and salvage. Other measures, such as fertilization, genetic improvement, and increased use, were not taken into account.

The National Forest lands occur primarily in the western United States. Possible increases in harvests would arise from a continuing series of programs of intensified management on lands estimated to represent the most promising opportunities for intensification (i.e., lands that would return 5 percent or more on investment, assuming future prices for softwood lumber and plywood at 30 percent above 1970 levels). If 275 thousand acres were treated annually, the increased harvest would be 1.6 billion board feet by 1980 and as much as 13 billion board feet by 2020. The estimated increases in harvests from such a program would be 3 percent by 1980 and 25 percent by 2020. Most of the increase would come from increasing the capture of gross growth through thinnings and improvement cuttings. In addition, the allowable cut on these National Forest lands would be raised under present sustained yield computational practices because of the "allowable cut effect," the increase in computed permissible harvest of existing old-growth resulting from taking into account the anticipated higher yields from the managed stands.

The miscellaneous private lands considered in the Outlook Study of intensive management potentials occur primarily in the southern states. For these areas, future harvest increases would arise primarily from reforestation and thus would not occur for 25 to 30 years. Assuming that 12.7 million acres were placed under accelerated management, increased harvests would be negligible until 2000 when they would reach 1.0 billion board feet annually. Harvests from intensified management would, however, reach 2.5 billion board feet by 2020.

Site Improvement

The capacity of land to grow trees is termed "site quality". Many indices are used to estimate site, among them being the height of main canopy trees at a standard age, and the identification of the particular piece of land in terms of soil type, moisture relations, topographic location, and the kinds of vegetation currently occupying it (Spurr 1952).

In the Outlook Study, site is categorized directly in terms of its productive capacity. More precisely, it is classified by the mean annual growth in cubic feet at culmination of mean annual increment in fully stocked natural stands. The site classes recognized are: I. land capable of growing 165 cubic feet per acre per year or more; II. 120-165 cubic feet per acre per year; III. 85-120; IV. 50-85; and V. 20-50 cubic feet per acre per year potential growth. In much of the Outlook Study, data for Sites I and II are combined, necessitating similar grouping in this report. Also in this report, the mean annual increment within each site class is assumed to be 160 for Sites I and II combined, 110 for Site III, 70 for Site IV, and 40 for Site V.

As with agricultural land, the productive capacity of forest land may be improved. Because of the length of the forest rotation and the consequent generally low return on investments, relatively little site improvement in forests has actually been undertaken in the United States to date.

Forest sites may be improved physically through such measures as drainage, irrigation, and cultivation; or chemically through fertilization and weed control.

Many forest sites are too wet for optimal growth. Drainage has been employed successfully to improve the growth of spruce and other lowland forest types in northern Europe for many years. Some three million acres have been drained in Finland and nearly one million acres have been similarly treated in Sweden. In the latter country, growth responses of from 15 to 60 cubic feet per acre per year are not uncommon (Stoeckler 1963). Drainage in similar situations in the Lake States of the United States, however, has been inconsequential.

Drainage of forest sites has far greater application in wetlands of the coastal plain of the southern United States. On many pocosin and flatwood sites, growth of loblolly and slash pine may be increased from negligible levels to the middle range by drainage. In North Carolina, 21-year-old loblolly and slash pines planted within 200 feet of drainage canals produced over one cord per acre per year contrasted to 0.15 cord per acre annually on a similar but undrained site (Miller and Maki 1957). Growth of 19-year-old slash pine on a wet sandy flat in northwest Florida was 50 percent greater in the 10 years after drainage (15.4 feet) than that (10 feet) predicted for the undrained condition (Young and Brendemuehl 1973). Drainage of such sites will result in a release of nutrients in the soil. Several million acres fall in this category, a high percentage of which have phosphate-deficient soils. On these, a combination of drainage plus fertilization with phosphate would improve the growth of pine forests substantially. Bedding (mounding soil in long rows) also stimulates the growth of planted pines on wet sites by improving drainage and increasing soil aeration.

For much of the United States, lack of soil moisture is an important factor limiting tree growth on upland sites in the late summer and early fall. It follows that irrigation increases tree growth substantially. Irrigation is only practicable, though, when a plentiful supply of cheap water is available to irrigate a level site. Irrigation may be locally feasible in growing poplars on alluvial river valleys, but its application otherwise will be strictly limited.

Cultivation is also important in preparing receptive mineral seedbeds for direct seeding. Where an impermeable lower soil horizon or hardpan impedes the passage of water both upward and downward, deep soil plowing may be effective in breaking up the hardpan to create both a better relation between soil and moisture and more growing space for tree roots.

In recent years, much research has been carried out to improve nutrient relationships in forest soils, and substantial areas of forest have been fertilized commercially. In the last decade, some 900,000 acres (mainly Douglas-fir) have been fertilized in the Pacific Northwest, and over 400,000 acres have been treated in the Southeast (slash and loblolly pine). The great bulk of this has been done by private industry.

In the Douglas-fir region, a high of 220,000 acres was fertilized with nitrogen in 1972, chiefly by one company. Strand and Miller (1969) believe that the optimal rate of nitrogen fertilization would lie between 150 and 300 pounds per acre during a five-to seven-year period. More recently, Stanley P. Gessel (personal communication, 1975, University of Washington) has concluded that stands treated with nitrogen fertilizer produce an average of 50 cubic feet per acre per year increased growth in the four years after fertilization. Low quality sites not only produce more response than high quality sites, but do so more consistently. A safe generalization based upon current knowledge would be that urea or ammonium nitrate applied at five-year intervals will result in an increase of 15 to 20 percent in the volume increment of Douglas-fir stands on average sites.

In the Southeast, a high of 87,000 acres was treated in 1972, chiefly through the adding of phosphate fertilizer to poorly drained flatwoods sites in the southern Coastal Plain. Bengtson (1968) has surveyed systematically the potential increases in wood production through fertilization of forest land in the South, citing the literature on the subject to that date. Projecting his judgment for a 30-year period, he concludes that for the East Central Uplands, the outlook for profitable use of fertilizers is not promising. For the Lower Valley of the Mississippi and similar bottomlands, forest fertilization will not contribute greatly to production until better silvicultural practices are developed and applied extensively. In the Southeastern Uplands, however, judicious selection of acres to be treated can lead to increased total production in this area of perhaps 5 percent. The greatest potential gain, though, is in the Coastal Plain where a substantial increase in production, conservatively 10 percent for the region as a whole, can come through fertilization and drainage of poorly-drained and phosphate-deficient sites. Bengtson bases the largest gain on the conclusion that volume increase of 30 percent could be obtained from treating perhaps 25 percent of the flatwoods pine stands. Three to five million acres of coastal flatwoods need phosphate to be productive.

The net effect of an extensive program of fertilization and drainage would be to raise the site quality of a portion of the forest land in the United States. Assuming for the sake of simplification that such efforts are confined to nitrogen fertilization of 4.7 million acres in the Douglas-fir and related mesophytic conifer types of the Pacific Coast, and to phosphate fertilization and drainage of 5.8 million acres in moist loblolly and slash pine types in the South, and assuming that the total acreages of these types remain essentially unchanged, we may tentatively modify the acreages of the different site classes as indicated in Table 5. Assuming that the growth in each site class remains the same, site amelioration would result in an increase of 5.5 percent in the productivity of Pacific Coast Douglas-fir and related types and of 3.2 percent in that of southern pine types. The exercise is highly speculative but at the same time indicative of possible gains.

Conversion of Forest Type

In the Outlook Study, forest site quality is estimated on the basis of the vegetation currently occupying the area at the time of the forest survey. Since some of our commercial forest land is currently unstocked, and since an even greater amount of it is stocked with tree species that are growing more slowly than others that are equally well adapted to grow on the same sites, the net effect is that the Outlook Study substantially underestimates the growth potential of United States commercial forests in these respects.

The gains from conversion of an existing forest to a suitable faster-growing type can be estimated readily from yield tables provided that either (1) yield tables for differing species or types are based upon site as defined by soil type, topographic, and other non-tree characteristics, or (2) site index of one type can be related to that for another type through correlation analysis. An example of the first is provided by Assman (1970) for northern Europe. He found, for example, that the yield of spruce was at least twice that of beech on the same site, and that American red oak outproduced native European oaks on the same site by more than two times.

Site index correlations have been published by Doolittle (1958) for different species growing on the same site in the Southern Appalachians, by Carmean and Vasilevsky (1971) for northern Minnesota, and by Dietchman and Green (1965) for the northern Rocky Mountain region. Although no systematic study has been made of comparable American site index and yield table data, spot checks would indicate that in many cases yield of forests can be raised from 50 to 150 percent by species conversion.

By far the largest opportunity for changing forest type is in the southern pine region but opportunities also exist in the Lake States, Central States and New England. In the South, a very large area that could grow pines well is currently growing hardwoods poorly (Murphy and Knight 1974). Much of this land once supported pine, but it has reverted to hardwoods through the exclusion of fire or the harvesting of the pines leaving the cut-over site to be taken over by hardwoods. The region has over 30 million acres of mixed oak-pine forest and over 88 million acres of hardwood. If we assume that one-half of the mixed-wood type and one-tenth of the upland hardwoods on sites III-V could profitably be converted to pine, the pine acreage in the South could be

Table 5

Possible Improvement in Site Quality of Douglas-fir and Southern Pine Types through Fertilization

Type and Site Class	Acreage: Outlook Study (000)	Acreage: After Fertilization (000)	Assumed Mean Annual Increment (cf./ac./yr.)	Total Annual Increment (million cubic feet): Outlook Study	Total Annual Increment (million cubic feet): After Fertilization
Douglas-fir, Hemlock, Sitka Spruce, Redwood					
I,II	13,700	15,000	160	2,192	2,400
III	6,500	8,000	110	715	880
IV	8,200	6,000	70	574	420
V	1,200	600	40	48	24
Total	29,600	29,600		3,529	3,724
Southern Pine					
I,II	5,800	6,000	160	928	960
III	21,900	23,000	110	2,409	2,530
IV	32,000	35,000	70	2,240	2,450
V	8,300	4,000	40	332	160
Total	68,000	68,000		5,909	6,100

increased by 20 million acres. If we further assume that the site will be raised by at least one class by such conversion, the area of southern pine by site classes would be augmented as shown in Table 6. In this estimate, the base is that provided by Table 5 after site improvement from fertilization and drainage. Such a conversion could increase the potential yield of southern pine by as much as 39 percent over the projected growth after site amelioration, or 40 percent over projected growth based on acreages and site classes as delineated in the Outlook Study, without taking into consideration the effects of site improvement.

Improving Stocking Through Reforestation

Probably the single most important factor in maintaining the productivity of the forests of the United States is the development and maintenance of full stocking through a nationwide program of seeding and planting where and when necessary. The Outlook Study reports a total of 20.7 million acres of non-stocked commercial forest land, or 4.2 percent of our commercial forest land: 4.8 million are in the South, 3.7 million are in the Pacific Coast region, 9.6 million are in the North, and 2.7 million are in the Rocky Mountains.

Many harvested areas lie idle for one, two, or even more years before regeneration is attained. If planting can be done immediately after harvesting rather than one year later, yields can be increased by 4 percent over a southern pine rotation of 25 years. Before this can be accomplished, we must improve initial survival and stocking of new stands by fully using presently available knowledge on growing, handling, and outplanting seedlings. Twenty-five year records from throughout the South showed that first year survival on 250,000 acres of planted slash and loblolly pine ranged from 53 to 83 percent; average survival for this 250,000 acres was 71 percent (Schultz 1975). Average survival for 9 conifer species planted throughout the Lake States was 50 percent at age 11 (Rudolph 1950). From 5 to 25 percent of each year's plantings is a failure due to poor survival (that is, less than 300 trees survive to age 5).

During the 11-year period from 1960 to 1970, a total of 1.477 million acres was planted or direct seeded annually in the United States. Assuming a 15 percent failure rate, regeneration probably averaged 1.3 million acres. More than 60 percent of the regeneration was in the South, and 76 percent was carried out by forest industry and other private owners.

Table 6

Increased Acreage of Southern Pine
from Species Conversion and Planting

	Area in Acres (000)					
Site Class	From Out-look Study	After Site Improvement	Oak-pine Conversions	Hardwood Conversions	Non-stocked Conversions	Total After Treatments
I,II	5,800	6,000	2,000	---	---	8,000
III	21,900	23,000	10,000	2,000	1,500	36,500
IV	32,000	35,000	3,000	3,000	2,500	43,500
V	8,300	4,000	---	---	---	4,000
Total	68,000	68,000	15,000	5,000	4,000	92,000

A rough estimate of the maximum annual planting program that might develop over the years may be derived for the Douglas-fir and related conifers on the Pacific Coast and for southern pines.

For Douglas-fir and other mesophytic conifers, we estimate a total of 29 million acres in Sites I, II, III, and IV (capable of growing 85 cubic-feet per acre per year) after fertilization of some five million acres to improve site quality (Table 5). If we assume that conversion periods will be 50 to 60 years and that all stands will be eventually clearcut and the sites replanted, the area planted annually would be either 580 or 483 thousand acres. If the conversion were carried out over a shorter period of time, the area to be planted annually would be greater. Considering that not all stands will be regenerated by clearcutting and planting, and that more than 300 thousand acres are currently being planted in all timber types in the region, there seems to be no major biological barrier to the achievement of full stocking on all the better sites for the Douglas-fir type over the period of approximately half a century.

For southern pines, we estimate a potential acreage of 68 million acres of Site IV or better (more than 50 cubic feet per acre per year). This includes site amelioration treatment to 5.8 million acres, planting of four million acres of non-stocked lands, and conversion by planting of 20 million acres (Table 5). Assuming that this effort is carried through over the next 30 to 40 years, and assuming that the 64 million acres of southern pine on Sites I - III would be regenerated by clearcutting and planting, we see that an annual planting program of 2.2 million acres would be needed. Quicker conversion would require more planting each year. Again, since present planting levels already exceed a million acres per year, this goal does not seem unattainable.

We may conclude, therefore, that for the two principal timber-growing regions in the country, it would be feasible to achieve full stocking as well as species conversion over 50 to 60 years for Douglas-fir and 30 to 40 years for southern pine.

Genetic Improvement

It is at the time of planting the new forest that the possibility of genetic improvement becomes real. The potential increased productivity from wide-spread application of forest tree improvement practices has been summarized by Barber (1968) with particular reference to the southern pine forests. He concludes that through an intensive program of plus-tree selection, seed orchard establishment, and progeny testing in southern pine, the projected increase in growth from a first-generation seed orchard would be on the order of 10 to 25 percent. Each generation of seed orchards would require 10 to 12 years. In the Pacific Northwest, Forest Service geneticists similarly estimate an increment of 10 to 20 percent from the first generation of seed orchards, but an interval of 15 to 20 years between generations.

Conservatively, we may estimate a gain for major conifer species in the United States of 10 to 15 percent per generation of seed orchards and an interval of 15 to 20 years between generations, or roughly 1 percent per year over the next century.

Major gains from improved genetic selection apply only to species which are managed by a clearcutting and artificial regeneration. This restricts the choice of species to conifers (mainly southern pine and Douglas-fir), short rotation fiber crops (e.g., aspen, cottonwood, sycamore), and fine hardwoods such as walnut and ash. Within these forest types, genetic improvement would apply only to areas that are clearcut and planted, seeded or vegetatively propagated. Even for these, it would take many years to develop a sufficient supply of improved seed for regionwide application.

The introduction of genetically faster-growing trees into the forest stand does not guarantee that they will indeed grow faster. For this to occur, additional growing space is needed, and this must be achieved through regular thinnings as the stand matures. It may well be that a plantation of genetically superior trees that is regularly thinned will produce more usable timber volume than would be predicted by adding the growth improvement expected from thinning alone to that expected from genetic improvement alone.

For areas actually planted, the potential increases in yield may be greater than indicated above because of gains from disease resistance. In the South, both slash and loblolly pines are attacked by fusiform rust. Although it is difficult to estimate the improvement possible through the selection of seed from parents which are fusiform-rust resistant, a doubling of resistance in plantations established from such seed is quite possible over the next 10 years.

Weeding

The cutting back or killing back of unwanted vegetation to free wanted trees in the seedling stage to grow is often an essential silvicultural practice. If sites are to be kept fully stocked with specified tree species, other plants or trees with less desirable growth or value characteristics must be prevented from taking over. For example, weeding is frequently necessary to bring planted conifer seedlings through to form the overstory of the new stand. Similarly, the cutting of mature pine stands will frequently result in turning the site over to the hardwood and brush understory which had developed under the old pine stand. The control of such unwanted vegetation through cutting it back, use of herbicides, or controlled burning must be planned for and executed if the affected sites are to be counted on to produce the desired forest stand. The costs of such treatment become a necessary part of the costs of management.

Mechanical or chemical weed control can play an important role in both water and nutrient management by reducing competition from unwanted trees and plants at the time of forestation and during early stand development. For example, mechanical control of ground vegetation more than doubled the volume of 4-year-old loblolly pine in the North Carolina Coastal Plain (Hansen and Johnson 1974).

Thinnings

Forest stands that are frequently thinned do not produce any greater biomass than comparable healthy stands that remain unthinned. The effect of thinning is rather to concentrate the biomass production on the better quality and potentially more valuable trees (Spurr 1952). In short, a thinned stand does not produce more total volume, but it does produce bigger trees in a shorter period of time. For short rotations, therefore, the board-foot production of forest may be increased by thinning, even though the total cubic-foot volume may be unchanged or reduced.

As fully-stocked forest stands develop, competition greatly reduces the number of living trees. The reduction in the gross growth or increment of the stand resulting from this natural mortality results in a substantially lessened net growth or increment. In an extreme example, Spurr (1963) reconstructed the annual mortality and gross growth of a fast-growing Monterey pine plantation in New Zealand. At age 35, the gross annual increment was 516 cubic feet per acre per year or 55 percent greater than the net annual increment of 332 cubic feet per acre per year. The difference will normally be less under less ideal growing conditions.

Normal yield tables assume normal mortality. The difference between estimated stand volumes at different ages is, therefore, the net growth. In some yield studies, however, separate estimates of mortality have been provided, which, when added to net growth, produce estimates of gross growth. In addition, gross growth yield tables have been developed for a number of species in recent years. By comparing these with older normal yield tables that predict net growth, we can estimate the amount of mortality that might be salvaged through thinnings. Ostrom and Gibbs (1973) have summarized several of these comparisons for western conifers (Table 7). They concluded that, under very intensive management, harvests close to the gross yields should be attainable in most timber types unless natural disasters intervene. This could mean an increase of about 20 to 60 percent above normal yield in various species. It has been estimated that yield of Pacific Northwest conifers can be increased from 30 to 35 percent if stand density is controlled by frequent thinnings throughout a normal rotation (Robert E. Buckman 1975, personal communication, U.S. Forest Service).

Recent efforts to estimate timber yields under intensive management predict similar gains. Working with Douglas-fir permanent sample plot data in New Zealand, Spurr (1963) predicted that following three thinnings at ages 30, 40, and 50, a 60-year-old managed stand would produce 427 cubic feet per acre per year, or 21 percent more than the 352 cubic feet produced by the comparable unthinned stand. Results of long-term experiments in Europe (Assman 1970) indicate that with frequent light thinning, spruce stands yielded more than 90 percent of the potential gross yield, or approximately 130 percent of normal yield. Gingrich (1971) developed yield predictions for managed upland hardwoods in the Central States. Assuming thinnings at ten-year intervals beginning at age 30, the cumulative total yield under management at age 60 for stands on medium sites (Site Index 65) would be 62 cubic feet per acre per year or 14 percent greater than the 55 cubic feet predicted by the normal yield table for unthinned stands. Summarizing a long-term study initiated in a 17-year-old loblolly pine stand in 1930, Andrulot et al. (1972) found that at age 50, gross mean annual increment was 121 to 122 cubic feet per acre per year on the thinned and unthinned plots respectively; but that the net increment on the unthinned plots was only 98 cubic feet per acre per year, while on the thinned plots, it was 119, or 20 percent greater. The Weyerhaeuser Company has carried out extensive research in conceptualizing a target forest that can be achieved through intensive management. On the assumption that growth can be recovered through an intensive thinning regime, they predict an increase in cubic-foot yield of 25 percent for Douglas-

Table 7

Relation of Normal Yield to Gross Yield for Different Species and Sites at age 100

Species and source	Site index	Normal yield (cu.ft.)[1]	Gross yield (cu.ft.)	Volume increase (cu.ft.)	Relative increase (percent)
Douglas-fir	100	7,620	13,300	5,680	75
(Curus 1967,	140	13,270	18,400	5,130	39
McArdle 1961)	170	16,610	23,500	6,890	41
Lodgepole pine	30	2,194	3,768	1,574	72
(Dahms 1964)	50	4,563	6,975	2,412	53
	70	6,932	10,182	3,250	47
Western white pine (Watt 1960)	all	8,770	11,310	2,540	29
Ponderosa pine	80	5,650	7,373	1,723	30
(Meyer 1961)	120	11,350	14,045	2,695	24
	160	19,350	23,710	4,360	23

[1] Volume to tip

Source: Ostrom and Gibbs (1973)

-fir stands grown in Site II at optimum density levels on a 60-year rotation.

The above citations only sample the recent work that has been done on the potential yield from intensive silvicultural management. The evidence presented is episodic rather than comprehensive, but the data are in broad agreement. In general, it seems safe to conclude that for most species on average to better sites managed for medium-length rotations, gross increment will range from 15 percent to 35 percent greater than the net yield indicated by normal yield tables. Furthermore, most of this gross increment (perhaps 90 percent) can be used through thinnings commenced early in the life of the stand and carried out at a maximum of 10-year intervals. In the absence of badly-needed growth data in the form of managed-stand yield tables on a gross growth basis for all major forest types in the United States, we may assume that normal yield table values can be increased by 25 percent if silvicultural management in the form of regular thinnings can be applied. However, southern pines and other fast-growing species on short rotations should be considered exceptions to this generalization. The evidence now available suggests that biomass gains from thinnings will be small or perhaps negative under such conditions. Once the rotations are extended, however, the capture of mortality becomes important.

Protection

Improved protection of the forest from fire, insects, and diseases is an obvious way to increase the productivity of the forest and the percentage that is actually harvested and used by man.

Annual mortality losses from all natural causes are estimated in the Outlook Study to be about 4.5 billion cubic feet of growing stock. These losses nullify about one-fifth of the total annual forest growth in the United States. Reduction in these losses through improved timber, fire, and pest management may provide the single greatest means of improving timber production.

According to the Outlook Study, federal and state agencies spent $201 million for forest fire protection in 1970. It is estimated that counties, private operators, and others spent an additional $120 million that year for hazard reduction, such as slash burning and prescribed burning, and for other unreported fire protection activities. The total protected area burned was 2.1 million acres in 1970. An additional million acres of unprotected land also burned that year. Increased expenditures for fire control might well result in less forest loss from fire, although it should be noted that the annual area burned has changed very little in recent years. On the other hand, reducing the acreage burned by wildfires even by 10 percent could mean a savings in excess of 100 million cubic feet of wood each year.

Management practices which maintain trees in healthy growing conditions (e.g., breeding for disease resistance, properly matching species to site, adequate tree spacing, prompt salvage of dead or dying timber, biological or chemical control measures for suppressing insect and disease outbreaks) must be diligently practiced if managers are to reduce this tremendous waste.

On the positive side, prescribed burning has long been an important component of forest management, especially in the southern pine forests. Burning every 3 to 5 years reduces the buildup of natural fuels, forestalls damage from possible wildfires, kills invading hardwood trees, maintains subclimax conifer stands in a healthy growing condition, and may enhance tree growth. Fire is often a valuable and inexpensive adjunct to mechanical site preparation prior to planting. On many areas throughout the country fire alone is a sufficient site treatment for establishing healthy new stands.

Expenditures for control of diseases, insects, and other forest pests have averaged about $12 million per year, mostly from federal funds. Again the possibility exists that greater expenditures would result in less loss and more forest products available for harvest.

The Forest Service estimates that total loss from fire, insects, disease, storms, and other destructive agents has risen from 3.9 billion cubic feet in 1952 to 4.3 billion in 1962 and 4.5 billion in 1970. Under a continuation of 1970 levels of management, it is estimated that mortality will rise slightly to 4.9 billion cubic feet in 1985 and to 5.2 billion in 2000. With better forest protection, it is certainly silviculturally feasible to reduce mortality to between 3 and 4 billion cubic feet annually. To what extent it is economical to increase the costs of forest protection to achieve a greater actual harvest of one to two billion cubic feet per year from the forest is a separate and complex matter.

Increasing Allowable Cut

A frequent objection to increased investment in forest management is that it takes so many years to raise a tree to maturity that the small return on the investment renders it uneconomic. A contrary line of reasoning conceptualizes the whole forest as the management unit and concludes that what is done on one acre has immediate effects on what should be done on other acres within the same unit, and consequently upon the value of the larger operation as a whole.

Another aspect of this complex subject is the "allowable cut effect." In a forest managed on sustained yield principles with the annual harvest related in some fashion to the annual growth, any silvicultural action that increases the annual growth will immediately permit an increase in the annual harvest. Thus, an investment in silvicultural management will immediately affect the value of the property as a whole. It is conceivable that the cost of planting will be recovered in the same year through an increased harvest. Without going into the many ramifications, we point out that increased investments in protection should raise the annual allowable cut to the extent that future losses can be predictably reduced and, therefore, the amount of harvestable material increased. As another example, immediate planting of a cut-over site with one to two-year old nursery stock will shorten the rotation by a number of years--at least one and often as much as five to ten if the alternative is to wait for a periodic seed crop needed to naturally reseed the area. The increased yield predictable from both shortening the rotation and guaranteeing full stocking (weeding must be undertaken if needed) again has an allowable cut effect in increasing the productivity of the whole management unit and permitting an immediate increased harvest. In still another situation, many acres in the Rocky Mountains and Pacific Coast are occupied by overmature timber stands with little or no net growth. Similarly, many acres in the East and South are occupied by culled and understocked forest stands, often of the wrong species with much less growth than the potential for the site if fully stocked with suitable tree species. In both cases, the conversion of the forests to fast-growing trees forming fully-stocked stands will greatly increase the productivity of the management unit and permit increased harvest. The computation of the actual amount of gain in allowable cut is complex and involves many factors including the size and age distribution of the forests in the management unit. It must be remembered, however, that the allowable cut effect occurs only when a forest working circle is managed on a sustained yield basis and when the allowable cut is computed on a volume-growth regulation basis. Furthermore, some forest economists challenge the validity of these basic assumptions.

The question of the allowable cut effect is a highly controversial one, and the panel does not take any position on it, but simply draws attention to its existence. It is essentially a managerial and economic issue rather than a biological one.

INCREASED USE OF THE FOREST BIOMASS

The term "biomass" means the total weight of animal and plant material in an ecological community or system. The biomass of a forest ecosystem thus consists of all the trees, understory plants, animals including insects and other arthropods, total soil biota, and similar elements. Although considerable data have been accumulated over the last century on the volume, weight, and energy dynamics of the various components of the forest, it fell to Ovington (1965) in the 1950s to integrate such data into a systems context. More recently, scientists in several countries working with forest ecosystems as part of the International Biological Program have added greatly to the statistical base and to our understanding of the biological productivity of the forest in terms of biomass and energy relationships.

Biomass studies are tedious, time-consuming, and expensive. Despite the large amount of effort invested, therefore, only a relatively few forests of small area have been studied in detail and these have not been chosen to represent statistically any larger population. We have little or no basis, therefore, for expanding data obtained from biomass sample plots to the forests of the United States as a whole. Because of the paucity of representativeness of biomass sample studies, our current effort to evaluate the biological productivity of the forests of the United States has had to rely upon conventional forest sample plots in which the measurement is concentrated upon estimating the current volume and the growth in volume of the bole of the trees in the forest, excluding the stump and the top of the tree. At the same time, we recognize the present importance and the potential applicability of forest biomass studies. It may be of value to assess rather briefly the possibilities of increasing the use of the forest biomass, ranging from the simple closer use of the bole through complete tree use, to an evaluation of total biomass potential.

Closer Use of the Bole

In conventional logging, many trees and portions of trees unmerchantable because of defect are left in the woods. Even for those trees taken, a large share of the bole (main stem) is left unused after completion of the manufacturing process. The amount lost is relatively small in the case of managed even-aged stands of commercial species harvested at rotation age for pulp as well as for lumber, and relatively great in the case of unmanaged old-growth stands that are highly defective and harvested primarily for lumber. The former situation is frequently encountered on industrial forest lands in the southern pine region, while the latter is the rule where old-growth stands are harvested in the Pacific Northwest. In a recent study of the status of timber use on the Pacific Northwest, Grantham (1974) estimated that of the annual harvest of 69.2 million tons, 14 million tons or 20 percent is left in the woods as logging residues, and 5.7 million tons or 8 percent is left unused in the sawmill. If we add to this 1.1 million tons of residues from veneer logs, the total unused residue is 21.2 million tons or 31 percent of the total annual harvest. For the United States as a whole, Lassen and Hair (1970) estimated an annual (1968) volume of two billion cubic feet of logging residues, plus an additional 1.7 billion cubic feet from primary manufacturing residues. At 35 pounds per cubic foot, this represents a total of 65 million tons of unused residues.

At the immediate and practical level, measurable gains can be achieved through improved efficiency in the conversion of saw logs to lumber (PAPTE 1973). At present, only 40 percent of the wood in the log is recovered in the form of lumber. Saeman (PAPTE 1973) believes that with no new equipment, but with investment in management and maintenance, the average mill can profitably increase its recovery. Furthermore, the addition of automated systems based on predetermined arithmetic solutions to optimum sawing problems could raise the recovery factor by perhaps an additional 10 percent through the elimination of human error, although the volume gain may not necessarily be in sizes and grades demanded in the market. The increase in lumber production of more than 20 percent from 40 percent of the wood in the bole to nearly 50 percent would be partly at the expense of pulp chips and other products and would not be solely at the expense of waste residues. Nevertheless, the gains would be real and well worth the effort required to achieve them.

In several field tests, yields have indeed been increased substantially. For aspen in Michigan, Napier (1972) demonstrated that a harvesting system designed to produce chips in the forest could produce 84 tons per acre compared to 41 tons from conventional pulpwood harvest. Working with lodgepole pine in Wyoming, Gardner and Hann (1972) were able to increase yield 35 percent by near complete harvesting which used tops, all trees with a stem diameter greater than three inches and all sound residue more than six feet long and six inches in diameter at the large end. These increased yields, however, do involve the inclusion in the harvest of large amounts of bark. As a result, at the present time, the use of this small dimension material is not economic under most conditions.

The stump and tap roots of southern pines contain substantial wood in a concentrated form suitable for chipping. Koch (1974) described a prototype tubular shear with which the tree can be sheared below the ground and removed whole, opening up the possibility of an increase in the usable harvest of as much as 20 percent from young plantations of slash pine on rock-free sites.

Complete Tree Use

In addition to closer use of the tree bole above the stump to a minimum diameter near the top, the possiblity exists for using part or all of stump, bole tip, branches, foliage, fruits, and root systems. As one phase of the biomass approach, considerable work has been done in recent years by forest scientists in measuring the potential of these other elements. Much of this work has been done at the Complete Tree Institute of the University of Maine (Young 1964).

The literature on complete tree use has been summarized by Keays (1971). The contribution of various parts of the tree to its total weight obviously varies. In gross terms, however, rough averages may be assigned. Taking the merchantable bole as 100, an additional 5 to 10 percent will be found in the unmerchantable top, 5 or more percent in the stump root system, 5 percent in the large branches, 20 percent in the foliage and small branches, 15 percent in the small root system, and 10 percent in bark throughout the tree. Granted large variation in these values, it is apparent that not much more than 60 percent of the wood and bark in the average tree is in the part removed in the conventional logging operation.

At the same time, it must be remembered that the merchantable bole is relatively low in mineral nutrient content, a large portion of the nutrients being concentrated in the growing tip, foliage, fruits, small branches and small roots. William Pritchett (personal communication, 1975, University of Florida) estimates that whole tree harvesting might increase pulping yields 25 percent, but that it would result in doubling the amount of nutrients taken from the site. It must be remembered, though, that such a complete withdrawal takes place only once each rotation and that the total effect is much less than it is for agricultural crops. Whereas, under normal bole logging, a balanced nutrient cycle develops in which a low level of nutrient availability can be maintained indefinitely, more complete harvest of the tree would require substantial amounts of nutrient input. From a biological point of view, the nutrient-rich parts of trees should be left in the forest. Also, nitrogen-fixing and other nutrient-accumulating plants such as red alder should be encouraged as part of the silvicultural management of the forest.

Total Ecosystem Biomass

Although there is no basis for assuming the use of other parts of the forest ecosystem than the mature tree, total ecosystem biomass studies currently being carried out by ecologists are exceedingly important in adding to our understanding of the forest as a biological complex. The state of the art is well summarized in Productivity of Forest Ecosystems: Proceedings of the Brussels Symposium (UNESCO 1971), particularly in articles by Duvigneaud, Whittaker and Woodwell, and Olson.

The depth of information obtained in total forest biomass studies is illustrated in Table 8, taken from Whittaker and Woodwell's paper in the UNESCO Symposium (1971).

For the 43-year-old oak-pine forest at the Brookhaven National Laboratory, shrubs and herbs annually produce 13 percent additional dry matter to that produced by the trees alone. Only 14 percent of the annual increment in dry matter in this one example is lodged in the stem wood. The mean annual increment of stem wood is about 45 cubic feet per acre per year. The old growth cove and spruce-fir forests have a mean annual increment of stem wood of about 115 and 120 cubic feet per acre per year.

A principal result of the work of Whittaker (1966) in the Great Smoky Mountains is his conclusion that the net production of many late successional forests lie in the range of 1200 to 1500 grams dry weight per square meter per year. Assuming that 20 percent of this accrues to the merchantable bole and that the dry wood weighs 30 pounds per cubic feet, this is equivalent to 70 to 90 cubic feet per acre per year bole increment. Whittaker's estimate is, therefore, comparable with the 74 cubic feet per acre per year estimated by the Outlook Study as the potential growth of the commercial forests in the United States.

Intensive Biomass Management

Over and above a more complete use of the merchantable boles in the forest ecosystem lies the intriguing possibility of increasing total biomass production of the forest ecosystem through the selection of highly efficient photosynthesizers and growing them under intense cultivation over short rotations.

Essentially, a return is recommended to a form of the coppice system, that was employed extensively in Europe and the eastern United States during the nineteenth century, to produce fuelwood from hardwood stands regenerated by sprouting on short rotations. In its present-day

Table 8 Net production and related dimensions of temperate-zone forests; (a) a young oak-pine forest at Brookhaven National Laboratory, Long Island, New York (data from an intensive study of Whittaker and Woodwell 1968, 1969):(b)a deciduous cove forest at 1,310 m elevation: and (c) a spruce-fir forest at 1,800 m elevation, Great Smoky Mountains, Tennessee (field measurements and estimates of Whittaker 1966, samples 23 and 29)

	Oak-pine forest		Cove forest		Spruce-fir forest	
	Net production	Biomass	Net production	Biomass	Net production	Biomass
Totals, net production ($g/m^2/yr$) and biomass (kg/m^2), dry matter, for:						
Trees	1,060.0	9.7	1,300.0	57.8	1,175.0	39.6
Shrubs	130.0	0.46	2.6	0.01	33.0	0.14
Herbs	6.0	0.01	75.0	0.12	44.0	0.06
Thallophytes		<0.01		0.02		0.04
Percentage of totals for trees in:						
Stem wood	14.0	36.1	33.0	67.0	31.9	64.0
Stem bark	2.5	8.4	3.9	6.0	3.7	6.5
Branch wood and bark	23.3	16.9	17.0	12.8	15.2	10.0
Leaves	33.1	4.2	30.7	0.7	31.0	3.4
Fruits and flowers	2.1	0.2	1.9	0.03	2.2	0.1
Roots	25.0	34.2	13.5	13.5	16.0	16.0
Biomass accumulation ratio	8.5		43.5		31.9	
Weighted mean tree age, yr	43.3		222.0		161.-	
Weighted mean tree height, m	7.6		34.0		21.3	
Basal area, wood and bark, m^2/ha	15.6		54.2		55.6	
Basal area (wood) increment, $m^2/ha/yr$	0.356		0.445		0.54	
Mean wood radial increment, mm/yr	0.86		0.73		0.96	
Estimated volume increment, $cm^3/m^2/yr$	159.0		547.0		534.-	
Parabolic stem wood volume estimate, m^3/ha	70.0		851.0		547.-	
Conic stem wood surface estimate, m^2/m^2	0.21		0.50		0.52	
Stem bark area ratio, m^2/m^2	0.30		0.6		0.-	
Branch bark area ratio, m^2/m^2	1.2		1.6		-.-	
Leaf area ratio, m^2/m^2	3.8		6.2		14.8	
Chlorophyll, g/m^2	1.9		2.2		3.0	
Tree stratum individual-point coverage, percent	126.0		268.0		168.-	
Light penetration to ground, percent	5.9		0.2		1.4	

Source: Productivity of forest ecosystems. Proceedings of the Brussels Symposium. UNESCO 1971

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manifestation (Schreiner 1970), the proposal is to use such fast-growing species as cottonwood, sycamore, red alder, or aspen reproduced by sprouting (or from root suckers in the case of aspen), to cultivate them intensively and to harvest them mechanically on rotations of two to four years (Ribe 1974). Yields of several tons of oven-dry plant material per acre per year are predicted on the basis of small plot studies, a multifold increase on that actually obtained from conventional forest management (Gordon 1975).

Were such yields actually attainable over extensive areas without necessitating heavy energy investments in the form of fertilization, irrigation, cultivation, and mechanical harvesting, short-rotation silviculture would indeed have considerable promise. Unfortunately, so far, we have not been overly successful in growing hardwoods in plantations at all, let alone growing them at the rates attained from localized trials of genetically superior stock under intensive care in the nursery or other carefully monitored conditions. This is not to say that the experimental work is less than soundly based, but rather that we have notably failed to transfer the results of such small-scale research to large-scale commercial operations.

The increasing need for alternative energy sources to fossil fuels has resulted in a renewed interest in growing wood and agricultural products for fuel. Speculative inquiries into this possibility may be extremely stimulating (Alich and Inman 1974; Szego and Kemp 1973), but are all too often based upon biological and silvicultural assumptions which have not been confirmed either by basic research or by applied field trials.

Nevertheless, the potential is great. For instance, Young (1975) estimates the forests of Maine contain as much biologically-produced weight (biomass) outside the merchantable boles as is contained inside them. In addition, the below-ground portions of the forest are thought to contain one-third as much biomass as the above-ground portions. But, at the same time, wood has high costs of collection in both energy and dollars required for extraction. Under present conditions, Grantham and Ellis (1974) conclude that logging residue is and will continue to be too expensive for use as fuel only, but it is a potentially attractive source of material for products.

While research should be continued on the possibility of greatly increasing the total biomass potential of the forest through intensive management of genetically superior species on rotations of two to four years, it would be unrealistic at present to assume that such techniques will have any widespread application in the near future.

AREA OF COMMERCIAL FOREST LAND IN THE UNITED STATES

There are almost 500 million acres of commercial forest land in the United States. Its distribution by types of ownership and region are summarized in Table 9. The Forest Service defines commercial forest land as forested land not withdrawn from timber production (as is the case for National Park lands and Wilderness Areas) and capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible areas are included.

Since the Forest Service defines "commercial forest" solely in terms of productivity, the resulting estimate will exceed the area that can be logged at any given time. As of the date of the current estimate (1970), the acreage is high because the Forest Service's estimate of commercial timber lands includes (Greentree Associates 1973): (1) private lands where commercial harvest is not allowed; (2) areas too steep or unstable to log without unacceptable environmental damage; (3) sites on which adequately stocked stands cannot be produced; (4) areas economically inaccessible; and (5) a portion of the inventory on lands where harvest is restricted (but not excluded) by law or regulation to protect other values.

These considerations are recognized by the Forest Service itself. In the Outlook Study, some five million acres of forest in the Rocky Mountain area are excluded for one or more of the reasons cited. Wikstrom and Hutchison (1971) found that 22 percent of the classified commercial forest land in six western national forests was not currently available for timber management and harvest. However, the impact on allowable cut proved to be less than the reduction in area. From economic considerations, Vaux (1973) estimated that 39 percent of the commercial forest land in California could not produce timber at costs equal to or below the forecast market price.

Several have argued for a concentration of timber production upon the most productive sites (PAPTE 1973, Spurr 1974, Clawson 1974), pointing out that timber growing can be deemphasized (but not discontinued) on as much as a quarter to a third of our National Forests with only a minimal impact on total timber production. It should be remembered, though, that in actual forests, highly productive sites are frequently intermixed with less productive sites on an areal basis. Blocks of land dedicated to intensive timber growing, therefore, will often contain an admixture of poor sites; while other blocks of land on which multiple-use management is emphasized and where timber management is extensive will contain areas of high site quality.

Table 9

Area of Commercial Timberland in the United States, by Type of Ownership and Section, January 1, 1970

Type of ownership	Total United States Area	Total United States Proportion	North	South	Rocky Mountains	Pacific Coast
	Thousand acres	Percent	Thousand acres	Thousand acres	Thousand acres	Thousand acres
Federal:						
National Forest	91,924	18	10,458	10,764	39,787	30,915
Bureau of Land Management	4,762	1	75	11	2,024	2,652
Bureau of Indian Affairs	5,388	1	815	220	2,809	2,044
Other Federal	4,534	1	963	3,282	78	211
Total Federal	107,109	21	12,311	14,277	44,699	35,822
State	21,423	4	13,076	2,321	2,198	3,828
County and municipal	7,589	2	6,525	681	71	312
Forest industry	67,341	14	17,563	35,325	2,234	12,219
Farm	131,135	26	51,017	65,137	8,379	6,602
Miscellaneous private	165,101	33	77,409	74,801	4,051	8,840
All ownerships	499,697	100	177,901	192,542	61,632	67,622

Source: The Outlook for Timber in the United States, U.S. Department of Agriculture Forest Service (1974)

North: Including and east of North and South Dakota, Nebraska and Kansas. Including and north of Missouri, Kentucky, West Virginia and Maryland.

South: Including and south of Oklahoma, Arkansas, Tennessee and Virginia.

Rocky Mountains: Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, and New Mexico.

Pacific Coast: Alaska, Washington, Oregon, and California.

Despite these suggestive reports, however, we have no overall basis for discounting the acreage estimates provided for us by the Outlook Study. In using these data, we must constantly bear in mind that the acreage estimates are undoubtedly too high. In the Pacific Northwest and southern pine regions, the economic value of timber growing should, to some extent, counter pressures to withdraw commercial forest land for recreational use or to convert high quality forest land into lower quality agricultural land.

The commercial forest area of the United States will continue to decline in the future. Suburban sprawl, highways, and pipelines will reduce the area available to grow trees. In addition, it is possible that some forested lands will be cleared for agriculture. Drainage and flood control in the Mississippi Delta has permitted conversion of forests to agriculture in that area. The United States Department of Agriculture Economic Research Service (USDA 1974) estimates that there are 66.5 million acres of forest and "other" lands that could be used for agriculture, of which 27.3 million acres are in the Coastal Plains and Piedmont, 12.8 million acres are in the Northeast and Northern Great Lakes, and 10.4 million acres are in the Appalachian and Ozark Mountains. All of this forested land, however, is classified by the Economic Research Service as being of low potential for conversion to cropland.

Among lands remaining forested, substantial acreages are expected to be withdrawn from timber production in order to be used as parks, wilderness areas, streamside and roadside reserve strips, and protection forests on lands too steep or fragile to be logged.

In the Outlook Study, the area of commercial timber land in the United States, currently 499.7 million acres, is projected to drop to 494 million acres in 1980, 489 million in 1990, and 484 million in the year 2000.

These reductions seem low. In his consultant's report to PAPTE, Marty assumes a reduction in the 1970 softwood acreage base of 20 percent on public and other private lands, and of 5 percent on forest industry ownerships, resulting in a reduction overall of 17 percent in the softwood forest land acreage.

Again, we have not the data to predict the decline accurately, but the indications are that it will be fairly substantial. Furthermore, while past withdrawals for wilderness and recreational use have been to a considerable extent from non-commercial or low site forest land, future withdrawals will inevitably be to a greater extent from more productive commercial forest lands.

The areas of commercial forest land in the Pacific Coast region and in the South are stratified by forest type, size class and site in Tables 10 and 11. For the Pacific Coast (Table 11), the Douglas-fir, hemlock-sitka spruce, and redwood types are combined in one column as are the ponderosa pine, larch, and lodgepole pine types in another. For the South (Table 10), the longleaf-slash and loblolly-shortleaf pine types are combined with limited acreages of other softwoods in the first column. Hardwoods are divided into upland hardwoods consisting primarily of oak-hickory but also including small acreages of maple-beech-birch, and lowland hardwoods consisting primarily of oak-gum-cypress but also including smaller acreages of elm-ash-cottonwood. These acreage data provide the base for projecting the increased yield potential from intensified forest management in these two regions, a topic that is dealt with elsewhere in the report.

OVERALL POTENTIAL OF UNITED STATES FORESTS

In concluding the section on the potential productivity of the United States with regard to wood, we may estimate in broad terms what could be achieved at different levels of management, leaving unanswered at present the probability of each different level being economically justifiable or politically or socially feasible. We assume that the forests of the United States as a whole will be managed in all instances on a sustained yield basis, and that annual harvesting will be closely related to annual growth, at least on the average over a period of years.

Continuation of 1970 Levels of Management

Forest management over the past twenty years has been growing steadily more intensive. It seems appropriate, therefore, to discount the possibility of a downgrading in forest practices and to join with the Forest Service in its Outlook Study by taking the continuation of 1970 levels of management as our base line. Summarizing the projections of the Outlook Study to 1985 and 2000, we find that the United States, with an annual harvest of 14 billion cubic feet of wood (225 million tons of wood and bark) in 1970 could produce 17.5 billion cubic feet (283 million tons) in 1985 and 20.3 billion cubic feet (330 million tons) in 2000 (Table 12). Much of the increase would derive from increased use of current hardwood growth.

Taking into account changes in the acreage of forest land as predicted in the Outlook Study, production per acre would rise from 30 cubic feet per acre per year in 1970 to 37 in 1985 and 43 in 2000. Much of this improvement again

Table 10

Area of Commercial Timberland
by Forest Type and Site, 1970-South*

(Thousand acres)

Forest Type	Site Classes				
	I,II	III	IV	V	Total
Softwoods	5,825	21,850	31,998	8,318	67,993
Oak-pine	2,630	8,163	15,430	4,718	30,942
Upland-Hardwoods	1,923	9,343	28,794	16,744	58,806
Lowland-Hardwoods	3,061	13,839	11,740	3,381	32,024
Non-stocked	36	254	1,660	2,820	4,771
Total	13,478	53,452	89,626	35,984	192,542

Source: The Outlook for Timber in the United States, U.S. Department of Agriculture Forest Service (1974)

*Data may not add to totals because of truncating.

Table 11

Area of Commercial Timberland
by Forest Type and Site, 1970-Pacific Coast*
(Thousand acres)

Forest type	Site Classes				
	I,II	III	IV	V	Total
Douglas-fir Hemlock-Sitka spruce Redwood	13,728	6,458	8,245	1,194	29,627
Ponderosa pine Lodgepole pine Larch-pine	1,895	4,482	8,616	2,719	17,712
Fir-spruce	2,348	2,004	2,948	727	8,029
Western Hardwoods	4,184	1,946	1,980	434	8,545
Non-stocked	1,470	680	1,113	442	3,707
Total	23,628	15,572	22,904	5,518	67,622

Source: The Outlook for Timber in the United States. U.S Department of Agriculture Forest Service (1974)

*Data may not add to totals because of truncating.

Table 12

Prediction Production of Roundwood Timber
Assuming the Continuation of 1970 Levels of Management

	1970	1985	2000
		billion cubic feet	
Production			
Softwoods	9.6	11.0	12.1
Hardwoods	4.4	6.5	8.2
Total	14.0	17.5	20.3
Area		million acres	
Softwoods	207	209	213
Hardwoods	267	263	261
Non-stocked	21	15	10
Total	495	487	484
Production per acre		cubic feet per acre	
Softwoods	46	53	57
Hardwoods	16	25	31
Total	30	37	43

Volume can be converted to weight basis by multiplying by 27.4 pounds per cubic foot for softwoods and 32.8 pounds per cubic foot for hardwoods.

Source: The Outlook for Timber in the United States, U.S. Department of Agriculture Forest Service (1974)

in would be attributable to increased use of hardwoods. For softwoods, production would increase from 46 cubic feet per acre per year in 1970 to 53 in 1985 to 57 in 2000.

A Revised Estimate of Production Potential

Any effort to estimate the total productivity of United States forests must be highly tentative and based upon assumptions which greatly simplify the actual situation. In our approach, we predict production in terms of the total bole volume of trees 5 inches and over in diameter, breast high above stump, and excluding the top above a top diameter of 4 inches, with the understanding that incomplete use of this portion of the bole will result in lower production and that the potential exists for substantially greater production through complete tree use.

The use of forest land to grow trees for materials use and the intensity of management of such lands to grow such products are highly dependent upon economic considerations, upon political and management decisions in the case of public land, and upon ownership motivation and management decisions in the case of private forest lands. Inevitably, public lands will be withdrawn from timber production and assigned to other uses. Similarly, the owners of small tracts of forest will often neither be interested nor find it economically profitable to manage their holdings intensively for timber production. It is not our present responsibility to evaluate and predict the course of the social, political, and economic factors that will play a large part in determining the actual future course of timber production in the United States. Our assignment is rather to assess the biological productive potential. We have broadened our inquiry only by assuming that the better the forest site, the more intensive will be the management, and that management will, on the average, continue to be more intensive for softwoods in general, and for Douglas-fir and southern pine in particular, than for hardwoods and for other softwood species. The exact nature of the simplifying assumptions are detailed in the following pages.

Projected Forest Areas

The projected acreage of commercial forest land in the United States for each broad site productivity class and for softwood and hardwood types separately is summarized in Table 13.

In developing this projection, the following assumptions were made. First, the acreage of commercial land is predicted to decline from 495 million to 475 million acres,

Table 13

Projected Changes in Area of Commercial Forest Land under Intensive Management by Site Class and Species Group

	Site Productivity Class				
	I,II	III	IV	V	Total
	(million acres)				
Softwoods					
1970	34	60	94	54	242
Projected, 2020	38	75	101	47	261
Hardwoods					
1970	16	54	95	67	232
Projected, 2020	15	50	78	58	201
Non-stocked					
1970	2	2	6	11	21
Projected, 2020	0	0	3	10	13
Total					
1970	52	116	195	132	495
Projected, 2020	53	125	182	115	475

the level predicted in the Outlook Study for the year 2020. Second, all Site I, II and III non-stocked lands, three million acres of Site IV lands and one million of Site V would be reforested with softwoods. Third, 4.9 million acres of Douglas-fir types would be raised one site class through nitrogen fertilization, and 5.8 million acres of southern pine types would also be raised one site class through drainage and phosphate fertilization (Table 5). Fourth, 15 million acres of pine-hardwood and five million acres of upland hardwood in the South would be converted through clearcutting and planting to southern pines with an average increase in site quality of one class, owing to the faster growth rate of pines on these sites (Table 6). Fifth and finally, commercial forest lands would be maintained well stocked with desirable species by planting and weeding as needed to produce 90 percent of normal yield table growth on Sites I and II, 80 percent on Sites III, 70 percent on Site IV and 60 percent on Site V.

Under these assumptions, and rounding off each category to the nearest million acres, it will be seen that the acreage of softwoods would be increased from 242 million to 261 million acres despite the overall loss of 20 million acres of commercial forest land, and that most of this increase would be on the better sites. The assumptions are optimistic but technically feasible and economically well within reality.

Projected Volumes

To obtain the projected volume of timber produced, the number of acres in each category is multiplied by the assumed production per acre per year. If the total area was fully-stocked so that yield table predictions could actually be produced, it was assumed that the production per acre would be the mid-point in each site productivity class. (For the top site category, the mid-point was weighted downward to account for the fact that this class contains more acreage near the lower end of its range than at the upper end.) As previously discussed, however, yield table values cannot actually be achieved over large acreages. We assumed, therefore, that management would be sufficiently intensive to produce 90 percent of normal yield table values on the highest sites, based on European experience, and slightly less intensive on each descending site class producing 80 percent of yield on Site III lands, 70 percent on Site IV, and 60 percent on Site V.

Applying these assumptions, we obtain a mean annual production of 145 cubic feet per acre per year on Sites I and II to 21 on Site V. Multiplying these values by the appropriate acreage projections, we estimate a potential productivity of softwoods of over 17 billion cubic feet per year and hardwoods of over 11 billion for a total of 28.5 billion cubic feet (Table 14). This estimated productive potential is twice that of 1970 consumption of 14 billion cubic feet.

In this projection, anticipated production is 67 cubic feet per acre for softwoods, and 56 cubic feet per acre for hardwoods. For all species, it is 62 cubic feet per acre, compared to the present actual rate of 30 cubic feet per acre per year.

These estimates are based on revised acreage projections detailed above and the simple assumption that the level of management will decline with site class. In addition, there exists possible gains through realizing a greater percent of the gross production through an intensive thinning regime, and of obtaining faster growth rates through a broadly-applied tree improvement program.

Thinning and Genetic Improvement

The possible gains through thinning and use of improved genetic materials has been discussed earlier. We concluded that, in general, normal yield table values can be increased by 25 percent by regular thinnings, and that on those areas clearcut and planted with softwoods, growth would be increased by about one percent per year if tree improvement programs were vigorously applied on a broad scale.

Just as it is highly improbable that all forest lands can be kept fully stocked so as to produce the full yields predicted by normal yield tables, it is equally improbable that intensive thinning and tree-improvement regimes can be applied to all forest lands. In the latter case, it is likely that the main applications will be on the better forest sites in the commercially important and already well-managed Douglas-fir and southern pine regions. On this assumption, and admitting the great degree of simplification inherent in it, we can make a rough estimate of the potential effect on biological productivity if thinning and genetic improvement are carried out on the better sites in these two regions.

For both thinning and genetic improvement, we postulate an average improvement of yield of 15 percent on Sites I and II, of 10 percent on Site III, and of 5 percent on Site IV. No gain is predicted for Site V. These predictions are substantially less than the theoretical gain, but take into account the probability that as the site quality decreases, so does the likelihood that thinning operations will be carried out at regular intervals, that thinnings will have

Table 14

Projected Productivity of U.S. Commercial Forests under Intensive Management by Site Classes and Species Groups

	Site Productivity Class				
	I,II	III	IV	V	Total
Projected Growth	cubic feet per acre per year				
Normal yield	161.5	102.5	67.5	35.0	
Management intensity	90%	80%	70%	60%	
Projected yield	145	82	47	21	
Projected Production	million cubic feet per year				
Softwoods					
U. S.	5,510	6,150	4,747	987	17,394
Added Douglas fir	602	128	30	0	760
Added Southern pine	344	360	215	0	1,119
Total	6,456	6,838	4,992	987	19,273
Hardwoods	2,175	4,100	3,666	1,218	11,159
Total					
U. S.	7,685	10,250	8,413	2,205	28,553
With added DP & SP	8,631	10,938	8,658	2,205	30,432

tree improvement program. As with other assumptions, this one is made to fall within the realm of being entirely feasible from a silvicultural viewpoint, and reasonably possible within the range of future economic, political and social conditions.

Applying the potential gain in growth from thinning and genetic improvement, we predict an increase in productive potential of 760 million cubic feet annually in the Douglas-fir region and 1,119 million cubic feet from southern pine. Adding these two gains to the earlier estimate, we predict a total biological productive potential of 19 billion cubic feet (290 million tons of wood and bark) for all softwoods, 11 billion cubic feet for hardwoods (200 million tons), and over 30 billion cubic feet (490 million tons) for all species.

CHAPTER 5

SUMMARY OF PART I

PRODUCTION POTENTIAL OF UNITED STATES FORESTS

It is entirely feasible to double the production of wood from the forests of the United States through the application of current technology, while continuing to manage our forests on a sustained yield basis. Whether or not it is economically feasible to do so is a different question. Whatever the answer, it must be understood that the increases in growth we prognosticate are only those resulting from management practices which we consider immediately reasonable and practicable. The total biological potential of forests is much greater.

Our general conclusion, therefore, is that the biological productivity of the commercial forest lands of the United States is such that, where economic and social conditions permit, the net realizable growth of these forests could be doubled within half a century by the widespread application of proven silvicultural practices. Following our own lines of evidence and reasoning, we confirm the findings of others who have reached similar conclusions. We realize that political and economic restraints may result in a lesser increase in productivity. At the same time, we wish to point out that, with widespread application of intensive silvicultural practices, with complete use of our hardwood resources, and with complete tree use, our potential productivity would be closer to three times the present level rather than the doubling we feel is eminently practicable.

We should note that, while the authors of the National Academy of Sciences' report on Agricultural Production Efficiency (1975) point to the possibility that we may be approaching the limits of improvement of growth for some agricultural products, this does not hold for wood. Due to the long life span of tree crops and the relatively low historical intensity of their management, the practice of silviculture is far less advanced than the practice of agriculture. Under the current state of the art, relatively modest investments in forest management will result in substantial increments in the biological production efficiency of trees.

RESEARCH NEEDS

Concerning the biological productivity of our forests, it is important to stress the great importance of a continuing research program designed to elucidate the various factors treated in this report. Despite the substantial level and generally high quality of past investigations, the issues raised are so new that they cannot have been sufficiently studied by forest scientists.

Specifically, it is essential that we work toward the development of a revised and more broadly supported national forest survey that will present forest data on a collective biological basis, so that it can be interpreted at several levels of potential use as economic conditions change or are predicted to change. Ideally, forest survey data should provide estimates of the volume of the total boles of trees and the weight of their total biomass by component parts. Such information should be generalized by species, forest types, and classes of site and size. In short, we need to generalize better than we can today from specific studies of complete tree analyses and forest ecosystem biomass studies to better predict the effects of fuller tree use and of different silvicultural management practices.

Although considerable specific information exists on the biological and technical aspects of the various approaches to timber production under intensive management, substantial research is needed to predict the impact of such programs on site improvement, forest type conversion, reforestation, genetic improvement, weedings and thinnings of the area that can and should be involved, the results that can be expected, and the predicted cost-benefit relations. Large gains can also be expected from improved techniques for protecting forests from insects and diseases.

The interaction of increasingly more complete tree use and the nutrient cycle within the forest is poorly understood, yet it is of critical importance. As more and more of the tree is harvested, a greater proportion of the nutrient capital is taken from the site. The replenishment of this nutrient capital through natural processes will ordinarily compensate for the long-cycle periodic removal of part of the boles of the largest trees. At the other extreme, short-cycle removal of much of the forest biomass may seriously "mine" the forest soil and have a deleterious effect on the forest site. We need to know how often and how much of the forest production can be safely removed by forest type and site class.

Research must continue to develop managed-stand yield tables to predict accurately timber production as affected by cultural treatments. Results will have wide applicability in improving forest survey predictions and land-use planning decisions.

A topic not covered in this report but critical to the problem is the computation of allowable cut for the forests of the United States. We have touched upon only one aspect of this, the allowable cut effect. The assumptions and techniques by which the permissible annual cut of each class of ownership is computed will have great impact upon how and to what extent the biological growth of our forests is productively harvested.

Still another area requiring research is the socio-economic aspect of forestry. We have speculated at length about the motives of small woodland owners and the environmentally oriented groups toward intensive forestry; yet we know far too little about the impacts of these groups on future timber growing and on wood supplies.

Finally, information is needed on the energy requirements of growing timber. Research is largely lacking on this newly critical issue, so much so that the topic was omitted from our survey. In the future, energy costs, productions, and balances will figure in forest management decisions just as ecological and economic factors already do, and immediate effort is needed to develop this important facet.

REFERENCES - PART I

Alich, J.A., Jr. and R.E. Inman (1974) Effective utilization of solar energy to produce clean fuel. Stanford Research Institute Project Number 2643. 161 pp.

Andrulot, E.R., L.P. Blackwell and P.V. Burns (1972) Effects of thinning on yield of loblolly pine in central Louisiana. Louisiana Tech University Bulletin 6. 145 pp.

Assman, E. (1970) Principles of forest yield study. Pergamon Press, New York. 506 pp.

Barber, J.C. (1968) Tree improvement -- how much can we increase wood production? United States Department of Agriculture, Forest Service, ms. 14 pp.

Bengtson, G.W. (1968) Potential increases in wood production through fertilization of forest land in the South. Proceedings 47th Annual Meeting Appalachian Section. Society of American Foresters February 8-9, 1968: 31-38

Boyce, S.G. (1974) The biological potential for the Southeast. Southern Lumberman 229:71-75.

Carmean, W.H. and A. Vasilevsky (1971) Site index comparisons for tree species in northern Minnesota. United States Department of Agriculture, Forest Service, Research Paper NC-65. 8 pp.

Clawson, M., Editor (1974) Forest policy for the future. Resources for the Future, Inc. Washington, D.C. 360 pp.

Deitchman, G.H. and A.W. Green (1965) Relations between western white pine site index and tree height of several associated species. United States Department of Agriculture, Forest Service, Research Paper INT-22. 28 pp.

Doolittle, W.T. (1958) Site index comparisons for several forest species in the Southern Appalachians. Soil Science Society of America, Proceedings 22:455-458.

Eriksson, H. (1967) A comparison between the yield figures for permanent sample plots and those for the stand as a whole. Department of Forest Yield Research, The Royal College of Forestry, Stockholm. Research Note 14. 72 pp.

Gardner, R.B. and D.W. Hann (1972) Utilization of lodgepole pine logging residues in Wyoming increases fiber yield.

United States Department of Agriculture, Forest Service Research Note INT-160. 6 pp.

Gingrich, S.F. (1971) Management of young and intermediate stands of upland hardwoods. United States Department of Agriculture, Forest Service, Research Paper NE-195. 26 pp.

Gordon, J.C. (1975) The productive potential of woody plants. Iowa State Journal of Research 49(3):267-274.

Grantham, J.B. (1974) Status of timber utilization on the Pacific Coast. United States Department of Agriculture, Forest Service General Technical Report PNW-29. 42 pp.

Grantham, J.B. and T.H. Ellis (1974). Potentials of wood for producing energy. Journal of Forestry 72(9):552-556.

Greentree Associates (1973) Critique of the outlook for timber in the United States. Lansing, Michigan. 51 pp.

Hair, D. and R.B. Phelps (1971) The demand and price situation for forest products 1972-73. United States Department of Agriculture, Forest Service, Miscellaneous Publication 1239. 87 pp.

Hansen, R.A. and N.E. Johnson (1974) Culture of the growing forest: one company's approach. Journal of Forestry 72:686-691

Keays, J.L. (1971) Complete-tree utilization. An analysis of the literature. Forest Products Laboratory, Canadian Forestry Service Information Report, VP-X-69. 5 vols.

Koch, P. (1974) Harvesting southern pine with taproots can extend pulpwood resource significantly. Journal of Forestry 72(5):266-268.

Lassen, L.E. and D. Hair (1970) Potential gains in wood supplies through improved technology. Journal of Forestry 68(7):404-407.

Maclean, C.D. and C.L. Bolsinger. (1973) Estimating productivity on sites with a low stocking capacity. United States Department of Agriculture, Forest Service Research Paper PNW-152. 18 pp.

Miller, W.D. and T.E. Maki (1957) Planting pines in pocosins. Journal of Forestry 55:659-663.

Murphy, P.A. and H.A. Knight (1974) Hardwood resources on southern pine sites. Forest Products Journal 24(7):13-16.

Napier, D.A. (1972) Total tree harvesting doubles fiber tonnage from aspen stand. Journal of Forestry 70:343-344.

National Academy of Sciences, (1975) Agricultural Production Efficiency. Committee on Agricultural Production Efficiency. Washington, D.C.: National Academy of Sciences, 199 pp.

Ostrom, C.E. and C.B. Gibbs (1973) Biological potential for and biological constraints on timber yield. United States Department of Agriculture, Forest Service, draft ms. 40 pp.

Ovington, J.D. (1965) Woodlands. English Universities Press. London, 154 pp.

PAPTE (1973) Report of the president's advisory panel on timber and the environment. United States Government Printing Office 541 pp.

Ribe, J.H. (1974) A review of short rotation forestry with comments on prospect of meeting future demand for forest-products, University of Maine at Orono, Life Sciences and Agriculture Experiment Station Miscellaneous Report, 160. 52 pp.

Rudolph, P.O. (1950) Forest plantations in the Lake States. United States Department of Agriculture, Technical Bulletin 1010. 171 pp.

Schreiner, E.J. (1970) Mini-rotation forestry. United States Department of Agriculture, Forest Service Research Paper NE-174. 32 pp.

Schultz, R.P. (1975) Intensive culture of southern pines: maximum yields on short rotations. Iowa State Journal of Research 49(3):325-337.

Southern Forest Resource Analysis Committee (1969) The South's third forest. 111 pp.

Spurr, S.H. (1952) Forest inventory. New York: The Ronald Press Co.

Spurr, S.H. (1963) Growth and mortality of a 1925 planting of Pinus radiata on pumice. New Zealand Journal of Forestry 8(4):560-569.

Spurr, S.H. (1963) Growth of Douglas-fir in New Zealand. New Zealand Forest Service Technical Paper 43. 54 pp.

Spurr, S.H. (1974) Timber and the environment: reflections on American forest policy. Journal of Forestry 72(1):17-20.

Staebler, G.R. (1972) Concentrating timber production efforts. Society of American Foresters, Proceedings 1972 National Convention, Hot Springs, Arkansas. pp. 74-81.

Stoeckler, J.H. (1963) A review of forest and swamp drainage methods in Northern Europe. Journal of Forestry 61:99-104.

Strand, R.F. and R.E. Miller (1969) Douglas-fir growth can be increased. Report from Pacific Northwest shows. Forest Industries. October 1969. pp. 29-31.

Szego, G.C. and C.C. Kemp (1973) Energy forests and fuel plantations. Chemtech, May 1973. pp. 275-284.

UNESCO (1971) Productivity of forest ecosystems: proceedings of the Brussels symposium. UNESCO. Paris. 707 pp.

United States Department of Agriculture (1974) The outlook for timber in the United States. Forest Service. Forest Resource Report 20. 374 pp.

Vaux, H.J. (1973) How much land do we need for timber growing? Journal of Forestry 71(7):399-403.

Whittaker, R.H. (1966) Forest dimensions and production in the Great Smoky Mountains. Ecology, 77:103-121.

Wikstrom, J.H. and S.B. Hutchison (1971) Stratification of forest land for timber management planning on the western National Forests. United States Department of Agriculture, Forest Service Research Paper INT-108. 38 pp.

Young, C.E., Jr. and R.H. Brendemuehl (1973) Response of slash pine to drainage and rainfall. United States Department of Agriculture, Forest Service Research. Note SE-186. 8 pp.

Young, H.E. (1964) The complete tree concept -- a challenge and an opportunity. Proceedings of the Society of American Foresters, Denver, Colorado, 1964:231-233.

Young, H.E. (1975) The enormous potential of the forests. Journal of Forestry 73(2):99-102.

PART II

AGRICULTURAL PRODUCTION OF INDUSTRIAL MATERIALS[1]

CHAPTER 6

INTRODUCTION

Although forests currently produce the greatest portion of renewable materials with industrial uses, the productive potential of agricultural cropland cannot be overlooked in this assessment of possible future resources.

A few agricultural materials are produced in the United States primarily for industrial use. Of these, cotton fiber is by far the most important. Flax, grown for its linseed oil, is the only other such crop grown in quantity in the United States. Elsewhere in the world, a variety of other vegetable fibers are grown for export to this country, as are a limited number of oilseed crops with primary industrial uses.

The second category of agricultural industrial materials consists of those that are grown primarily for food but have important secondary industrial uses. In the United States, wool is often a secondary product to lamb meat and mutton. Similarly, fats and hides are important secondary to meat products in the beef cattle industry. Among agricultural crop products, peanut oil and soybean oil have important secondary uses as industrial materials. Corn starch is also used in substantial amounts in paper, textiles and other industrial purposes.

The third category consists of agricultural materials produced in the United States primarily for food, but with residues that are potentially suitable for industrial use. These include wheat and other cereal straws, bagasse, corn stalks, and animal wastes and by-products.

We will consider the potential of each of these groups in turn. Since physical capabilities are seldom dominant in the United States today, we emphasize economic projections based upon assessments of future supplies.

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CHAPTER 7

AGRICULTURAL MATERIALS GROWN FOR INDUSTRIAL USE

COTTON

Cotton is important both for the production of lint and cottonseed. For every 480-pound bale of cotton lint, 825 pounds of cottonseed are also produced. Historically, out of each ton of cottonseed crushed, oil accounts for 16 percent of the derived products, meal for 46 percent, hulls for 24 percent, and linters for 9 percent, with 5 percent being lost.

The production of cotton in this country has changed little since the middle 1920s (Table 15). (All statistics are from the United States Department of Agriculture 1974 and earlier.) During the same period world production of cotton has increased as has the production of synthetic fibers.

Cotton acreage in the United States has declined steadily from a high of 44.6 million acres in 1926 to 13.0 million in 1972. Yields per acre have risen steadily over the years to compensate. The United States is a major exporter and a limited importer of cotton.

Recent estimates indicated that the United States is still the world's largest producer of cotton with a 1974-75 (August to July) output of 2.9 million tons (12.1 million bales of 480 pounds). This nation's percentage share of world production has been steadily declining over the years, however, from 63 percent in 1920 to 19 percent in 1974.

The second largest producer, the U.S.S.R., is only slightly behind the United States with current production estimated at 2.88 million tons (12 million bales) for 1974-75. The People's Republic of China is the world's third largest cotton producing nation with an estimated crop of 2.3 million tons (9.5 million bales), and India is fourth with 1.2 million tons (5.2 million bales). These four nations account for 63 percent of the current total world production of cotton.

In a preliminary study in 1974, the Economic Research Service of the United States Department of Agriculture estimated future production of cotton lint under a series of alternative assumptions (Quance 1974; Smith et al, 1974) Its Agricultural Baseline projection assumes a medium growth (series E) in population, moderate growth in income, and

Table 15

U. S. COTTON LINT PRODUCTION

	U. S. Production			World Production	U. S. Imports		U. S. Exports	
Year	Acreage Harvested 1000 acres	Weight 1000 tons	Farm Value $1000	Weight 1000 tons	Weight 1000 tons	Value $1000	Weight 1000 tons	Value $1000
1920	34,408	3,357	1,066,759	5,337	66	44,666	1,392	599,139
1925	44,386	4,026	1,579,936	7,060	84	50,210	2,027	914,190
1930	42,444	3,483	658,981	6,344	27	5,328	1,762	422,106
1935	27,509	2,659	590,021	6,535	37	9,265	1,599	392,015
1940	23,861	3,141	621,310	7,180	51	10,750	313	66,942
1945	17,029	2,254	1,014,823	5,340	83	29,252	907	416,796
1950	17,843	2,503	2,005,684	7,630	46	42,368	1,107	934,564
1955	16,928	3,680	2,379,030	10,918	36	27,110	560	372,801
1960	15,309	3,568	2,154,165	11,693	40	25,344	1,809	936,799
1965	13,615	3,743	2,106,088	13,297	29	22,491	790	486,169
1970	11,155	2,541	1,101,227	12,863	9	6,397	966	492,200
1972	12,984	3,289	1,755,603	14,324	18	N/A	1,273	N/A
1973	11,970	3,112	2,779,504	14,999	16	N/A	1,379	N/A

Source: U. S. Department of Agriculture, Economic Research Service (1974a).

moderate growth in farm exports. It is summarized for 1985 and 2000 in Table 16. In this projection, a declining demand indicated by a per capita consumption dropping from 16 pounds in 1974 to 14 in 1985 and to 12 pounds in 2000, coupled with little change in per-acre yields, would result in a decline in acreage planted to cotton from a present 13 million acres to slightly more than ten million acres. A more realistic scenario would include a continuing rise in yields per acre.

The projection that cotton acreage will continue to decline through the year 2000 has been questioned by Michael J. Pallansch, Assistant Administrator of the Agricultural Research Service, United States Department of Agriculture. Demand may not continue to fall if, indeed as many believe, the competitive inroads by petroleum-based fibers into cotton's traditional markets have ended, and that some reversal of past losses will occur. For instance, cotton/synthetic blend levels may well shift toward a higher cotton content. Also, future trends in heating and cooling of homes and offices may well change, due to higher energy costs and result in increased demand for cotton and wool apparel.

Another factor that might favor the increased use of cotton is the relatively low amount of energy required for its production. Gatewood (1973) estimated that the production of cotton requires only one-fifth as much energy as that of synthetic fiber. Also, environmentally, cotton products are biodegradable.

Reflecting these more optimistic prospects, the Cotton Council of America has provided projections of cotton production and energy requirements to achieve production at low, medium and high levels of per capita consumption for 1985 and 2000 (Tables 17 and 18). The 1985 range of per capita consumption of 14-18 pounds was projected in an economic analysis by Dudley (1974). The range for the year 2000 was increased to 15-20 pounds because of the projected 155 percent increase in real per capita income assumed in the economic parameters. A moderate increase in exports to 4 million bales in 1985 and 5 million in 2000 was based on the assumption that foreign countries will continue to have an increasing level of demand for feed and food crops, and this will constrain cotton production. Only moderate yield increases were assumed and the application rate of fertilizer was assumed to remain about the same. Fuels used in growing crops were assumed to drop by 5 percent for each period due to the emerging trend toward minimum tillage and fuel conservation. Lower use of pesticides were predicated upon acreage shifts away from areas that are the heaviest consumers of pesticides and the development of insect and disease resistant varieties. The intensity of labor was

Table 16

COTTON PRODUCTION AS PROJECTED
BY U.S.D.A. ECONOMIC RESEARCH SERVICE

	1972	1985	2000
Acreage - million acres	12,984	10,409	10,073
Yield - pounds per acre	507	506	515
Production - million bales	13.3	11.0	10.8
Imports - million bales	0.1	0.1	0.1
Exports - million bales	3.3	4.2	4.3
Net U.S. Consumption - million bales	10.1	6.9	6.6
Consumption per capita	18.7	14.0	12.0

Source: U. S. Department of Agriculture, Economic Research Service (1974a).

Table 17

COTTON PROJECTION SUMMARY FOR 1985
Cotton Council of America

	1972 Base Data	Low	Medium	High
Per Capita Cotton Demand (lbs)	20	14	16	18
Population (1,000,000)		235	235	235
Domestic Demand (millions of 480-lb. bales)	10.0	6.86	7.85	8.83
Exports (millions of 480-lb. bales)	3.3	4.0	4.0	4.0
Total Demand (millions of 480-lb. bales)	13.3	10.86	11.85	12.83
Yield per Harvested Acre (lbs.)	507	515	515	515
Abandonment (%)		5	5	5
Planted Acreage (millions)	14	10.13	11.04	11.96
Harvested Acreage (millions)	12.98	9.62	10.49	11.36
Inputs for Production				
Fertilizer (millions nutrient lbs.)	1,500	1,116	1,217	1,317
Fuel (million gallons)		246	268	290
Pesticides (million lbs. active ingred.)	112	68.5	74.7	80.9
Seed (thousand tons)	180	127	138	149
Labor (million man-hours)	202	127	139	150
Irrigated Acreage (millions)	3.44	3.30	3.59	3.89
Harvesting (millions of 480-lb. bales)	13.27	10.87	11.85	12.83
Ginning (millions of 480-lb. bales)	13.27	10.87	11.85	12.83
Cottonseed (millions tons)	5.44	4.48	4.89	5.29
Energy Consumption				
Total energy consumed through ginning (billions Btu)				
Fuel		31,920	34,774	37,629
Fertilizer		2,051	2,237	2,421
Pesticides		783	854	924
Irrigation		13,038	14,184	15,370
Ginning		1,669	1,819	1,970
Total		49,461	53,868	58,314
Btu Per lb. Lint		9,488	9,470	9,469
Kw. Hr./lb. Lint	3.30	2.781	2.776	2.775
Cost of Production				
Total Cost Per Harvested Acre of Producing Lint and Seed	$156	$250	$322	$413
Cost of Producing a Pound of Lint Adjusted for Seed Value at $150/ton		.36	.50	.67

Source: U. S. Department of Agriculture, Economic Research Service (1974a).

Table 18

COTTON PROJECTION SUMMARY FOR 2000
Cotton Council of America

	Low	Medium	High
Per Capita Cotton Demand (lbs.)	15	17.5	20
Population (1,000,000)	264	264	264
Domestic Demand (millions of 480-lb. bales)	8.26	9.64	11.02
Exports (millions of 480-lb. bales)	5.0	5.0	5.0
Total Demand (millions of 480-lb. bales)	13.26	14.64	16.02
Yield Per Acre (lbs.)	540	540	540
Abandonment (%)	4	4	4
Planted Acreage (millions)	12.28	13.56	14.83
Harvested Acreage (millions)	11.79	13.01	14.24
Inputs for Production			
Fertilizer (millions nutrient lbs.)	1,368	1,510	1,652
Fuel (million gallons)	286	316	346
Pesticides (million lbs. active ingred.)	60.9	67.2	73.5
Seed (thousand tons)	154	169	185
Labor (million man-hours)	128	142	155
Irrigated Acreage (millions)	3.46	3.82	4.18
Harvesting (millions of 480-lb. bales)	13.26	14.64	16.02
Ginning (millions of 480-lb. bales)	13.26	14.64	16.02
Cottonseed (million tons)	5.64	6.22	6.81
Energy Consumption			
Total energy consumed through ginning (billions Btu)			
Fuel	37,123	41,017	44,911
Fertilizer	2,514	2,775	3,036
Pesticides	696	768	840
Irrigation	13,6711	15,093	16,516
Ginning	2,035	2,248	2,460
Total	56,039	61,901	67,763
Btu Per lb. Lint	8,804	8,809	8,812
Kw. Hr./lb. Lint	2.58	2.58	2.58
Cost of Production			
Total Cost per Harvested Acres of Producing Lint and Seed	$311	$496	$783
Cost of Producing a Pound of Lint Adjusted for Seed Value at $190/ton	.41	.75	1.28

Source: U. S. Department of Agriculture, Economic Research Service (1974a).

as estimated to drop 15 percent by 1985 and another 15 percent by 2000 because of the trend toward minimum tillage and improved pesticides. Irrigated acreage was expected to decline because of the falling water table in the high plains of Texas.

In terms of acreage, cotton currently accounts for 13 million, or less than 4 percent of the total United States crop acreage of 360 million acres. The projected acreage is expected to drop to 10 million acres by 2000 in the Economic Research Service projections and to range from 11.8 to 14.2 million acres in the low and high levels of the Cotton Council of America projections. Since cotton was grown on as many as 45 million acres in the mid 1920s (albeit to a considerable extent on non-irrigated lands not used for cotton today), there is obviously no shortage of farm land suitable for meeting future cotton demands in the United States. Whether or not these lands will be used for cotton will depend upon the relative profitability of growing alternative feed and food crops on them.

In terms of yields per acre, both sets of projections assume only modest improvement to 515 or 540 pounds per acre as compared to 507 in 1972. The National Research Council's 1975 report on Agricultural Production Efficiency indicates clearly that substantially higher yields are biologically feasible through the application of more intensive agricultural practices. For example hybrid cotton is a possibility for potentially producing much higher yields.

We may safely conclude, therefore, that the limitations of cotton production in the United States are imposed to a much greater extent by economic restraints than by the availability of suitable farm land or by biological considerations.

FLAX

Flax is grown in the United States primarily for the linseed oil obtained from flaxseed, although a small amount of flax straw (36,000 tons) is pulped for cigarette and electrical condenser paper. It is grown primarily in the Dakotas and adjoining states in the northern Great Plains.

United States production of flaxseed peaked in the early 1950's (Table 19) and has since declined severely. In 1970, the United States production of 839,000 tons was 19 percent of the world production of 4,478,000 tons. Of the United States production, 165,000 tons or 20 percent was exported. By 1974, the acreage planted to flax had dropped to 1.64 million, the yield per harvested acre had dropped from 10.4

in 1970 to 8.1 and the production had dropped from 30 million bushels in 1970 to 13 million in 1974.

Considerable uncertainties face flaxseed as a crop. The level of production might be reduced even further if the demand for food crops increases, since synthetics could at least partially replace linseed oil for many industrial uses. Another oil crop, sunflower seed, may be replacing flaxseed in some producing areas.

The United States Department of Agriculture, Economic Research Service estimates that production of flaxseed will increase slightly to 784,000 tons in 1985 and drop to 700,000 tons in 2000 (Smith et al. 1974). The corresponding acreage devoted to the crop would increase to 2.16 million bushels in 1985 and drop to 1.78 million in 2000. Yields would increase from 12.9 bushels per acre in 1985 to 14.3 bushels per acre in 2000. Two-thirds of the crop would be used for industrial purposes in the United States and the rest exported.

The above projections are probably optimistic since the long-term trend of flax production in the United States has been downward for nearly a quarter century. Even if realized, however, the projected production figures would impose no major load on United States agricultural land. As with cotton, the limitations on flaxseed production in this country are economic and not the result of shortages of suitable land or limits of biological production.

MISCELLANEOUS INDUSTRIAL CROPS

Other than cotton and flax, a number of other vegetable fibers are imported into the United States but not grown domestically. Of these, the most important is jute, which is largely imported in the manufactured form (Table 20). Since these fibers are from crops grown primarily in tropical and semi-tropical countries, their potential in the United States is limited. There are, however a few *Agave* species of possible industrial value that thrive in the southwestern states.

Only 276 tons of silk were imported into the United States in 1972. There was no domestic production. On the other hand, Texas produced about 5000 tons of mohair from the Angora goat in 1972, and accounted for about 30 percent of the world's production.

Of the vegetable oils, tung oil is used primarily for industrial purposes. The production of tung nuts from tung tree plantations dropped from a high of 123 thousand tons in 1964 to 12 thousand tons in 1970, at which time estimates

Table 19

PRODUCTION OF FLAXSEED
IN THE UNITED STATES

Year	Acreage Harvested 1000 Acres	Weight 1000 (Tons)	Farm Value $1000
1920			
1925	3,022	625	50,577
1930	3,780	607	34,950
1935	2,126	418	21,181
1940	3,182	866	43,793
1945	3,785	968	99,912
1950	4,090	1,127	134,531
1955	4,914	1,132	117,349
1960	3,342	851	80,533
1965	2,775	991	99,168
1970	2,888	839	71,803
1972	1,151	389	39,213
1974	1,645	373	126,034

One ton of flaxseed will yield 722 pounds of linseed oil.

Source: U. S. Department of Agriculture, Economic Research Service (1974a).

Table 20

VEGETABLE FIBERS IMPORTED
INTO THE UNITED STATES, 1972

	Tons
Bast fibers	
Jute - raw	14,764
manufactured	447,406
Flax	3,084
Leaf fibers	
Abaca or manila	20,528
Sisal	15,401
Henequen	39,710
Seed and Fruit-hair fibers	
Cotton	18,000
Coir	4,135
Kapok	12,361

Source: U. S. Department of Agriculture, Economic Research Service (1974a).

s were discontinued. Production was concentrated in Florida, Alabama, Mississippi, and Louisiana. Coconut oil is extensively used in industrial detergents, and castor oil, though used in only small quantities, is also important.

None of these miscellaneous industrial crops would appear to impose any increased demands upon United States crop lands over the forthcoming decades.

AGRICULTURAL MATERIALS WITH IMPORTANT SECONDARY INDUSTRIAL USES

Wool

Also affected by market competition with synthetic fibers is wool, the principal animal fiber. From a peak United States population of 56 million sheep in 1942, numbers dropped to 18.7 million in 1972. The tonnage of wool produced has similarly dropped by two-thirds to 83 thousand in 1972 (Table 21). The average weight of wool per sheep has remained at approximately 8.5 pounds over recent years.

While United States production of raw wool has decreased, world production has increased. The United States share of world production dropped from 10 percent in 1940 to less than 3 percent in 1970.

Wool production in the United States will probably not depend on demand for wool or even on the value of wool. Wool is produced in this country largely as a by-product of meat production, and its removal is essential to the survival of sheep in most of the United States. Wool does represent a portion of income to the sheep raiser. This situation may change if synthetics increase substantially in cost or if demand for wool increases greatly.

Sheep are competitive with cattle in the use of range. Under western range conditions, sheep consume larger proportions of browse and shrubby plants and smaller proportions of grass than cattle. Optimum range rise comes from joint grazing by sheep and cattle. Sheep are generally more efficient producers of meat than cattle because of their higher prolificacy and shorter growing period, and are reported to be about 26 percent more efficient than cattle on the range. Cattle, however, seem to make better use than sheep of low cost grain.

The present ratio of the value of cattle to sheep is 5.2 to 1. In the past, sheep numbers have generally increased

Table 21

U. S. RAW WOOL PRODUCTION

Year	U. S. Production thousand tons (1)	U. S. Production million dollars	Wool Production thousand tons (1)	U. S. Imports (2) thousand tons
1920	147	$114	1,526	N/A
1925	150	100	1,680	49
1930	207	69	1,852	54
1935	214	70	1,802	70
1940	217	106	2,090	107
1945	189	129	1,895	255
1950	125	135	2,000	233
1955	141	103	2,342	124
1960	149	111	2,820	114
1965	112	95	2,920	136
1970	88	57	3,077	77
1972	83	56		

1 Includes both shorn and pulled wool, grease basis.
2 Clean content apparel and carpet wool.

Source: U. S. Department of Agriculture, Economic Research Service (1974a).

relative to cattle when the ratio of relative values has fallen below 7 to 1. Because of this favorable economic ratio, and because of substantial technological advances in the breeding and rearing of sheep, Clair E. Terrill of the ARS projects an increase in sheep numbers to begin in the next 2 years and to reach a 50 percent increase by 1985. Available technology should permit a further 50 percent increase by 2000. Thus, we could go from 15 million sheep in 1975 to 22 million in 1985 and to 235 million in 2000. If this were to happen, wool production would increase from 69 million tons in 1974 to 93 million tons in 1985 and 940 million in 2000. Obviously, these predictions assume major changes in what the American public habitually eats and wears, as well as a reversal of the long-term decline in the United States sheep industry.

The ERS forecasts a decline in the amount of meat produced by sheep and lambs by 1985 to 35 percent of the 1970-72 average (Smith et al. 1974). Dudley (1974) also estimates that the consumption of wool will decrease from 2 pounds per capita in 1968-70 to 1 pound per capita in 1985.

In either case, the value of the wool itself will have relatively little direct effect upon the numbers of sheep and lambs raised in the United States in the future. Rather, the demand for their meat will be the principal determining factor.

Should the use of range be substantially increased both for cattle and sheep, biological factors could well be limiting in the future. However, this is a problem for those concerned with agricultural food production. For both animals, industrial uses are secondary to food.

Animal By-Products

Animal by-products form a recurring and renewable resource that contributes significantly to our national economy. The two major by-products are hides and skins, and fats. The number of hides available is directly related to the number of animals slaughtered. Cattle hides have constituted the main raw materials for leather production; only a small number of pigskins are tanned for leather. The recent development of a mechanical pigskin puller could make pigskins more readily available for tanning, and thus pigskins hold considerable potential for increasing our supplies of leather. Currently, pigskins are used primarily for the production of gelatin, and their ultimate use will be controlled by the competitive position of the two markets.

Animal fats consist primarily of tallow and grease from cattle, and lard from hogs. In recent years, over 5 billion pounds of tallow and grease have been produced annually. About half of this quantity has been exported. Of the domestic production in 1973, the largest market has been animal feed (37 percent), followed by fatty acid production (30 percent), soap (21 percent), lubricants (4 percent) and miscellaneous uses (8 percent). Animal fats, which are of a hydrocarbon nature, constitute a renewable resource that has a potential for supplementing our growing demands for petroleum needed in the manufacture of petrochemicals. Lard production has decreased from 2.6 billion pounds in 1960 to 1.6 billion in 1972.

The production of these products is entirely dependent upon the number of animals raised for food. Preliminary projections of the ERS indicate a slaughter of 50 million head of cattle in 1985 and of 61 million head in the year 2000, compared with a total of 36 million in 1972 (Smith et al. 1974). Comparable projections for hog slaughter are 106 million for 1985 and 120 million in 2000, compared with 86 million in 1972. The resulting production of tallow and grease from cattle and lard from hogs would rise from 7.2 billion pounds in 1972 to 9.4 billion pounds in 1985, and to 11.3 billion pounds in 2000.

The quantities of major animal by-products (fats, hides) available would thus seem to be sufficient to supply both domestic and foreign demand for the rest of this century. Substantially expanded supplies of cattle hides, pigskins and tallow should be available. Lard production should plateau at a level not too different from that of recent years.

Oilseed Crops

Oil from cottonseed is an important secondary product from the cotton plant, which is primarily grown for its fiber. In addition, several other oilseed crops grown primarily for the feed and food value of their seed have important secondary industrial uses. Soybean and peanut crops are the most important of these.

Of the total United States consumption of fats and oils of 16 billion pounds in 1972, 5 billion, or about one-third, was used for industrial purposes. Of this industrial usage of 5,338 million pounds, 724 million pounds or 14 percent was used in the manufacture of soap, and 569 million pounds or 11 percent was used in drying-oil products. Both categories of use have been declining in recent years. About one-third of the production of peanut oil goes into industrial uses, while less than one-fifth of soybean oil is similarly used.

In contrast to flaxseed, a crop whose production has declined substantially in recent years, the production of both soybeans and peanuts has increased over time (Table 22).

The history of soybeans since 1950 has been one of moderately increasing yields up to 1971 and a dramatically increasing harvested acreage. Yield per acre increased by 28 percent between 1950 and 1973. Acreage, however, increased more than four-fold in the same 24-year span. The overall result was a five-fold increase in production.

Peanuts contrast with soybeans in that yield has increased dramatically while acreage has actually decreased since 1950. Between 1950 and 1973, yield increased 2-1/2 times while acreage dropped by one-third. Production increased 70 percent during the same period.

The ERS projects increases in the yield of soybeans from 28 bushels per harvested acre in 1972 to 32 in 1985 and 34 in 2000 (Smith et al., 1974). The acreage devoted to the crop is expected to rise from 46 million acres harvested in 1972 to 66 million in 1985 and 85 million in 2000. The projected production would then move up from 1.3 billion bushels in 1972 to 2.0 billion in 1985 and 2.9 billion in 2000.

These yield projections are based upon expected levels of technology and pesticide and fertilizer application rates in the respective years.

According to Billy E. Caldwell (personal communication, 1975, U.S. Department of Agriculture), there is no biological reason that these trends will not change, and the United States average yield in 1985 could be 38 to 40 bushels per acre and nearly 50 for the year 2000. The limitations on soybeans are both environmental and biological. Current varieties will yield 80 bushels per acre with proper technology; the major limiting factor is water.

For peanuts, the ERS projects that the 1972 yield of 2,203 pounds per harvested acre will rise to 2,739 in 1985 and 3,079 in 2000 (Smith et al., 1974). Acreage, at present closely controlled by the U.S.D.A., will increase from 1.5 million acres harvested in 1972 to 1.8 million in 1985 and 2.1 million acres in 2000. Thus, production would go up from 3.3 billion pounds in 1972 to 4.8 billion in 1985 and 6.4 billion in 2000.

Table 22

PRODUCTION OF SOYBEANS AND PEANUTS IN THE UNITED STATES

	Soybeans			Peanuts		
Year	Acreage Harvested 1000 acres	Weight 1000 tons	Farm Value $1000	Acreage Harvested 1000 acres	Weight 1000 tons	Farm Value $1000
1925	415	146	11,430	996	361	30,836
1930	1,074	418	19,058	1,073	349	24,462
1935	2,915	1,467	35,565	1,497	576	36,181
1940	4,807	2,341	70,224	2,052	883	58,850
1945	10,740	5,795	402,234	3,160	1,021	168,878
1050	13,807	8,977	737,760	2,262	1,018	221,881
1955	18,620	11,210	830,909	1,669	774	181,985
1960	23,655	16,659	1,184,910	1,395	859	171,991
1965	34,449	25,368	2,151,305	1,435	1,192	272,000
1970	42,249	33,813	3,214,710	1,467	1,489	383,000
1972	45,755	38,488	4,451,797	1,486	1,637	475,000

One ton of peanuts yields 626 pounds of oil, and one ton of soybeans yields 364 pounds of oil.

Source: U. S. Department of Agriculture, Economic Research Service (1974a).

of the long runner variety.

In summary, we see that both soybeans and peanuts are expanding crops likely to be more important in the future than at present. Their industrial uses are decidedly secondary to their uses for feed and food, both in amount used and even more so in the dollar value of such uses. Future acreage devoted to them in the United States, therefore, will be determined in large part by relative economic returns from other food crops that can be grown on the same sites.

Residues From Agricultural Food Crops

Residues of food crops often have an industrial use. Some residues, such as wheat straw, are left in the field; others, such as bagasse, are concentrated at a processing site; still others, such as vegetable oil foots and animal tallows, are a result of the manufacturing process. Manure is available in large quantities at cattle feedlots, and processed sewer sludge is similarly concentrated at urban sewage disposal plants. Only small quantities of these residues are currently used as industrial materials because of low value coupled with high collecting and processing costs. Yet the potential uses for these large organic materials are great, should there be an economic incentive or should national policy require their use.

Wheat and other cereal straws normally left in the field amounted to over 130 million tons dry weight in 1972. As recently as 1950, some 50 pulp mills in the United States produced 650,000 tons of pulp from wheat straw. Although currently discontinued, this once important source of cellulose could be used again.

Bagasse is available in large quantities at sugar mills, but it must be dried and stored until needed. Of 5.5 million tons produced annually, only 218,000 tons are currently used for pulp and wallboard. Much of the rest is used for fuel in sugar mills. A small amount of flax straw is also pulped.

Other field crop residues, chiefly corn stalks, contribute to a grand total of more than 300 million tons of plant fibers available annually if needed.

Animal waste and by-products are important potential sources of organic materials (Anderson 1972). It has been estimated that 26 million tons of dry organic solids are currently available each year as manure from the largest poultry and hog operations and from feedlots with 1,000 or more head of cattle. An additional 23 million tons of organic waste are annually available from the largest processing facilities, such as canneries, mills, slaughter houses, and dairies.

The utilization of waste organic materials from agriculture involves more than a purely economic problem. These wastes also constitute an immense pollution problem (Wadleigh 1968). Stream eutrophication and contamination may arise from the disposal of animal organic wastes. Crop residues may harbor breeding populations of destructive insects and diseases. Increasingly, the industrial use of agricultural residues, even if not profitable, may be the best way of reducing waste pollution.

In summary, agricultural residues, such as straw, stalks, and manure, are potential sources of organic material and fuel. Concentrations of such materials, as at sugar cane mills and feedlots, may well be increasingly economically usable in the future, especially since disposal is often a necessity. At least 50 million tons (dry weight) per year of animal and plant residues are currently collectible and offer possibilities for use as fuel or in industry.

Future production of plant and animal residues will be almost entirely determined by food requirements and use. If we assume continued population increase and to produce, concomitantly, an increase in agricultural residues. The extent to which these will be used for industrial purposes is uncertain, but they will be abundantly available.

CHAPTER 8

UNITED STATES CROPLAND: SIZE AND POTENTIAL

CROPLAND ACREAGE IN THE UNITED STATES

An estimated 360 million acres were used for crops in the 48 contiguous states in 1974, excluding idle cropland and cropland pasture. Including these categories, the total cropland is about 430 million acres, and this is approximately the maximum amount cropped at any time during this century in the United States. Since 1949, some 70 million acres have been dropped from the cropland base, chiefly in areas characterized by broken terrain, small fields and small ownership units. During the same period, from 35 to 40 million acres have been added.

According to unpublished data compiled by the ERS, there are currently some 10 million acres of high quality (Class I) land suitable for conversion into regular cultivation (Smith et al., 1974). An additional 250 million acres could be used for cropland, but they are subject to climatic limitations, and to problems related to soil, drainage, and erosion. Less than 100 million acres are considered high in potential for conversion into cropland.

The ERS concludes that there is adequate cropland available to fill domestic United States needs and expected foreign demand for several decades. With continued favorable prices for farm products, no constraints on land use, and a reasonable rate of development, land could be converted to cropland as needed to fill our long term food and fiber needs. A degree of food security and an expansion of foreign trade would increase the need for cropland.

It does not necessarily follow that increased agricultural crop production will result in more land being cultivated. Part or all of whatever increased needs may develop will undoubtedly be met by more intensive farming of lands already being cropped. In the future we may be concerned primarily with optimum production per unit of land. It may also be that we now have about all the row-crop land we will use, and that much of the land now considered as reserve could better be used for forage and pasture, timber, and recreation.

AGRICULTURAL PRODUCTION EFFICIENCY

The National Academy of Sciences has recently (1975b) published a report on the productivity and efficiency of United States agriculture. The Report distinguished between the ability of the land to produce a yield of crop, i.e. productivity, and the capacity to produce desired results with a minimum expenditure of time, money, energy, or materials, i.e. efficiency.

Productivity is subject to biological limitations. First, for every set of soil, water, climate, nutrient, and other conditions there is some upper limit for the yield of every crop and livestock product. We do not know precisely where these upper limits are, but agronomists are thinking optimistically of 300-500 bushels of corn per acre, 300 bushels of small grain, and 200 bushels of soybeans. Second, since these upper limits are defined in terms of relatively ideal conditions, we have what we term a "field gap" between this yield limit and the actual yields obtained under farm situations. Reports from the field claim as high as 300 bushels of corn and 200 bushels of wheat per acre, but averages on even the better farms are only one-half of these reported levels. Much of our newer technology enables us to increase yields gradually and reduce the field gap. Only in rare and doubtful instances, however, has any research finding raised the biological ceiling. One of our tasks has been to examine these biological limitations that impose either temporary or permanent limitations on the productivity of our farms.

No major scientific breakthrough comparable with hybrid corn or DDT can be reasonably predicted for the next one or two decades. There remain, however, promising potentials for improving productivity from application of known technology and from new technology now in the research and development phases. Long-range planning based on continued linear upward projections of productivity of all parts of agriculture, though, can be hazardous.

The large gains in the past quarter century that came from concentrating production on the more optimum sites for individual crops; planting and pruning for maximum leaf area indexes; elimination of severe weed competition; improvement of defenses against insects, disease, and nematodes; and better farm mechanization will be difficult to duplicate over the next 25 years. However, further improvements in the same areas will continue to enhance productivity for the next decade or so. Also, the genetic variability of plants should permit continued upgrading of gains in yield and quality.

On balance, however, biological realities suggest a slowing of the rate of increase of productivity for most crops in the foreseeable future, even though the theoretical yield limits are far ahead.

Among livestock, current limitations appear greatest in reproductive efficiency, resistance to disease, adaptability to unfavorable weather, and ability to convert feed energy to animal protein. These are likely to restrict major gains in livestock production efficiency for the near future.

Some research-based advances, such as more twinning in cattle, more frequent lamb crops, and larger pig litters should, however, improve animal productivity. Gains in efficiency of milk production and improved carcass yields for livestock should continue. Fowl and egg production technology seems close to the point of leveling off, and breakthroughs are needed before further gains in egg production and feed conversion efficiencies occur. Overall, gains in livestock productivity appear probable through the next decade or two.

Integral to the assessment of agricultural production efficiency is elucidation of the relationship between the input of energy and productivity. Handler (1970) and other have criticized the inefficiency of modern agriculture in converting calories of total energy input to calories of output in harvested products. The Agricultural Production Efficiency report (NRC 1975b) responds to this contention with an analysis of the energetics of agricultural production. It summarizes the efficiency of energy use on the farm in the following language:

> Farming, like other segments of the economy, must seek ways to increase its efficiency of energy use. Since agriculture produces energy-containing products of food and fiber, but consumes free solar energy and substantial quantities of increasingly expensive fossil fuels and electric power, the relationships are complex.
>
> Crops capture 1 percent or less of the photosynthetically useful sunlight that reaches earth, and for most crops only half of this capture energy is stored in food products. In the next step in the food chain, farm animals convert 4-10 percent of the energy in feeds into meat food energy. Broilers and hogs are about twice as efficient as cattle in converting feed energy to meat food energy.
>
> In the transition from primitive to modern agriculture, fuel energy has been substituted for muscular energy. Energy consumption in today's agriculture includes tractor fuels, electricity, and the

manufacture and transportation of fertilizers, feeds, pesticides, machinery and other inputs. Such agricultural uses accounted for about 3.5 percent of the total national energy consumption in 1972.

In contradiction to some popular reports, our cereal crops produce about 3-5 calories of food and fiber energy for each calorie of energy consumed. Because plants are as yet the primary harvesters of free solar energy and the net producers of energy materials on a renewable base, agriculture is assuming a uniquely distinctive role in this nation's economic and energy trade balance. Furthermore, nonsolar energy is used in agriculture some 100-500 times more effectively than plants use sunlight.

Utopian dreams of returning to a relatively primitive agriculture destitute of mechanical power, fertilizers, and pesticides are unrealistic because adequate food for the world's population cannot be produced under such systems.

Our analysis has indicated, however, that significant differences in efficiency of energy use exist among modern cropping systems. Consequently, adoption of more efficient systems can result in energy economies.

Other potentials for assisting in the fuel crisis include developing plants with more efficient photosynthetic ability, minimizing tillage practices, utilizing energy in crop and animal wastes, and further enhancing the capability of ruminant animals to produce meat, milk, and fiber from roughages.

PROJECTED UNITED STATES AGRICULTURAL PRODUCTION

The growth in population in the United States and the world has increased the demand for food and fiber from agriculture, especially from United States agriculture. The consequent rapid disappearance of surplus land resources raises many important questions concerning future needs and alternatives. In recent years we have become more aware of the limits to expansion of productive capacity, which will have an impact on the prospects and potential for future growth. Several studies have been undertaken, in recognition of these questions, to evaluate and project future needs with respect to land and water resources and environmental implications.

Carr and Culver (1972), for the United States Commission on Population Growth and the American Future, projected the productive capacity of United States agriculture to 2000 based on five scenarios derived from alternative combinations of assumptions concerning population growth, economic growth and restriction of production technology. With respect to production technology, the concern of the study "is chiefly, but not entirely, with the level of fertilizer and pesticide (insecticide, herbicide, fungicide) usage, the level of hormones and medications in animal feed, and the methods of animal waste disposal from concentrated feeding operations."

Under all five alternatives, assumptions made about trends over the next 30 years in crop yields and the mix between present agricultural crops and possible substitutes resulted in an increase in harvested cropland from 344 million acres in 1970 to from 359 to 438 million acres in the year 2000. In three of the scenarios, this increase would be at the expense of the 60 million acres of cropland that were idle in 1970. In the other two scenarios, it would come in part from new cropland currently in pasture and range, timberland, or idle nonagricultural land. Fertilizer use was projected to increase in all cases, and pesticide use in several. The report concluded that "American agriculture appears capable, in terms of resource adequacy, technology, and structural flexibility, of meeting the challenges of the year 2000. Even under the most demanding assumptions about population and constraints on technology, food and fiber needs could be met without great difficulty, but would require some increase in prices." However, it was pointed out that one of the chief limiting factors to expanded agricultural production in some areas may be the availability of water for irrigation.

In this regard, a similar study was conducted by the National Water Commission (1973), which was charged with the task of making projections of water requirements by 2000 and "identifying alternative ways of meeting these requirements." Of paramount importance in this study were the water needs of agriculture. Eleven alternative futures for agriculture were studied by Earl O. Heady, Howard C. Madsen and others forecasting national land use for the year 2000 for various combinations of assumptions as to future farm policy, United States population, water price, export level, and level of technology.

For a free market serving a future population of 300 million with water prices and exports continuing at present levels, the acreage devoted to dryland annual crops was forecast to rise from 176 million acres in 1964 to 190 million acres in 2000. Irrigated annual cropland under the same conditions was forecast to drop from 13.3 to 6.1 million acres during the same time period.

The most demanding projection assumed a population of 325 million, doubling exports, and advanced technology, leading to a land demand of 219 million acres for dryland annual crops and 8 million acres for irrigated annual crops. Even under these assumptions, 4.5 million acres of cropland and hayland would remain unused.

"The results of the study, based on conservative yield trends, indicate that United States agriculture would not be faced with aggregative strains on food producing capacity and water supplies relative to needs in the year 2000 under any of the alternative futures considered." If more vegetable protein were consumed by people, both the land area and water required for irrigation would be decreased substantially. Concerning expansion of agricultural production and exports it was stated, "if the nation decides to plan for greater crop production, such a decision should be based on thorough consideration of all of the possible options, looking to achieving greater production goals in the most efficient way possible. And if as a matter of national policy the nation decides to increase its food export capability by a program of subsidizing the reclamation of land, a decision we do not recommend, it should do so in full awareness that the general taxpayer would be providing an indirect export subsidy for foodstuffs."

In a 1974 summary of current and projected land uses in the United States, the ERS concluded that, with a population growth of 30 percent and a moderate increase in exports, the acreage of cropland harvested would decline from 286 million acres out of a total of 333 million in 1969 to 272 million acres harvested out of a total cropland acreage of 298 million in the year 2000. Even if there were no limitation on crop acreage and cost-price relations for agricultural projections were favorable, the acreage of cropland harvested would only be about 340 to 350 million. This level of land demand could be met by a more complete use of land currently in farms and through a continued increase in new croplands being developed at the current rate. In these projections, the acreage of land required for roughage and food grain production was expected to decrease by about 20 million, while land devoted to soybeans and other oil crops was projected to increase by 8 million acres.

The ERS study concludes with a discussion of some of the problem areas which affect land usage and land use policy such as changes in demand for food and fiber and competing uses for land. It assumes that the available land and productivity levels are easily capable of providing for domestic demand and that export demand will determine the extent to which agricultural productivity is maximized.

The projections of the National Water Commission and the Commission on Population, Resources and the Environment rely on optimistic assumptions such as a continuation of past trends with no unexpected surprises. Since their publication, significant changes have taken place on the United States agricultural scene. Subsidized land reserves have already disappeared as farmers attempt to maximize food production. The combined effect of the devalued dollar with respect to rising real incomes in other countries (i.e. the U.S.S.R.) have placed an increased demand on agricultural exports. The importation of foreign oil places a tremendous burden on the balance of trade, for which agricultural exports are becoming increasingly important. We have our own need for building up reserves and for food security. Furthermore the vagaries of weather in the United States and worldwide, which are contributing to starvation, malnutrition, and rapid depletion of food reserves in many areas, while the world population continues to increase, add further impetus to the realization that we cannot afford to be complacent about our agricultural productive capacity both now and in the future.

The Agricultural Production Efficiency Report (NRC 1975b) summarizes the above projections and its own evaluation in the following terms:

> Numerous projections have been made concerning population, changing nutritional habits, and food supplies. An analysis of these projections reinforces our concern that man's capability for foreseeing the future, even in terms of food supply, is fraught with many uncertainties.
>
> Past projections have usually underestimated the productivity of major crops in the United States. Recent projections to the year 2000 assume large increases in productivity to satisfy United States populations up to 280 million. At a population of 325 million, however, assuming increased exports, even the general adoption of advanced technology would place pressure on the nation's productive capacity. The optimistic projections place reliance on subsidized land reserves; but, as we have seen, most of these are already being returned to production. Current levels of food exports were not anticipated in any of the projections.
>
> Models and mathematics, can help us examine the consequences of alternative assumptions, but the assumptions themselves are fraught with uncertainties. Resultant predictions and recommendations may deceive the unwary who assume without critical analysis of

underlying premises that statistics are more accurate than verbal descriptions.

For the next decade or so, available evidence indicates that food, feed, and fiber will be adequate for this country and for reasonable exports; but this adequacy does not preclude price increases, temporary local shortages, and drastic world shortages. Because of the increasing importance of agricultural exports in the nation's world monetary position and the pending world food shortages, there is an urgent need for agricultural research to receive increasing emphasis and much greater support. The future well-being of mankind could be at stake.

In a recent study (NRC 1975a), the Board on Agriculture and Renewable Resources sought to identify technologies that could enhance food production in the United States and help to meet the food needs of a growing world population and the demand from increasingly affluent societies. The research and development programs recommended in that report are equally applicable to increased production of agricultural materials for industrial purposes.

CHAPTER 9

SUMMARY OF PART II

CURRENT PRODUCTIVITY

Of the agricultural materials grown primarily for industrial purposes in the United States, only cotton and flax are of major importance. The production of both has declined in recent years. Although higher prices of synthetic fibers derived from petroleum may make it possible for cotton to regain some lost markets, it is unlikely that either crop will make undue new demands on agricultural acreage in the United States.

Major by-products of agricultural materials grown for food find substantial industrial usage in the cases of wool, animal fats and hides, and certain oilseed crops such as soybeans and peanuts. In each instance, however, the amount of industrial product available will be directly dependent upon the demand for and the production of the basic food or feed material.

The same can be said for agricultural residues, whether crop residues such as cereal straws, bagasse and corn stalks, or animal residues such as manure. Whatever the industrial use it will have little effect upon the level of productivity of the food resource.

POTENTIAL PRODUCTIVITY

More cropland is available in the United States than is currently being cropped. Productivity per acre can be increased substantially through more intensive agricultural practices based upon available technology. Manpower and energy demands may be lessened through careful management.

Recent surveys of projected demand for agricultural products indicate that the United States can produce its own food needs and supply reasonable export markets through the year 2000 if present trends continue. The productivity of cotton, flax and other agricultural materials used for industrial purposes constitutes but a small portion of the American agricultural production. The report on Agricultural Production Efficiency (NRC 1975b), therefore, applies equally to agricultural industrial products as it does to agricultural food products. We see no basis for believing that either the level of biological productivity of agricultural lands or the amount of land available for

growing crops will limit agricultural production of industrial materials in the United States for the rest of the current century.

REFERENCES - PART II

Anderson, L.L. (1972) Energy potential from organic wastes: a review of the quantities and sources. U.S. Department of the Interior, Bureau of Mines Information Circular 8549, 16 pp.

Carr, A.B. and D.W. Culver (1972) Agriculture, population and the environment. Chapter 7 of Population, Resources, and the Environment, The Commission on Population Growth and the American Future Research Reports. Washington, D.C. pp. 183-211.

Dudley, G.E. (1974) U.S. textile fiber demand: price elasticities in major end-use markets. U.S. Department of Agriculture, Economic Research Service, Technical Bulletin 1500. 66 pp.

Gatewood, L.B., Jr. (1973) The energy crisis: can cotton help meet it? National Cotton Council of America, Memphis, Tenn., multilithed. 77 pp.

Handler, P., Editor (1970) Biology and the future of man. New York, London, and Toronto: Oxford University Press 936 pp.

National Research Council (1975a) Enhancement of Food Production for the United States, Board on Agriculture and Renewable Resources Washington, D.C.: National Academy of Sciences. 174 pp.

National Research Council (1975b) Agricultural Production Efficiency. Board on Agriculture and Renewable Resources Washington, D.C.: National Academy of Sciences 199 pp.

National Water Commission (1973) Water policies for the future. Final report to the President and to the Congress of the United States. Washington, D.C. 579 pp.

Quance, L. (1974) Demand projections -- a commodity outlook and economic situation update. Presented at the American Seed Trade Association Farm Seed Conference, Kansas City, Mo. 20 pp.

Smith, A., V. Harrison, C.J. Yeh, A. Fox and L. Quance (1974) Projections of the U.S. farm subsector and policy implications. Working Materials L.Q. 4.74. Economic Research Service, U.S. Department of Agriculture, Washington, D.C., 49 pp.

U.S. Department of Agriculture (1974a) Agricultural statistics 1974. Washington, D.C. 619 pp. (also previous similar publications)

U.S. Department of Agriculture, (1974b) Economic Research Service Our land and water resources: current and prospective supplies and uses. U.S. Department of Agriculture, Economic Research Service Miscellaneous Publication 1290. 54 pp.

Wadleigh, C.H. (1968) Wastes in relation to agriculture and forestry. U.S. Department of Agriculture Miscellaneous Publication 1065. 112 pp.