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RENEWABLE RESOURCES FOR INDUSTRIAL MATERIALS

A Report of 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.

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FOREWORD

Potential problems from changing 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 better to meet needs for materials in the future. Important factors (in addition to usual economic calculations) 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 choosing a material for a required performance in a given application, and 2) the increasing concern to minimize both consumption of energy and environmental impact.

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.

Six detailed studies were prepared for the Committee as background material for this report, copies of which may be reviewed at the office of the BARR, NRC, the STPO, NSF; or purchased from the National Technical Information Service, Springfield, Virginia. These reports are as follows:

- Biological Productivity of Renewable Resources Used as Industrial Materials.

- Renewable Resources for Structural and Architectural Purposes
- Fibers as Renewable Resources for Industrial Materials
- Extractives As a Renewable Resource for Industrial Materials
- The Potential of Lignocellulosic Materials for the Production of Chemicals, Fuels, and Energy
- Reference Materials System: A Source for Renewable Materials Assessment

James S. Bethel
Chairman, Committee on Renewable
Resources for Industrial Materials

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EXECUTIVE SUMMARY

Renewable resources in the form of forest and agricultural products are used in large quantities (4.4 billion tons of new basic materials consumed in 1972) for a wide variety of industrial purposes. Their uses for housing and other structural purposes, paper and paperboard, textiles, chemical feedstocks, and fuel constitute in the aggregate one of America's largest industrial sectors, and one that has continuously grown.

Society--and hence federal and state governments--should be concerned with the maintenance and development of our renewable forest and agricultural raw materials and their land base. They form a great and underused national resource, which has potential substitutability for nonrenewable resources, and is largely independent of foreign imports. At no time in our history has there been a greater need to expand and improve the use of the nation's renewable resources.

NATIONAL GOALS FOR RENEWABLE RESOURCES

The materials available and potentially available from renewable resources can be used as alternatives to materials currently obtained from nonrenewable resources to augment national and world materials supplies, to improve energy conservation in materials supply and use and to relieve dependence upon foreign sources of energy and materials and accompanying balance of payment problems.

Although the need to address the role and attributes of materials in the U.S. economy in a broad systems framework is quite apparent, little substantive work has been done in this area. The concept of the Reference Materials System (RMS) has been used in this study as a framework for material assessment and, more specifically, to address the substitution of renewable materials for nonrenewables in particular end uses. The orderly and rational development of national goals for renewable resources requires the evaluation of alternative materials supply systems in terms of resource supply; available technology; and energy, manpower, and capital requirements.

Accordingly, CORRIM recommends as a top priority that there be established under the Office of Science and Technology Policy in the Executive Office of the President, an advisory office for policy issues related to the use of renewable materials. Studies undertaken by this office should include an evaluation of the nation's materials supply systems, its capacity to develop and advance new technology, and an evaluation of manpower and training needs in the field of renewable resources materials.

RENEWABLE RESOURCES PRODUCTIVITY

CORRIM's general conclusion concerning the supply of renewable resources is that the biological productivity (net realizable growth) of the commercial forest lands of the U.S. could be doubled within a half-century by the immediate and widespread application of proven silvicultural practices, provided economic and social conditions permit. Of the agricultural materials deliberately grown for industrial materials in the U.S., only cotton and flax are of major importance, and CORRIM concludes that modest increases in production are feasible. The production of secondary agricultural materials (wool, fats, and hides are secondary products to meat production; peanut oil and soybean oil are secondary to food production) will be a function of the level of food production.

Accordingly, CORRIM recommends as top priority that the USDA through its forestry research program evaluate and improve the National Forest survey, and evaluate the opportunities to increase materials supply through intensive forest management that will more nearly achieve maximum use of biological potential. USDA should immediately develop production-scale demonstration tree farms that use the best available technology for achievement of maximum materials productivity. USDA should also develop methods for assaying the productivity of secondary agricultural materials that might be converted to industrial materials.

RENEWABLE RESOURCES BASE

Increases in the resource base can be achieved through study of materials improvement and conservation. Research in wood science and technology has been declining in the past 20 years. Most of the federal research investment in this area is directed toward the Forest Products Laboratory of the Forest Service. Its research program has been reduced in size and its efforts in basic research in materials science have been curtailed. Among the universities, several significant programs in wood science and technology have been phased out, presumably in economy moves. There are only eight major universities still pursuing important materials research and education in the field of wood science and technology.

There is a shortage of scientific and technical manpower with respect to research on renewable materials. A similar attrition has occurred with respect to research on renewable materials of agricultural origin. In contrast, the federal government has recognized the need for massive levels of research in the nonrenewable resources and energy fields.

Accordingly, CORRIM recommends that the National Science Foundation (NSF) foster and support the creation and maintenance of a limited number of university centers of research in renewable materials at institutions with substantial faculty and facility commitments to this field of study. CORRIM also recommends that NSF develop programs to use industrial research and development capability in cooperation with the university renewable materials centers and the Forest Products Laboratory to encourage early applications of new technology in the production of renewable materials.

SUMMARY AND RECOMMENDATIONS

Renewable resources in the form of forest and agricultural products have long been used in large quantities for a wide variety of industrial purposes. Their uses for housing and other structural purposes, paper and paperboard, textiles, chemical feedstocks, and fuel constitute in the aggregate one of America's largest sectors, and one that has continuously grown.

Coal and petroleum are the remains of plants and animals accumulated over the geologic past. As we contemplate diminished and more costly supplies of these nonrenewable resources, it becomes increasingly important that we assess the current capacity of the plants and animals on the earth to produce organic materials on an annual renewable basis. It is also important that we understand the technical feasibility of using these renewable resources for industrial purposes so that we can take advantage of their potential as economic conditions and national policy considerations dictate.

The principal renewable industrial material is wood. Nearly a quarter-billion tons are used in the U.S. each year. Agricultural products used for industrial purposes include cotton, wool, and other natural fibers for textiles; flax and other oilseed crops, most of which have only secondary uses in industry; and animal by-products. Large quantities of agricultural wastes and residues also have potential uses in industry.

Society--and hence federal and state governments--should have interests in the maintenance and development of our renewable forest and agricultural raw materials since they form a great national resource that is a potential substitute for nonrenewable resources and is largely independent of foreign imports. At no time in our history has there been a greater need to expand and improve the use of the nation's renewable resources.

As supply problems of the nonrenewable resources become more and more critical, the technology for substitution of renewable for nonrenewable resources to meet material needs must be available. This technology must be developed for use before the readily available reservoirs of nonrenewable resources are in short supply worldwide, or when supplies of nonrenewable resources may come largely under foreign control, and/or when there are substantial energy conservation opportunities inherent in the substitution.

The following sections summarize the general findings and recommendations of the Committee on the supply of renewable resources, both forest-based materials and agricultural materials, increasing production and use, institutional setting for renewable resources, and substitution. The Committee gives the recommendations in this section top priority; they should be implemented before action is taken on the remaining recommendations. More detailed considerations including recommendations are given in the sections on structural materials, paper and paperboard, textiles, chemicals, fuel from biomass, and extractives.

SUPPLY
(See Chapter 4)

Forest-Based Materials

In 1970, U.S. consumption of wood was 15.1 billion cubic feet (241 million tons). Fourteen billion cubic feet (225 million tons) were produced in the U.S., 2.4 billion (38 million tons) were imported, and 1.4 billion cubic feet (21 million tons) were exported.

In the same year, the 495 million acres of commercial forest in the U.S. grew 18.6 billion cubic feet or 33 percent more than removals. As discussed later in this report, the Committee has reservations concerning the utility of the national forest survey as a basis for making materials supply estimates. Softwood (conifers) sawtimber, however, was being cut much more heavily than it was being replaced by growth (removals exceeded growth by 18 percent). Nonetheless, the U.S. is currently growing wood faster than it is harvesting the forest.

The Forest Service estimates that, if the U.S. forests continue to be managed at its defined 1970 levels of intensity, they will produce 17.5 billion cubic feet (280 million tons) annually by 1985 and 20 billion cubic feet (330 million tons) by the year 2000.

We already possess the technical competence to manage our forests much more intensively. Should economic and policy conditions permit, we could substantially increase the productivity of American forests through such measures as fertilization, drainage, and irrigation to improve the growing potential of forest lands; the conversion of slower-growing forests of less valuable species to faster-growing stands of more valuable species; intensified reforestation efforts; greater use of genetically-improved growing stock;

weeding operations to favor a more desirable species in mixed stands; thinnings to presalvage expected mortality and to concentrate growth on harvestable stems; and intensified forest protection against fire, insects, and diseases to reduce losses from these causes.

Since the U.S. has had an ample supply of wood materials in the past, there has been no need to use its forest land efficiently to produce industrial materials. Because it takes several decades to grow a crop of trees, prudence suggests that we begin extensive testing of the new production technology now so that when price and policy suggest more intensive management, the methods required will be operationally available. Since the federal government is a major custodian of forest land that is diverse with respect to species composition, site quality, and geographical location, it should immediately establish such intensively managed demonstration tree farms on the national forests. At the same time information can be derived on such environmental effects as watershed protection, soil nutrient depletion, ground water storage, etc. These management demonstrations should draw upon the best technology available from the universities, private industry, and the federal experiment stations.

Under the widespread application of such intensified management programs, we estimate that within 50 years the commercial forests of the U.S. could produce 19 billion cubic feet of softwoods annually (290 million tons of wood and bark), 11 billion cubic feet of hardwoods (200 million tons), or a total of 30 billion cubic feet (490 million tons).

The above projections are based upon the amount of wood produced in the main stem (bole) of trees at least 5 inches in diameter (DBH), above a 1-foot stump up to a 4-inch diameter top. Only about half of the total biomass of the tree is included by this definition. Complete harvest of the stump, top, and large branches could easily increase usable yields from the forest by 25 percent.

The general conclusion of the Committee on Renewable Resources for Industrial Materials (CORRIM) is that the biological productivity of the commercial forest lands of the U.S. 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 immediate widespread application of proven silvicultural practices. We realize that political and economic restraints may result in a lesser increase in productivity. It should be pointed out that with widespread application of intensive silvicultural practices, with complete use of our hardwood resources, and with complete tree use, the potential productivity would be closer to three times the present level rather than the doubling we feel is imminently practicable. 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. At the present state of the art, relatively modest investments in forest management will result in substantial increments in the biological production efficiency of trees.

Steps should be taken toward the development of a revised and more broadly supported national forest survey. 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. These estimates should be devoid of any assumptions concerning probable use. Such information should be generalized by species, forest types, site classes, and size classes. In short, it is necessary to generalize better than can be done today from specific studies of complete tree analyses and forest ecosystem biomass studies to enable better predictions of 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 information is needed to predict the impact of such programs in site improvement, forest type conversion, reforestation, genetic improvement, weedings, and thinnings in terms 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 and yet 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.

Still another area where information is lacking is the socioeconomic aspect of forestry. We have speculated at length about the motives of small woodland owners and the environmentally oriented groups toward intensive forestry;

yet too little is known about the impacts of these groups on future timber growing and on wood supplies.

Finally, a greater understanding is needed of the energy requirements of growing timber. Information is largely lacking on this newly critical issue, so much so that the topic had to be omitted from our study. It seems apparent that, in the future, energy costs, production, and net energy balances will figure in forest management decisions just as ecological and economic factors already do.

With these considerations in mind, CORRIM recommends as top priority that

- The U.S. Department of Agriculture (USDA) improve and enlarge the national forest survey to:
  (1) develop the physical census data on a total forest basis so that it can be interpreted under various assumptions of land use, utilization levels, and economic feasibility; and

  (2) improve the methods used to obtain the census including use of the latest technology in sampling, biometric analysis, and photogrammetry.

- USDA, through its forestry research program, evaluate the socioeconomic aspects of forestry. This should be done with special reference to ownership objectives of nonindustrial private forest landowners and to objectives and concerns of the federal forest land users whose interest is in nontimber uses. These objectives should be related to intensive timber management and materials supply.

- USDA, through its forestry research program, evaluate the opportunities to increase materials supply through intensive forest management that will more nearly achieve maximum use of biological potential, particularly on high site forest lands. It should immediately develop production scale demonstration tree farms that utilize the best available technology for achievement of maximum materials productivity.

- USDA in cooperation with the Energy Research and Development Administration (ERDA) evaluate the energy requirements of timber production and the opportunities to decrease the dependence of these activities on external energy supplies.

Agricultural Materials

Of the agricultural materials grown primarily for industrial purposes in the U.S., only cotton and flax are of major importance. The production of each has not risen 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 U.S.

Products of animals and plants grown for food and feed also find substantial use for industrial materials 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 largely dependent upon the demand for and the production of the basic food or feed material.

The same can be said for agricultural residues, whether such crop residues as cereal straws, bagasse, and corn stalks, or such animal residues as manure. The quantities available for industrial use will be determined by the amounts grown for food and feed use.

More land suitable for cultivation is available in the U.S. than is currently being used. Productivity per acre can be increased substantially through more intensive agricultural practices based on available technology. Manpower and energy demands may be lessened through careful management.

Recent surveys of projected demand for agricultural products indicate that the U.S. can produce its own food needs and supply reasonable export markets through the year 2000 if present trends continue. This would mean that the quantity of agricultural residues that are candidates for conversion to industrial materials will continue at their present level or higher.

Therefore, CORRIM recommends as top priority that

- USDA, either through its own research program or through its cooperative program with the states, develop sampling and inventory methods for assessing the annual production of secondary agricultural products suitable for conversion to industrial materials.

- USDA conduct and report on an annual inventory of such materials with special attention to their location.

- USDA, in cooperation with the Environmental Protection Agency (EPA) and ERDA, evaluate the opportunities to moderate agricultural environmental impact and increase agricultural energy independence through increased use of secondary products for industrial materials.

INCREASING PRODUCTION AND USE
(See Chapter 12)

Increases in the resource base can be achieved through study of materials improvement and conservation. Research in wood science and technology has been declining in the past 20 years. Most of the federal research investment in this area is directed toward the Forest Products Laboratory. Its research program has been reduced in size and its efforts in basic research in materials science have been curtailed. Among the universities, several significant programs in wood science and technology have been phased out, presumably in economy moves. There are only eight major universities still pursuing important materials research and education in the field of wood science and technology. Accordingly, there is a shortage of scientific and technical manpower in this field. A similar attrition has occurred with respect to research on renewable materials of agricultural origin. In contrast, the federal government has recognized the need for massive levels of research in the nonrenewable resource and energy fields.

Therefore, CORRIM recommends that

- The National Science Foundation (NSF) foster and support the creation and maintenance of a limited number of university centers of research in renewable materials at institutions with substantial faculty and facility commitments to this field of study.

- NSF develop programs to use industrial research and development capability in cooperation with the university renewable materials centers and the Forest Products Laboratory to encourage the early applications of new technology in the production of renewable materials.

- The major forestry corporations with important research capability participate, as a matter of corporate policy, in cooperative research designed to produce published results.

MATERIALS USE
(See Chapters 6 - 10)

The materials available and potentially available from renewable resources can be used as alternatives to materials currently obtained from nonrenewable resources to augment national and world materials supplies, to improve energy conservation in materials supply and use, and to relieve dependence on foreign sources of energy and materials and accompanying balance of payment problems. The orderly and rational development of a national policy for the achievement of these objectives requires refinement of methods of evaluating alternative materials supply systems in terms of resource supply; available technology; and energy, manpower, and capital requirements.

The feasibility of any particular substitution depends largely on the relative prices of the alternative materials. Prices reflect the availability of the competing materials and the manpower, process energy, and capital required to convert them to useful products. The costs associated with supply of materials and their conversion can change very quickly.

Recent trends suggest that changes in relative costs are likely to favor increased substitution of renewable for nonrenewable materials in the long run. It is in the national interest to foster the advances in science and technology required to permit rapid conversion from one resource base to another when supply and cost of conversion favor such substitution.

CORRIM undertook to develop methods of systems analysis that would permit rational assessment of substitution potential in terms of the most important elements of cost. These methods provide a basis for setting priorities among relevant science and technology research opportunities.

The quantitative data base essential to the assessment of viable alternatives needs to be improved, particularly in relation to the use, durability, and maintenance of materials in specific applications.

The development of new technology will increase the options for substitution. It is important to evaluate national capacity to quickly develop new technology, to strengthen existing mechanisms for advancing such technology, and to create new mechanisms for technology improvement. The nation has not given the attention to science and technology in the field of renewable materials that has been devoted to nonrenewable materials and fuels, nor is there a focal point in government for such policy issues. The diverse character of land and factory ownership in the renewable materials sector makes it unlikely that major advances in science and technology in this field will quickly emerge unless it is fostered by the federal government. The number of universities engaged in significant research on the renewable materials is small and these programs are underfinanced. Industrial product research in this field is modest in comparison with that pursued in nonrenewable fields. Most companies are too small to justify the creation and operation of research programs. The few relatively large companies in the field confine many of their research efforts to those projects that can be protected on a proprietary basis. Some of these corporate research resources are very good and should be contracted for by the federal government to advance national goals through research.

Where corporations are willing to place the results of their more fundamental research in the public domain, they have contributed substantially to the advancement of science and technology related to the production and use of renewable resources. The action of a major lumber company in releasing to the scientific community their very extensive soil evaluation research is a good example. If the private sector were willing to share in the cost of broadly applicable research, it could broaden the base of research leading to generally available new knowledge.

Perhaps the most important resource for any industry is competent manpower. The level of research and development by the renewable materials industries could be raised by attracting and employing more well educated young people. Needed are professional scientists and technologists soundly educated in the disciplines underlying renewable materials. To back up the scientists and technologists and to carry out technical as well as mill operations, technicians with various levels of education will be needed. There is a great need for continuing education programs, which will increase in the future because of the increasing tempo of knowledge and change in the field.

Therefore, CORRIM recommends as top priority that

- Responsibility be established under the Office of Science and Technology Policy in the Executive Office of the President for policy issues of science and technology in the field of renewable resource materials. Studies undertaken by this office should include an evaluation of the nation's material supply systems and its capacity to develop and advance new technology and an evaluation of manpower and training needs in the field of renewable resource materials.

- USDA increase its research efforts in the use of agricultural based primary and secondary materials.
- USDA, at the Forest Products Laboratory, increase emphasis in its programs of research on renewable materials and increase cooperation with industries and universities that are engaged in the forest products field.

THE INSTITUTIONAL SETTING FOR RENEWABLE MATERIALS USE
(See Chapters 5 and 12)

The restrictions of law and government regulations can increase the requirements for capital, energy, and manpower in the conversion of a resource to a material and affect the competitive position of renewable resource materials. If renew-able resources are to be substituted for nonrenewable resources, price relationships must change in favor of renewable resources through one or a combination of the following: (1) rising relative costs of nonrenewable or inorganic raw materials, (2) increased productivity in improved management leading to cost reductions at any of the various links in the system from natural growth to ultimate use, and (3) modification of existing institutional barriers leading to lower relative costs in the renewable resource system.

A large number of institutional factors can be enumerated that stimulate or hinder forest and agricultural raw materials production. Among the most important are the following:

1. Taxation of forest lands and forest yields. While capital gains treatment has greatly stimulated investment in forest, real estate taxes, especially if applied to standing timber, have become an increasing burden. It has been correctly argued that the real estate tax, applied yearly to the same standing crop, entails a form of multiple taxation if compared with an annual crop.

2. Environmental regulations and forest production acts. In the last few years acts have proliferated that are discouraging small landowners who do not have the resources to comply with the generally intricate set of rules and

regulations. Similarly, new water and air pollution abatement regulations for industrial plants have siphoned off large capital investments from plant and capacity expansion to pollution control equipment.

3. Regulation of transportation. The bulky structure of wood products means that the location of transportation sites has a significant impact on materials flow and availability. The deterioration of the railroad system in the U.S. and the Jones Act (requiring shipments between U.S. ports to be in U.S. vessels) have had significant impacts on the renewable materials supply.

4. Building codes and consumer standards. Codes and standards ranging from new flammability standards for children's sleepwear to the great diversity of often outdated and conflicting building codes have had an obvious impact. Many institutional and social factors make it difficult to change the building codes. Furthermore, the system of codes has the weight of its own inertia mitigating against change. Consequently, the codes have failed to respond to changes in the technology of building materials and therefore many of the codes are overly conservative and thus expensive; significant saving in material consumption is possible in this area alone.

The Committee has studied the institutional setting for renewable materials use both from a domestic and an international vantage point. One might categorize the major domestic institutional factors as follows: First, there are the well-known factors such as the objectives of small private forest owners with their disinterest in forest management, outdated building codes, and management of the national forests. These issues have been argued in other forums and their resolution does not appear to be held up because of a lack of scientific information. Second, there are the emerging issues of environmental regulation, forest practice acts, and occupational health and safety regulations. The impacts of these developments are now unclear but potentially serious. The rationalization or optimization of these regulatory policies will require a great deal of research and professional input over an extended period of time. A third category of issues involves factors that are highly significant for renewable resources but which have implications, extending well beyond renewable resources. These include rationalization of the U.S. transportation system and the manipulation of monetary and housing programs which impact so severely on the demand for forest products in the construction industry.

In the international area, it is not clear whether it is national policy to achieve a domestically balanced timber budget, an internationally balanced timber budget, or no balance in the timber budget. The nation does not now have any kind of balance in its timber budget. It is dependent upon foreign sources for a significant part of its renewable materials supply apparently as a matter either of preference or indifference. It is in the national interest to evaluate its posture with respect to its future role as a supplier of renewable materials to meet its own needs and as a contributor to world supplies. Clearly it is not possible to achieve an internally balanced timber budget in the immediate future and it is not obvious that this would be desirable if it were possible.

Therefore, CORRIM recommends as top priority that

- USDA undertake as a response to its obligations under the Humphrey-Rarick Act to evaluate the influence of institute barriers on the balance of trade in wood internally and externally.
- The Department of State, through its Agency for International Development (AID), initiate a program of development of bilateral cooperation with developing countries in the field of renewable materials where there is likely to be a mutual advantage to the strengthening of renewable materials production by these countries.

SUBSTITUTION
(See Chapter 5)

There are very few industrial materials for which another material is not technically substitutable. Furthermore, there are few industrial materials for which there is only one substitution option. While a number of technical options exist, it is not clear which options are economically most attractive in the long run and which are socially acceptable.

Possibilities in the case of energy are to shift from petroleum to nuclear fuels, geothermal energy, solar energy, coal, wood, some plant and animal residues, and urban waste. Wood has a long history of use as a fuel and clearly could be used again. However, it is presently used for other purposes than fuels or, in the case of residue left in the forest, is expensive to collect and deliver to fuel consumption sites. The same problems exist with some of the other potential petroleum substitutes. Thus, a decision to divert a renewable material to use as fuel could result in a supply shortage or an increase in supply cost in the system currently using such a material.

Although the need to address the role and attributes of materials in the U.S. economy in a broad systems framework is quite apparent, little substantive work has been done in this area. The concept of the Reference Materials System (RMS) has been used in this study as a framework for material assessment and, more specifically, to address the substitution of renewable materials for nonrenewables in particular end uses. This technique facilitates the integration of diverse information on the technical, economic, and environmental aspects of the materials system and the analysis of materials use and substitution.

The concept of an RMS is a description of the major components of the materials system, specifying the processes ranging from extraction of resources through their refinement, transportation, fabrication, and installation at the point of end use. An aggregate RMS in simplified form is shown in Figure 1. At the left hand side is a listing of resources corresponding to the materials to be considered while the products and end uses are listed on the right hand side. The series of "activities," e.g., growing, harvesting, transporation, and fabrication, that a typical resource has to go through to become a useful material for an end use, are listed on top of the figure.

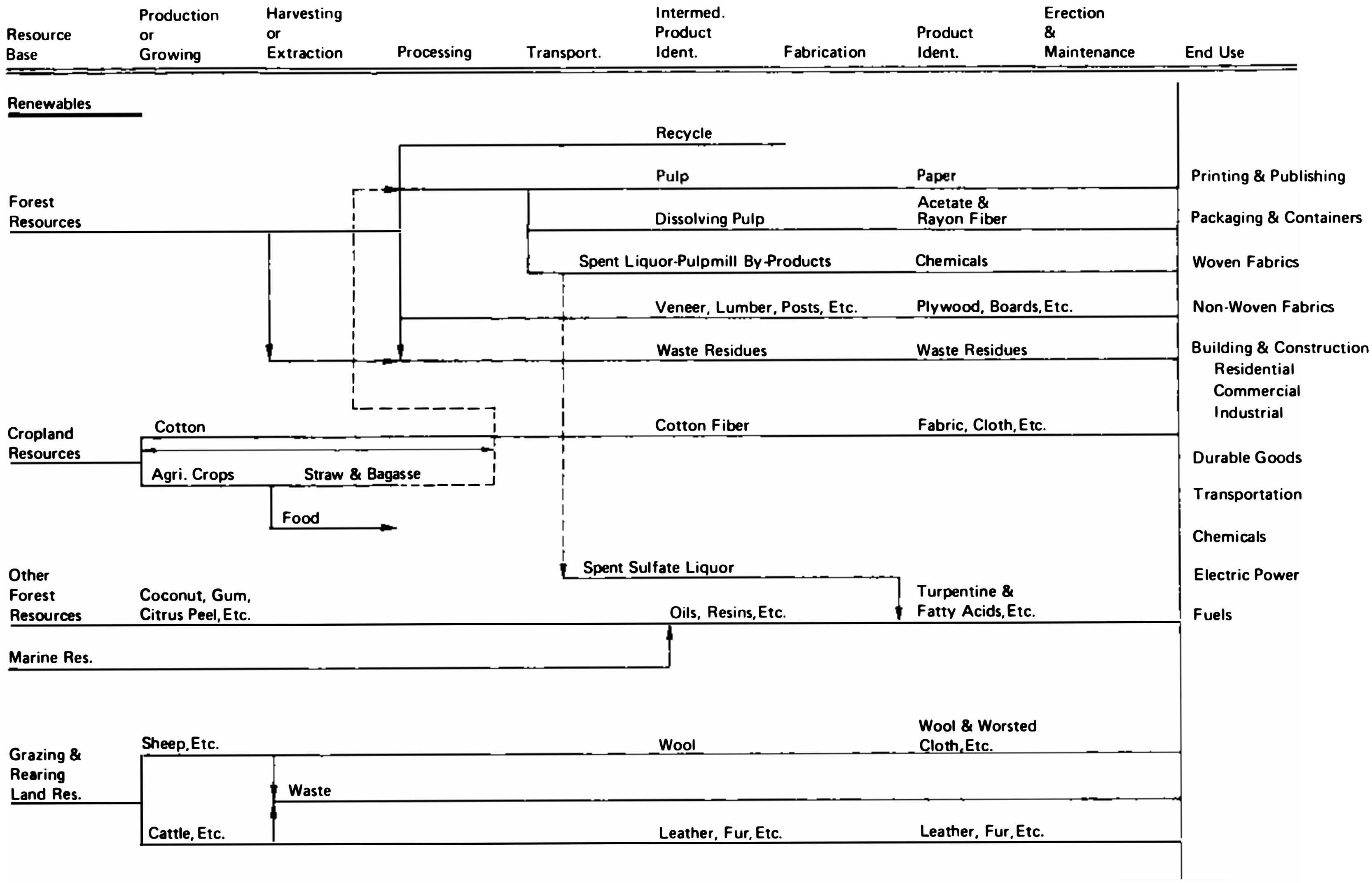


FIGURE 1 SIMPLIFIED REFERENCE MATERIALS SYSTEM

A completed RMS is a network representation of the flow of materials from the resource side through all of the "activities" to the end uses. Each "activity" in the trajectory represents a technical process or production step that is characterized by both a flow element and several data elements (e.g., land use, energy requirements, fertilizer and chemicals, labor, and cost). An RMS with all the available information has been developed for the historical year 1972.

To use the RMS in evaluating the impact of a new materials technology, the characteristics of the technology must first be defined in terms of resource consumption, fabrication, environmental effects, energy consumption, etc. The impact of the new technology can be estimated by comparing the new tallies with the old ones. The same approach was used for analysis of materials use and substitution.

Efforts to construct and use the RMS to evaluate potential substitutions within the domain of renewable resources and between renewable and nonrenewable resources clearly indicate the need for a better information base as a condition precedent to the establishment of a national policy for materials.

Therefore, CORRIM recommends that

- The U.S. Department of Commerce (U.S. COM) be directed to develop and maintain a data bank on the flows and factor input requirements for materials produced from renewable and nonrenewable resources.

Structural Materials
(See Chapter 6)

Timber finds its largest use in the production of structural wood products, including not only lumber but also plywood, particleboard, flakeboard and insulating board, which serve in primary forms as building materials and from which innumerable secondary products are made. About 63 percent of all wood produced in the U.S. is currently used for primary structural materials. We estimate that this will drop to about 50 percent by the year 2000. Over half the lumber and panel products produced in 1970 were used for the construction of housing and light industrial buildings, and only a slight decrease in this percentage of the total demand for these products in the year 2000 is projected for building construction.

In 1970, approximately 62 percent of the structural wood consumed in the U.S. entered the market as lumber, 14 percent as plywood, 11 percent as building board, and 13 percent as cooperage, poles, posts, and other miscellaneous commodities. Reconstituted wood products are gaining a larger share of the market at the expense of lumber because of the trend toward smaller sizes and poorer qualities of the raw material, improvements in processing technology, and modifications in techniques of building construction. This trend will continue.

Structural wood products have remained competitive in the U.S. economy. While annual lumber consumption remained fairly constant from about 1908 until the mid-1960s, it has risen about 20 percent since then. The price of lumber has risen more or less steadily since 1800 at a rate averaging about 1.7 percent annually, compounded. Structural wood products should continue to be competitive. Not only are potential supplies available to allow for modest increases in production, but structural wood products have generally lower energy requirements than alternative materials.

No consistent differences in manpower and capital requirements are indicated for systems incorporating wood and non-wood components. It appears clear that, where the conservation of energy is of prime importance, wood is the preferable material for residential and light commercial construction.

The diminishing supply of large logs suitable for lumber of large dimensions and for plywood, the necessity of using an increasingly higher percentage of that part of the forest biomass that has previously been considered forest residue, and the economic desirability of complete use of all raw materials entering processing, combine as strong incentives for the development of new reconstituted structural products alternative to lumber and plywood. Important among those which are technically and economically feasible and can be expected soon to enter the market are lumber laminated from veneer and a variety of designs of reconstituted structural wood. The former, fabricated from veneer unsuitable for plywood, can serve the same function as lumber of large dimension, but can be used more efficiently in engineered structures because variability can be better controlled. The latter, reconstituted from strands or flakes generated largely from what is now forest residue or from low-grade hardwood logs (which are in oversupply), can be used as alternatives to lumber or plywood, depending on the design. The use of structural flakeboard for sheathing in building construction--a function now served largely by plywood--is particularly promising.

Inasmuch as the future structural products mix must consist of ever-increasing percentages of reconstituted products, concentrated research must be directed toward improving processes of manufacturing structural materials suitable for exterior and interior use from hardwood and softwood flakes, strands, veneer, fiber, and pieces of small size alone or in combination.

Assuming a high level of technology resulting from advances through research and development and an adequate technical manpower pool, it appears safe to forecast that the nation's needs for structural and architectural wood materials based on the forest resource can be met, but they will be met with a product mix substantially different from that now in use.

Data developed during the course of this study strongly suggest that, on the basis of man-hours, capital, and particularly energy requirements, structural wood products are clearly superior to non-wood alternatives. Their technical suitability in residential and light-frame commercial building construction is widely recognized.

Because of its inherent favorable physical and aesthetic characteristics, wood can potentially regain the market for institutional and household furnishings and windows, which has been invaded by materials based on nonrenewable resources, providing that economic conditions are favorable.

A long established trend toward the increasing use of every tree and every species can be expected to continue through the year 2000, with the upper limit to be determined from site and economic considerations. This trend, in combination with the driving forces influencing the use of wood as structural material, will result in a structural-product mix in which new and reconstituted wood products will contribute an ever-increasing share toward meeting the total anticipated needs for structural and architectural wood products.

Therefore, CORRIM recommends that:

- Studies be initiated to develop improved processes for manufacturing structural materials from hardwood and softwood flakes, strands, veneer, fiber, and pieces of small size, alone or in combination with other materials. In order to be effective commercially, these studies must be followed by pilot plant evaluation.

- Additional research efforts be focused on the further development of reconstituted products for both exterior and interior structural applications from a wide spectrum of softwood and hardwood species.

- A research effort be devoted to developing an inexpensive, nonpetroleum-based exterior adhesive competitive in function and current price with the durable phenol-formaldehyde adhesives used in the manufacture of exterior, reconstituted structural wood products. Lignin should be studied as a potential source for the development of such adhesives.

- Research be directed to the development of economical green-wood and bark burners for direct-fired dryers and wood-fired boilers inasmuch as a major portion of the energy required for the manufacture of wood structural materials can be provided from residue.

- Research and development be directed toward developing dryers, heating vats, and hot presses of high thermal efficiency and toward the reduction of power consumption in all phases of logging, manufacture, and transport.

- Research be devoted to design concepts which are structurally more efficient inasmuch as manpower, energy, capital depreciation, and material required for structures are all positively correlated with weight. Research should also be devoted to decreasing weight through increasing the strength and stiffness of components from which wood structures are built.

Paper and Paperboard
(See Chapter 7)

The paper industry in the U.S. depends on the forest for 98 percent of the fiber used in the production of paper, paperboard, and related fiber products. The remaining fiber is mainly from cotton linters, rags, bagasse, and flax. Approximately 35 percent of the raw material taken from the forest is converted to fiber-based products. We predict that by the year 2000, fiber-based products will account for approximately 46 percent, with structural wood products dropping from 63 to 50 percent in the same period of time.

The American paper and paperboard industry has experienced rapid continuous growth with production increasing 3 1/2 times over the past 30 years. Per capita consumption has risen from 294 pounds in 1942 to 616 pounds in 1972 and 618 pounds in 1974.

Paper and paperboard products have, in the main, resisted invasion by products made from petrochemicals and other nonrenewable materials. Losses of part of the market in food packaging and milk containers have been generally counterbalanced by gains in the use of such products as corrugated shipping containers, office copying papers, nonwoven fabrics from pulp, and new composite products containing paper.

The demand for wood fiber should continue to increase. Although energy requirements for processing are high, they are generally lower than for alternative materials. The prospects to meet this demand are for a modest increase in raw wood supply, substantially more efficient use of this supply, and technological progress in the industry.

The paper industry is a major consumer of energy (kwh Eq 320 billion which is greater than that consumed by the plastics, rolled aluminum, or plate-glass industries). However, the energy consumed per ton is less than for any of these other materials. Also the energy cost (8-12 percent of total manufacturing cost) is less than for such nonrenewable materials as plastics or aluminum.

The paper industry now supplies as much as 42 percent of its energy need from its own process wastes. Therefore, as purchased fuel and power costs increase, the effect on the cost of a ton of paper may be less than the increase in cost of a competitor's product made from a nonrenewable resource. New technology to improve this capability would further increase this advantage and save imported fuel.

Almost all the lignin and other organic material removed from wood in the pulping process is converted into heat and energy during the chemical recovery process. Tall oil and turpentine are important by-products of softwood pulp mills.

Research is under way to reduce energy consumption at the various process steps in the manufacturing operations, such as in refining and drying. Other energy-saving research includes recovering low-level heat from process streams (better heat exchange and recycling), improving generation of energy from processing wastes (better recovery furnace operation), producing low energy/high yield products, and reducing the fiber weight in the end-use product.

In recent years there has been a continuing trend toward more efficient processing and use of wood by the paper industry. For example, since 1960 there has been a decline in the amount of wood used per unit ton of all pulp types, from a figure of 1.60 cords per ton to 1.51 cords per ton in 1973. This reduction is partly due to the use of greater percentages of hardwood, but primarily it is the result of technological changes that have made it possible to run higher yield pulps in the manufacture of packaging papers and paperboard.

Since 1950 there has been a shift, not only to a greater use of hardwoods (presently about 25 percent of all wood pulped), but to the wider use of sawmill residues, i.e., integrated use. In 1973, about 38 percent of all wood pulped was in the form of wood manufacturing residues (32.5%) and logging residues (5.2%), compared to only 17 percent in 1960. Taking into account recycled waste paper and other residual fibers, more than half the fiber supply that the industry draws upon comes from fibers that would otherwise be discarded. This leads to a fuller use of the forest on an integrated operational basis.

Today about 22 percent of paper fiber is recycled. In recent years the industry has thoroughly assessed the potential for recycling. It is believed that waste paper recycling will peak at some value under 30 percent. This figure is based on the economics and technology of collection, handling, and transportation. This appears to be quite reasonable for the U.S. market and quality demands, since research has shown that the virgin fiber has lost its strength potential after the third recycle. It is possible to regenerate some of its lost potential by chemical treatment, but costs and pollution are factors that mitigate against such efforts.

As more and more of our major cities burn their organic wastes for heat and energy, a good portion of the wastepaper will be used. Only the higher quality and readily collectable clean waste will be recycled for more paper.

Since 1970, the concept of whole tree use has resulted in some usage of whole tree chips for pulping (includes the whole tree above the ground: trunk, branches, twigs, leaves and bark). As further demands are made on wood and costs rise, there is no question that greater dependence upon the use of the whole tree will occur. Full use of the forest resource, together with the use of wood manufacturing wastes, will greatly enhance our fiber supply. Moreover, it will lead to better forest management practices to achieve optimum growth rates.

Although wood costs alone will cause a trend toward the use of a wider spectrum of wood fibers, developing technologies will also help in the use of lower quality fiber and in obtaining higher pulp yields. This is fortunate and will help realize their development and application at an early date.

Some laws relating to forest practice require increased timber production such as through the requirement of reforestation. However, other federal and state laws and agency regulations relating to land practices, processing, and products have a very considerable impact on the pulp and paper industry usually in the form of restrictions and constraints. These include legislation concerning the environment, packaging (generally, packaging is subject to regulations as severe as the food it contains), health and safety (for example, required noise reduction could cost $2 billion), container specifications and constrictions concerning design and performance, tariff rates for preferential incentives (such as to encourage the use of secondary fibers), and consumer protection, which can influence the choice of materials (such as flame proofing).

Meeting environmental regulations is costly. In 1972, capital expenditures for pollution abatement equipment cost the industry $339 million. Other costs relating to this problem, such as operation and research, amounted to $243 million. Marked progress has been made by the pulp and paper industry in pollution control, but there is industry-wide concern over its ability to sustain environmental protection expenditures in excess of the $0.5 billion annual level that has been met during the past three years. This includes considerable research expenditures necessary for the development of the best pollution control technology.

There is great potential for greater and more effective use of our renewable resources for paper, paperboard, and new industrial materials and for enhancing the efficiency of processing technology and use of capital.

Therefore, CORRIM recommends

- Development of cost-effective and technically-sound methods for (a) recovering from the forest whole trees as well as forest residues of small and irregular size, (b) pulping and producing acceptable fiber products from biomass, and (c) more effective recycling.

- Enhancement of the efficiency of producing and using energy in order (a) to reduce processing costs, (b) to improve the competitive position of products from renewable fiber resources versus products from nonrenewable resources, and (c) to contribute to the improvement of the overall national energy situation. This effort should include studies on (a) reduction of energy used in processing, such as by heat exchangers, thermal recycling, and closed loop systems, (b) improved generation of energy from processing wastes, and (c) production of high-yield products of lower energy consumption.

- Development of pulping, bleaching, and other production processes that combine enhancement of the quality of the environment with improved processing technology and efficiency.

- Improvement of the competitive position of paper and paperboard products with respect to products made from petrochemicals, metals (foils, containers, etc.), and other nonrenewable materials, by enhancement of the quality and properties of present paper and paperboard and products and by the development of new products.

Textiles
(See Chapter 7)

In 1972, textile mills in the U.S. used 5.9 million tons of fibers. Nearly half (48%) was from renewable resources, including cotton (33%), wool (2%), and cellulosics (rayon and acetate produced from wood and cotton linters, 13%). The largest portion (52%) was from nonrenewable resources, chiefly from petroleum (47%), and textile glass (5%).

The history of the textile industry in the U.S. over the past decade has been one of declining use of cotton and wool and of great expansion of non-cellulosics (nylon, acrylic, olefin and polyester) from fossil fuels.

While production of cotton in the U.S. has remained fairly level over recent years, exports of much of the crop (39% in 1972) have taken up the surplus over U.S. textile mill needs. However, land is available for increased production of cotton in this country. Also, the production of a pound of cotton fiber requires only a small proportion of the energy required to produce a pound of synthetic fiber (3.36 vs. 16.32 kilowatt-hours per pound of fiber). This includes the production of 1.75 pounds of cottonseed per pound of fiber. Oil and protein from this seed are becoming increasingly valuable and provide 14-20 percent of the gross revenue from cotton production. Assuming that technological advances can make cotton more competitive in the durable-press and flammability areas, that the costs of producing non-cellulosic fibers increase, and that export markets will continue, we predict a modest increase in the production of cotton, perhaps from 14 million bales in 1972 to 16 million bales in 2000.

U.S. mills consumed 110 thousand tons of wool on a scoured basis in 1972, less than half the amount used in 1962. Although wool has excellent comfort and fashion characteristics, its competitive position has been seriously eroded by man-made fibers. Fluctuating wool prices and lack of availability during periods of high demand have been partially responsible for serious market losses.

The energy requirements for growing wool are even less than for cotton. Sheep are more efficient meat producers than cattle, a situation that could influence future meat production and thereby simultaneously increase the supply of wool. Stability in wool prices and markets would first have to be overcome.

With the exception of furs, fibrous materials produced by animals are the by-products of the meat and poultry industry, which leads to a lack of response of supply to demand, with fluctuation in prices. Hides and leather are the major products, with a production of 3 billion pounds of hides and 898 million pounds of leather in 1972. Exports amounted to 879 million pounds of cured hides and 143 million pounds of leather. Other production figures for 1972 were 22 million pieces of fur, 8 million pounds of pulled wool, 75 million pounds of cattle hair (mostly wasted), and 1.1 billion pounds of feathers (mostly converted and used as a source of protein in animal feed).

Meat production is expected to increase in the future, which will bring about an increase in the above products. Total hide production is expected to increase by a third in 1985 and by over 70 percent in 2000. Future hide and leather production will meet domestic demand and allow for export surpluses. Leather footwear production is expected to keep pace with population growth, but increased use of leather in garments is anticipated.

The major raw material base for the production of cellulosic fibers are wood and cotton linters. Man-made cellulosic fiber production is confronted with serious environmental pollution abatement costs, high energy costs

(20.42 kilowatt-hours per pound of fiber), and very large capital expenditures. As a result, plant capacity for chemical cellulose (dissolving pulp) has declined from 1.805 million tons in 1972 to 1.695 million tons in 1975 and is expected to continue to decline to 1.465 million tons by 1980.

Therefore, CORRIM recommends that

- Research be directed to improve agricultural fiber properties for enhancement of consumer acceptance, to reduce costs of cleaning and processing, to meet regulatory requirements including flammability, air pollution, and workers' health and safety such as from cotton dust, and specifically to develop improved knitting and weaving technology for cotton.

Chemicals
(See Chapter 8)

In 1974, the total U.S. production of plastics, noncellulosic fibers, and synthetic rubber amounted to almost 37 billion pounds (over 18 million tons). About 95 percent of these materials are conceptually (but not necessarily economically) derivable from cellulose, hemicelluloses and lignin. The amount of wood necessary to produce these plastics and chemicals would be about 60 percent of that annually used by the pulp and paper industry.

Lignocellulosic raw materials in the form of wood and agricultural residues are available without creating a supply problem for conventional uses of wood and wood fiber.

Currently about 6 percent of the nation's total availability of oil and natural gas is used as a raw material for chemicals that form the base of the U.S. plastics and chemicals industry. Production of organic chemicals from petroleum has a substantial economic advantage as compared to organic chemicals produced from other sources. Substantial R&D expenditures on other sources, including wood, agricultural residues, and coal, have been essentially moribund for the past several decades. Price and availability problems of oil and natural gas, however, point to the opportunity of producing chemicals from renewable resources.

Opportunities for substitution of renewable lignocellulosic raw materials from wood and agricultural residues for petroleum-based materials can be classified as follows:

1. Cellulose, being a naturally occurring high polymer, can be modified to produce cellulose derivatives (primarily rayon and cellophane--both regenerated cellulose) without substantial alteration of the cellulose structure. Cellulose-based plastics have a number of valuable properties but have been generally more costly than petrochemically based plastics. Development of less capital intensive processes, higher yields, and the production of new and further modified cellulose derivatives would make a major impact upon the overall use of cellulose as a chemical raw material.

2. Lignocellulosic materials also can be broken down to produce chemical feedstocks. Of the 18 million tons of synthetic polymers produced in the U.S., most are derivable from ethylene (47%), butadiene (12%), and phenol (36%). These building blocks are all obtainable in good yields from wood. Ethylene and butadiene can be made from ethanol, which in turn can be made by fermentation of glucose, the hydrolysis product of cellulose.

$$\begin{tikzcd}
\text{Cellulose} \arrow[r, "\text{hydrolysis}"] & \text{glucose} \arrow[rr, phantom, "\text{fermentation}"] & & \text{ethanol} \arrow[dl] \arrow[dr] & \\
& & \text{butadiene} \arrow[d] & & \text{ethylene} \arrow[d] \\
& & \text{synthetic rubbers} & & \text{thermoplastic polymers}
\end{tikzcd}$$

Phenol and related compounds are obtainable from the hydrogenation or hydrogenolysis of lignin.

Lignin → phenols → phenolic resins, polyesters, etc.

The major technological problem in cellulose conversion to feedstocks lies in the improvement of cellulose hydrolysis to overcome problems of rate of reaction and decomposition of sugars resulting from the relative chemical inaccessibility of cellulose.

Lignins, on the other hand, constitute a potential source of aromatic chemicals as lignin consists of approximately 40 percent aromatic compounds such as benzene and 50 percent as phenol. The production of phenolic products from the lignin component of wood and agricultural residues by various hydrogenolysis techniques has been demonstrated, but no commercial production has been attempted. Other applications of lignin that are in need of considerable research investment are those that use this material in as high a polymeric state as possible, as a rigid plastic, filler, adhesive, or additive, for example in lieu of carbon black for strengthening rubber.

Hemicelluloses are another constituent of lignocellulose materials that have not reached their potential as chemical feedstocks. The components of hemicellulose are pentoses and hexoses, which are simple sugars readily obtainable by hydrolysis and present in the waste streams of paper pulp processes, e.g., sulfite waste liquors contain approximately 2 million tons of free sugars that could also be used for fermentation to ethanol or yeast production.

3. Kraft black liquors contain major quantities of carboxylic acids (16 million tons) that could be captured for a higher valued substitute use than for fuel.

4. Furfural, at one time used for the production of nylon, can be produced from pentoses occurring in both wood and agricultural residues.

Another approach to the production of chemical feedstocks is the production of synthesis gas from lignocellulosic sources by high temperature heating. Synthesis gas can be converted to methanol, ammonia, methane, and other hydrocarbons by the same technique used with synthesis gas produced from coal. Urban solid waste or possibly wood could be used as the base for synthesis gas production.

In conjunction with the 38 million tons of chemical pulp produced annually, approximately 19 million tons of lignin are obtained in soluble form. It is burned or otherwise disposed of; thus almost the entire amount of lignin required for conversion to phenol and benzene would be available without a need for additional wood, but an alternate fuel for recovery boilers would be required. Another lignin source is the residues obtained from hydrolysis of lignocellulosic materials.

An approach that will allow lower unit product cost is the use of a multi-product manufacturing process that uses all of the components of the available lignocellulosic raw material. A similar approach is used in the oil, meat packing, and coal for chemicals industries.

In-depth engineering and economic analyses should be made of such schemes; they should be evaluated in comparison with chemicals production from coal and petroleum over a range of raw materials cost. If such a comparison shows potential utility, then it is recommended that a pilot plant study be made.

The substantial economic advantage of tonnage chemicals, plastics and polymers derived from fossil fuels has resulted in minimal levels of research being undertaken on the chemical use of lignocellulosic materials over the last few decades. The application of modern scientific techniques and technology to these renewable resources offers the opportunity of replacing to some unknown extent a great variety of products now derived from fossil fuels.

Cellulose, lignin, and hemicelluloses are already polymers and can be converted to useful products without the expenditure of large quantities of energy. However, conversion of cellulose to rayon, cellophane, cellulose esters and cellulose ethers is very energy and capital intensive. Process improvements in the production and derivativization of chemical cellulose as well as the regeneration or shaping of the cellulose derivatives to reduce production costs are needed in order for significant expansion to occur to replace petrochemically based polymers. Additionally, substantial opportunities exist to expand the use of cellulose derivatives by property modification to suit industrial needs.

The conversion of wood, agricultural, and urban residues into chemicals for the production of most of our chemicals and plastics derived from petroleum is conceptually feasible. With refinements in technology, a large integrated plant utilizing all components of the wood for production of ethanol (to be further processed to ethylene and butadiene), phenols, and furfural would be approaching economic feasibility at current petrochemical prices. If crude oil prices continue to climb at a faster rate than wood costs and conversion costs, the economic feasibility of chemicals for polymers from wood would become certain.

There is an abundance of lignocellulose potentially available in the U.S. beyond that needed for structural, packaging, and communications applications. This material could provide the basis for a substantial chemicals industry well into the future.

For conservation of energy and materials, the logical sequence of approaches to obtaining chemicals and polymers from lignocellulose is as follows:

1. Recovery of lignocellulosic chemicals from waste streams of existing manufacturing operations now

using these materials as a source of heat for chemical recovery, and from urban and agricultural solid waste.

2. Conversion of cellulose, lignin, and hemicelluloses and their derivatives into useful products taking advantage of their existing polymeric structure.

3. Conversion of cellulose, lignin, and hemicelluloses into chemical intermediates that can be reassembled into useful polymers.

In practice the energy requirements to achieve these objectives may not prove to be increasing in the order listed. A strong research program should be directed at all the approaches, and engineering and economic analyses carried on concurrently with the conceptual development of processes and modified products.

Therefore, CORRIM recommends that:

- Technology should be more highly developed in
    1. Collection, transportation and sorting of lignocellulosic raw materials,
    2. Production, derivation and regeneration of chemical cellulose and development of new structure-property-performance products,
    3. Applications for lignin as a material based on its chemical and physical properties,
    4. Development of technology of composites and blends of lignocelluloses with other materials,
    5. Conversion of cellulose to sugars,
    6. Conversion of oils from wood liquefaction into useful monomers,
    7. Conversion of lignin to phenols, and
    8. Economic and engineering analyses of wood conversion processes compared to coal.

Fuel and Energy
(See Chapter 9)

Of the approximately 68 quads [1 quad (q) = 10^{15} Btu] of energy used in the U.S. in 1970, about 52 q were derived from oil and natural gas, 14 q from coal, 1 q from hydroelectric power, 0.7 q (1974) from nuclear energies, 0.8 q from waste liquor and bark burning in the paper industry, and 0.2 q from fuelwood. Forecasts point to accommodation of future energy needs primarily by expansion of coal and nuclear energy production. Another option which has received only limited examination at this time is the use of energy from lignocellulosic materials. Sweden now gets 8 percent of her energy from wood and Finland 15 percent.

What is not generally known is that, considering wood used for energy directly by wood-based industries, even now in the U.S. wood and wood-based materials are used by industry to generate more power than is produced by nuclear electric power stations. Lignocellulosic materials may be used in a variety of ways as a source of energy as follows:

1. Direct combustion of wood and agricultural residues
2. Gasification to produce low Btu gas and/or methanol
3. Pyrolysis to form low Btu gas and charcoal
4. Liquefaction to produce oil and hydrocarbon fuels
5. Anaerobic fermentation to produce methane
6. Enzymatic or acid hydrolysis to sugars for fermentation to ethanol.

Use of wood and some agricultural residues for energy production will generally be less damaging to the environment than the use of coal. For example, lignocellulosics contain little or no sulfur and mining operations are not involved.

For energy production by direct combustion the best opportunities would appear to be in the wood-based industries. Gasification of lignocellulosics for the production of low Btu gas or conversion to methanol would appear to have some technical advantages over gasification of coal. By pyrolysis, charcoal can be produced in addition to synthesis gas. The production of oil and hydrocarbon fuels from lignocellulosics also has been demonstrated. Anaerobic fermentation of biological organic compounds to produce methane and the hydrolysis of these materials to produce sugars for fermentation to alcohol both involve problems of chemical accessibility in the substrate and rather long reaction times.

It has been calculated that if all collectible waste biomass in the U.S. was converted to energy production, this would satisfy 12 percent of the national energy consumption. Agricultural residues and urban wastes constitute a greater potential source of energy than forest residues. This does not consider very large volumes of currently underused hardwoods in the national inventory, nor does it consider the potential for substantially increasing forest production for fuel use.

Therefore, CORRIM recommends that

- Research be undertaken upon the further development of the technology of the use of lignocellulosic residues for energy generation by forest products and agricultural manufacturing industries to make them more energy self-sufficient.
- Indirect energy generation involving gasification, and liquefaction (synthesis gas, methanol, liquid hydrocarbons) be explored for special situations, although direct combustion would appear to be the preferred mode of energy generation for in-plant use. Of these alternatives, the production of low Btu gas would appear to have wider general application. The demonstration tree farms previously proposed for development by the Forest Service should include areas where fuel production is a major potential use.

Extractives
(See Chapter 10)

Extractives comprise a group of substances of small volume, diverse nature, and versatile character. Their use as by-products from the production and processing of materials of forest, agricultural, and marine origin promises to contribute to the economic feasibility of technologies based on renewable resources. Their nature as chemical raw materials for the manufacture of industrial goods may be crucial to the competitiveness of an industry relying on continuous supplies of plant and animal matters. Naval stores by-products from the kraft pulping of pines and tallow and grease from the rendering of beef appear to hold the greatest potential for partially replacing many of the petroleum-based raw materials in industrial manufacturing processes.

Therefore, CORRIM recommends that

- Research to increase production of unsaturated fatty acids from renewable sources be pursued by a combination of improvements in tall oil recovery, chemical conversion of tallow fatty acids and development of new oilseed crops on low quality lands.
- Research be undertaken on the possibilities to increase the availability and use of oleoresins by the development of herbicide systems (e.g., "paraquat" treatment), and by intensive research on improved products from resin acids and monoterpenes.

CHAPTER 1

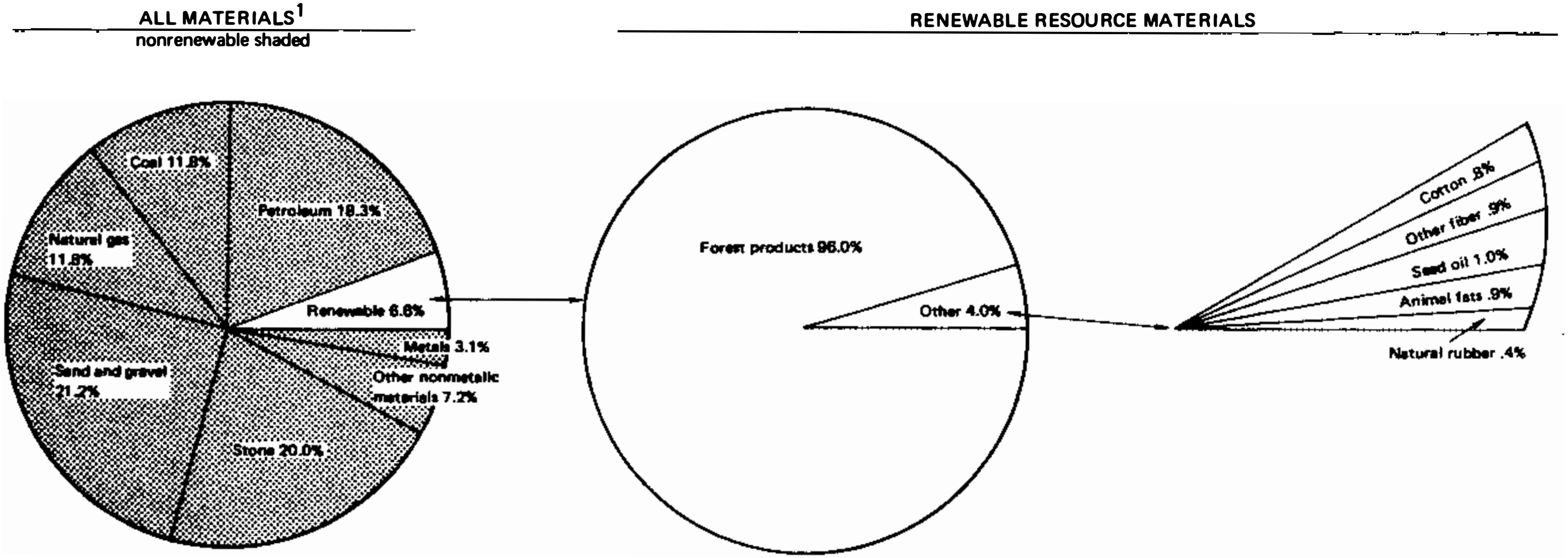
INTRODUCTION

Renewable resources have been used as sources of industrial materials since the dawn of history. Wood and agricultural residues have long been used as fuels. Plant and animal fibers were the original textile raw materials and, despite the rapid growth of the synthetic fiber industry, are still very widely used. Furthermore, almost any petrochemical can be duplicated by a wood chemical.

The distinguishing characteristic of the renewable natural resources is that they grow, that our consumption is not limited to the supply present at any given moment because that supply is constantly being augmented by natural growth, and that the extent of this growth is, to a substantial degree, in man's hands. The concept of harvesting solar energy, though much discussed recently, is not really new. The farmer, the livestock producer, and the forest manager have long been "harvesting" solar energy in the form of renewable resources. Unaided, Nature produces substantial volumes of plant growth by converting a small percentage of the solar energy into cellulose and other materials; and man can affect greatly, within rather wide limits, the volume, the kind, and the use of these plant materials.

Figure 1 places renewable resources for industrial materials in the wider context of all industrial materials, renewable and nonrenewable. The left diagram, derived from data contained in the report of the National Commission on Materials Policy (NCMP 1973), illustrates the percentage breakdown of the 4.4 billion tons of new basic industrial materials consumed in 1972, which is equivalent to 42,500 lb per person.

Renewable resources account for 6.6 percent of all these materials and account for more than twice the use of metals. Some 41.2 percent of all materials consumed, however, consist of petroleum products, coal, and natural gas--nonrenewable resources that derive from incompletely decomposed plant and animal matter accumulated over millenia and stored in subterranean deposits where they were gradually modified. In the right diagram, forest products by weight are shown to account for approximately 96 percent



[1] Source: Report of the National Commission on Materials Policy, June 1973.

Figure 1 USAGE OF BASIC RAW MATERIALS IN THE UNITED STATES (% of Weight Used) by weight of the renewable resources consumed, the remaining 4 percent being divided among natural rubber, animal fats, seed oils, cotton, and other fibers.

Although a similar set of diagrams portraying the value of materials consumed would emphasize the importance of these materials, it is extremely difficult to produce an unbiased valuation chart. The main reason for this is the difficulty of defining comparable stages of production for all of these materials and obtaining appropriate statistics to apply to them. Without well-defined comparability, certain materials may appear in such a chart valued at or near the final product stage where accumulated value added is high whereas other materials may be valued at an early production stage where accumulated value added is low. Discrepancies in data, definitions of comparability, and valuation procedures for these widely different materials presently lead to a very distorted and largely meaningless portrayal when valuation charts are used.

Of first importance in the study of renewable resources for industrial materials was an assessment of the present and potential future supply of the resources that were prospective candidates for substitution of nonrenewable resources. The renewable resources of concern are the immediate products of plant and animal growth. A large quantity of the plants and animals deliberately produced by man are utilized for food. These materials were not the direct concern of the present study except in the case of materials that were interchangeable between food and industrial material, as for example soybeans. Indirectly, food production was of interest to the study since the residues of many food production activities are prospective industrial materials, and vice versa in the case of cotton production where cottonseed oil and protein are by-products.

From the standpoint of quantity, the principal renewable resource used in manufacturing is wood. It is estimated that more than 95 percent of the weight of renewable resources currently used for industrial materials is wood. The remainder is made up of a great many plant and animal materials, many the by-products of food production. Accordingly, an assessment of the potential production of wood for the next several decades was crucial to the study. It became important to deal separately with those renewable resources that are produced primarily for materials and those that are essentially by-products of the production of food. The opportunities for manipulating the level of supply are different in the two cases.

Wood as an industrial material source is a complex material. The product of biosynthesis, it is an elaborate structural matrix comprised of natural polymers. The principal structural component is carbohydrate in the form of celluloses and limicelluloses, polymers built up from the simple sugars.

The other major structural component is lignin, a three-dimensional polymer formed from phenylpropane units, which have grown into a complicated, randomly structured, large molecule containing many different kinds of linkages. The carbohydrates and lignins make up the major part of wood substance. The proportions in these two categories vary from species to species. In general softwoods have a higher carbohydrate fraction than hardwood. In addition to the structural polymers, many woods contain additional organic substances. These chemicals do not make up the basic structural matrix of the wood substance and can be removed by extraction with a variety of solvents including water, alcohol, benzene, ether and the like. They are collectively referred to as wood extractives.

The extractives common to wood include such substances as dyestuffs, tannins, oleoresins, oils, and fats. These occur in woods in varying quantities and mixtures. The presence or absence of a particular extractive is a species characteristic.

The natural polymers are organized into a tissue matrix as walls of cells of various sizes and shapes and cementing layers that hold the cells together. Some cells are fiber-like in shape, some are brick-shaped and others resemble short cylinders or barrels. Some cells are thick-walled and some are thin-walled. The combinations of cells of varying sizes and shapes is characteristic of a species.

The structure of wood is more or less important depending upon it use. If wood is used for fuel, the chemical composition of the wood determines its calorific value on a unit of weight basis. The organization of the molecules into cell walls and cementing layers, as well as the size and shape of cells and their arrangement in the tissue matrix is not important in this use.

If wood is used as a structural material the shape of cells and their arrangement in the tissue matrix and the ratio of cell wall substance to open space is of great importance since these factors determine the mechanical properties of the wood, i.e. its behavior under stress. If wood is used as a fiber source, then the size and shape of the fiber-like cells and their proportion to the whole structure are of great significance. These characteristics govern product yield and performance. If wood is used as a chemical, then chemical composition is important, but tissue architecture is not.

The chemicals that comprise the wood are assembled using solar energy in the photosynthetic process. This natural material requires a great deal of energy for its biosynthesis. When it can be used as a material in very much the same form as it occurs in a tree wood can be put to use with a modest application of processing energy. This is the case, for example, when it is used as a pole or a piling. A little more energy is used to shape the round stem into boards or timbers. If, however, it is necessary to disassemble the wood into its components and to re-assemble the components into a tailored material, the amount of energy required for processing increases substantially. Considerable energy is required to break the chemical bonds that link polymers together and that combine monomers into polymers. Additional energy is necessary if these building blocks have to be re-assembled. The same operations that consume energy also require the input of manpower and capital. The conservation of energy, manpower, and capital resources inherent in the use of wood in essentially its natural form can disappear with the need for extensive tailoring.

This study differs from other natural resource studies in that it attempts to examine biological productivity as a materials supply function. The usual renewable resource study examines the resource and its productivity and then says, "How can I use it?" In this study, we have attempted to examine materials needs and then ask how we can produce renewable resources to meet those needs. In this sense, this study is more akin to analyses engaged in by materials scientists whose scientific perspective has developed largely from the conversion of minerals to materials.

There is a fundamental difference, however, between the problem of meeting materials needs from minerals and meeting them from biological products. The materials scientist whose study is minerals and their derivatives typically views his raw material as a relatively simple conglomerate or mixture that has to be purified or simplified through disassembly into metallurgical feed stocks that can then be assembled into tailored materials. The scientist who studies plant and animal substances as materials usually starts with a raw material that is an elaborate structural matrix often comprised of complex natural polymers. Sometimes this plant or animal material is treated just as though it were a mineral and disassembled into a tailored material. But more commonly the task of the scientist or engineer working with biological materials is to convert the plant or animal substance into a useful material with as little disassembly as possible. The original structure was created through the growth process utilizing solar energy. The nearer the biological materials scientist can come to utilizing the original plant or animal anatomy in his finished material, the more he can maximize the utility of the original solar energy input and minimize the amount of processing energy that he will have to provide. Because biological materials are complex, the energy required to disassemble and re-assemble them can be great on a ton of product basis. The energy conservation value inherent in renewable-resources-based materials and derived from the use of solar energy in original biological synthesis can be quickly lost if too much work must be done to modify the properties of the material to meet the desires of users.

The major focus of this report is the forests of the U.S., and the wood grown in such forests. Approximately 60 domestic and 30 foreign tree species are judged to have significant commercial importance. The types of woods, chemicals, and other properties of these many species are very great.

The ancient use of wood for fuel has largely ended in the U.S., but the major uses of wood for lumber, plywood, paper, and other wood fiber products continue and are likely to increase in importance. In the future there may well be added a greatly increased use of wood as a source of useful chemicals of many kinds.

If the wood from the forest is to meet human needs, it must be harvested, processed, and transported. These are man-processes, where methods of processing, costs, and returns are dominant. The economics of renewable natural resource use is critical: Does a proposed use pay, not only in the usual dollar terms, but also in terms of use of scarce raw materials, especially energy, and in terms of environmental impact? We could indeed again use wood extensively for fuel, as we once did, but will it be economic on any considerable scale? Wood for construction, packaging, and for communication (paper) has strong economic position. While many chemicals can be manufactured from wood, the economics of doing so are less clear. In particular, what are the alternative sources of the same end products, or of substitutes for them, and how do the costs and advantages of wood-derived and other products compare? Furthermore, is it worth diverting wood from lumber and other products into alternative uses?

In making this study, the many goods and services other than wood from the forests in the U.S. were also considered. Forests are used as a place for recreation, as a home for wildlife, as wilderness areas, as a source of water, and for other purposes. The range of such uses is considerable. They occur not only on publicly-owned forests, but on privately owned forests as well. All forests, regardless of ownership, serve as watersheds and as homes for wildlife, although forest management may affect the output of either water or wildlife.

A million or more individuals own forest land, often in rather small properties, primarily for their personal enjoyment. There exist complex interrelations among the various forest uses, some being reasonably compatible, or capable of being made so, with other uses, while other pairs of uses are wholly incompatible. By careful management, the compatibilities can be increased and the incompatibilities reduced or separated onto different forested areas, and by intensive management the total output of all forest goods and services can be increased greatly.

Social, institutional, and political forces influence forest use and output. The biological potentials of the forest set limits to the output of each of the various products and services of the forest, but the social and related factors may reduce substantially the actual output. The test of economic feasibility or profitability may be decisive in some situations but not in all; other limitations may arise.

This report analyzes the production, processing, commodity flows, and uses of the various renewable natural resources. As stated earlier, particular attention is given to wood since in volume and value terms this is the largest single renewable natural resource, but attention is also given to such plant fibers as cotton and to the by-products of food production processes. Emphasis is placed on the biological, technological, and scientific aspects of the production, processing, and use aspects of renewable natural resources. All of this is done within the framework of the society and economy as these are likely to exist in the U.S. during the next few decades; alternative assumptions on both social and economic relationships are presented. Accurate, detailed calculations of the economic feasibility of many of the biological potentials of the renewable natural resources are impossible; there are simply too many unknowns at this date. Wherever possible, judgments about economic feasibility have been expressed. Until new processes or new uses of some materials are tried on a commercial scale, an accurate assessment of economic feasibility is impossible.

The basic resource underlying the production of renewables is land. Ideally, projections of renewable materials supply would be based on a detailed and accurate census of the area of land available for materials production, the current inventory of materials, and the productive capacity of the land. Unfortunately, the information required for these assessments is far from precise--both with respect to current inventory and productive capability of the land. This is particularly true of forest products.

The U.S. has been a net importer of wood for the past six decades. If this means that the nation is facing a wood shortage, then clearly a major study of the opportunities for substitution of renewable resources as industrial materials would be a trivial exercise. However, even the inadequate inventory data presently available clearly indicates that the nation is currently producing more wood than it uses and is capable of producing much. Given this, the effort to evaluate substitution prospects is worthwhile.

Another set of parameters of the study that were examined were the legitimate criteria for substitution feasibility. The numbers of industrial materials that can be produced from renewable resources are legion. Many industrial materials are now regularly produced from renewable resources in very large quantities. Many other industrial materials have been produced from renewable resources in the past but have been replaced in the market by competitive materials derived from nonrenewables. Clearly these could be produced from renewables again in a favorable market environment.

CHAPTER 2

HISTORICAL PERSPECTIVE

The development of the U.S. from a collection of poor colonies to an affluent nation has been based very largely upon ability to effectively use a rich endowment of natural resources. These resources included vast areas of highly productive land and tremendous reservoirs of minerals, fossil fuels, and plant and animal biomass from natural forests and grasslands. The fossil fuels, coal, petroleum and natural gas were themselves forms of stored plant biomass or derivatives. The plant and animal materials were the most easily accessible and therefore in the beginning the most widely used materials.

In using these natural plant and animal materials, the colonist was exploiting some very intricate and complex structures assembled by natural growth processes. These materials were derived originally from photosynthesis--a production system driven by solar energy. As long as the settler was willing to use the plant or animal material in essentially the form in which it occurred in the producing organism, he was able to take full advantage of the material synthesizing biological process. If he insisted upon changing the natural plant or animal material to better meet his needs, he had to modify it and this required the input of additional energy.

Since plants and animals are highly variable in nature, one alternative to modification that was available to the settler was to search for a natural material that came close to satisfying his requirements. Another option was to grow crops or animals to meet his material needs, choosing as gene sources individuals whose properties as materials matched his preferences.

The primary production unit in colonial America was the individual family. These units were widely dispersed in an abundant natural resource matrix, which included large areas of land suitable for agricultural production and natural forests carrying heavy volumes of timber and supporting large numbers of game animals. These individual family units found these plants and animals to be good sources of materials because they could be exploited with simple and inexpensive hand tools.

As the social structure became more elaborate, the plant and animal components were used for the production of industrial materials in factories as contrasted with the earlier exploitation by the family unit. The metals and fossil fuels also increased in importance as a social infrastructure was developed that permitted extraction of these deposits and their conversion to products at central manufacturing sites. Wood was originally the most important source of fuel for heating of buildings, power for industry, and for transportation via rail and boat. When the tremendous deposits of coal and later petroleum became available at low cost, these sources of fuel rapidly replaced wood and agricultural residues as sources of energy. With the increases in available supply of low cost energy, metals were substituted for plant materials in many industrial uses. Inexpensive hydroelectric power encouraged massive growth of the aluminum industry. Petrochemicals from low cost oil and natural gas became the base for a large and flourishing plastics industry.

The easily accessible coal, petroleum, and metal deposits required relatively little investment of capital, manpower, and energy per ton of material extracted. As demand grew and it became necessary to look to second- and third-order deposits, that is, those that were more remote, deeper, or less concentrated, the opportunity to draw upon other nations' first-order resources was often attractive. Raw materials were imported when they were less expensive than were comparable materials from domestic supply. This was particularly true in cases where the most easily accessible sources of domestic resources had been exhausted and where similar resources in other countries were less costly than domestic supplies at second and third levels of difficulty of resource extraction. Increases in U.S. labor costs encouraged the development of foreign sources where labor intensive extraction operations were less expensive. In some cases, materials were required that were simply not available within the borders of the U.S.

But America also shared its natural resources with the rest of the world. The abundant and easily exploited plant and animal materials were some of the best sources of the foreign exchange needed to permit purchase of European manufactured goods. The ships that brought a new group of immigrants to America commonly returned to Europe with a load of cotton or a cargo of timber.

As long as natural resources were in ample supply relative to demand either from domestic or foreign sources, the drain upon these resources was not a matter of great public concern in the U.S. During the past decade, however, this public attitude toward raw material supply has changed dramatically. In some instances, the most accessible and easily exploited reservoirs of natural resources have been exhausted or are nearly exhausted. Extraction of raw materials that are at second and third levels of accessibility is much more costly in terms of capital requirements, manpower needs, and energy demands per ton of extracted product. Furthermore, extraction of these hard-to-get raw materials frequently has a greater impact upon the environment than was the case for first-order resources.

The American public today is much more sensitive to what it perceives to be an adverse environmental impact than was the case 10 or 20 years ago. A relatively new body of law and government regulations at federal, state, and local levels has made the use of these harder-to-get resources more difficult and in some cases have cast doubt upon their real availability.

Increasing areas of land are placed under land-use zoning classifications that remove them from the materials resource base. This is often done before there has been any serious exploration to determine whether they contain reservoirs of metals or fossil fuels. Increasing scarcity of new energy supplies with its accompanying increased cost, partly related to the problems of crude oil supply, has cast its shadow over the supply of many industrial materials whose energy requirements for extraction and conversion are high.

Sharply rising prices for energy in its various forms, sometime scarcities of some kinds of energy, evident environmental problems, loss of some environmental amenities, and related events have aroused an immense popular concern in the U.S. within the past decade. Increasingly, the questions are being asked: Has the country enough natural resources for its own health and well-being, or can it buy the needed resource materials elsewhere? Will we as a people strangle in our own solid waste and effluents? What does the future hold, and are we doomed to severely curtailed living conditions?

Questions of this sort are not new in kind--they have been asked by thoughtful people for 200 years or more; but the recent questioning is both sharper and fresher. In the past generation there have been a considerable number of special boards or commissions that have studied the natural resource situation in the U.S. Similarly, there have been studies of materials supplies and energy supplies. But the scale of truly public involvement and concern is much greater in recent years than it has ever been. Inability to buy gasoline at the service station pump has impressed many a person in a way that no amount of reasoned evidence and no amount of clear writing would ever have done.

In this wave of popular concern, much of the attention has been directed toward the fossil fuels and minerals--the so-called nonrenewable resources. But there is increasing interest in the materials that are derived from plant and animal components--the renewable resources. As supply problems related to some of the nonrenewable resources appear to be more and more intractable, the possibility of substituting renewable for nonrenewable resources in an effort to meet material needs seems to many to be worthy of exploration.

Substitution between renewable and nonrenewable resources in materials production is not a new phenomenon. It goes on all of the time and has been going on for centuries in response to changes in the market place. As the supply of some natural resources becomes more limited, intervention by governments can induce large and sudden changes in the price and availability of critical raw materials. The embargo and price increases on crude petroleum imposed by the major oil-producing countries of the Middle East during 1974 brought this problem very forcibly to the attention of the American people. This sort of action is not likely to be confined to petroleum in the long run and it may not be confined to nonrenewable resources. The Regional Tropical Forest Management Advisor for Asia and the Far East of the United Nations Food and Agriculture Organization recently stated (Fraser 1975):

> Just as the Organization of Petroleum Exporting Countries has managed to raise the price of oil by joint efforts thereby encouraging people to reduce waste and at the same time conserving the remaining resources, so similar action is needed with wood if the forests are to be conserved and governments create a situation where they can really influence what is going on in the forest. A start has been made in this direction with the formation of SEALPA (South East Asian Lumber Producers Association), and it is hoped that they will be successful in improving the situation.

Normal market-directed response to such changes may be so slow as to cause socially unacceptable consequences. Just as actions by governments can induce these perturbations, actions by other governments can accelerate corrective responses provided that the need has been anticipated and the proper foundation in science and technology has been laid. The U.S. is not in the most favorable position to respond to such a challenge in the domain of renewable resources as industrial materials. Most of the research in biological materials science is pursued by private industry or the federal government and is directed at the solution of immediate pressing problems.

As of 1963 there were 24 universities in the U.S. offering professional programs in wood materials sciences, although few of these consistently produced as many as 10 graduates per year (Ellis 1964). Over the years, these programs had produced 3121 graduates at the bachelor, master, and doctorate levels. Since that time 4 of the largest and best established programs--University of Michigan, Michigan State University, Duke, and Yale--have dropped all or a major portion of their programs in this field. Over the years through 1963 these 4 programs had accounted for about 23 percent of the graduates in wood materials sciences (Ellis 1964). A very small number of universities are engaged in materials research related to renewable resources and this number has diminished in the past 20 years. Graduate student enrollment in this field is very small. There is no counterpart in the renewable materials field of the university materials research centers on the nonrenewables side established first by the Advanced Research Projects Agency of the Department of Defense (ARPA) and expanded under the aegis of the Materials Research Division of the National Science Foundation (NSF). Accordingly, the pool of research talent available to advance knowledge in this field is small and its potential for growth is poor.

It is believed that it is important to assess the potential of substituting renewable resources for nonrenewable resources in situations where (1) readily available reservoirs of nonrenewable resources are in short supply worldwide, (2) supplies of nonrenewable resources are very largely under foreign control, and/or (3) there are substantial energy conservation opportunities inherent in the substitution. If this nation is to be buffered against the kind of economic and social disruption that accompanied the drastic change in petroleum supply, it cannot afford to wait until a materials substitution is needed before it develops the required technology. The technological base in this area has been allowed to deteriorate and must be given new vigor in order to stimulate a healthy climate of strong competition among alternative materials.

CHAPTER 3

NATURE OF RENEWABLE MATERIALS AND COMPARISON WITH NONRENEWABLE SYSTEMS

STRUCTURE AND PROPERTIES OF RENEWABLE MATERIALS

Chemical Composition

The components of plants and animals that are used for industrial materials vary over a broad spectrum of structure and properties. Some substances, such as animal manures, are for the most part unstructured. Wood, on the other hand, has a very complex and variable anatomy, which influences its use as a material.

The major portion of the biomass of the living organisms in the ecosystems of the world is water. Following water, the other principal components of plant and animal tissues are carbohydrates (usually in the form of cellulose, other polysaccharides and sugars), lignins, proteins, and fats. Plants are the principal sources of carbohydrates and lignins, while animals are the principal sources of proteins and fats.

Protein is a composite polymer consisting basically of 21 amino acids. Among industrial materials composed mainly of protein are wool, other animal hairs, silk, feathers, hides, and leather.

Cellulose and hemicelluloses are carbohydrate polymers built up from simple sugars. Cellulose is a long chain polymer of glucose (dextrose) anhydride units differing from starch only in the way the glucose anhydride units are arranged. Hemicelluloses are shorter and often branched polymers of 5 carbon sugar anhydrides (pentoses), such as xylose, or 6 carbon sugar anhydrides (hexoses) other than glucose. Lignin is a three-dimensional polymer formed from phenylpropane units that have grown into a complicated, randomly structured, large molecule containing many different kinds of linkages.

Cotton, a plant seed hair, is almost pure cellulose. Plant tissues containing lignin are termed <u>lignified tissues</u> or <u>lignocellulose</u>. The latter are widespread, typical examples being wood, cereal straws, bagasse, bamboo and the stems and other tissues of many plants. Lignocellulosic materials contain approximately 50 percent cellulose and 20 to 30 percent each of hemicellulose and lignin.

Lignin, cellulose, and other sugar polymers are the end products of photosynthesis and contribute a readily available and renewable source of carbon. Carbon is the basis of the majority of all organic industrial materials.

In addition to these major chemical components, the plants and animals contain as integral parts of their structure many hundreds of other chemicals. Some are present in many plant and animal specimens, while others occur rarely and only in certain species. Many chemical substances, such as dyestuffs and tannins, were first used directly as extracts from plant and animal substances. Later, they were synthesized from coal tars and petroleum using the natural materials as chemical models.

Extractives

Extractives occur in plant and animal materials to the extent of a few to some 50 percent by weight. For the greatest part they are of an oleoresinous or fatty nature, with the oleoresins being confined to a few woody species, mainly pine. Oils and fats are found in such plant crops as soy, cotton, and flax, as well as in trees, animals, and fish. Oleoresins (turpentine and rosin) are hydrocarbons with mono- and di-terpenoid structures; fats and oils are glycerides, of mostly saturated and unsaturated fatty acids, respectively. Tallow, lard, and sperm oil are the major representatives of animal fats and oils. These substances can be extracted from the plant and animal tissues using inert solvents including water, alcohol, ether, naphtha, and benzene. The extractives vary greatly from species to species in character and quantity.

Lignocellulosic Materials

Wood, the most plentiful of all of the renewable resources used for industrial materials, is the major component of the stems of the perennial higher plants. It is a plant tissue, xylem, made up of a vast number of cells produced in the plant growth process by the cambium, a lateral meristem located between the bark and the wood. Only a small fraction of the wood in a tree of any size is actually living tissue--a few rows of cells under the cambial layer. The major part of the woody stem consists of the cell wall skeleton of cells whose living functions have ceased. In most tree species the majority of the cells that comprise the xylem are long tubular structures with tapered ends; tracheids in the softwoods (gymnosperms) and fibers in the hardwoods (angiosperms). These elongated cells are oriented so that their long axes parallel the long axis of the tree stem. The cell walls of the xylem cells are comprised of fibrils, strand-like conglomerates of cellulose molecules sometimes regularly arranged to form a crystalline structure and sometimes disarranged in a semicrystalline or an amorphous form. Other polysaccharides (hemicellulose) may also be present, usually in the more amorphous areas. These cells are bonded together by a natural adhesive, lignin.

Wood and other plant tissues containing lignin, cellulose, and hemicellulose are classified as lignocellulosic materials. These three major components may be present in varying proportions, depending upon the specific plant in which they occur. In crop residues and in wood, they occur in the approximate proportion of 50 percent cellulose, 25 percent lignin, and 25 percent hemicellulose. However, softwoods (gymnosperms) normally contain more lignin (up to 30%) and less hemicellulose (approximately 20%) than the hardwoods (angiosperms) and crop residues, which contain closer to 20 percent lignin and a correspondingly higher percentage of hemicellulose. Also, the chemical character of the lignin polymer differs among the softwoods, the hardwoods, and crop residues.

The properties of wood are a function of its chemical composition and the physical arrangement of its component parts. Because of the orientation of the cells, and of the fibrils and macromolecules that comprise the cell wall, wood is anisotropic in its properties. It responds to stress differently when the stress is imposed parallel to the long axis of the cells than when it is imposed at an angle to that axis. Wood shrinks when it dries below the fiber saturation point, and, for a given change in moisture content, it shrinks differently along different axes. [Fiber saturation point is defined as the moisture content that prevails when the cell cavities contain no free water and the cell walls are saturated with bound water.]

Fiber Materials

In addition to wood, many plant and animal tissues contain fibers that are useful as materials. Fibers have played a prominent role in the welfare of man from the earliest civilizations to the present. They are found widely in the animal and plant kingdoms. A classification outline of the more prominent industrial fibers, together with their dimensions, is given in Table 1.

Animal and plant fibers are both built up from polymeric molecules; however, animal fibers are of protein origin and plant fibers consist mainly of cellulose. Cotton fiber is nearly pure cellulose, whereas wood fibers also contain varying amounts of other polysaccharides (collectively termed hemicellulose) and lignin depending upon the fiber separation (pulping) process. A mechanically separated fiber retains most of the chemical composition of the wood, whereas a bleached chemical pulp is largely cellulose.

Plant fibers are all single cells of a long hollow tubular shape. A cotton fiber, for example, is from 1000 to 3000 times as long as its diameter; likewise, wood fibers are up to 1000 times longer than their width.

The walls of plant fibers are made up of layers, usually three. The middle layer, whose thickness varies, is the controlling factor in the thickness of the cell wall since the other layers are very thin. The structure of the layers is fibrillar, with the fibrils of the outer and inner layers oriented at a considerable angle to the longitudinal axis, and those of the middle layer aligned at only a small angle from the fiber axis.

The cotton fiber has collapsed walls and appears as a flattened, twisted tube with spiral convolutions. Although wood and straw fibers often retain their rounded tubular form, depending upon cell wall thickness; after drying on a paper sheet, many of these walls are collapsed also and present a flattened appearance.

About 94 to 95 percent of the world's paper products are made from wood fiber; the remainder is made mostly from cotton linters, cereal straws, and bagasse. Ninety percent or more of the volume of softwoods (gymnosperms) is composed of fibers termed tracheids. These are longer than the fibers of hardwoods (angiosperms). Hardwoods have a smaller fiber content and these are shorter than the softwood fibers. Also, hardwoods have a considerable amount of vessel segments, which are thin-walled wide cells.

Wool, mohair, silk, and cotton fibers have length and other characteristics that lend themselves readily to spinning and weaving into cloth and other textile products. The thermal property of wool and the moisture-absorbing property of cotton, as well as their appearance and wearability, make them ideal for apparel. Wood fibers, as well as straw and bagasse fibers, are much shorter than

Table 1

Classification and Sizes of Fibers

Class	Species or origin	Fiber diameter (μ)	Fiber length Average (mm)
I. Plant fibers			
A. Fruit fibers			
1. Seed hair	Cotton	16-21	12-33
2. Pod	Kapok	20-45	10-30
3. Husk	Coir	12-24	0.4-1.0
B. Stem and Leaf Fibers	Abaca	16-32	4.0
	Sisal & Henequen	20-32	1.5-4.0
C. Grass fibers	Wheat & other cereal straws	7-24	1.50
	Bagasse	10-34	1.70
	Bamboo	7-27	2.40
D. Bast fibers			
1. Herbaceous	Flax	12-26	25
	Jute	20-25	2.0
2. Woody plants	Inner bark fibers		
E. Wood fibers			
1. Gymnosperms	Southern pine	35-45	4.33
	Douglas-fir	35-45	3.40
	Western hemlock	30-40	2.96
	Balsam fir	30-40	3.40
	White spruce	25-30	3.31
2. Angiosperms	Red alder		1.19
	Red gum	34	1.82
	White birch		1.38
	Beech		1.28
	Aspen		1.32
II. Animal fibers			
A.	Wool*	10-100	25-460
	Mohair		
	Furs		
	Silk		
III. Mineral fibers			
	Asbestos		
	Glass		
IV. Man-made fibers			
A. Cellulosics	Rayon		
	Asbestos		
B. Synthetics	Polyamid		
	Polacrylics		
	Polyesters		
	Polyolefins		

*Fine merino wool is 10-30μ, carpet and mixed wool 20-100μ in diameter.

cotton and are less flexible. Hence, they do not have the properties for spinning and weaving. They are excellent, however, for papermaking by forming a wet web of interlaced fibers from a water suspension. Upon drying, the individual fibers become bonded to each other by hydrogen bridges between the hydroxyl groups of adjacent fibers.

Although wood fibers, as stated above, do not have the form and properties for spinning and weaving, they can be dissolved and recast into filaments and staple fibers that are excellent for spinning, knitting, and weaving. Rayon and acetate are produced from wood through a purification, dissolution, and regeneration process.

Animal skins and hides are composed mainly of a fibrous protein (collagen) layer termed the corium, overlaid by a thin epidermal layer. The corium consists of fiber bundles interwoven as a three-dimensional fabric, which gives the skin its strength and elasticity. When the skin is combined with a tanning agent, the fibrous protein is rendered immune to bacterial and enzyme attack, while retaining its desirable physical properties and fibrous structure. The tanned hide is termed leather.

ORIGIN OF RENEWABLE MATERIALS AND FOSSIL FUELS

The complex polymeric structures that comprise plant and animal substances are synthesized through the use of solar energy, direct products of photosynthesis. As animal materials derive from the metabolism of the plants by the animals, the energy source is ultimately the same. Man has benefited for centuries from the fact that these complex polymeric structures were available to him as materials. They provided the models for many similar structures that he later learned to synthesize from chemical feedstocks derived from coal, oil, and natural gas.

Fossil fuels are themselves the derivatives of plant and animal substances accumulated many millenia ago and stored in subterranean deposits where they gradually decomposed and were modified under the conditions of storage under pressure and the absence of air. It is not surprising that almost any material that can be synthesized from coal, oil, and natural gas can also be synthesized from current biological materials. To do so often requires the duplication or simulation using fresh materials of the decomposition and modification processes that occurred over thousands of years of subterranean storage. Although feasible technologically, this procedure is uneconomical if the fossil materials already so modified by nature are readily available.

The biological materials scientist has a potential advantage over the geological materials scientist in that he starts with a material produced under a natural process. Much of the work required to produce the basic material has been done in the growth process, provided that the user is willing to accept the material in essentially the form in which it occurs in nature. In contrast, most geological substances must be substantially modified before they are useful materials. The work required to convert the geological substances to useful materials is a part of the conversion technology and requires substantial input of manpower and process energy. Since materials of geological origin have to be synthesized in any case, there is every reason to attempt to tailor them precisely to meet user needs. Materials of biological origin can also be tailored to user needs, but this usually requires that they first be disassembled from their original plant or animal substance form and then re-assembled into the designed material. Just as the assembly of materials from geological sources requires substantial work fueled by process energy, so the disassembly and re-assembly of materials from biological sources also requires much work and the input of substantial processing energy.

RENEWABILITY

A material may be defined as "renewable" if the supply can be restored or replenished when the initial stock has been exhausted. In this sense, geological materials deriving as they do from a relatively static condition are commonly thought of as nonrenewable. Biological materials derived from dynamic growth processes are thought of as renewable. While this is a useful pragmatic distinction and one which has formed the basis for this study, it is probably too simplistic to have theoretical generality.

It can be argued that the substances that make up the earth rarely escape the planet. Even though they have been used in material products and are discarded, they remain in some form to be synthesized into some material to be used again. They may be captured as waste and recycled into another version of the same material, perhaps again and again. The gaseous effluents from burning coal, oil, or natural gas may become part of the photosynthetic process that produces biological materials.

Some materials of biological origin are renewable in their present form only in theory. The large redwood and Douglas fir logs that are the source of much of our clear lumber can be replenished as materials only if forests are managed on rotations that are several hundred years long.

The same is true of some of the fine hardwoods used for fancy veneers. Some of this long-term management is indeed pursued as for example the case of the Spessart oaks in Germany. But it is unlikely that much forest land can be devoted to this long-term activity, at least where materials supply is the primary, or even an acceptable, objective.

Renewability of natural resources for materials must then be thought of in terms of some time frame. It is not an absolute thing but rather a ratio of the rate of resource replenishment to the rate of resource depletion. A wood material may have a low renewability ratio no matter how feasible is its growth from a biological standpoint, if its rate of stock depletion is high relative to its rate of stock renewal. A metal on the other hand could have a high renewability ratio if, through recycling and modest exploitation, the rate of renewal of supply is high relative to its rate of depletion.

In terms of achieving a high renewability ratio the materials of biological origin have the advantage of growth as a biological phenomenon. They have the disadvantage that their production is confined to the land surface of the earth (except for materials derived from fish, whales, seaweed, and other marine and freshwater life). Furthermore, much of this land surface is not available for materials production because it is allocated to other uses.

The materials of geological origin have the theoretical advantage of being available from the whole mass of the earth, though the size of the present resources is severely limited by the status of current subterranean exploration and extraction technology and the rapid rise in energy requirement to extract per unit of distance from the earth's surface.

While renewability of a resource ought to be thought of as a ratio of replenishment rate to depletion rate, it is nonetheless true that today the renewability ratio for most materials of biological origin is much higher than the renewability ratio for most materials of geological origin. Accordingly, this report will continue to use renewable resource as a synonym for resource of biological origin and nonrenewable resource as a synonym for resource of geological origin.

RECYCLING AND BIODEGRADATION

Primary Recycling

Renewable resources can contribute to improvement in the renewability ratio through recycling. Because renewable resources are biodegradable, they have two feedback cycles. The primary feedback cycle involves return of the plant and animal materials to the ecosystem to be incorporated into future materials production. This feedback can occur at almost any point in the materials production cycle. The residues from the original harvesting operation are easily recycled to the ecosystem, and this is almost invariably done. Cotton plant residues and logging slash, for example, almost invariably remain on the land and are quickly incorporated into the soil to contribute to the production of the next crop. This recycling activity requires very little effort on the part of the producer. Once the material is removed from the site and transported to and concentrated at a processing point, the recycling effort must be a much more deliberate effort. It rarely pays to return waste materials to the land in terms of the value contributed to the production of the next crop.

Materials that are discarded after use are likely to be even farther from the resource-producing land base than the residues of manufacture. Increasing restrictions on the disposal of manufacturing plant residues and urban solid waste mean that municipalities must pay for the disposal of solid waste. If the cost of removal of the waste material is charged to that activity, then primary recycling that is technologically feasible often becomes economically feasible.

Material Recycling

Secondary recycling, that is, reusing the material as a material, is logistically simpler but of limited utility with renewable resources. The most common form of secondary recycling of renewable resources is in the production of pulp and paper. It is very common practice for the trim and other waste of a pulp or paper plant to be returned to the beaters and become part of a new furnish. Waste paper collected after use can be repulped and incorporated into a new pulp furnish and, in fact, there are some manufacturing plants in the country that operate entirely with a waste paper raw material supply. Today, about 22 percent of paper fiber is recycled. The potential for recycling is quite well-known. In addition to the residues from the pulp and paper industry itself, the residues from other wood processing operations can also be converted to pulp and paper. Waste wood products from urban forestry, construction, demolition, pallets, railroad box cars, and other similar sources have all been shown to be usable raw materials sources. Some of them are already being utilized, and it is reasonable to expect this source of fiber to grow in importance where locations of fiber product manufacture are strategically located to this supply.

A study conducted by the Midwest Research Institute (1973) for the paper industry forecast that a peak of under 30 percent of waste paper will be recycled. The fact that virgin fiber is known to lose most of its strength after three cycles and the fact that repeated recycling introduces serious problems in the accumulation of such noncellulosic residues as inks, fillers, sizes, and coatings suggests that this projected limit on secondary recycling of paper is reasonable.

Organic Wastes

The greatest opportunities for recycling of renewable resources lie in the utilization of organic wastes. These are largely residues of the production and utilization of foods and of biological materials. These organic wastes tend to be heterogeneous mixtures of substances. The composition of wood waste is reasonably uniform at about 50 percent carbon, 6 percent hydrogen, 44 percent oxygen by weight on a moisture-free basis. Agricultural crop wastes are largely comprised of the structural portions of plants and do not differ greatly from wood in relative amounts of carbon, hydrogen, and oxygen on a moisture-free basis. Municipal solid wastes consist of wood-derived products together with garbage, plastics, fabrics, and inorganics (metals, glass, and soil). Although municipal solid wastes are much less homogeneous in composition than wood wastes, on a large scale in a given location and season the composition is surprisingly uniform and the elemental chemical content (CHO ratio) of the organic portion is much like that of wood wastes on a moisture-free basis.

Tremendous quantities of human and animal waste products are being generated, which have great pollution potential if improperly managed. These wastes do, however, contain useful plant nutrients and organic materials that could be assets to agricultural and energy production.

Liquid and fecal animal waste are produced primarily from cattle, swine, and poultry. The moisture content of this material varies from 30 to 85 percent, depending on animal type. Most of the dry matter in manures is organic waste material from animal digestion of feeds. This organic fraction varies with the type of animal and type of feed. Although chemical composition is highly variable, animal waste (feces and urine) contains about 3 kg nitrogen, 2 kg phosphorus, and 3 kg potassium, plus numerous trace elements per metric ton of wet weight. These components are valuable as plant nutrients and organic matter for the enrichment of soils.

Historically, most animal waste was generated at small family farms, collected, hauled to the farmland, and spread as fertilizer. Prior to 1950, farm manure thus used was a major fertilizer for crop production. More recently, economics and mechanization factors have resulted in concentrating large numbers of animals in small areas, thereby generating tremendous quantities of organic waste and disposal problems. During 1970, for example, cattle feedlots with at least a 1,000 head capacity increased 7 percent to 2,271 lots, and the largest percentage gain was on larger lots with 32,000 or greater head capacity. These 1,000 plus head lots accounted for 55 percent of the 1970 feed marketings. At the same time, lots of less than 1,000 head capacity decreased 4 percent to 180,329 lots (Peterson et al. 1971).

In addition to animal waste, solid wastes are produced from municipal waste water treatment plants. This material contains 35 to 47 percent organic matter, 2.6 to 5.6 percent nitrogen, 2.8 to 3.4 percent phosphorus, and a large assortment of other chemical elements. Historically, most of the solid waste has been disposed by landfill, ocean disposal, or incineration, but recently potentials of this material as a nutrient fertilizer or energy source have been recognized.

RESOURCE DISPERSION

One characteristic of renewable resources that influences their use as industrial materials is an extensive and very dispersed geographic base. Slightly more than half of the land area of the U.S. is in agricultural or forest use. This 1.2 billion acres produces biological substances, some of which are either actually or potentially usable as industrial materials. In the case of some forests and agricultural land dedicated to such agricultural crops as cotton, the major product of the land is industrial material. In the case of land dedicated to food production, the potential industrial material is in the form of food crop residues. Approximately 1180.5 million acres of the land in the U.S is forest and cropland, 64 percent of which is used primarily to produce industrial material. Industrial material is a by-product of food production on the remaining 36 percent. The plant components of this large production apparatus are solar energy collectors. It is this feature of the biological materials system that makes it attractive as a substitute for some portion of the geological materials system. It promises alleviation of major pollution problems.

On the other hand, this same feature of geographical dispersion is the source of many of the problems encountered in efforts to implement substitution of renewable for nonrenewable resources for industrial materials. Converting these resources into materials requires a large collection system feeding a central processing facility with raw materials. When the biological crop requires many years of growth before it can be harvested for conversion, as in the case of forest products, the area required to service the conversion facility on a continuing basis becomes very large indeed. This collection system is inevitably energy-consuming itself. The nonrenewable resources, metals and fossil fuels, are usually concentrated on relatively few acres of surface area. Often the conversion facility can be located near the concentration of raw material. In any case, a single transportation route between resource *in situ* and conversion facility is adequate. The multi-route collection system typical of renewable resource exploitation does not compare favorably.

CHAPTER 4

MATERIALS SUPPLY

PRIMARY AND SECONDARY MATERIALS RESOURCES

As previously noted, renewable resources for industrial materials fall into two categories. Primary renewable materials resources emerge from a biological production system that produces plants or animals for the deliberate purpose of supplying materials to industry. Secondary renewable materials resources are substances that develop as by-products or residues of biological production systems whose primary objective is to produce food, feed, or other nonmaterial goods or services. Problems associated with estimating inventory and productivity are quite different for the two types of resources. Cotton fiber is a classical example of a primary renewable resource. When land is dedicated by the landowner to the production of cotton, the primary objective is to produce cotton fiber. The choice of seed and cultivation procedures are made for the purpose of controlling quantity and quality of fiber. The amount of land allocated to cotton production is likely to be determined by the landowner's estimate of the amount of fiber he can market at a profit.

Cottonseed, on the other hand, is a secondary resource. The amount of cottonseed available in any one year is a function of the amount of cotton fiber produced. This is not to say that the secondary resource is not important. In the case of cotton, the ability to market the secondary resource cottonseed has probably made it possible for many American cotton producers to stay in the cotton fiber business in the face of foreign competition.

Wool can be either a primary or a secondary resource depending upon the kind of wool involved. Shorn wool is usually obtained from shearing live animals bred for high wool yields. It is a primary resource when the principal objective of the grower is to produce successive crops of wool. Pulled wool, on the other hand, is a secondary resource. It is generally a by-product of mutton varieties of sheep and is obtained from the pelts of slaughtered animals.

Forest resources are usually thought of as primary resources, though this is not invariably the case. Where forests are owned by individuals and firms for the purpose of producing wood, the forest resource is clearly a primary resource. Forests are unusual among biological crops, however, in that very large areas of forest land are in public ownership--federal ownership, for the most part. These forests are managed under a multiple-use system which, as it is practiced over large areas, effectively constrains the maximization of materials production. In many areas materials production is either prohibited or severely restricted. With respect to the problem of increasing the supply of renewable resources as substitutes for nonrenewable resources for industrial materials, emphasis must clearly be placed upon the primary renewable resources production of wood.

A wide range of plant and animal products are used as industrial materials. In the U.S., however, only a few account for any appreciable portion of the total (Table 1). Wood is the most important, accounting for more than a quarter billion tons per year, and over $6 billion per year in value at local delivery points in 1974. Of the vegetable fibers, cotton is the most important, with an annual production of nearly three million tons and value over $2 billion at local delivery points for the fiber alone in 1974. Wool is the other important natural fiber produced in the U.S. with more than half the U.S. needs, or 88,000 tons, produced annually at home. Vegetable fibers other than cotton are used in relatively small amounts and are almost entirely imported into the U.S.

FOREST RESOURCES

A total of 754 million acres, a third of all land in the U.S., is classified as forest land. These lands range in elevation from sea level to 12,000 feet and include 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 U.S. with regard to acreage of commercial forest land, forest yield, growth, and harvest is under continual study by the Forest Service, and is summarized by the U.S. Department of Agriculture (USDA) at intervals of approximately 10 years. The most recent updating of forest statistics is contained in _The Outlook for Timber in the United States_ (hereafter termed the

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	1,425

*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).

Outlook Study), published in 1974 (USDA 1974d). This report summarizes recent trends in forest land and timber resources in the U.S., and projects future trends in timber supplies through intensified management and use at home, and through greater reliance upon world timber resources abroad.

Of the 754 million acres of forest land in the U.S., the Forest Service classifies about two-thirds as commercial forest land. In its inventory, it reports on this 500 million acres. The remaining one-third is classified as noncommercial for one of the following reasons:

1. About 211 million acres are classified noncommercial because they are judged to be capable to producing less than 20 cubic feet of wood per acre per year--an arbitrary commercial threshold.

2. About 20 million acres are classified noncommercial because they are public lands classified as park or wilderness or were being studied for such classification.

3. About 22.5 million acres are classified noncommercial because, while they are public lands not excluded from the timber base as parks or wilderness land and capable of producing more than 20 cubic feet per year, they are in central Alaska and considered inaccessible.

Table 2 indicates, for the forest land classified by the Forest Service as commercial, the distribution of areas among regions and types of ownership.

It should be noted that all privately owned forest land judged to be capable of producing more than 20 cubic feet per acre is assumed to be commercial forest land. Given the owner's land-use objectives, many of these areas are as qualified for noncommercial status as are the excluded public lands in terms of their real contributions or prospective contributions to the timber production base. Of this 500 million acres of so-called commercial forest land, slightly more than 100 million is in federal ownership, 29 million in local public ownership, and the remaining 363 million acres in private ownership. Sixty-seven million acres of the private land is owned by forest industries and generally under some form of management, while 296 million, or approximately 60 percent is in a variety of private non-industrial ownership categories. The diversity of ownership of our forest land and therefore diversity of management objectives must be recognized in planning programs to increase forest production. A corollary to this ownership pattern is that non-industrial private land may have a high

Table 2

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

Type of Ownership	Total U.S.		North	South	Rocky Mountains	Pacific Coast
	Area Thousand Acres	Proportion	(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	5,888	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.

productive potential because of location and site but may be producing far less than capability because of management.

The forests of the U.S. are biologically diverse; more than 40 major forest types include some 60 tree species of major importance and perhaps as many again of minor importance. Each species has its distinct geographic range, particular ecological requirements, unique physical and chemical properties, and its own set of commercial uses. The conifers or softwoods such as spruce, pine, and Douglas fir, are the most fully used--for structural lumber, plywood and veneer, and for paper pulp. Resinous pines produce naval stores. Broadleaved trees or hardwoods, such as oak, maple, or hickory, are used for specialty products as solid wood or as plywood and veneers for furniture, pallets, flooring, and in many other forms, including paper and paperboard. Briefly then, wood comes from many different species of trees, has a wide range of characteristics and a diversity of uses.

In order to examine supply, productivity, and growth, it is necessary to establish terms of reference for measurement. The content of total tree including bole, branches, twigs, leaves, fruit, bark, and roots is termed biomass, usually measured as dry weight. The more common measurement of "commercial volume" will be used rather than biomass in most of this report since its primary objective concerns industrial use of wood. Commercial volume refers only to volume of wood in the main bole or stem of the tree above a 1-foot stump up to a minimum diameter of 4 inches inside bark.

Projections of present and potential future materials supplies from the forest used in this study are based on information from the Outlook Study (USDA 1974d). These are the only comprehensive data available covering the entire nation. Typical of most comprehensive national and regional forest inventories, they are deficient as a data base for evaluating materials supplies. Some of these deficiencies are discussed in the following sections.

Inventory Measures

For reasons lost almost in antiquity, forests have been measured with reference to their product output, the units of measurement having been developed at a time when there was only one marketed product, lumber. The board-foot is still used today. One board-foot is theoretically a piece of lumber 1-foot square and 1-inch thick. In practice, however, this is never the case. The variations arise from a variety of causes, resulting in a board-foot measure that is a highly inaccurate measure even of sawn lumber.

Lumber is 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. Under the American lumber standards a nominal 2 inches by 8 inches dry, surfaced board must have a minimum dimension of 1 1/2 inches by 7 1/2 inches. Thus a board of minimum dimensions in this nominal size would have a cross section slightly more than 70 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 pr acise. 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 persistent but crude 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. These are 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.

The nature of all log rules requires that they be based on 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 the employed. Regardless of the general validity of the geometrical and algebraic procedures used in devising a log rule, it is obvious that assumptions based on manufacturing practices of a century ago bear little relationship to modern technology. Manufacturers have, of course, accomodated to the inaccuracies and imprecision of log rules. Such criteria as "overrun" and "board-foot/cubic-foot ratio" represent efforts to estimate true volume from the inaccurate estimates in terms of board-foot volume provided by use of 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 on estimated lumber recovery, make no technological sense at all.

With the advent of large-scale electronic computers, the possibility of using simulation models to predict product recovery under the manufacturing conditions actually projected for use has been explored. A large number of such computerized models have been constructed and are in use (Holmes 1976). Evaluation of logs made in terms of actual solid volume or weight can be accomplished with much more precision than can predictions of 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 that is 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 that 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, minimum useable top diameter, and, in some cases, the mixture of logs that are potentially recoverable. When volume tables are based on 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 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 full tree use becomes more widely practiced, failure to accurately estimate the volumes in the non-merchantable fraction of the tree is an important mensurational deficiency.

Similarly, volume tables based on 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 for 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, 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 are faced with having to 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 do not permit the generalization of the results to large forest areas. Botanists and foresters are both concerned with forest biomass, but the two groups are working independently by and large with little or no joint effort on using and interpreting data.

The measurement of growth is subject to the same inherent problems as 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 permit the counting and measurement of growth rings. The former technique is the best, 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 accourate estimates 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 predictions. Stand-table projection is much less satisfactory if applied to an entire forest or region than on a stand-by-stand basis.

Consumption of Timber in 1970

The Outlook Study (USDA 1974d) provides data on the U.S. timber situation in 1970. The apparent consumption is derived by taking the annual removals from U.S. forests, adding in timber imports, and subtracting timber exports. The overall estimates are summarized in Table 3. 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

Table 3

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) species, as given in the Wood Handbook (USDA 1974f) by the total volume of that species in the U.S. 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.

It will be seen that the U.S. is a net importer of timber products both for hardwoods and for softwoods. The total consumption of timber in the U.S. 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 rate much lower 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 U.S. was estimated as 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.

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 U.S. estimated from normal yield tables would have been 74 cubic feet per acre per year, or almost twice the estimated net annual growth. Much of this 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 much faster-growing second-growth forests.

Projected Supply in 1985 and 2000

In the Outlook Study (USDA 1974d), the Forest Service has projected future timber supplies of the U.S. 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 baseline 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 treated, assistance to private forest landowners, support of forestry research, expenditures for forest roads and mileage developed, and the like.

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 (President's Advisory Panel on Timber and the Environment 1973, referred to after this as PAPTE). 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.

Assuming the continuance of 1970 level investments and these forest management achievements, the trends in productive potential of the U.S. forests are highlighted in Table 4. The data for 1985 are interpolated from the Outlook Study. Compared with a total in 1970 of 14 billion cubic feet, production for the year 2000 is estimated at 20.3 billion, or an increase of 45 percent. Much of this gain is attributed to anticipated increases in the use of hardwoods and increasingly smaller sized trees, as the availability of trees in the present larger sawtimber size decreases.

The demand for timber products in 1985 and 2000 will, of course, depend upon many factors, including ones that cannot be forecast at this time. Potential consumption in terms of cubic-foot needs projected by the Forest Service in the Outlook Study are based on medium projections of growth in population and economic activity. Assuming that timber prices retain their 1970 relative price levels compared to all commodities, projected consumption would be 18 billion cubic feet by 1985 and 20 billion by 2000. Such a consumption could be met on a nationwide basis (but not necessarily species by species, size class by size class, or region by region) were the Forest Service production estimates based on a continuation of 1970 levels of management to be met.

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).

Should, however, the prices of timber products relative to nonrenewable products continue to rise over the next quarter of a century at the historic rate--1.5 percent per year for lumber, 1.0 percent per year for plywood, and 0.5 percent per year for paper, then projected consumption would be for 16 billion cubic feet in 1985 and 19 billion cubic feet by 2000. This level of demand could be fairly easily met in the absence of serious restraints by the continuation of 1970 levels of management.

Recent sharp increases in the relative prices of petroleum, natural gas, coal, iron, and aluminum have raised for the first time the possibility that the relative prices of timber products might decline in the future rather than increase in continuation with past historical trends. Were this to happen in the next 25 years, consumption of timber products would be in the neighborhood of 25 to 30 billion cubic feet by the year 2000. This level of demand could only be met by the early adoption of a nationwide program of intensive forest management or by greatly increased imports of timber products. Otherwise, the relative prices of timber would have to rise to the point where supply and demand would fall into balance.

Increasing Forest Productivity

Forest science has given us a relatively good understanding of the factors that determine rate of forest production. They are indeed not greatly different from those that control agricultural production. Increasing forest production while maintaining a fixed or decreasing land base does require a definite plan of action involving further elaboration of factors determining forest production and application of existing information in the management of forest lands. It is perhaps also necessary to point out that changes in production of the forest crop require a different time scale than those for the most agricultural production. A given forest may occupy any given acre from 10 to more than 100 years before harvest; therefore, the need for long-range management planning and even longer range research is obvious.

Increasing Timber Production Through Intensive Management

A wide variety of opportunities exist for increasing timber production through intensive management (Ostrom and Gibbs 1973). The principal approaches include: (1) improving the site through fertilization, drainage, and irrigation; (2) converting forest areas to faster-growing species; (3) improving stocking and shortening the rotation through reforestation; (4) introducing genetically faster-growing trees; (5) stimulating the growth of the desired species through weeding; (6) recovering a larger share of the gross growth through thinnings; and (7) reducing losses from fire, insects, and diseases through better forest protection.

Forest sites may be improved physically through such measures as drainage, irrigation, and cultivation; or chemically through fertilization. On many pocosin and flatwood sites of the coastal plain of the southern U.S., growth of loblolly and slash pine may be increased from negligible levels to the middle range by drainage; fertilization with phosphate also improves the growth of these pine forests substantially.

In recent years, much research has been carried out to improve nutrient relationships in forest soils, and substantial areas of forests have been fertilized commercially. In the last decade, some 900,000 acres have been fertilized in the Pacific Northwest (mainly Douglas fir) and over 400,000 acres have been treated in the Southeast (mainly slash and loblolly pine). The great bulk of this commercial fertilization has been by private industry. A safe generalization based upon current knowledge would be that nitrogen fertilizer applied at 5-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, with a similar fertilization program, growth increases of 30 percent could be obtained on perhaps 25 percent of the forest land.

In the Outlook Study (USDA 1974d), forest site quality is estimated on the basis of the vegetation currently occupying the area at the time of the forest survey. Since much 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 U.S. commercial forests in these respects.

Although opportunities for changing forest type exist throughout the country, by far the largest opportunity is in the southern pine region. There, a very large area that could grow pines and other fast-growing conifers well is currently growing hardwoods poorly. Much land in the South once supported pine, but has reverted to hardwoods through the exclusion of fire or harvesting the pines without immediately reseeding or replanting the cut-over site with pine. The region has over 30 million acres of mixed oak and pine forest and over 88 million acres of hardwood. Assuming that half of the mixed wood type and a tenth of the upland hardwoods on Sites III-V could be profitably converted to pine, the pine acreage in the South could be increased by 20 million acres.

Probably the single most important factor in maintaining the productivity of U.S. forests 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.

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 or 2 percent over a rotation of 50 years.

It is at the time of planting the new forest that the possibility of genetic improvement becomes real. Through an intensive program of plus-tree selection, seed orchard establishment, and progeny testing in southern pine, the projected increase in growth in the southern pine forests 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 rather than the 30 or 40 years anticipated as the rotation age for southern pine plantiations. Similarly, in the Pacific Northwest geneticists estimate a gain of 10 to 20 years between generations. Conservatively, the gain for major conifer species in the U.S. would be 10 to 15 percent per generation of see orchards. At an interval of 15 to 20 years between generations, the gain would be about 1 percent per year over the next half-century.

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. It has been estimated that the 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.

For most species on average to better sites managed for medium-length rotations, gross increment will range from 15 percent to 35 percent (average 25 percent) greater than the net yield indicated by normal yield tables, and that most of this gross increment (perhaps 90 percent) can be used through thinnings begun early in the life of the stand and carried out at a maximum of 10-year intervals.

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 a fifth of the total annual U.S. forest growth. Reducing these losses through improved timber, fire, and pest management may provide the single greatest means of improving timber production. 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 economically feasible to increase the costs of forest protection to achieve an increase in actual harvest of 1 to 2 billion cubic feet per year from the forest is a separate and complex matter.

In addition, the possibility exists of using a higher proportion of the wood and other parts of trees. The definition of growing stock adopted by the Forest Service in the Outlook Study includes the wood in the main stem or bole of all trees over 5 inches in diameter at breast height above a 1-foot stump up to a top diameter of 4 inches. Thus, the stump, the top, and all the bark are excluded from the official statistics. Obviously the opportunity exists for closer use of the bole. In addition, it is technically feasible to harvest smaller trees as well as large branches, stump, and the major part of the root system. Even the foliage could be harvested and possibly used. Fuller use of the forest biomass is mechanically feasible and should be considered in any biological approach to forest productivity, whether or not it is economical to do so.

An Estimate of Production Potential

In developing a projection of future forest areas the following assumptions were made: First, the acreage of commercial land is predicted to decline from 495 million to 475 million acres, the level prodicted 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. Fourth, 15 million acres of pine and 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 due to the faster growth rate of pines on these sites.

Under these assumptions, and rounding off each category to the nearest million acres, 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. Most of this increase would be on the better sites. The assumptions are optimistic but technically feasible and economically well within reality.

The projected volume of timber produced is obtained by multiplying the number of acres in each category by the assumed production per acre per year. If the total area was fully-stocked so that yield table predictions could actually be realized, 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.) Yield table values, however, cannot actually be achieved over large acreages. It was therefore assumed that management would be sufficiently intensive to produce 90 percent of yield table values on the highest sites, based on European experience. Assuming slightly less intensive management on each descending site class, we project 80 percent of yield table production on Site III lands, 70 percent on Site IV, and 60 percent on Site V.

Applying these assumptions, the mean annual production would range from 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, the potential productivity would be over 17 billion cubic feet per year of softwoods and over 11 billion of hardwoods for a total of 28.5 billion cubic feet. This estimated productive potential is twice that of 1970 consumption of 14 billion cubic feet.

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, possibilities exist for realizing a greater percent of the gross production through an intensive thinning regime and for obtaining faster growth rates through a broadly applied tree improvement program. In general, normal yield table values can be increased by 25 percent by regular thinnings, and on those areas clearcut and planted with softwoods, growth would be increased by about 1 percent per year if tree improvement programs were vigorously applied on a broad scale.

For both thinning and genetic improvement in the Douglas fir and southern pine regions, an average improvement of yield of 15 percent is postulated 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 limited applicability for short rotation southern pine, and that clearcutting will be followed immediately by full planting with genetically-improved stock derived from a large and intensive tree improvement program.

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

The biological productivity of the commercial forest lands of the U.S. is such that, where economic and social conditions permit, the net realizable growth of these forests could be doubled within a half-century by the widespread application of proven silvicultural practices. Political and economic restraints may result in a lesser increase in productivity. At the same time, with widespread application of intensive silvicultural practices, with complete use of hardwood resources and complete tree use, the potential productivity of U.S. forests would be closer to three times the present level rather than the doubling that is imminently practicable.

It should not be forgotten that the productive potential of 30 billion cubic feet is a biological potential that can only be achieved through intensive application of existing silvicultural technology. This estimate does not take into account such restraints as the lack of motivation on the part of small woodland owners, regulations imposed to satisfy environmental concerns, and failure to initiate and carry through the intensive management plan on the necessary scale.

Forest Resource Material Production Base

If the forests of the U.S. are to have a much more important role as sources of materials in the future than they have in the past, then it is important to improve on our knowledge of the forest resource material production base. As has already been noted, on some forest lands wood is a primary renewable materials resource; on other forest lands it is a secondary renewable materials resource, and on still other forest lands it is not a materials resource at all. From a materials supply standpoint, it is important to know at any given point in time and with as much precision as possible how many acres in each region, in each land ownership class, and in each site quality class fall into each renewable resources class. The best opportunity to increase materials supply from forests is to concentrate our national efforts on the primary resource lands.

Unfortunately, we cannot say with any great confidence how large this primary resource land base is. Obvious cases where we do know the land base are the federal forest lands that are legally excluded from the materials supply base, such as parks or wilderness, and the industrial forest ownerships that are managed for timber production and are therefore primary renewable material resources. On much of the remaining public land and non-industrial privately owned forest land the situation with respect to dominant use objective is much less clear. Much private land has been withdrawn from timber production by a decision of the owner. In the case of much federal and state owned forest land, the legal obligation to practice multiple use has converted a long accepted forest land-use policy into a planning no-mans-land in which real long-range planning at least for renewable resource materials supply has become a practical impossibility. J.S.D. Richardson, the distinguished British forester, has noted that (Richardson 1974):

> In many countries of the developed world, the traditional wood production orientation of forest managers is being increasingly questioned. In the smaller countries of Europe (e.g., Holland and Denmark) forests are now managed primarily for recreation, with the harvesting of cellulose a by-product of decreasing importance; in North America, that opiate of the forest profession--multiple use--is being given real substance, partly by pressures generated by the Sierra Club, the Environmental Defense Fund, and other conservation lobbies.

A recent invocation of a very narrow and restrictive interpretation of the Forest Service Organic Act of 1897 (the U.S. Fourth Circuit Court of Appeals Monongahela decision, Izaak Walton League vs. Butz, 1975), if it became generally applicable to National Forest lands, would certainly eliminate much of this vast acreage from the category of primary renewable materials resource. It is not our purpose to judge the merits of present land-use restrictions on public forest lands but simply to point out that they cast doubt on the ability of the federal government and some states to manage forest land as a producer of a primary renewable materials resource.

A similar situation prevails with respect to non-industrial private forest land. Here even less is known about the motives of the owners with respect to long-term materials supply or the ability of the owners to undertake the intensive forest management required to increase materials supply if indeed this is an objective.

The problem of assessing the materials supply potential of America's forest land is important. The existing obligation of the Forest Service to do this dating back to the McSweeney-McNary Act was expanded and reinforced with the passage of the Humphrey-Rarick Act in 1974. But many other organizations are also engaged in these kinds of assessments. The Public Land Law Review Commission (1970), PAPTE (1973), NCMP (1973), and the NRC Committee on Renewable Resources for Industrial Materials (CORRIM) have studied various aspects of the timber supply problem from a national vantage point in the last five years. In addition, at least six states have undertaken similar studies for their own territories. Only one organization is in a strategic position to make the kind of national forest census that can provide a sound basis for such assessments--the USDA Forest Service. The Forest Service ought to be permitted to improve the quality of the census operation and financed for that purpose. In so doing, it should carefully separate its report on the forest census from its own interpretation of the meaning of the census. The census information with field documentation of sampling intensity and sampling variation divorced from any use, silvicultural, economic, or management assumptions should be freely available so that research organizations in states, private industry, universities, or on a federal level can make their own independent assessments.

Major changes in the supply of nonrenewable resources, the cost or availability of processing energy, and social attitudes toward forest land use can occur over a relatively short time span. The production of a crop of trees requires several decades. It is therefore important that the science and technology required for intensive forest management be tested on an operational scale so that demonstrations, at a production level, are available for the guidance of forest land managers when these forest practices are indicated. Since these operational procedures will vary with species mix, site quality, and product objective, a substantial number of pilot-scale operational demonstrations will be required if they are to be representative of the spectrum of forestry materials supply opportunities. The knowledge of potentially feasible methodology is available in the research centers of the Forest Service, the forestry research organizations of the universities, and the research centers of the major forestry companies. Planning for these demonstrations should draw upon all of these intellectual resources.

A planning team representing each of these components could be established to plan such demonstrations including the design of the management plan to be field-tested. Such production experiments should be bold in their concept and should include methods that may not be economically feasible at the time of installation but that have prospects for feasibility under some future economic conditions. Such large-scale production experiments can serve a useful purpose in testing the validity of speculations concerning such environmental consequences of intensive forest management practices as watershed protection, soil nutrient depletion, ground water storage, etc.

AGRICULTURAL RESOURCES

Introduction

Although forests presently produce the greatest portion of renewable materials for industry, the productive potential of other ecosystems, particularly agricultural cropland, cannot be overlooked in this assessment of possible future resources.

Very few agricultural materials are produced in the U.S. primarily for industrial use. Of these, cotton is by far the most important; flax, grown for its linseed oil, is the only other such crop grown in quantity. 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.

Primary Agricultural Materials

The acreage planted to cotton in the U.S. has steadily decreased from a high of 45 million acres in 1926 to 14 million in 1972. During the same period, yields per acre have steadily increased with the result that the total production of cotton has remained more or less level, the 1972 production being 3.3 million tons of lint, 380.3 thousand tons of linters, and 667.6 tons of cottonseed oil. Economic projections by the Cotton Council of America and by the USDA Economic Research Service (USDA 1974e) foresee a general continuation of these trends with cotton production being concentrated on 10 to 14 million acres of U.S. cropland by the year 2000 (USDA 1974c). Since cotton was grown on 45 million acres in the 1920s, albeit to a considerable extent on nonirrigated lands not used for cotton today, there is obviously no shortage of farmland suitable for meeting future cotton demands in the U.S. Whether or not these lands will actually be used for cotton will depend upon the relative profitability of growing alternative feed and food crops on them. Limitations of cotton production in the U.S. are, and seem destined to continue to be, imposed to a much greater extent by economic restraints than by the availability of suitable farmland.

The growing of flax in the U.S. has steadily declined from a high of nearly 5 million acres producing over 1 million tons of flaxseed in the 1950s, to little more than a million acres producing less than a half-million tons of flaxseed in the early 1970s. 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. There seems to be little likelihood that future demand for flaxseed will impose a major load on U.S. agricultural land. As with cotton, the limitations on flaxseed production in this country are economic, rather than being imposed by shortages of suitable land or by biological considerations.

Secondary Agricultural Materials

The second category of agricultural industrial materials consists of those grown primarily for food that have important secondary industrial uses. In the U.S., wool is commonly a secondary product to meat in the economics of the sheep industry. Similarly, fats and hides are important secondary products to meat in the beef cattle industry. Among agricultural crops, peanut oil and soybean oil have important secondary uses as industrial materials.

U.S. wool production has decreased markedly in recent years, dropping from 217,000 tons in 1940 to 83,000 in 1972. The trends could be reversed, however, should the increasing cost of grain-fed beef and synthetic fibers result in an increased demand for lamb and wool. Range resources appear to be ample to accommodate probable demand for sheep in the forthcoming decades.

The quantities of major animal by-products (fats and hides) projected to be available during the rest of the century seem to be sufficient to supply both domestic and export demand for this period. 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.

The production of both soybeans and peanuts has increased in recent years. The history of soybeans since 1950 has been one of moderately increasing yields and dramatically increasing harvested acreages. Yield per acre increased by 28 percent between 1950 and 1973. Acreage, however, increased more than fourfold in the same 24-year span. The overall result was an increase in production from 9 million tons in 1950 to over 38 million.

Peanuts contrast with soybeans in that yield has increased greatly while acreage has actually decreased since 1950. In the time period from 1950 to 1973, yield increased 2 1/2 times while acreage dropped by a third. Production increased from 1 million tons in 1950 to over 1.6 million in 1972.

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 terms of amount used and even more so in terms of the dollar value of such uses. The acreage devoted to them in the U.S., therefore, will be determined in large measure by relative economic returns from other food crops that can be grown on the same lands.

Agricultural Residues

The third category of agricultural materials consists of those grown primarily for food that leave residues either in the field or in the processing plant that have industrial potential. These include wheat and other cereal straws, bagasse, cornstalks, and animal wastes and by-products.

Some of this material, such as wheat straw, is left in the field; others, such as bagasse, are concentrated at a processing site; and still others, such as vegetable oil foots and animal tallows, are residues of the manufacturing process. Cow manure is available in large quantities at feedlots, and processed sewer sludge is similarly concentrated at urban sewage disposal plants. By and large, relatively little of these residues are used as industrial materials because of their generally low value and high collecting and processing costs.

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 this use has now disappeared because of economic conditions, it is available, and wheat straw may again be needed as a source of cellulose.

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

Other field crop residues, chiefly cornstalks, contribute to the grand total of over 300 million tons of plant fibers annually available if needed.

Animal waste and by-products are important potential sources of organic materials. 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 a thousand or more head of cattle. An additional 23 million tons of organic waste is annually available from the large processing facilities, such as canneries, mills, slaughter houses, and dairies.

How to use waste organic materials from agriculture is more than an economic problem: It is an immense pollution problem. Stream eutrophication and contamination, in particular, 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.

Future production of plant and animal residues will be almost entirely determined by food requirements and use. Assuming continued population increases, food needs are almost certain to increase and produce a concomitant increase in agricultural residues. The extent to which these will be used for industrial purposes is, however, uncertain. They will be, however, abundantly available.

Agriculture Resource Materials Production Base

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 one time during this century in the U.S. 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 the USDA Economic Research Service, there are currently some 10 million acres of Class I land suitable for conversion into regular cultivation (USDA 1974c). An additional 250 million acres could be used for cropland but are subject to climatic limitations, and soil, drainage, and erosion problems. Less than 100 million acres of these categories are considered to have high potential for conversion into cropland.

Adequate cropland seems to be available to fill U.S. domestic 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 food, feed, and fiber needs.

Recent surveys of projected demand for agricultural products indicate that the U.S. can produce its own food needs and supply export markets through the year 2000 if present trends continue. The whole subject of agricultural production efficiency has recently been reviewed in a report of the National Academy of Sciences (National Research Council 1975, referred to after this as NRC). The productivity of cotton, flax, and other agricultural materials used for industrial purposes constitutes but a small portion of American agricultural production. The 1975 NRC report, therefore, applies equally to agricultural industrial products and agricultural food products. CORRIM sees no basis for believing that either the biological productivity of agricultural lands or the lands available for growing crops will limit agricultural production of industrial materials in the U.S. for the rest of the current century.

CHAPTER 5

SUBSTITUTION

THE BASIS FOR SUBSTITUTION OF MATERIALS

The history of the use of substances as industrial materials is replete with substitution among substances. Minerals have been substituted for wood in construction materials. Petroleum-based plastics have been substituted for paper as some packaging materials. Natural rubber was substantially replaced by synthetic rubber, and now the reverse substitution is occurring. Substitutions are also common within major industrial material categories: One wood product is frequently substituted for another, one metal for another. Plywood has been substituted for lumber in many cases, and hardwoods for softwoods in pulp manufacturing, among others. In fact there are very few industrial materials for which another material is not technically substitutable. Furthermore, there are few industrial materials for which there is only one substitution option.

Decisions with respect to substitution are often strictly a matter of cost and/or of prior capital investment. If the effect of making a substitution involves scrapping conversion facilities designed to use the original materials, changes in organization, equipment, and the mix of human skills required, it will be undertaken only if the economic advantages are considerable and are over a period of years. The necessity to abruptly consider substitution arose most recently with the oil embargo. Many nations had permitted themselves to depend on foreign sources of a critical raw material without having made provisions for substitution. The subsequent increase in the price of petroleum has suggested that, in addition to providing for the short-term substitution needed in the case of an embargo, it may be desirable to also search for long-term alternatives to petroleum as an energy source or as a raw material. While a number of technical options exist, it is not clear at this time which options are economically most attractive in the long run and which are socially acceptable. Possibilities in the case of energy are to shift to nuclear fuels, solar energy, geothermal energy, coal, wood, some plant and animal residues, and urban waste. Wood, of course, has a long history of use as a fuel and clearly could be used again. However, it is presently used for other purposes than fuels or, in the case of residue left in the forests, is quite expensive to collect and deliver to fuel consumption sites. The same problems exist with some of the other potential petroleum substitutes. Thus a decision to divert a plant or animal substance to use as a fuel material could result in a supply shortage or an increase in supply cost in the system currently using such a material.

The number of technically feasible materials substitution alternatives available to the nation and its industries for the solution of supply problems is legion. Lists of potential substitutions are very long. Arguments over the advantages and disadvantages of a particular candidate for substitution can be pursued in great detail. These exercises tend to be meaningful only at a particular point in time. The purpose of this study was to examine the basis for evaluating substitution opportunities and to assess social and institutional restrictions on substitutions that might significantly reduce the number of available options in the long run.

The choice among resources to be used in the production of a material is likely to be based on the quantity and quality of its long-term supply potential, the capital required to exploit it, the availability of the necessary manpower, the energy that must be added to convert it to the useful form, environmental impacts, tastes and preferences, and a whole host of institutional factors. The methods of materials supply systems analysis developed in this study explore these parameters and examine their interactions.

THE REFERENCE MATERIALS SYSTEM

The materials system is quite complex in view of the availability of many natural resources either of a renewable or nonrenewable character. While the materials system is central to the operation of a modern society, this system has many other attributes involving effects on employment, energy needs, capital requirements, and the environment. If data on these key aspects were organized in a rational, systematic manner, a powerful tool would be available as a framework for economic analysis of substitution alternatives.

Although the need to address the role and attributes of materials in the U.S. economy in a broad systems framework is quite apparent, little substantive work has been done in this area. An exception is the effort at Brookhaven National Laboratory to define the use of energy in the economy using the concept of the Reference Materials System

(RMS). This technique provided this study with a framework for the materials assessment that was needed in order to consider the future role of the renewables as a source of materials and, more specifically, as substitutes for nonrenewables in particular end uses. This technique facilitates the integration of diverse information on the technical, economic, and environmental aspects of the materials system and the analysis of material use and substitution. The scope of RMS is outlined in Figure 1.

At the left side is a list of resources, renewable and nonrenewable, that may be considered. Products and end uses are listed on the right side and the "activities" involved in converting a resource to the end uses are listed across the top. A completed RMS presents a network representation (Figure 2) of the flow of materials from the resources side through all of the activities to the specified end uses. A path linking the activities that reflect the steps necessary to convert a specific resources to a specific end use is called a trajectory. Each "activity" in the trajectory represents a technical process or production step that will be characterized by a flow element in terms of quantity of material and such data elements as requirements for labor, capital, energy, land use, fertilizer, etc. In fact, one would ideally construct a separate network representation (or set of trajectories) for each data element or factor input. Depending on one's interest or on what factor of production is considered critical, one would analyze a particular trajectory (such as the labor trajectory, or the energy trajectory, etc.). In RMS trajectories presented as examples, materials flow and energy requirement data are used more frequently than manpower and capital requirement data because materials flow and energy data were more readily available and complete, not because CORRIM gave any special priority to materials flow and energy over manpower and capital requirements.

The RMS system may be used as a basis for analyzing factors that could affect the role of renewable resources in the economy. The analyses are accomplished by using a perturbation technique whereby incremental changes in resources availability or availability of various production factors are traced.

Renewable Resource	Production (growing)	Harvesting or Extraction	Processing	Transportation (aggregate)	Fabrication and Recycling	Product Identification	Utilizing Systems (Installation and Operating Requirements)	End Use
Forest Products Soybeans Cotton Bagasse Misc. Agriculture and Wastes Rubber Leather and Hides Marine Products including Agriculture algae fish oils	Land use Energy Fertilizer and Chemicals Labor Environmental -solid waste Capital Cost Operating Cost Institutional and organization problems			Data Elements to be identified for each resource/activity combination		Lumber Plywood Paper Particle Board and fibreboard Chemicals Fibres and woven fabrics Non-woven fabrics Elastomers Fuels Plastics Drugs		Commercial and industrial structures Housing Furniture and upholstry Energy -fuel -power Textiles -clothing -softgoods (footware) -packaging Communication Disposable Products -packaging -other Recreation (competes for use of land)
Nonrenewable Resource Iron and Steel Aluminum Copper Oil and Gas Coal Cement and Concrete								

FIGURE 1: Scope of Reference Materials System and Data Elements

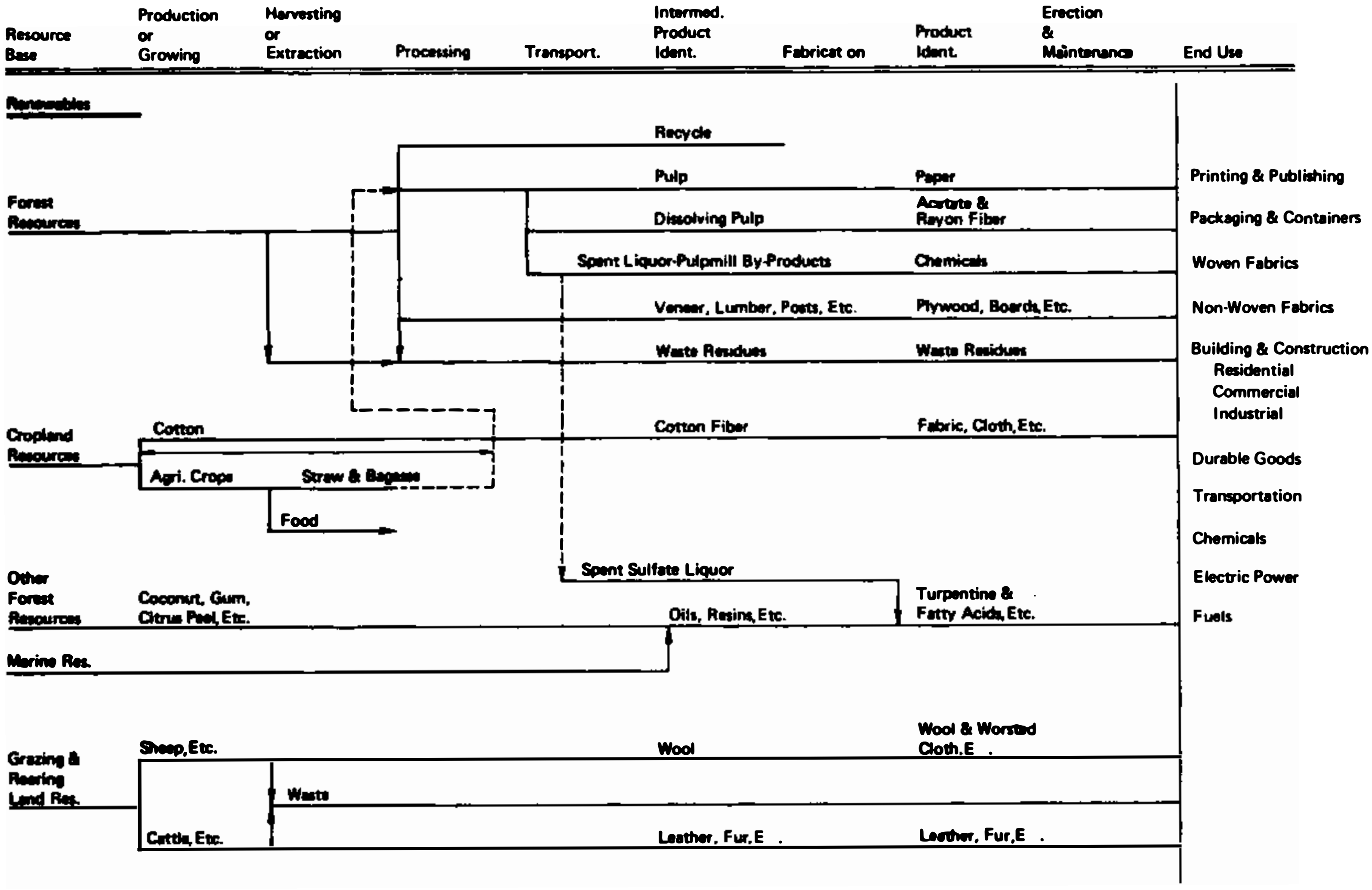


FIGURE 2 SIMPLIFIED REFERENCE MATERIALS SYSTEM

The resources and end uses described in the system are as follows:

Resources	End Uses
Renewable:	
Forests - hardwood	Printing and publishing
- softwood	Packaging and containers
Other forest resources	Fibers - woven fabrics
- coconuts	Non-woven fabrics
- citrus peel	Building and construction
- other	-residential
Agricultural crops	-commercial
Livestock	-industry (non-energy)
	-energy, electric utilities
	-energy, other than electric
Nonrenewable:	
Steel	Durable goods
Aluminum	Transportation
Cement and Concrete	Chemicals
Glass	Electric power, fuels
Crude oil and natural gas	Other fuels
Coal	

The activities included in the system are:

Production or growing
Harvesting or extraction
Processing
Transport (aggregated shipments during all flow stages)
Fabrication in primary form
Installation, erection, and maintenance

The latter category, particularly the maintenance requirements, are of special importance in the selection of materials for optimal life cycle usage. Unfortunately, the data available at this stage of development of RMS were quite sparse, and much more work needs to be done. Data on durability and re-usability of materials were even sparser. The RMS network represents a comprehensive view of the materials system that is quite useful as a tool for the analysis of alternative materials, technology, and policies.

A considerable effort was made by CORRIM to gather current data on the flows of renewable resources and the attendant requirements for labor, energy, capital, and other factors. This information is presented in detail in the study reports cited in the Foreword and the data are organized into detailed RMS in the report - Reference Materials System: A Source for Renewable Materials Assessment. In that report the system is broken down into subsystems and individual trajectories. Some of that detailed information is presented elsewhere in this report in the discussion of specific supply and use issues. As examples of these RMS Figure 3 presents physical flows for the year 1972 and Figure 4 presents the corresponding energy requirements. Capital and labor requirements and environmental consequences are equally important in the assessment of alternative materials. However, early in the CORRIM study it became apparent that there were not sufficient data presently available to allow development of complete RMS for these factors, nor was there sufficient time to accomplish detailed studies to develop these data. Consequently, the trajectories developed in this report emphasize the mass flows and energy requirements for which adequate data were obtained. Partial trajectories for these other factors are available in the above-mentioned report. Concentration on mass flow and energy obviously constrains the analyses presented. However, since the one input, energy, which is least subject to change is incorporated in the CORRIM analyses, this shortcoming may be less severe than expected. To the extent that data for the other factors may become available in the future, they may be easily displayed in this same format. The data collection effort by CORRIM was a monumental task, given the many sources and units of measurement. For analytical methods such as RMS to be useful in decision making, it is important that this nation have readily available and consistently measured data on the flows and factor inputs relevant to renewable and nonrenewable materials production activities.

These requirements may be converted to unit requirements on the basis of either a pound of material throughout for each activity or some unit of the final material product delivered to an end use. In one of the case studies that follows this discussion, for example, the conversion was made in the case of energy to the requirements for electric and non-electric energy per unit of final product (e.g., milk carton, bag, or meat tray).

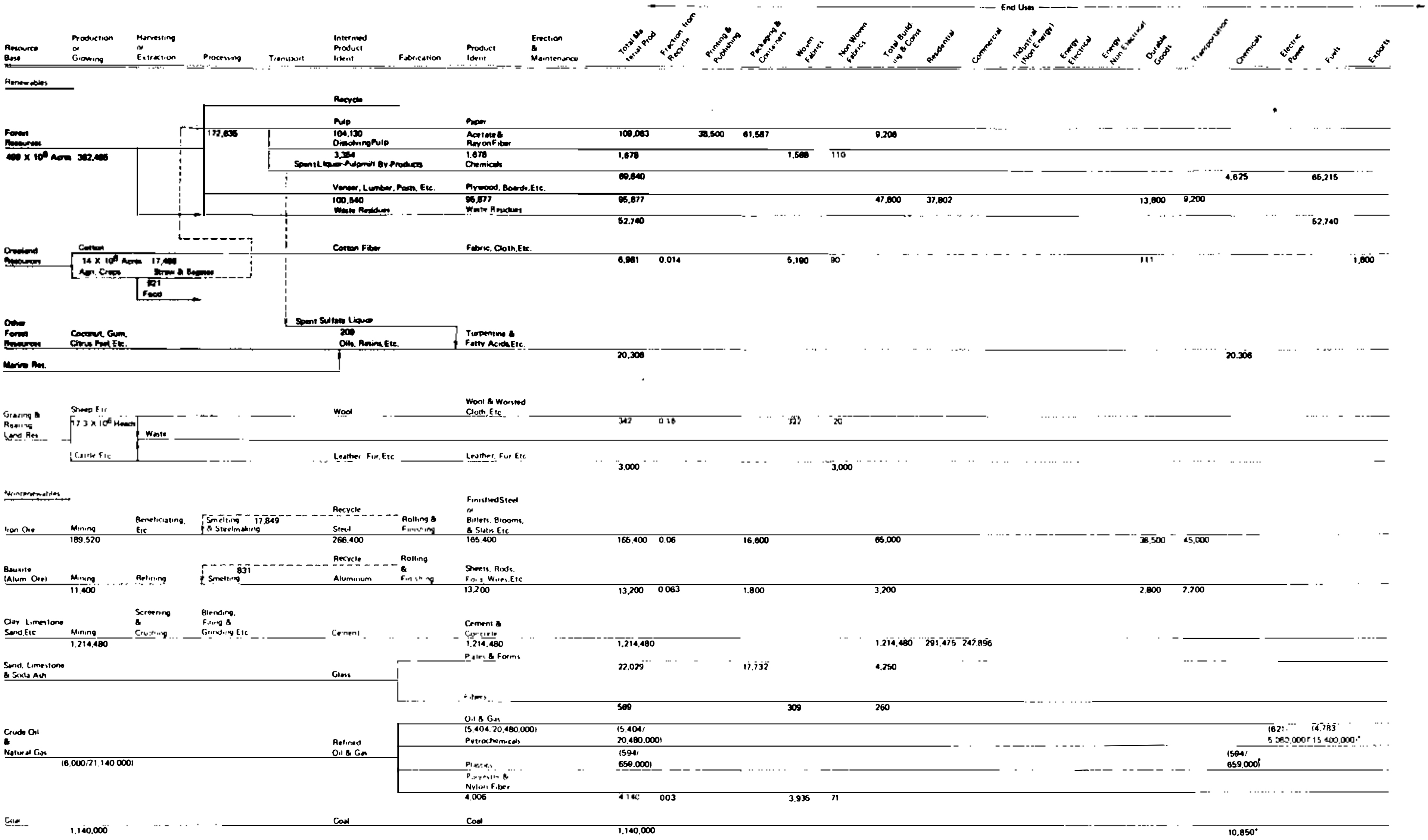
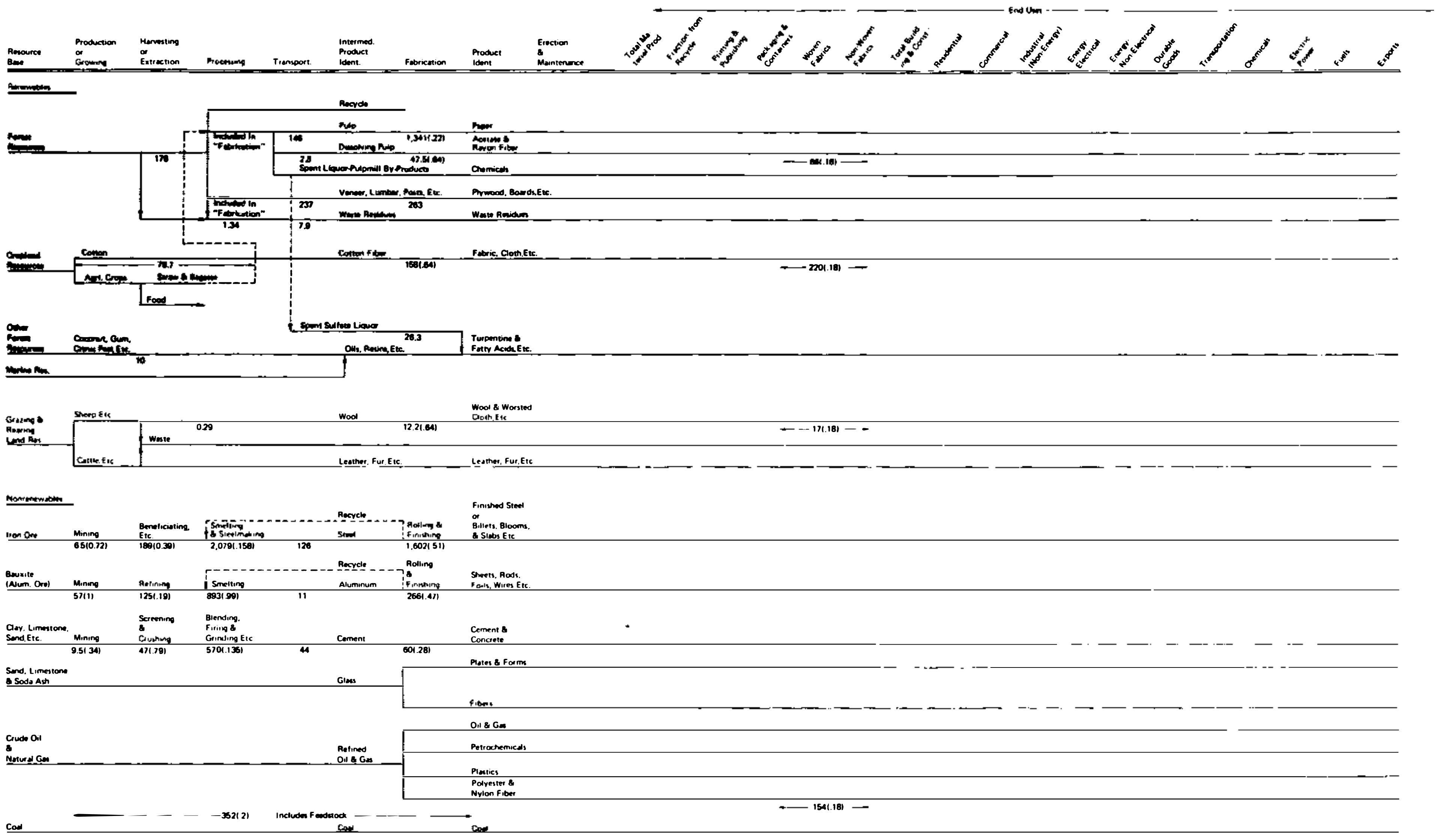


FIGURE 3 REFERENCE MATERIAL SYSTEM Mass Flow in Million Pounds (Year 1972)

*NOTES 1 In the oil & gas trajectory, the numbers in the parentheses, separated by slash, are million barrels of oil & million ft^3 of gas, respectively
2 The numbers with asterisks, confined only to oil & gas and coal trajectories, indicate flows in terms of primary resources instead of products



NOTE Numbers in the parentheses refer to the fraction electrical, at a heat rate of 10,500 Btu per KWH

FIGURE 4 REFERENCE MATERIAL SYSTEM Energy Requirement in 10^{12} Btu (Year 1972)

Analysis of Materials Use and Substitution

The Reference Materials System is used for the analysis of materials use and substitution by the technique of perturbation analysis. The reference system reflects current and projected use patterns, assuming little dramatic change in the role of renewables. Depending on the details of the analysis to be performed, RMS may be used at the level of aggregation presented in a previous section or at the more detailed level. Regardless of the level of detail used in the analysis, however, the results may be presented for overview or policy purposes in RMS format used in the previous section of this report.

The technique of perturbation analysis involves the following basic steps:

1. Analysis of the specific end use involved in a use or substitution problem.

2. Definition of any new processes to be used in the affected trajectory from the resources to the specific end use (definition of losses; energy, labor, and capital requirements; and environmental effects).

3. Revision of flows through the affected trajectories in RMS to reflect the revised use or substitution of materials and/or new processes.

4. Accumulation and tabulation of resources, energy, labor, capital, and environmental consequences of the use or substitution.

In analyzing the specific nature of the substitution, it is necessary to address the specific application. The mass ratio of substitution (e.g., pounds of paper that would replace a pound of plastic) depend on the specific application and the nature of the material. One would thus have to focus, for example, on paper bags as a substitute for polyethylene bags. The determination of these substitution ratios must be done exogenously to RMS and the results reflected in the revised or perturbed RMS. A considerable amount of data were developed in this study to determine such mass ratios in residential construction.

The definition of the technical characteristics of new processes must also be done exogenously to RMS by people with a processing background. The intent of RMS format is to capture those characteristics of the technology that are important to materials policy. Such technical detail, or reality, is often overlooked in policy formulation because it is not available in a consistent and comprehensive format.

Following these steps, the perturbation of the appropriate trajectories and the accumulation of information on detailed consequences is straightforward using RMS. In the case of an analysis of the substitution of paper bags for polyethylene bags, for example, the flows through the wood to paper trajectory would increase by the appropriate amount, while the flow of crude oil and natural gas through the petrochemical trajectory would be decreased. The full materials system implications may then be traced all the way back to the forest and the source of the oil, imported or domestic. The results of the analysis may then be used as a basis of support or revision of the original use or substitution measure.

When used in this fashion, RMS can be a useful technique for the analysis of materials policy. It must be recognized that the technique focuses on the physical structure of the system and its requirements. Thus, although substitution analysis may be performed in a rather direct manner; in cases of more general policy analysis, the effects of a policy action on the supply or demand for materials used, and on the physical structure of the system, must be developed or estimated prior to use of RMS.

Case Study in Substitution Analysis

The Reference Materials System provides a basis for analysis of the consequences of materials substitution. The RMS data on mass flow, energy, labor, and capital requirements allows these factors to be addressed in some detail. In order to demonstrate the application of RMS to materials substitution analysis, two illustrative case studies have been developed. These deal with the areas of construction, where wood competes with such minerals as aluminum, steel, and products derived from petroleum, and of containers and packaging, where paper products compete with plastics and glass.

These case studies illustrate the use of RMS to analyze energy requirements of alternative materials used in the same end use. It should be remembered that, before economic analysis can be performed, similar RMS analyses should be performed on labor requirements, capital cost requirements, and other aspects important to the situation. These case studies are therefore illustrations of the use of RMS and insights gained, rather than a complete economic analysis among the alternatives presented.

Case Study #1 Building & Construction

Table 1 presents data found in the statistical appendix to the special study report Renewable Resources for Structural and Architectural Purposes listed in the Foreword. These data are quantities of the material components and energy used per 100 square feet of construction of a particular type of exterior building wall. The energy aspects detailed for each component are fuel used in logging or extraction (col. 2), manufacturing energy (cols. 3,4), transportation fuel (col. 5), and energy produced from manufacturing residues (col. 7). The latter represents production of energy as a by-product of making the exterior wall, whereas the former three categories represent energy consumption. Net energy required or "net energy drain" is the difference between the total energy consumed and the energy produced.

The upper trajectory in Figure 5 presents this information summarized in RMS format. The oven dry weights of the fabricated components (col. 1) have been converted from tons to pounds and are given as the first number in parenthesis beside each component as listed under Product Identification in RMS. Thus 0.104 oven-dry tons of gypsum is equivalent to 208 pounds. The sum of the weights of the components per 100 square feet of construction is 684 pounds. The manufacturing energy value for each fabricated component is the second number in these parenthesis. For example, the 110 pounds of plywood sheathing used required 0.008 million Btu of manufacturing electrical energy plus 0.370 million Btu of manufacturing heat for a total of 0.378 million Btu. In the transportation activity, these 684 pounds of components required an aggregate of 0.432 million Btu (obtained by summing column 5 of Table 5). Similarly, logging or extraction to obtain raw materials to produce these 684 pounds of final components took 0.204 million Btu (col. 2). In this case manufacturing activities on raw materials produced residues that were converted to 0.931 million Btu (col. 7) of energy that were available. This "gain" in energy is signified by the dashed back arrow indicating a return to the system. The net energy drain to produce these 684 pounds of components for 100 square feet of wall is obtained by summing the energy consumptions and subtracting energy production:

Table 1

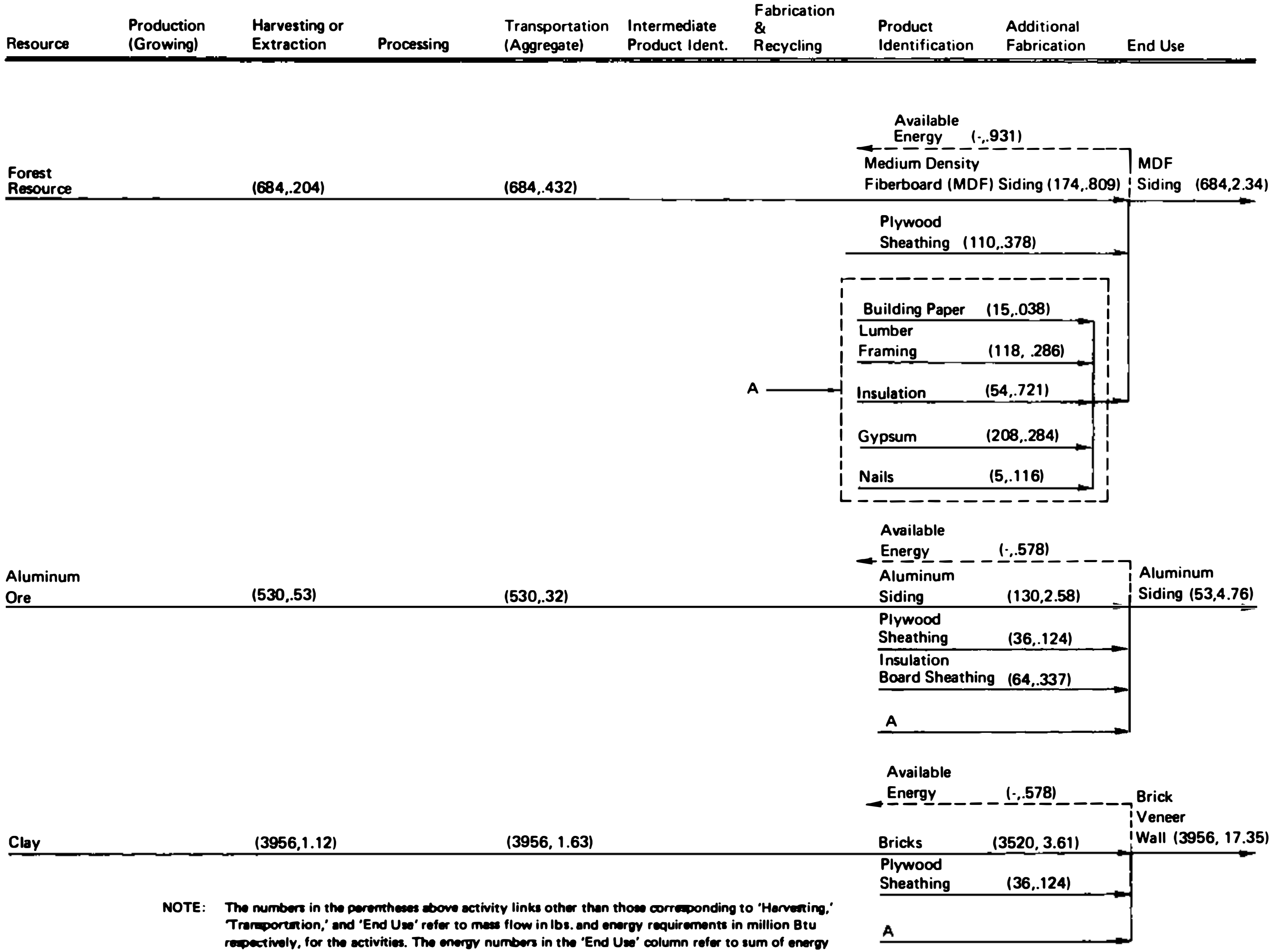
Exterior Wall: Medium-Density Fiberboard Siding, Plywood Sheathing, 2 x 4 frame
Total NET ENERGY requirement per 100 square feet of construction1/2/:2.541 million Btu

Component	Weight ovendry	Logging fuel	Manufacture Electric	Manufacture Heat	Transport 3/ fuel	Gross total	Available mfg. residue energy	Net 2/ total
	Tons	*Million Btu thermal (oil equivalent)*						
Siding, 1/2 in. MDF @ 42 lb/ft^3	0.087	0.068	0.326	0.483	0.100	0.977	0.238	0.739
Sheathing 3/8 in. plywood	.055	.041	.008	.370	.114	.533	.203	.330
Building paper	.0075	.001	------.038-----		.005	.044	0	.044
Framing, lumber	.059	.056	.046	.240	.116	.458	.490	.172
Insulation (2 in. bats)	.027	.017	------.721-----		.025	.763	0	.763
Gypsum	.104	.015	------.284-----		.068	.367	0	.367
Nails	.0025	.006	------.116-----		.004	.126	0	.126
			.380	1.093				
			1.159					
Total	0.3420	0.204	2.632		0.432	3.268		2.541
Percent (of gross)		6.3	80.5		13.2	100.0		

1/ Horizontal projection of roof structures.

2/ Assumes energy from residuals can be internally used or exchanged in manufacturing phase only (not logging or transport).

3/ Commodity factory to retail yard to house site.



NOTE: The numbers in the parentheses above activity links other than those corresponding to 'Harvesting,' 'Transportation,' and 'End Use' refer to mass flow in lbs. and energy requirements in million Btu respectively, for the activities. The energy numbers in the 'End Use' column refer to sum of energy values along the entire trajectory, while the two numbers in each parentheses in the 'Harvesting' and 'Transportation' columns denote the total mass flow of all materials used for the end use and energy corresponding to such mass flow, respectively.

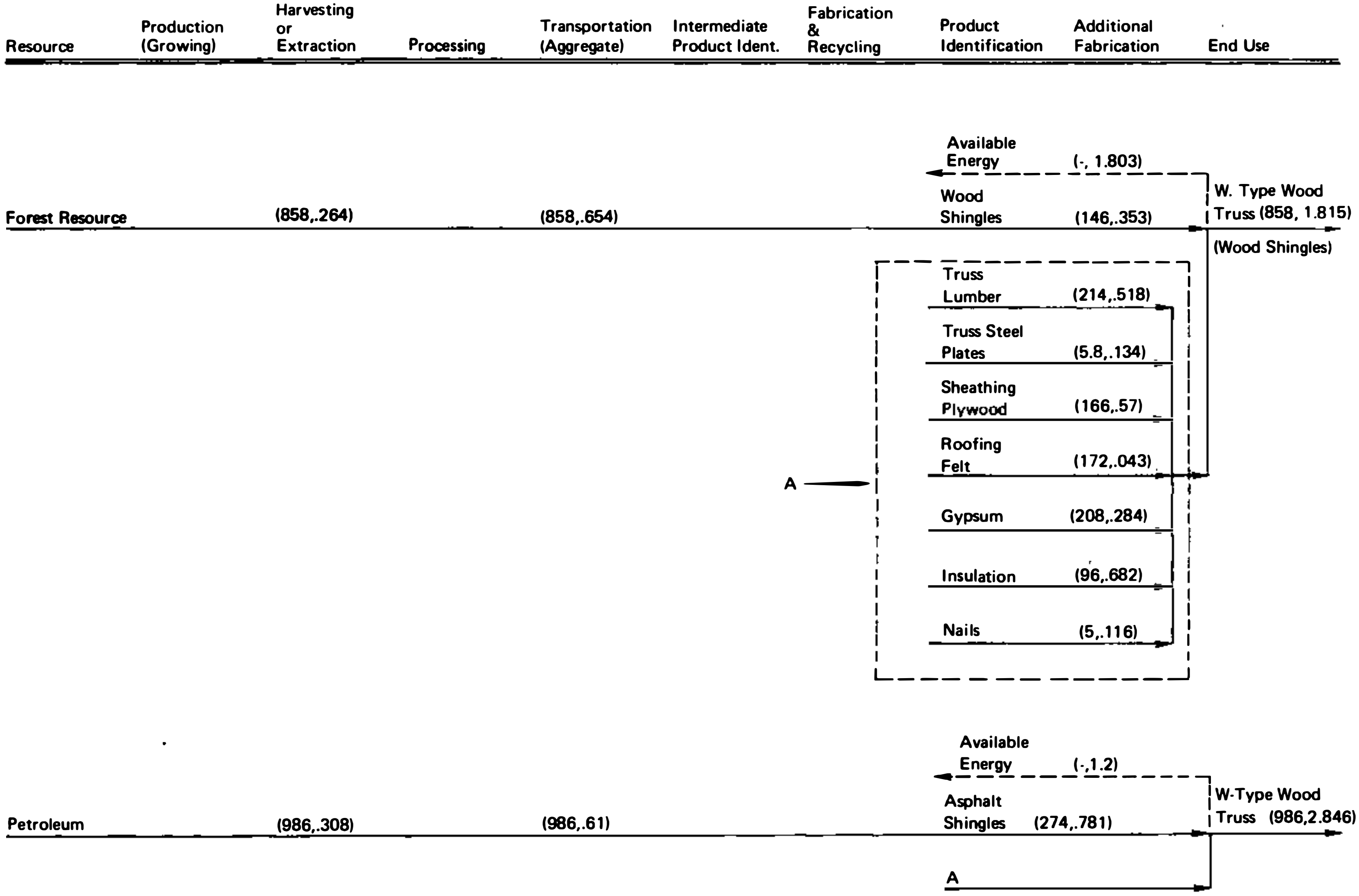
FIGURE 5 FOR 100 FT^2 EXTERIOR SIDING (BLDG. & CONST. SECTOR)
(Mass flow in lbs; energy requirements in million Btu.)

Million Btu		
0.204	Harvest, Extraction	
0.432	Transportation	
0.809	Medium density fiberboard siding	Manufacturing
0.378	Plywood sheathing	
0.038	Building paper	
0.286	Lumber framing	
0.721	Insulation	
0.284	Gypsum	
0.116	Nails	
3.268	Total Consumption	
-.931	Energy produced from manufacturing residues	
2.337	Net	

The trajectories for the aluminum and brick wall competitors were similarly derived. The component marked "A" in these trajectories refers to the dashed box labelled "A" in the medium-density fiberboard trajectory, which remains unchanged for the three cases.

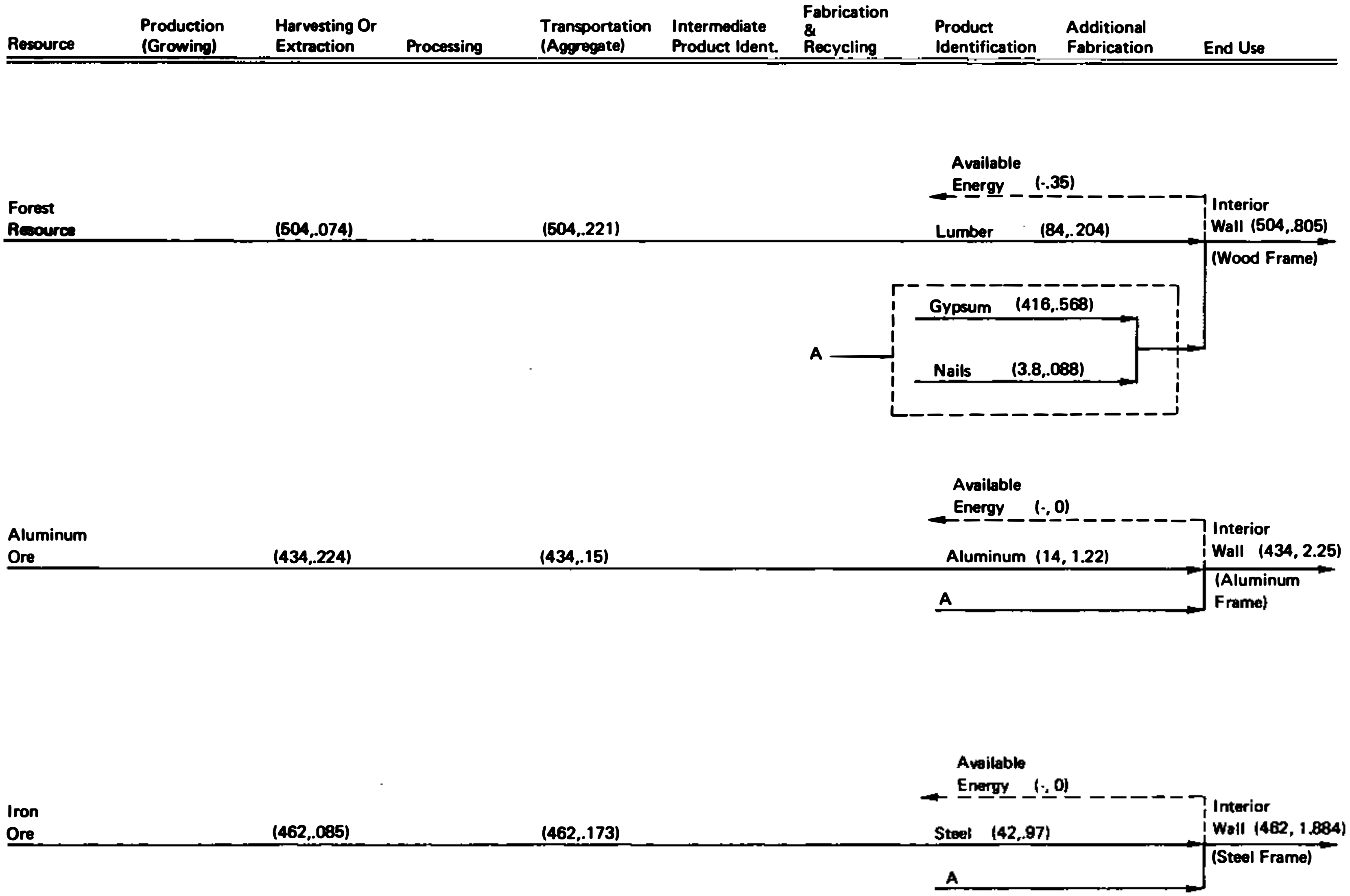
The apparent discrepancy between the net energy RMS figure and the one in Table 1 can be resolved as follows. The figure in the table is based on the assumption that the energy from residues from these products can only be used internally or exchanged in the manufacturing phase only for this product and could not be channeled to other uses, which in unduly conservative. The RMS calculation recognizes that this energy would be channeled to other uses.

Three different construction end uses are examined--interior walls, exterior walls, and roofing--for the purpose of comparing energy requirements for different kinds of materials. The forest resource was chosen for each construction end use, while such nonrenewable resources as aluminum, iron, clay, and petroleum were selected as alternative materials. An RMS was developed for each resources to provide the flow of materials in pounds and energy in million Btu required for each step through each system shown in Figures 5, 6, and 7. The RMS trajectories include harvesting, transportation, and manufacturing energy up to the construction site. The energy requirements do not include erection because, in general, the energy required for erection is relatively very low. The energy requirements for harvesting and transportation are aggregates for each end use, and pounds of material shown at these steps are the total for all materials used in this process. The energy requirement for the manufacturing step under "Fabrication" is disaggregated, showing energy required for each material use. Also shown in RMS diagrams is the



NOTE: The numbers in the parentheses above activity links other than those corresponding to 'Harvesting,' 'Transportation,' and 'End Use' refer to mass flow in lbs. and energy requirements in million Btu respectively, for the activities. The energy numbers in the 'End Use' column refer to sum of energy values along the entire trajectory, while the two numbers in each parentheses in the 'Harvesting' and 'Transportation' columns denote the total mass flow of all materials used for the end use and energy corresponding to such mass flow, respectively.

FIGURE 6 FOR 100 FT^2 ROOFING (BLDG. & CONST. SECTOR)
(Mass flow in lbs; energy requirements in million Btu.)



NOTE: The numbers in the parentheses above activity links other than those corresponding to 'Harvesting,' 'Transportation,' and 'End Use' refer to mass flow in lbs. and energy requirements in million Btu respectively, for the activities. The energy numbers in the 'End Use' column refer to sum of energy values along the entire trajectory, while the two numbers in each parentheses in the 'Harvesting' and 'Transportation' columns denote the total mass flow of all materials used for the end use and energy corresponding to such mass flow, respectively.

FIGURE 7 FOR 100 FT^2 INTERIOR SIDING (BLDG. & CONST. SECTOR)
(Mass flow in lbs.; energy requirements in million Btu.)

available energy or residual energy left from the manufacturing process.

In viewing RMS flows it is apparent that the wood resources requires less energy than any other material used for construction designs. Of the three shown, the energy differences for exterior siding are the most significant, with brick walls requiring 17.35 million Btu, aluminum siding 4.75 million Btu, and medium-density fiberboard 2.34 million Btu. The brick veneer walls require seven to eight times the energy of wood construction and those incorporating aluminum about twice that of wood.

As is the case with exterior walls, significant differences appear in energy requirements for interior walls. Walls incorporating metal framing require approximately two to three times the energy of those with wood framing. The least significant difference appears between roofing designs with wood shingles requiring 1.81 million Btu and those with asphalt shingles requiring 2.85 million Btu.

These comparisons are handicapped by a few obvious shortcomings. The durability and ease of maintenance over the life of the product have not been considered. Similarly, the insulation characteristics of the walls and roofs made up by the alternative raw materials have not been taken into account. Information on durability, ease of maintenance, and insulation is very sparse.

Case Study #2: Containers and Packaging

Due to the numerous possibilities for materials substitution that exist in the field of containers and packaging, this activity has formed the subject of one of our case studies. Packaging and containers are also important in view of the large amounts of energy consumed in packaging as compared to other consumer services, e.g., transportation, storage, and marketing, etc.

Packaging is used for three major classes of goods: durables, nondurables, and foodstuffs. An overwhelming fraction of the durable goods are packaged in corrugated cardboard; corrugated material is also most commonly used for packing these materials. Nondurables consisting of clothing, textiles, and chemicals require a wide variety of packaging characteristics, but this is even more true for foodstuffs, the third major area for packaging. Foodstuffs represent about 15 percent of the production activity of the U.S. economy and account for 60 percent of the total shipment value of the entire range of goods that are packaged.

This sector involves the widest variety and largest amount of packaging materials, apart from corrugated cardboard (produced from renewable resources) used for durables. In the following discussion, specific examples will be considered for which the technology for substitution already exists, i.e., those packaging cases in which both nonrenewables and renewables can be interchangeably used to meet certain packaging requirements. Such examples are listed below:

.Sanitary food containers, e.g., milk containers. Other uses include containment of butter, margarine, frozen foods, ice cream, shortening, etc.

.Trays for packaging meats, eggs, and produce.

.Flexible containers, e.g., bags and sacks.

Although labor requirements and costs are also significant factors in the comparison of alternative materials, this case study of materials for containers and packaging focuses exclusively on energy inputs.

In connection with sanitary food containers, two RMS trajectories are shown in Figure 8. These correspond to the case of half-gallon milk containers made out of plastic and paper, respectively. Mass flows and energy values shown in the figure under each activity link refer to requirements imposed by manufacture of one container of each type. Energy data derived from Makino and Berry (1973) is in terms of "gross" value of energy requirement.* Summing up all the energy components along the two trajectories, it is observed that a plastic bottle weighing 0.12 pound needs about 8,496 Btu, whereas an equivalent paper carton weighing 0.14 pound needs 6,053 Btu. Also, the plastic bottle requires 0.038 pound and 0.107 pound of natural gas and crude oil, respectively, as chemical feedstock, while an equivalent paper carton needs 0.28 pound of groundwood. Adding the energy content of raw materials, total energy inputs to plastic bottle and equivalent paper carton are 11,310 and 7,453 Btu, respectively. In Figure 9 two trajectories for the manufacture of size 6 meat trays from styrofoam and molded wood pulp, respectively are shown. The energy requirements in the two cases add up to 892 and 875 Btu, respectively. Here again, taking into account 0.0047 pound of natural gas and 0.013 pound of crude oil needed as chemical feedstocks in the case of the polystyrene tray and 0.064 pound of groundwood needed as raw material for one pulp tray, the total energy values increase to 1,236 and 1,195 Btu, respectively.

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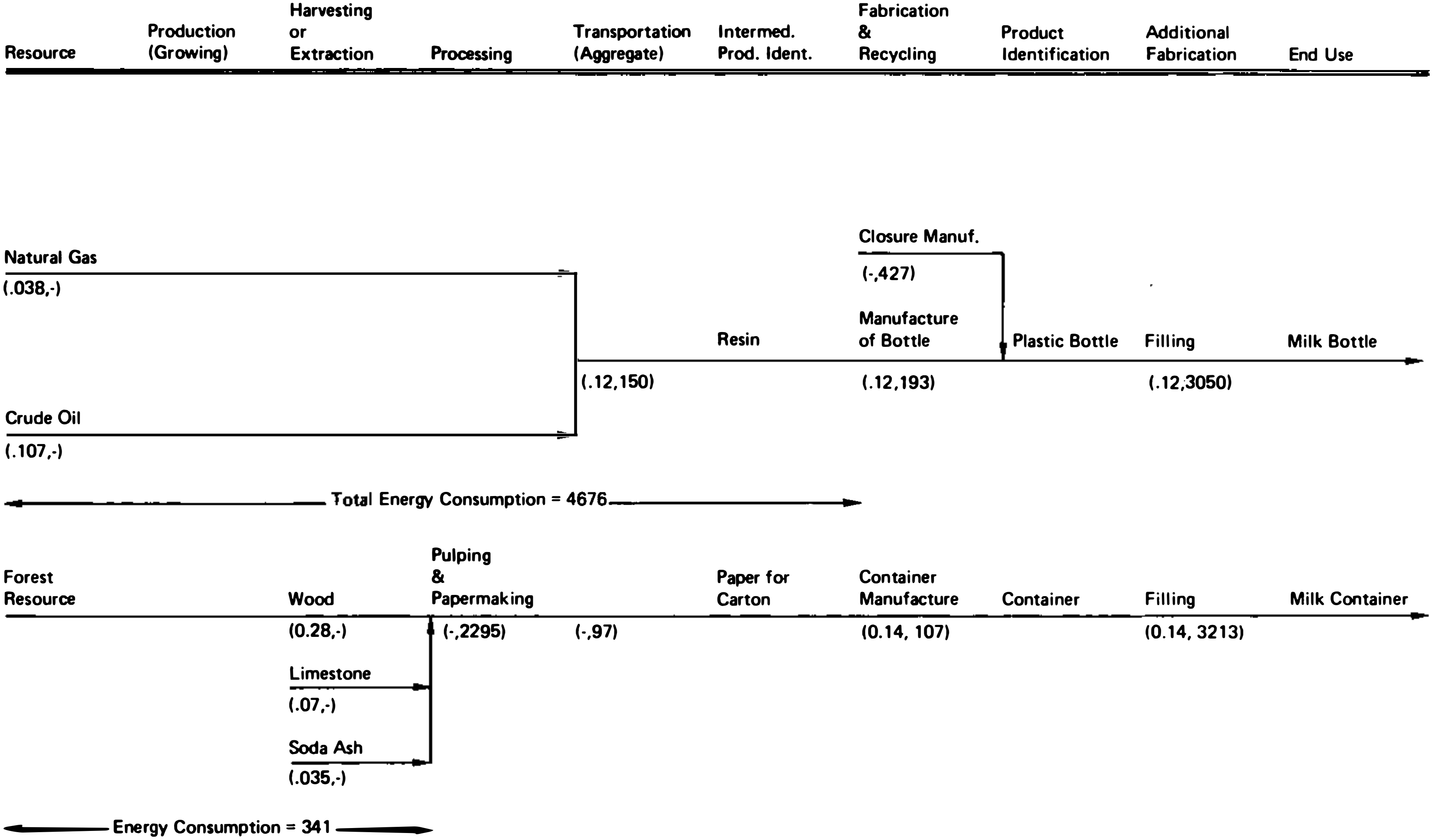
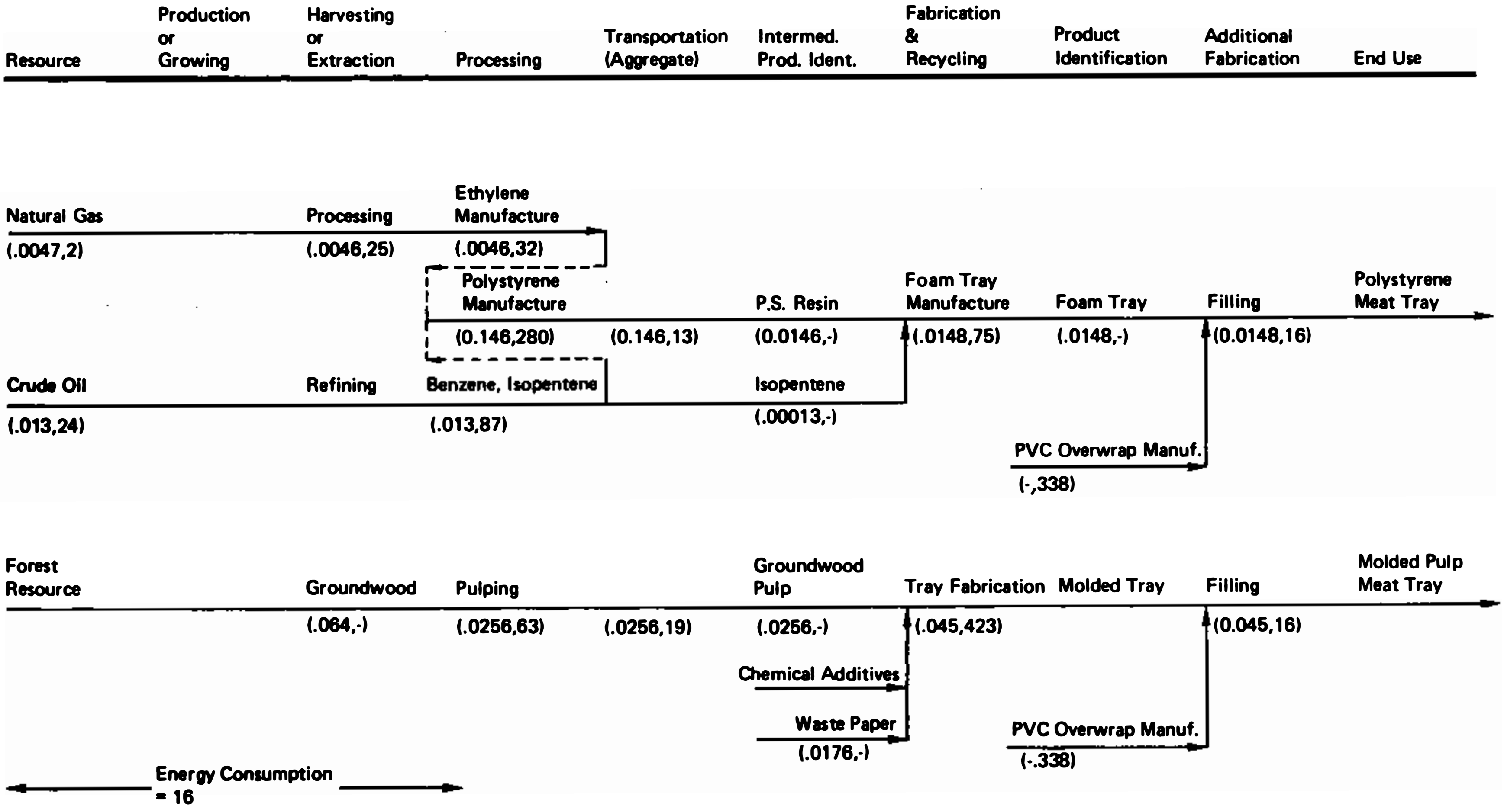
* Similar data were reported in Resource and Environmental Profile Analysis of Plastic and Non-Plastic Containers (1974), Midwest Research Institute, Kansas City.



Note: Numbers in the parentheses below the activity links refer to mass flow in lb & energy requirement in Btu respectively for the manufacture of one half-gallon milk container.

FIGURE 8 REFERENCE MATERIALS SYSTEM
Half Gallon Milk Container (Plastic Bottle Vs. Paper Carton)



Note: Numbers in the parentheses below the activity links refer to mass flow in lb. & energy requirement in Btu respectively for the manufacture of one size 6 meat tray.

FIGURE 9 REFERENCE MATERIALS SYSTEM
Size 6 Meat Tray (Polystyrene Vs. Molded Pulp)

In the case of "flexible containers," polyethylene is used for plastic bags and Kraft paper for paper bags. The energy cost of Kraft paper is about 20,500 Btu per pound, and of polyethylene, about 68,250 Btu per pound, or 3.3 times as much. However, a major portion of the Kraft paper energy use is derived from energy that is internally generated from processing by-products. But, because a medium-weight polyethylene bag weighs only half that of an equivalent paper bag, the ratio of energy consumption of plastic and paper bags is approximately 1.65:1.

The above comparison is not entirely fair to plastics if there is the possibility of re-using the plastic containers. As an example, a half-gallon plastic milk container uses about 8,500 Btu of energy to make and fill a single time. If it were re-used, and the washing and filling costs remained the same with each use (about 3,070 Btu), then the cost would drop to 5,785 Btu with one re-use, to 4,880 with two re-uses, and 4,427 with three re-uses. Similarly, although a single use of plastic bags requires more energy than paper bags, the two become comparable if the more durable polyethylene bags are re-used once. Despite significant energy savings as a result of re-use, it is not certain if creation of commercial facilities, to make such re-use possible is worthwhile.

The above results are summarized in Table 2.

Table 2

Energy Requirements For Manufacture of Containers

	Weight	Raw Material Requirements			Energy of Manufacture		Energy Content of Raw Materials	Total Energy per Container
Container Type	(lb)	Natural Gas (lb)	Crude Oil (lb)	Wood (lb)	(Btu)	(Btu/lb of Product)	(Btu)	(Btu)
1. Half Gallon Milk Container								
• Polyethylene Plastic	0.12	0.038	0.107	-	8,495 *5,445	70,790 *45,370	2,814	11,310
• Paper	0.14	-	-	0.28	6,053 *2,840	43,230 *20,280	1,400	7,453
2. Size 6 Meat Tray								
• Polystyrene Plastic	0.0148	0.0047	0.013	-	892	60,268	344	1,236
• Wood Pulp	0.045	-	-	0.064	875	19,440	320	1,195
3. Flexible Container (bag or sack)								
• Polyethylene Plastic	0.04	0.013	0.036	-	2,730	68,250	951	3,681
• Kraft Paper	0.08	-	-	0.16	1,640	20,500	800	2,440

***These values exclude energy required for filling the containers.**

Source: Makino and Berry (1973)

SOCIAL AND INSTITUTIONAL FACTORS INFLUENCING SUBSTITUTION

The activities evaluated by RMS may be influenced by social and institutional factors. The restrictions of law and government regulations can affect the supply of a resource. They can increase the requirements for capital, energy, and manpower in the conversion of a resources to a material to the point where the material is noncompetitive. The competitive position of renewable resources materials vis-a-vis nonrenewable resources materials is essentially a function of their relative price relationships. If renewable resources are to be substituted for nonrenewable resources, price relationships must change in favor of renewable resources through one or a combination of the following: (1) rising relative costs of nonrenewable resources, e.g., higher energy costs or increasing shortages of inorganic raw materials, (2) increased productivity in the renewable resources system through new technology or improved management leading to cost reductions at any of the various links in the system from natural growth to ultimate use, and (3) modification of existing institutional barriers leading to lower relative costs in the renewable resources system.

RMS was used to analyze substitution opportunities represented by a large number of comparisons between renewable and nonrenewable resources. These are described in detail in the individual reports listed in the Foreword and a number of examples have been presented here. These RMS analyses have not been exhaustive and many other comparisons of this kind ought to be similarly studied. All of RMS comparisons developed are based on current practice in the manufacture of products from both renewable and nonrenewable resources.

There are significant opportunities to improve the methods of using wood that will improve its performance as an industrial material. Many of these opportunities will be revealed by careful analysis of RMS trajectories and RMS analysis is a useful method for evaluating some of the consequences of changing wood use methods.

An example of such a change that needs to be evaluated is modification of standard lumber sizes. Lumber sizes now in use were developed at a time when manufacturing equipment was much less precise than it is now. These lumber sizes reflect levels of quality control that are at the bottom of current commercial practice. It is known that improved dimension control in lumber manufacture permits substantial improvement in yield of lumber from logs. The implications of improvements in standard lumber sizes and tolerances as reflected in improved yield ought to be evaluated through detailed RMS analysis.

Traditional designs for timber structures are often very wasteful of material. New design techniques have been developed that reduce the quantity of lumber required to produce a structure without adversely affecting its performance characteristics.

The information necessary to the type of substitution analysis represented by RMS is normally not collected in the form required. For many of the comparisons studied by CORRIM it was necessary to make estimates that were based on fragmentary data. If national planning for materials supply and conservation is to be undertaken, census information on materials, manpower, capital, and energy requirements at various stages of conversion should be assembled by the federal government. This would permit substitution analysis that could give some direction to federal R&D expenditures.

Factors Influencing Forest and Agricultural Practices

As indicated in the discussion of resources supply, the U.S. has a great undeveloped potential for the production of forest products. It should be possible to achieve the dual goals of increasing production and improving the environment. However, the forestry sector is particularly vulnerable to institutional and social constraints on materials production (Richardson 1974).

Forest Land Ownership

Forest land is owned for a variety of reasons ranging from commercial timber production to speculation or recreation and other personal satisfactions. These ownership objectives have a significant impact on the intensity of forest management that is practiced and the subsequent production of forestry products. Three general classes of ownership include forest industry lands, public forest lands, and small privately owned forest lands.

Forest industry lands include 13 percent of nearly 500 million acres classified by the Forest Service as having commercial potential. They are managed by companies that manufacture lumber, plywood, pulp, and paper and other wood products primarily to ensure supplies of raw materials for their own plants. As private companies, these companies manage their forest lands to minimize their raw material costs. This management has become more intensive in recent years and industry lands are generally very well managed. In the South, for example, the Forest Service projects that most industrial forest lands will be under intensive management by 1980 (PAPTE 1973).

Public forest lands comprise 27 percent of the area classified as suitable for commercial production. They are generally less intensively managed for timber production than are those of the forest industry. This is due to a variety of reasons, the most important of which is that public forests are managed for a variety of public purposes including recreation, wilderness, wildlife, watershed, education, etc. The public interest is multifaceted and the various publics have become increasingly concerned and vocal about how "their forests" are managed. As indicated in the chapter on Supply, the loosely defined mandate to practice multiple use has contributed to controversy concerning material use. The continuing controversy means that the potential output of raw materials from public forests in the future is considerably more uncertain than that of the industrial forest lands. The President's Advisory Panel on Timber and the Environment recommended in 1973 that intensive forestry management be applied to high quality lands in the National Forest system. The recommendation continues in controversy (PAPTE 1973).

Small private forests vary greatly with respect to potential productivity, size of ownership, and ownership objectives. These forests include some 60 percent of the potential commercial forest area. In general the owners are not practicing forest management but are holding the lands for speculation, recreation, or personal satisfaction. The turnover in ownership is relatively high. Prevailing economic incentives are simply not sufficient to attract these owners into managing for intensive raw material production, although timber or pulpwood sales are occasionally made.

One promising development, particularly in the South, is the expansion of long-term timber contracting. Close to 7 million acres of privately owned non-industrial woodlands are under long term (10 years or more) agreements with industry. The contract terms vary widely, but generally the product prices are adjusted by some mutually agreeable price index and the company manages the stand for increased production while the owner retains all other ownership rights. The majority of companies contacted were interested in increasing their long-term contracts to cover a large proportion of their raw material needs (Siegel 1974).

PAPTE recommends a federal program encouraging leasing of small private forest lands using similar principles and flexibility in its approach (PAPTE 1973).

Taxation of Forest Lands and Production

Landowners have always complained about high taxes. Any system of taxation must be judged first on its effectiveness, that is, its performance in raising the desired level of public revenues at a reasonable administrative cost. Any favoritism to one party must be made up from extra assessment on some other party. The second criterion is equity, that is, parties in equal circumstances should be treated in a similar fashion. The third consideration is an efficiency criterion. Is the taxing system providing incentives for the taxpayer to behave so as to further the broader public interests?

Let us focus here on the efficiency criterion and assume that the production of more forest products either now or in the future is in the public interest, and let us emphasize the influence of taxes on the intensity of forest management not the demand for forest land. In other words, nature provides eventually some sort of forest cover, where trees will grow, and since very little forestry is practiced on some 60 percent of commercial forest land, we are interested in the incentives or disincentives in the practice of forest management, not the ownership of forest land.

There are two general types of taxes of interest here, individual and corporate income taxes and real estate taxes. Federal and most state income taxes allow for capital gains treatment of income from forest products. This provides an incentive for the practice of forestry and is equitable in the sense that other businesses receive similar tax treatment. PAPTE said, "Capital gains tax treatment to timber crops has greatly stimulated investment in forestry by both industries and individuals."

The real estate tax is much more complex. It is clear that, under current cost/price conditions, real estate taxes constitute a major expense in managing timber lands--up to 40 to 60 percent of gross revenues (PAPTE 1973). Real estate taxes are ad valorem, usually based on the value of both the land base and the growing trees. These taxes are paid on an annual basis while income is received only periodically. Thus, it appears desirable to impose taxes to coincide with the times when incomes are received. Several states have adopted laws that permit separation of site and stand values and assessment of ad valorem taxes on the site and a severence or yield tax on the timber production (PAPTE 1973). It would also seem desirable to require payment of the severence tax when the land ownership changes since considerable amounts of non-industrial private forest lands are being held for speculation in non-forestry values.

Several states are experimenting with taxing forest land on the basis of productivity of the land base. In Tennessee, for example, timber is classified as a growing crop and is not subject to ad valorem taxes (Anon. 1975). The Tennessee practice should result in the greatest incentive for the practice of forest management. Other states provide preferential assessments for agricultural and forest land for its value as open space.

In some areas, second home developments or other high value land uses far from established communities have caused assessments on surrounding lands to be raised, penalizing farming and forestry operations. One possible solution to such problems might be a mechanism where the owners could retain or reduce prior assessments by deeding or selling development rights to the state or county.

There is abundant evidence that ad valorem real estate taxes are unevenly applied by various local governments (USDA 1935; Palo Alto Research Associates Inc. 1970; (referred to after this as PARA); Gregory 1972). It further seems desirable to modify the tax as applied to forest land to adopt severance taxes in lieu of ad valorem taxes on timber stands or to classify timber as a growing crop with safeguards to avoid speculation in land values. It is not clear that the level or incidence of taxes for non-industrial timberlands is the reason that present owners are not practicing forestry. They are, after all, now paying these taxes and declining to practice forestry with the intent to eventually increase their incomes.

Environmental Regulations and Forest Practice Acts

The past decade, in particular, has seen the passage of an enormous number of laws and regulations aimed at controlling air and water pollution and the use of potentially hazardous chemicals. This development and the legislation of forest practice acts in many states, has created great uncertainty for the farmer or forest manager. These uncertainties involve the difficulty of understanding what is currently required of him, what the enforcement policies will be, and whether in his long-term planning he should assume that he will be subject to even greater restrictions. The goals of these programs to improve the environment or stimulate better forestry practices are desirable, but frequently the administration is not. Ease of administration is obtained by defining simple physical standards and applying them across the board. This approach is inequitable because parties in different circumstances are treated uniformly, and it is inefficient because more resources are required for compliance than would be the case in a more flexible approach.

The use of fire as a management tool is regulated under various state air pollution control laws that may require permits and often specify the times and other requirements to be observed. Pesticides are regulated under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and companion laws in each state. The impact of the regulations is to restrict the choice of pesticides available, to require the licensing of commercial applicators, and restrict the method of application in certain instances (Weitzman 1975).

A much more important set of regulations is developing with respect to water pollution control. The Federal Water Pollution Control Act (FWPCA) requires the control of water pollution from identifiable point sources and from nonpoint sources. The initial approach of the Environmental Protection Agency (EPA) was to make a categorical exemption of all point source discharges relating to silvicultural activities from the point source discharge controls (July 5, 1973, EPA regulations, <u>Federal Register</u> 38(128):18003). EPA did not identify which specific silvicultural activities were, in fact, point source discharges and which were not; rather, EPA simply stated that whatever silvicultural activities are, in fact, point source discharges will be excused from the point source discharge permit requirements, although effluent limitations for them have never been established. Subsequent to its ruling, in the lawsuit before Judge Flannery, EPA argued that everywhere that polluted water flowed from a forest ditch or culvert into navigable water was in fact a point source discharge.* Others in that case argued that those flows of water did not constitute a discharge. The Court refused to address the question of what constitutes a point source discharge but maintained that EPA lacked authority to grant categorical exemptions to anything that was in fact a point source discharge and that EPA would have to identify in its rules which silvicultural activities were and which were not point source discharges. The implication is that, if silvicultural activities are "point sources," they will be subjected to both permit requirements and effluent standards. Inherent in this is the subtle difference between a "source" and a "discharge." EPA attempted to exclude "point source discharges" not "point sources" from permit requirements but the Court decision equates "source"

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*Natural Resource Defense Council, Inc. vs. Russell E. Train, Administrator, E.P.A. Civil Action 629-73, U.S. District Court, Washington, D.C.

to "discharge" and prohibits any categorical exemption regarding "point source discharges."

In EPA's proposed rules published on February 12, 1976 (Federal Register 41(30):6283[40 CFR]), EPA proposes that "the term 'silvicultural point source' means any discernible, confined and discrete conveyance relating to rock crushing, gravel washing, log sorting or log storage facility from which pollutants are discharged into navigable waters. This term does not include nonpoint source activities inherent to forest management such as nursery operations, site preparation, reforestation in all stages of growth, thinning, prescribed burning, pesticide and fire control, and harvesting operations from which runoff results from precipitation events. However, some of these activities may involve the discharge of dredged or fill material which would require a 404 permit." The explanation accompanying the proposed rule states in part: "Only those silvicultural activities that, as a result of controlled water use by a person, discharge pollutants through a discernible, confined and discrete conveyance into navigable waters are required to obtain a Section 402 Pollution Discharge Permit." Thus all silvicultural activities that can be described according to the proposed definition will be subject to all "point source" federal laws and regulations and all others will not be.

It is recognized that these are only proposed rules. The public had until March 25, 1976, to submit comments relative to them. As to nonpoint silvicultural activities, these will be subject to applicable requirements of Section 208 relative to areawide waste treatment management. However, it must be recognized that there is a great deal of disagreement concerning the interpretation of Section 208.

There is the possibility that regulation will proceed through a federal-state system, perhaps using local forest practice boards. Forest practices acts controlling cutting and silvicultural practices were first passed in the early 1940s and now exist in 16 states. The original acts focused on regeneration of new stands following harvesting. Emphasis in the new acts is broadened to include air and water quality, fisheries, soil, wildlife, etc. They involve creation of state and sub-state boards comprised of timber owners and/or others knowledgeable in forestry (Cornelius 1975). For example, EPA has proposed a model State Forest Practices Act patterned after the California Act. This proposal has a controversial requirement that a timber harvesting plan must be submitted and receive prior approval (Le Master 1975). However, in some parts of the U.S. the term state forest practices act is not held in any high esteem and will not necessarily be required under any interpretation of Section 208. It also appears that EPA has given up the model Forest Practices Act and that each state will be required to submit a proposed 208 plan that will be acceptable to EPA. These plans must be completed by 1978.

Regulation of forest practices has been a long-term success in increasing Finland's forestry production where small private ownerships comprise 65 percent of the forest land and account for almost 80 percent of the annual cut (Nyyssonen and Osara 1975). The apparent success of the Finnish experience stems from the use of locally representative forestry boards and a long and persistent effort to build a cooperative attitude between forest owners and forestry officials.

We are in a period where more research results on probable effects and acceptance of regulation are being demanded and more studies of trade-offs are needed. The state of scientific knowledge and the arts of farming and forestry are currently inadequate to predict the impact of given regulatory practices, under varying weather and site conditions, with reasonable accuracy in many cases. This period of uncertainty will continue for several more years for farm and forest managers. This uncertainty related to regulatory control translates into uncertainty of materials supply.

National Forest Management Policies

The National Forests contain over half the softwood timber volume and occupy a central position in public awareness of the importance of forest management. National Forest management policies are critically important in considering the use of renewable resources and in recent years they have been in the center of a national controversy.

The issues of National Forest management are complex but, to oversimplify, there are three schools of thought. Economists, numerous foresters, and industry people are calling for increased harvest of timber to salvage large amounts of wood now being lost in deteriorating mature stands and to enable more vigorous growth in new stands on the same sites. Environmentalist groups are fighting to preserve as much forest in wilderness condition as possible through political and court actions and budget reductions to restrict timber sales, road building, and management operations. The Forest Service is in the middle trying to balance opposing forces.

As a federal agency, the Forest Service is particularly vulnerable to criticism for engaging in intensive forest management practices designed to increase materials supply when these practices are perceived to be detrimental to aesthetic or recreation values. The Forest Service is mandated under the Multiple Use-Sustained Yield Act of 1960 to use these land-use principles in the management of the National Forests. Increasingly, the general provisions of this act have been very narrowly defined to interpret sustained yield to mean even flow and to interpret multiple use to mean every use and equal use. These attitudes toward the use of publicly owned forest land are not unique to the U.S. (Richardson 1974).

The President's Advisory Panel on Timber and the Environment recommends increased timber sales and adequate funding to provide for more intensive management of National Forest lands (PAPTE 1973). These recommendations have generated considerable controversy. Others have chided the sustained yield concept (i.e., maintenance of uniform harvest levels) of the Forest Service as an outdated concept conceived for an era of stability and certainty that no longer exists (Behan 1975).

The Forest and Rangeland Renewable Resources Planning Act of 1974 required that the Forest Service release its draft program for public comment in mid-August 1975. The act calls for long-range planning to insure that the U.S. has an adequate supply of forest resources in the future while maintaining the quality of the environment. The final report is due early in 1976. Environmental statements must be prepared and public comments received. The Forest Service must include adequate funding in its budget to carry out the plan or explain why it does not. The Resources Planning Act hopefully provides a method for achieving a workable consensus for managing the National Forests. The outcome will be a very significant factor in future supplies of forest products.

Federal Agricultural Policies

Federal agricultural policies have an impact on the supply and price of agriculturally produced industrial raw materials. These policies operate through a complex array of subsidies, loans, and restrictions on production. They impact directly on crop production and, in the case of industrial materials, are most significant at present in the production of cotton.

For a number of years the price of cotton was supported by accumulation of government stocks. The supported price of cotton tended to provide an incentive for the replacement of cotton by synthetic fibers.

Under 1973 legislation the cotton program operates to guarantee a return to the cotton producer through a payment equivalent to the difference between the market price and the "target" price, while the market price is established by competition in the marketplace. Favorable market conditions have resulted in prices above the target price and no payments have been made to producers under the present act, except in cases of crop failure.

Factors Influencing the Processing and Transportation of Renewable Resources

The major institutional factors impacting on manufacture of renewable resources products involve new environmental regulations, government safety and health regulations, regulation of transportation, and federal tax policy with respect to new investments.

Environmental Regulations

New air and water pollution abatement regulations have required substantial adjustments in manufacturing operations. The adjustments appear to be well along toward compliance, but the investment costs have been high. At sawmills, planing mills, and plywood plants disposal of solid waste formerly burned or buried has been replaced to a significant extent by recovery and use in the production of new products or use as fuel in the production process (U.S. Department of Commerce, 1975 [referred to after this as U.S. COM]).

The pulp and paper industry is the third largest consumer of water in manufacturing. Substantial progress has been achieved but, again, the costs have been high. Under the 1972 amendments to the Federal Water Pollution Control Act, industry will be required to meet two progressively stringent standards. The first level is use of the "best practicable control technology currently available." This level is to be implemented and enforced by July 1, 1977. The second standard states that, by July 1, 1983, point sources shall require application of the "best available technology economically achievable for such category or class." This may or may not require zero discharge, which has been interpreted by many to mean complete removal of heat, chemical, and other pollutants before discharge.

Interpretation of the act with regard to zero discharge is confusing. There is no requirement in Section 301 relative to additional effluent limitations to achieve the goal of eliminating discharges of pollutants by 1985, even though such a goal is noted in Section 101 of the act. Undoubtedly many will argue that the act does not require compliance with the zero discharge goal for 1985 unless it can be achieved by applying the "best available technology economically achievable for such category or class." Also the recent report of the National Commission on Water Quality (1976) seems to recommend against implementation of any such goal.

A study commissioned by the National Council of the Paper Industry for Air and Stream Improvement (1974) estimated that the costs of meeting the first standard will be $4.50 to $6.00 per ton of output. It was also estimated that additional capital costs required during the 1972-1977 period will exceed $1.2 billion.

In the 1972-1973 period, pollution abatement expenditures were about half of all primary pulp and paper industry investment. Some experts estimate that pollution abatement requirements will account for 10 to 15 percent of the capital outlays for new primary production facilities in the future (U.S. COM 1975a).

The costs of abating pollution are very high and the goal of "zero discharge" will be extremely costly. It appears that the wood products and textile industry can meet these costs through higher prices to consumers. However, many observers believe that the benefits of "zero discharge" are not worth the costs to society, ultimately the consumers. This is a central issue examined by the National Commission on Water Quality (1976).

Health and Safety Regulations (OSHA)

New federal regulations designed to protect the health and safety of industry workers are imposing large costs on all industries. These regulations involve dust, heat, noise and other factors in the industrial environment. An Occupational Safety and Health Administration (OSHA) regulation on cotton dust levels in textile mills was imposed in 1971 (Federal Register 36(157):15101-15104). The capital cost to textile mills for cotton dust control has been estimated at $960 million plus $53 million a year for operation and maintenance of the equipment, testing, etc. A new standard is being considered that would require capital expenditure of $1,440 million. With capital outlays amortized over 10 years at 9 percent interest, the total annual cost of the present standard would be $230 million or about 6.8 cents per pound of cotton used.

It is obvious that the health and safety of workers in the textile and wood products industries must receive reasonable protection. However, such regulations will be costly and final decisions on standards will have significant effects on the competitive position of renewable resources materials.

Regulation of Transportation

The energy crisis and the bankruptcy of several large railroads have brought the issues of transportation regulation before the public once again. The bulky nature of wood products, in particular, means that the structure of transportation rates has a significant impact on location of their production with respect to markets.

Transportation rates are particularly important to the forest industry in the Northwest. Here, we have the paradox of exports from Washington State to Japan in preference to eastern U.S. markets, while neighboring British Columbia competes in the same eastern markets. The reason is the Jones Act (The Merchant Marine Act of 1920, P.L. 261 as amended in 1935, 1936, and 1958) [46 USC 883 (1970), as amended PL 191 (1935) 49 Stat. 442; PL 835 (1936) Sec. 204, 904, 49 Stat. 1987, 2016; PL 85-508 (1958) Sec. 627(a), 72 Stat. 351.], which requires that all cargos between American ports be carried in vessels built, owned, and manned by Americans. The Jones Act has been subjected to spirited attack over the years by consumer groups and other interests. The U.S. Treasury Department has very rarely granted waivers and then only on a case-by-case basis (Economic Research Service 1975, personal communication, USDA, Washington, D.C.).

Informed observers in the Northwest note another competitive disadvantage with respect to British Columbia. Railroad rates on Canadian railroads for shipment of forest products eastward are lower by as much as 17 percent for comparable distances (J.S. Bethel 1975, personal communication, University of Washington, College of Forest Resources, Seattle).

Transportation costs represent approximately 25 percent of the delivered price of Canadian forest products. Approximately three-fourths of coastal British Columbia shipments are waterborne, and the bulk come to the U.S. Once on the ship, the cost of additional distance is low. In 1972 the cost of shipping 1,000 board-feet of lumber from

Vancouver to Boston was $35. In contrast, the cost of shipping by railroad to Boston was approximately $61. However, shipments from interior British Columbia normally move by rail or truck and not by water because of high costs of reloading on ships (Aspey et al. 1973).

The issue of upgrading and rationalizing the U.S. transportation system transcends the forest products industry, but the ultimate outcomes will have a significant impact on the location of production, processing, and markets served. The continuing controversy is another significant uncertainty in planning for forest materials production.

Federal Tax Policy on New Investments

There is considerable current debate on the desirability of the present level of industrial investment and the problem of technological obsolescence in American industry. Rapidly rising machinery costs have made existing depreciation schedules obsolete. Increasing capital requirements to meet environmental and health and safety regulations have reduced the proportion of new investment funds available for increasing productivity. While recommendations in this area are beyond the scope of this study, it is apparent that outcomes of the current debates on investment tax policies could have a significant impact on the role of renewable resources in the future.

Factors Influencing the Use of Renewable Resources Products

There are many institutional factors that influence the use of products from renewable resources. Two major categories of government policy, monetary and fiscal policies and consumer standards and building codes, are selected for emphasis here.

Federal Monetary and Fiscal Policies

Modern fiscal and monetary policies for stabilizing the general economy, dampening inflation, or stimulating employment, have had the effect of greatly destabilizing the flow of funds into construction activities. This condition is true both in direct government funding and indirectly in the private financial markets. The result is to create a wildly unstable market for lumber, plywood, and other building materials and to create a very inefficient operating pattern in the structural materials industry. The condition is widely recognized. This report has nothing new to contribute to the policy debate. However, it would be inappropriate to review institutional factors impacting on the use of renewable resources without drawing attention to perhaps the most significant obstacle to the efficient production and use of these materials.

Consumer Standards and Building Codes

The function of government standards and codes is to establish rules for the design, manufacture, or construction of safe and sanitary products and structures. The adoption of new consumer standards generally improved the welfare of society but will definitely have the impact of increasing the costs of these products. The National Cotton Council estimates that the cost of new flammability standards for children's sleepwear is about a dollar per garment higher or about $115 million per year.

In the case of building codes and standards, the situation is somewhat different. Recent innovations in building materials have made many of the old rules overly conservative and therefore overly expensive. Many knowledgeable observers have called for review and updating of these rules, recommending change from specification requirements, i.e. specifying a particular size or material to performance requirements.

There appears to be ample scientific evidence to support these recommendations. Inertia results from the many state and municipal governments, the variety of codes involved, and opposition from construction unions and materials manufacturers with a vested interest in the status quo. One positive force for reform both in terms of modernization and increased uniformity has been the requirements of the Department of Housing and Urban Development (HUD). Before qualifying for certain housing program assistance, state and municipal governments must adopt the HUD changes.

Factors Influencing International Trade in Renewable Resources Materials and Products

Constraints on international trade in wood products vary with the type of product and internal production patterns. Nations with heavy consumption of wood products tend to levy rather heavy tariffs on incoming finished products if they compete with domestic production but to admit raw materials and semi-manufactured items with little or no duty (Thomas et al. 1968). For example the U.S.

allows Canadian logs, lumber, pulp, and newsprint in without tariff but maintains a prohibitively high tariff on plywood (10 to 20 percent ad valorem).

Our plywood exports to the European Economic Community (EEC) are expected to decline some 5 percent this year to $80 million due to recently imposed trade restrictions. An EEC duty free quota of about 450 million square feet (3/8 inch thickness basis) has been assigned to U.S. softwood plywood exports. An entry duty of 13 percent ad valorem will apply to quantities in excess of that amount (U.S. COM 1975b).

In 1972 the United Kingdom, Denmark, and Ireland, former European Free Trade Association (EFTA) members, elected to join the European Economic Community or Common Market. Sweden, Finland, and Norway, non-EEC members and world traders in pulp and paper, sought and received special trade concessions from the Common Market in 1973 that provided them with progressively larger competitive advantages when trading with EEC in paper and board. After a transition period Sweden, Finland, Norway, Austria, and Portugal will be trading free of duty in these commodities. Imports from other countries, including the U.S. were to be subject to duty rates ranging upward from 12 percent.

Since Europe represents the largest foreign market for the U.S. paper industry, accounting for more than 40 percent of the total pulp, paper, and board exports, the U.S. paper industry has been seeking equivalency of treatment with respect to tariff rates on these commodities. In May 1974, President Nixon announced the results of successful broad-ranged negotiations, some of which affected paper and board trade. New duty rates for most-favored nations dealing with the expanded Common Market on products including Kraft paper and board are to decline from the current 11 percent gradually to 8 percent by 1979. While these tariff rates do not constitute equivalency of treatment, they do represent concessions. The forthcoming international trade negotiations may result in some further advances in this area (U.S. COM 1975b).

CHAPTER 6

RENEWABLE RESOURCES FOR STRUCTURAL AND ARCHITECTURAL PURPOSES

INTRODUCTION

Wood, with only minor exceptions, is the only renewable resource economically suitable for structural and architectural purposes. It has always been attractive to primitive societies as a structural material because it is easily available, it can be used in very nearly the form in which it grows, and if it requires modification for use, it can be worked with very simple tools. The pole house with thatch roof and walls has been the poor man's house in warm countries for centuries, and it is still extensively used in many tropical countries today. In colder climates the log cabin with split shake roof is the counterpart of the pole house. When it is desirable to convert the round pole or log to a board or timber for use, it can be done with a hand saw using a platform or pit. This method of manufacture is still used in many less-developed countries. The more sophisticated modern sawmills are typically small factories with band, sash, or circular saws driven by water wheels or steam, electric, or internal combustion engines. Some sawmills are very large, processing up to 1 million board feet per day, but this is the exception in the lumber industry.

Veneer and plywood are also wood products whose use dates back to antiquity. Very fine examples of the veneer makers have been discovered in the tombs of the pharaohs in Egypt. The Assyrian, Babylonian, and Roman cultures also developed the use of wood in lumber and veneer forms as structural and architectural materials.

In the U.S. the use of wood for structural and architectural purposes accounts for the greatest volume among all wood uses. Of some 250 million tons of raw wood--approximately equal to the combined production of all metals, cements, and plastics--that are processed each year by the nation's forest product industries (Cliff 1973), 63 percent is converted to lumber and rigid panels, which are, in turn, used in structures and in innumerable manufactured commodities. Projections of the Forest Service (USDA 1974d) indicate an approximate doubling of the demand for raw wood between the years 1970 and 2000, with lumber and rigid panels accounting for over 50 percent of the total demand. During this 30-year period of increasing wood demand, major changes are occurring in the size, quality, and mix of the raw-material base from the forests and in the environment that affect the manufacture of forest-based commodities.

The use of wood in lumber and panel forms takes maximum advantage of the basic biological structure of the parent tree and therefore maximum advantage of the photosynthetic process as a material synthesizer. It is in these forms as well that wood maximizes its advantage over most competitive materials in terms of energy required for use. RMS analysis provides a vehicle for studying the flow of forest-based materials into primary structural and architectural commodiites and for examining energy, manpower, and capital requirements in the manufacture of these primary products, and their conversion into "model" building systems, as compared with selected alternatives manufactured from nonrenewable raw materials.

Inventory data classify trees, largely on the basis of stem diameter, as sawtimber or pulpwood. Trees included in the first category yield logs generally considered of suitable size and quality to be converted to lumber or veneer, whereas trees in the second category have been generally considered too small for conversion into these two products. Technological advances in use, however, together with the economic practicalities of product manufacture from a given raw material supply, have largely eliminated the distinction between these categories from a use standpoint. Trees of all diameters, therefore, must now be considered part of the raw-material base for structural and architectural commodities in the form of lumber or of structural timbers and panels derived from smaller pieces of lumber or from veneer, flakes, particles, or fibers. Fiber for paper and other pulp-based products is similarly drawn from a reservoir of raw material from both categories. The old sawtimber and pulpwood categories are nevertheless used in RMS analysis as the National Forest Service still employs them.

Materials-flow trajectories (Figure 1) derived from 1970 data reported in The Outlook for Timber in the United States, hereafter referred to as the "Outlook Study" (USDA 1974d), indicate a usable raw material base for the forest products industry in 1970 of 193 million oven-dry (O.D.) tons of roundwood with bark intact. Of this, 115 million oven-dry tons are categorized as sawtimber, yielding 98 million tons of sawlogs and 17 million tons of veneer logs. The remaining 78 million tons are classified as pulpwood and polesize timber. Softwoods account for 135 million tons of

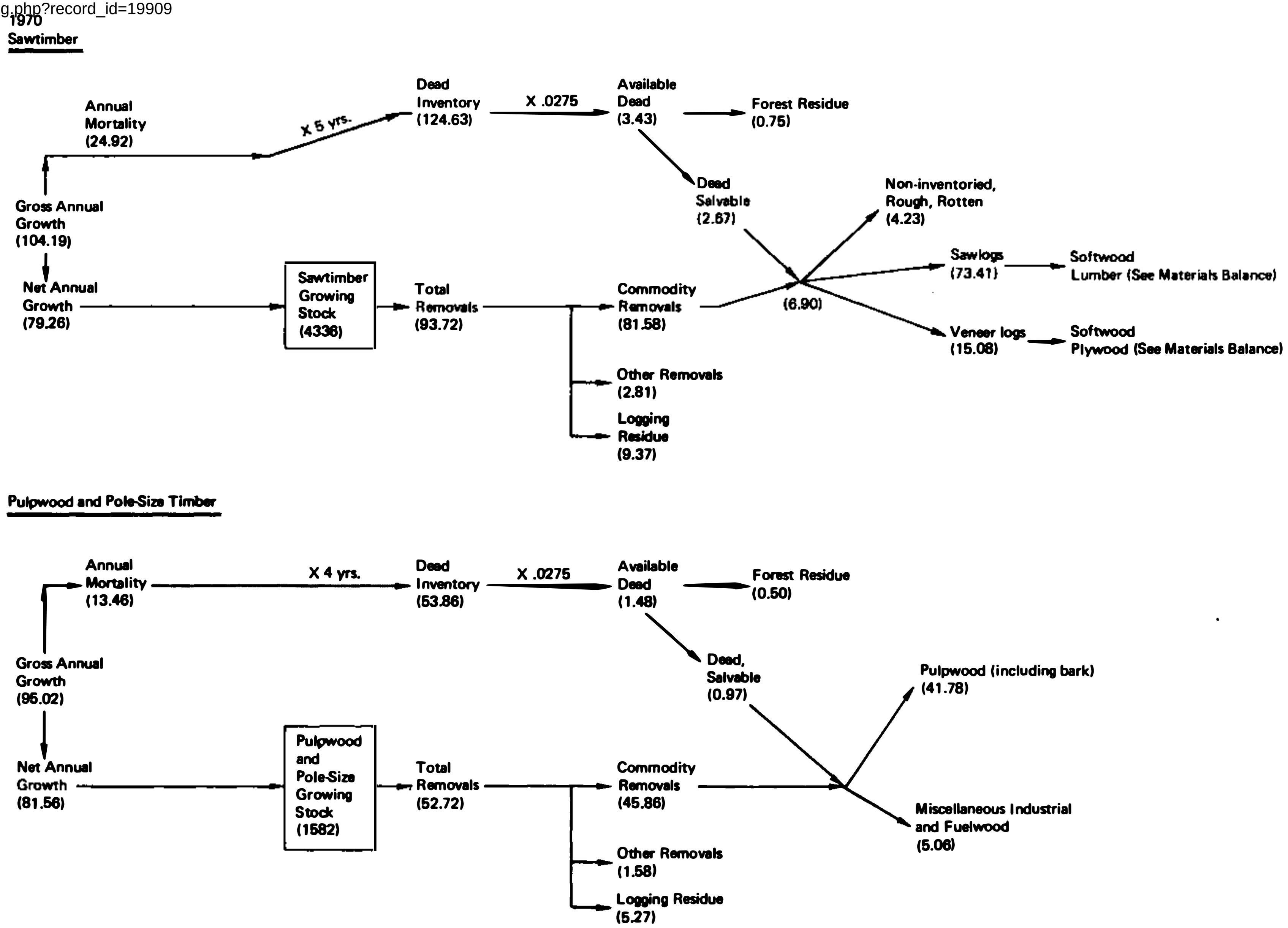


Figure 1 SOFTWOOD MATERIALS FLOW TRAJECTORIES (All data in Millions of Tons, O.D. weight[*])

[*] Based essentially on data provided in the Outlook Study (1974) of the U.S. Forest Service. Conversion of cubic feet to tons (O.D.) has been through multiplication by 0.0137. All values include bark. Data on growth and removal reflect current inventory standards. Complete-tree utilization, according to Keays (1971), would permit a commodity removal increase of 36% from the same growing stock equivalent to 44.31 million tons, or a net increase of 29.67 million tons after deduction of current logging residues from growing stock of 14.64 million tons.

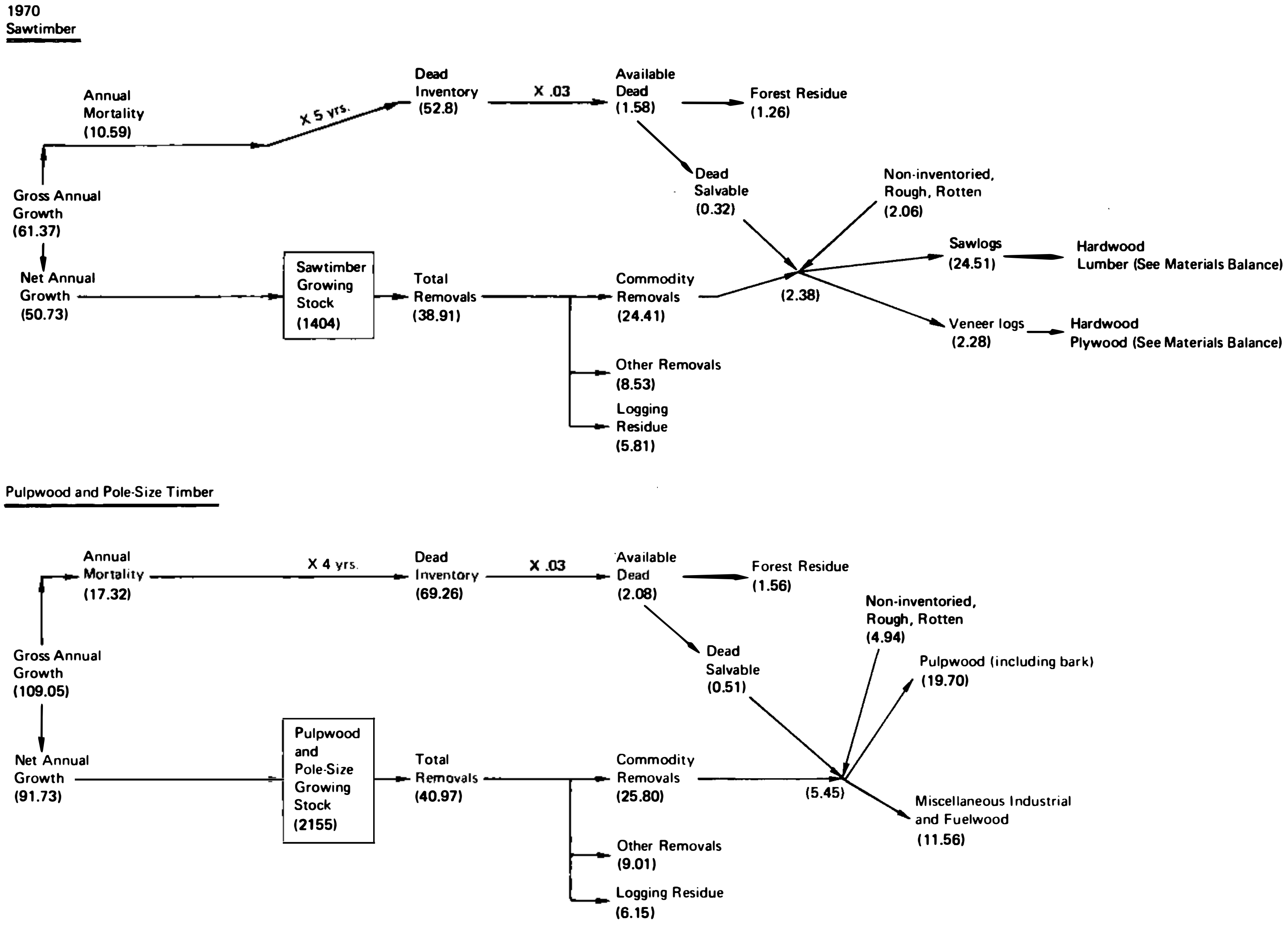


Figure 1 HARDWOOD MATERIALS FLOW TRAJECTORIES (All data in Millions of Tons, O.D. weight*)

*Based essentially on data provided in the Outlook Study (1974) of the U.S. Forest Service. Conversion of cubic feet to tons (O.D.) has been through multiplication by 0.0164. All values include bark. Data on growth and removal reflect current inventory standards. Complete-tree utilization, according to Keays (1971), would permit a commodity removal increase of 35% from the same growing stock equivalent to 17.58 million tons, or a net increase of 5.62 million tons after deduction of current logging residues from growing stock of 11.96 million tons.

material, approximately 70 percent of the total, of which 88 million tons are categorized as sawlogs and veneer logs. The remaining 58 million tons are hardwoods of which 27 million tons are sawlogs and veneer logs.

Manufactured from this raw-material mix flowing into industry are 42.8 million oven-dry tons of lumber and rigid panels suitable for building materials. Additionally yielded from this mix are 6.8 million tons of cooperage, piling, poles, posts, mine timbers, and other miscellaneous products, which are dependent in part for their utility on mechanical strength. In all, 26 percent of all raw material from the forests undergoing manufacture and 43 percent of all raw material classified as saw timber enter the market in the form of primary structural products.

For the purpose of this study, structural and architectural materials are considered to be those contributing to the form and structural integrity of the product. Emphasis is thus given to renewable resources that, in primary processed form, are characterized by reliably known physical and mechanical properties and are dimensionally suitable for structural use. Decorative and aesthetic characteristics, per se, are not considered. The study therefore concentrates on the processing of raw materials from the forest into prisms and rigid panels, which can in turn be fabricated into engineered and architecturally designed structures, and the flow of these materials into selected building components.

The basic structural materials manufactured from wood (Table 1) are therefore lumber, which is sawn or shaped from the log, and rigid panels. Panels are fabricated by reducing wood to veneer, particles, flakes, strands, or fibers that are, in turn, reconstituted into thin sheets by pressing between heated platens, usually in combination with an adhesive. Sheets thus formed are broadly classified as plywood--fabricated from veneer--and building board, which consists of an array of sheet products under generic classifications including particleboard, flakeboard, hardboard and insulation board.

Lumber and panels suitable as building materials are used in a wide spectrum of secondary products (i.e., products other than structures) that are not specifically included in this analysis. In 1970, 12 percent of all lumber, 9 percent of all plywood, and 19 percent of all building board was used in the manufacture of such secondary products as furniture, boats, truck bodies, and innumerable other items (Table 2). Of the secondary commodities using substantial quantities of primary structural materials, furniture manufactured in 1970 accounted for 7 percent of

Table 1

Utilization of Timber in the U.S. for Primary Structural and Architectural Commodities, 1970[1]

Primary Commodity	Approximate Yield (million oven-dry tons)		% of Total	
Softwood Lumber	23.4		47.2	
Hardwood Lumber	7.3		14.7	
Total Lumber		30.7		61.9
Softwood Plywood	6.3		12.7	
Hardwood Plywood	.4		.8	
Total Plywood		6.7		13.5
Hardboard	2.4		4.8	
Insulation board	1.2		2.5	
Particleboard	1.8		3.6	
Total Building Board		5.4		10.9
Cooperage, Piling, Poles, Posts, Mine Timbers	3.8		7.7	
Other Miscellaneous	3.0		6.0	
Total Miscellaneous		6.8		13.7
TOTAL		49.6		100.0

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

Table 2

Some Secondary Uses of Primary Commodities
(based on 1970 statistics)

COMMODITY

	Lumber		Plywood		Building Board (1)		Particle-board		Hardboard		Insulation Board	
	MM* tons	% total	MM* tons	% total	MM* tons	% total	MM* tons	% total	MM* tons	% total	MM* tons	% total
SECONDARY USE												
CONSTRUCTION												
Residential	13.2	43	3.3	49	2.3	43						
Non-Residential	2.8	9	0.7	10	0.6	10						
TOTAL CONSTRUCTION	16.0	52	4.0	59	2.9	53					1.8	83 (2)
MANUFACTURE												
Furniture	2.2	7	0.34	5			0.6	34	0.4	17		
Other	1.5	5	0.26	4			0.1	4	0.3	12		
TOTAL MANUFACTURE	3.7	12	0.60	9	1.0	19	0.7	38	0.7	29	0.2	
SHIPPING												
Pallets	2.5	8	-	-								
Other	2.1	7	-	-								
TOTAL SHIPPING	4.6	15	-	-								
MISC. USES	6.45	21	2.1	32	1.5	28						17
TOTAL	30.75	100	6.7	100	5.4	100	-	-	-	-	-	-

(1) Includes particleboard, hardboard, and insulation board
(2) Residential and non-residential construction combined

* M M Million oven-dry

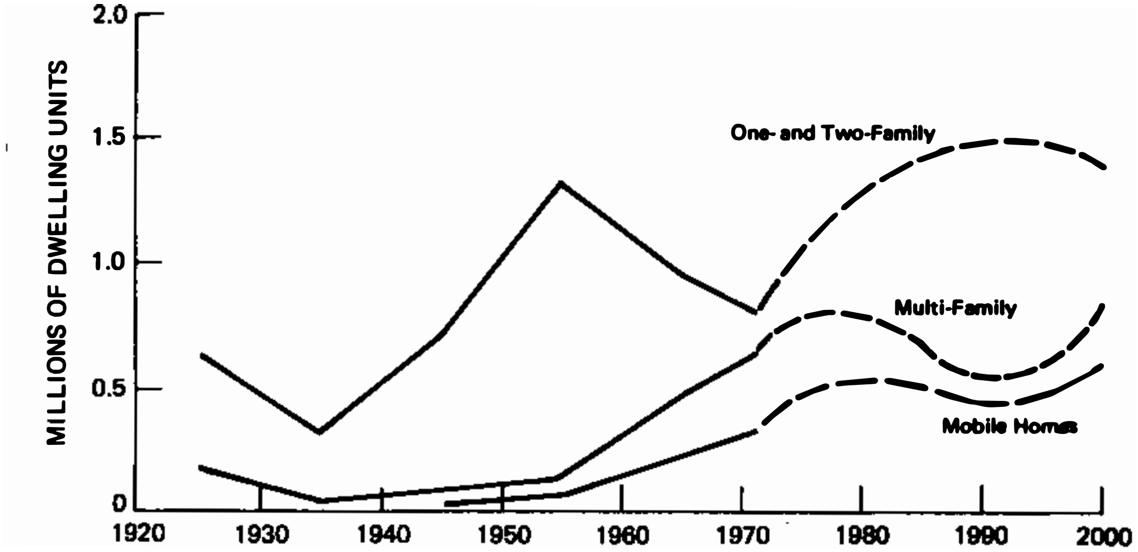
all lumber, 34 percent of all particleboard, and 17 percent of all hardboard. At the present time, approximately 60 percent of the rapidly expanding production of particleboard is used in furniture and allied products with the remaining 40 percent being used in construction. Importantly, a very high percentage of the lumber used in furniture manufacture is hardwood which currently has limited utility for structural and architectural applications.

Of particular significance, from the standpoint of hardwood use, is the demand for wood to be used in shipping in the form of wood containers, dunnage, blocking, and bracing and, most importantly, pallets. Since the early 1960s, the increase in wood used in shipping has been largely attributable to the increased demand for pallets: Pallets now consume approximately 15 percent of all lumber manufactured. Substantial increases in pallet consumption are projected in relation to growth in industrial production (Cliff 1973).

Sawn mainline railroad ties, which are in short supply, provide another important use for hardwoods of limited value for other purposes. Of more than 1 billion crossties supporting some 350,000 miles of railroad track in the United States today, many have been in place longer than their expected life; additionally, increased axle loads are accelerating mechanical deterioration of ties in place. The rate of crosstie replacement until the end of the century will be predictably high. Low-grade hardwoods in solid or laminated form are well suited to this need (Howe and Koch 1975).

Piling, poles, posts, and mine timbers, which are largely roundwood, constitute a significant tonnage of structural products as indicated in Table 1. Important among these are piling for which 28.8 million linear feet of roundwood were required in 1970, and poles of which 5.4 million were used during the same year.

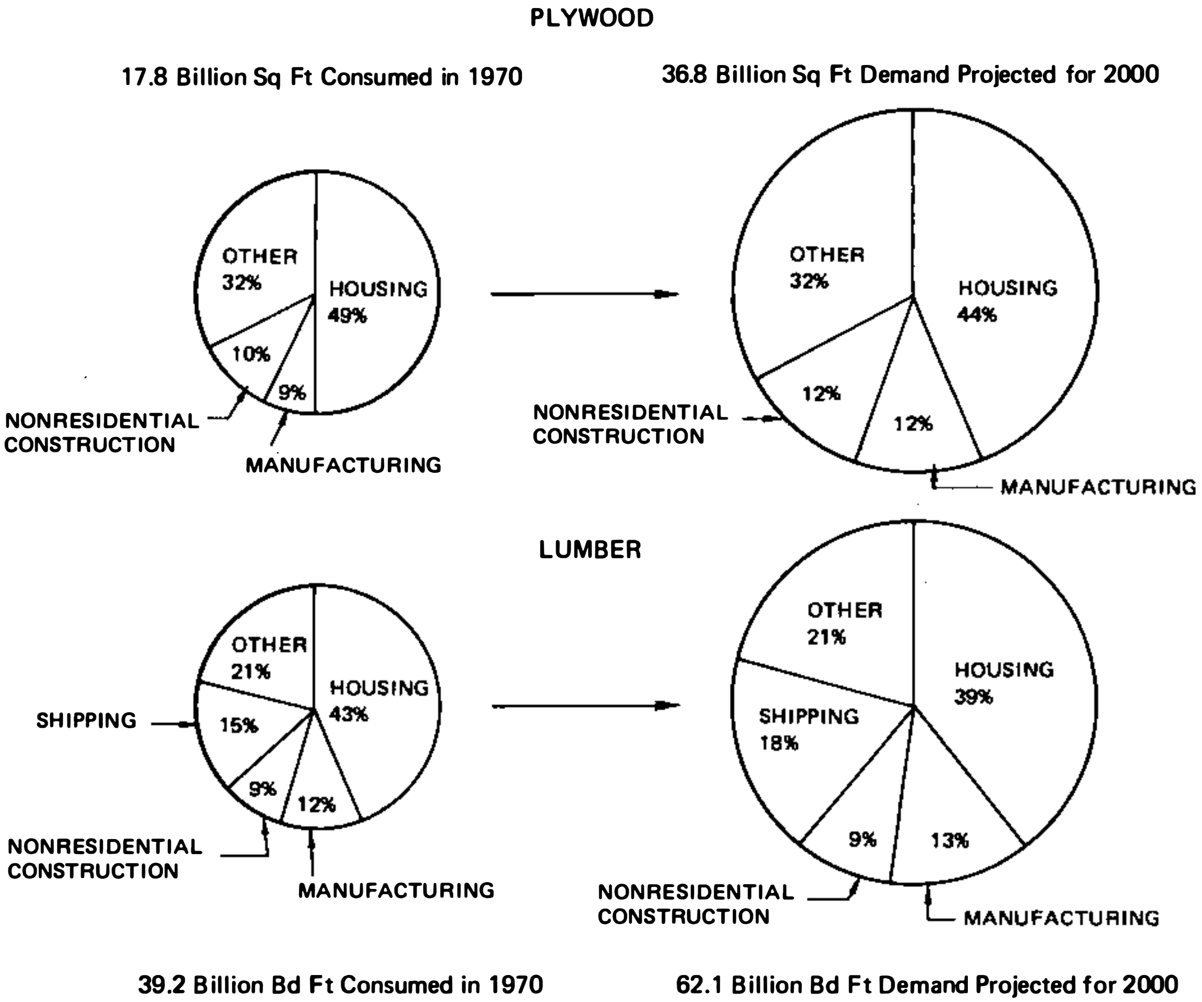
Of the wide spectrum of uses of lumber and rigid panels, residential and nonresidential light construction stand out as being, by a very substantial degree, the most important forms of secondary use. As indicated in Table 2, 52 percent of all lumber, 59 percent of all plywood, and 53 percent of all building board were consumed in construction in 1970. For each of these commodities, approximately 10 percent of the total volume of the product used was for nonresidential construction. As indicated in Figure 2, the demand for housing is projected to remain high through the year 2000. Importantly, the wood-based primary structural products required per housing unit are also projected to remain high (Figure 3). A high percentage of lumber and



Historical and projected demand for housing by type in the United States.

Figure 2 Historical and projected demand for housing by type in the U.S.

SOURCE: Cliff (1973)



PLYWOOD

17.8 Billion Sq Ft Consumed in 1970

36.8 Billion Sq Ft Demand Projected for 2000

LUMBER

39.2 Billion Bd Ft Consumed in 1970

62.1 Billion Bd Ft Demand Projected for 2000

NOTE: PERCENTAGES FOR USES MAY NOT ADD UP TO 100 DUE TO ROUNDING

Figure 3 Major uses of Plywood and Lumber—1970-2000

SOURCE: Cliff (1973)

plywood, which accounted for approximately three-quarters of the tonnage of primary structural products produced from wood in 1970, is projected to continue in housing until the year 2000, with a substantial increase in absolute volume of each product being devoted to this use (Figure 3).

ANALYSIS OF MATERIALS USED IN RESIDENTIAL AND LIGHT-FRAME CONSTRUCTION

Because of its importance to the total demand for wood products and because it constitutes a substantial potential market for commodities manufactured from nonrenewable resources, residential and light industrial construction was selected for analysis by this study in order to evaluate wood as a structural and architectural material. Representative designs of floor, wall, and roof constructions now in use or which are feasible in the foreseeable future were chosen for study. Wood-based and alternative structural materials incorporated in these designs were analyzed from the standpoints of energy, manpower, and capital requirements from the point of extraction of the raw material to erection on the building site. Changing manufacturing technologies resulting from changes in the forest resource are considered together with accompanying research and development needs.

Primary Materials and Their Use in Building Components

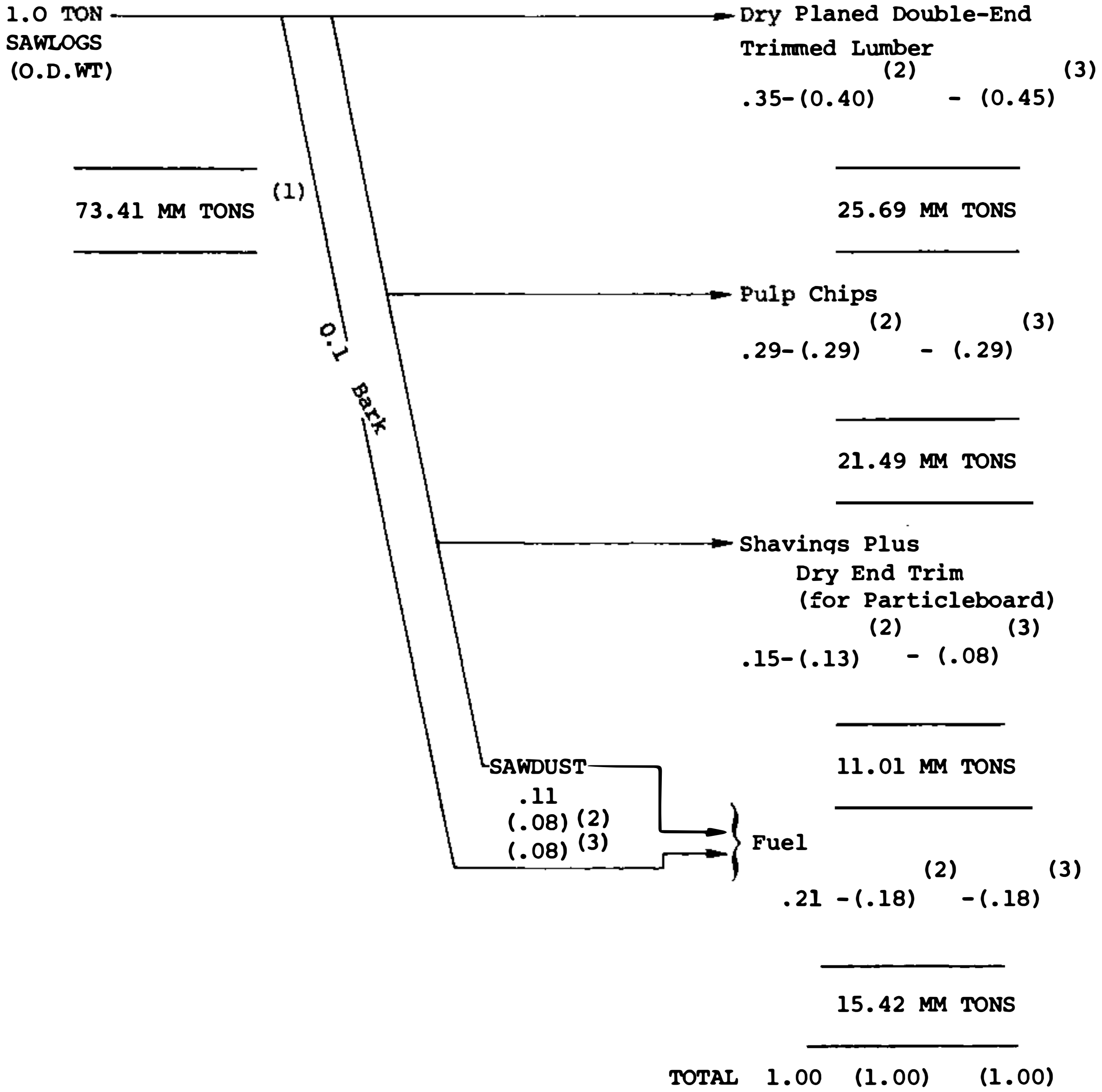
Eleven primary materials fabricated from the forest resource were selected for study. Of these, eight that make up a high percentage of all primary structural and architectural materials manufactured from wood are

1. softwood lumber,
2. hardwood lumber,
3. underlayment particleboard,
4. softwood plywood,
5. hardwood plywood,
6. medium-density fiberboard,
7. wet-formed insulation board, and
8. wet-formed hardboard.

The remaining three--structural flakeboard, reconstituted structural board, and lumber laminated from veneer--are technologically feasible and are expected to be in production in the foreseeable future. For each of these primary products, a materials-flow trajectory was developed on the basis of 1 oven-dry ton of entering raw material, as is illustrated for softwood lumber in Figure 4. All materials-flow trajectories were developed for manufacturing

Figure 4

Materials Balance for Softwood Lumber
(Based on oven-dry (o.d.) weight)



(1) Tonnage from materials-balance trajectory for the U.S.forest resource, 1970

(2) Predicted product and by-product recovery, 1985

(3) Predicted product and by-product recovery, 2000

operations designed to maximize the output of the primary product under consideration. The trajectories were based on averages attained in efficient manufacturing plants with data supplied by knowledgeable industrial sources.

Based on information from the materials-flow trajectories for all operations except the manufacture of reconstituted structural board, man-hours, energy (in the form of mechanical horsepower and pounds of steam), and capital depreciation for the operation of the manufacturing facility were prorated proportionately among the output products. For the most part--but not in all cases--proration was based on the weight of each product. Input requirements are considered reasonable averages for efficient manufacturing plants and were derived from manufacturers and knowledgeable industrial sources. Figure 5 illustrates the assignment of man-hours, energy, and capital depreciation to the principal and residual products of a softwood lumber mill.

Requirements for man-hours, energy, and depreciated capital were developed for harvesting and transport from stump to mill for the raw material supplied to the manufacturing plant on the basis of 1 oven-dry ton of mill input raw material. These data include requirements for harvest planning and layout, road construction and maintenance, equipment and its maintenance, supervision and support functions, harvesting, and stump-to-mill transport. For those primary products using input raw materials other than roundwood--e.g., chips, flakes, or particles--the manpower, energy, and capital assigned to preparation of the feed stock was included. Harvesting data were derived primarily on the basis of southern and west coast operations, but are considered representative of the nation at large because of the heavy concentrations of the forests and industries in these two areas.

Transportation mode and distance estimates from the manufacturing plant to the retail lumber yard (for wood-based commodities), together with manpower, energy, and capital requirements, were developed on the basis of statistics assembled by manufacturing and transportation associations and from information derived from manufacturing industries. Data on transport from the retail yard to building site was supplied by a geographically dispersed sample of retail distributors of building products. Erection data were provided by the National Association of Home Builders.

Data comparable to those assembled for wood-based structural and architectural products were developed for alternative building materials manufactured from non-

Figure 5

Softwood lumber requirements for man-power, energy, and capital depreciation in the Manufacturing Process of Softwood Lumber
(Based on 1.0 ton oven-dry (o.d.)weight of wood input - 1970)

1.0 TON
Barky
Sawlogs
(O.D.Wt.)

PRODUCT	MAN-HOURS	MECHANICAL HORSEPOWER	STEAM	DEPRECIATION OF CAPITAL FACILITIES
Tons (O.D.)		HP Hours	Pounds	Dollars
Dry Planed D.E.T. Lumber				
.35	.67	21.98	977	.86
Pulp Chips				
.29	.56	18.21	0	.70
Particleboard Furnish				
.15	.29	9.42	419	.36
Fuel				
.21	.40	13.19	0	.51
1.00	1.92	62.80	1396	2.43

renewable resources. information was computed from census data and from the Brookhaven Data Bank. Distribution of non-wood building materials from the retailer to the building site was assumed to be similar to that for wood-based materials.

In order to provide a basis for comparison of alternative structures, designs were developed for four roof, eight exterior-wall, three interior-wall, and six floor constructions. This array includes the most important designs for these components in use today and, additionally, several feasible designs that are not yet commonly used. The designs were selected to provide a realistic comparison between the use of wood-based components and alternative materials. Sections with an area of $100ft^2$ were selected for analysis in order to provide easy comparison, and eliminate the effect of door and window openings. Weights of materials required for each $100ft^2$ section were calculated (Table 3). For each composite $100ft^2$ section, requirements for man-hours, capital depreciation, and energy from material source to building site were computed for all materials in the design. These data provide a basis for assessing the energy, manpower, and capital cost effectiveness of alternative designs incorporating both wood and non-wood materials and for analyzing the contribution of the various components within a given design to the total requirements for manpower, energy, and capital.

The data on which this study is based are the best available within the time frame and resource limitations of this study. It is felt that they are adequate for the purpose of drawing meaningful comparisons and conclusions. It must be recognized, however, that many data lack precision and that all are averages of a highly variable base. Wood-processing industries are characterized by excessive variability in operating efficiency both within and between geographic regions. In many processing plants throughout the country, material that is residual to the primary product has limited or no utilization. Equipment is frequently obsolete and management support is often inadequate. Materials-flow trajectories and manpower, capital, and energy requirements derived from them are considered representative of efficiently operated plants in areas in which the primary processing industries are integrated. The data are representative of those processing plants that are economically viable and from which a significant percentage of primary structural and architectural materials flow and may be considered characteristic of progressive processing plants throughout the U.S.

Table 3

Descriptions of Floor, Roof, and Wall Constructions

Floors[1]

1. Wood joists (2 x 10 inch, 16 inches on center); plywood subfloor (1/2 inch); particle board underlayment (3/8 inch); carpet and pad. Total weight - 0.312 ton

2. Wood joists (2 x 10 inch, 24 inches on center); plywood subfloor (3/4 inch); oak strip flooring. Total weight - 0.293 ton

3. Wood joists (2 x 10 inch, 16 inches on center; plywood combination subfloor underlayment (5/8 inch); carpet and pad. Total weight - 0.260 ton

4. Concrete slab (4 inches thick on 6" gravel base); vapor barrier carpet and pad. Total weight - 4.860 tons

5. Steel joists ("C" section, 48 inches on center); plywood subfloor (1-1/8 inches); carpet and pad. Total weight - 0.614 ton

6. Lumber-Laminated from veneer joists (1.5 x 7.5 inches), 16 inches on center); structural flakeboard and subfloor (5/8 inch); carpet and pad. Total weight - 0.260 ton

Exterior Walls[2]

1. Plywood siding (5/8 inch) without sheathing. Total weight - 0.290 ton

2. Medium-density fiberboard siding (1/2 inch); plywood sheathing (3/8 inch); Total weight - 0.342 ton

3. Medium-density fiberboard siding (1/2 inch); insulation-board sheathing; (1/2 inch) with plywood (1/2 inch) corner bracing. Total weight - 0.377 ton

4. Concrete block without additional siding or insulation. Total weight - 1.999 tons

5. Aluminum siding (0.02 inch); insulation board sheathing (1/2 inch). Total weight - 0.265 ton

6. Medium-density fiberboard siding (1/2 inch); steel framing; insulation board sheathing (1/2 inch) with plywood (1/2 inch) corner bracing. Total weight - 0.323 ton

7. Aluminum framing with siding and sheathing as in number 6. Total weight - 0.293 ton

8. Brick siding; insulation board sheathing (1/2 inch) with plywood (1/2 inch) corner bracing. Total weight - 2.01 tons

Interior Walls[3]

1. Wood framing (2- x 3- inch, nominal). Total weight - 0.311 ton
2. Aluminum framing. Total weight - 0.217 ton
3. Steel framing. Total weight - 0.231 ton

Roofs[4]

(30 lb/sq ft live-load design)

1. Pitched roof with W-type wood trusses, plywood sheathing (1/2 inch); roofing felt and wood shingles. Total weight - 0.429 ton
2. Same as number 1 but with asphalt shingles. Total weight - 0.493 ton
3. Flat roof with steel rafters ("C" section, 7-1/4 inches in depth); plywood sheathing (1/2 inch); built-up roofing (3/8 inch). Total weight - 0.410 ton
4. Flat roof with lumber-laminated-from-veneer rafters; structural flakeboard sheathing (1/2 inch); built-up roofing (3/8 inch). Total weight - 0.449 ton

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[1] Weights of individual components in each design are shown in a detached appendix available from the National Academy of Sciences.

[2] All walls except numbers 4, 6, and 7 are standard framed walls with 2- x 4- inch (nominal) studs; 24 inches on center, with top and bottom plates, building paper, and gypsum board interior panels. All constructions are nailed. With the exception of number 4, all walls contain 2" mineral wool insulation batts which conformed to building standards at the time (1970).

[3] All interior walls are with 1/2 inch gypsum board on both sides, and non-load-bearing framing on 24-inch centers.

[4] All roofs are with 1/2 inch gypsum ceilings, 3.5 inch mineral wool insulation, nailed construction, and framing members 24 inches on center.

Flow of Materials in Primary Processing

A summary of information developed from trajectories of materials balances for the structural and architectural materials included in this study is shown in Table 4. Not surprisingly, the panel products reconstituted from fibers mechanically derived largely from bark-free chips and from underlayment particleboard show the highest percentage of primary product recovery. Table 4 also shows that the residue from these primary products did not provide raw material for other manufactured products.

Although all of the residual material from the manufacture of the reconstituted structural board was assigned to fuel, much of it could be used as a raw material for pulp or for other forms of reconstituted structural board, economic circumstances permitting.

The process selected to illustrate the manufacture of hardwood flakeboard is not now in use. The primary product could have, with equal validity, been considered hardwood lumber, the recovery of which, as may be noted from Table 4, exceeds that of conventionally sawn hardwood lumber as shown in the hardwood lumber materials balance data. Lumber from the illustrated hardwood flakeboard operation would be particularly useful for pallets, which are in increasing demand.

With the exception of the illustrated hardwood flakeboard operation, lumber and plywood recovery from hardwood is considerably lower than that from softwood, reflecting the generally lower quality of hardwood logs. Particularly noteworthy is the high percentage of pulp chips recovered from roundwood entering lumber and plywood manufacturing operations.

Man-hours, Capital, and Energy Requirements for Primary Products

Tables 5, 6, and 7 summarize, for wood-based and non-wood-based primary commodities, man-hour, capital, and energy requirements for extraction of the raw material, manufacture of the product, and transportation to the building site. This provides a basis for comparison of products from renewable and nonrenewable resources.

Wood products are, with few exceptions, more homogeneous in man-hour and capital requirements than are the non-wood-based commodities. Without exception, harvesting the forest resource and transporting it to the mill is more demanding in labor than is extraction of non-

Table 4
Materials Balance Summaries
(Based on one oven-dry ton input of forest-based raw material 1970)

WOOD-BASED PRIMARY STRUCTURAL COMMODITIES

PRINCIPAL PRODUCT	RECOVERY (Oven-Dry Ton)						
	Input Raw Material	Principal Product	Lumber	Pulp Chips	Fuel	Solubles and Volatiles	Other
Wet-formed Insulation Board(1)	1/2 bark-free chips 1/2 forest residual chip	1.04			0.05	0.10	
Underlayment particleboard(2)	Dry mill residue	.98			.11		
Wet-formed primary hardboard(3)	1/2 bark-free chips 1/2 forest residual chip	.87			.05	.10	
Medium-density fiberboard(4)	1/2 roundwood 1/2 bark-free chips	.86			.17	.06	
Reconstituted structural Board(5)	Roundwood	.63			.40		
Lumber laminated from veneer(6)	Roundwood	.47	studs .06	.29	.12		Particleboard furnish .07
Softwood plywood unsanded (7)	Roundwood	.45	studs .06	.30	.12		" .08
Structural flakeboard(8)	Roundwood	.35	.45		.22		
Softwood lumber	Roundwood	.35		.29	.21		" .15
Hardwood plywood (sanded)(9)	Roundwood	.30		.48	.23		Particleboard and medium-density fiberboard furnish
Hardwood lumber	Roundwood	.28		.29	.23		.20

(1) .19 ton starch, wax, and asphalt added raw materials. Mechanical pulping assumed.
(2) .087 ton adhesive and wax added.
(3) .02 ton adhesive and wax added.
(4) .09 ton adhesive and wax added.
(5) .03 ton adhesive and wax added.
(6) .01 ton adhesive added.
(7) .01 ton adhesive added.
(8) .024 ton resin and wax added to flakeboard component - assumes use of shaping lathe headrig.
(9) .01 ton adhesive added.

Table 5 (1)
Man-hour Requirements for Primary Commodities

WOOD-BASED COMMODITIES
(Man-Hours/Oven-Dry Ton)

	Logging or Extraction	Manufacture	Transport (Mill to Bldg Site)	Total
Medium-Density Fiberboard	3.43	2.86	2.08	8.37
Underlayment Particleboard	5.04	2.64	1.99	9.67
Softwood Lumber	3.92	3.06	3.06	10.04
Structural Flakeboard	3.97	3.99	2.14	10.10
Lumber Laminated from Veneer	3.08	4.53	3.06	10.67
Insulation Board	2.28	6.54	2.13	10.95
Softwood Sheathing Plywood	3.10	4.55	3.31	10.96
Hardwood Plywood	4.33	8.03	2.67	15.03
Oak Flooring	4.46	8.07	2.67	15.20
Wet-Formed Hardboard	2.72	14.72	2.08	19.52
TOTAL	36.33	58.99	25.19	120.51
% TOTAL	30%	49%	21%	
MEAN	3.6	5.9	2.5	12.05

NON-WOOD-BASED COMMODITIES
(Man-Hours/Ton)

Gravel	.08	0	1.03	1.11
Concrete Slab	.09	.79	1.03	1.91
Concrete Block	.09	1.75	1.24	3.08
Gypsum Board	.34	1.74	1.24	3.32
Clay Brick	.08	2.93	1.36	4.37
Liquid Asphalt	.10	4.30	1.33	5.73
Asphalt Shingles	.18	4.40	1.33	5.91
Tar Paper	.64	4.00	1.33	5.97
Vermiculite	.08	10.70	1.71	12.49
Steel Nails	.89	10.10	2.18	13.17
Steel Studs	.89	10.10	2.25	13.24
Steel Joists	.89	10.10	2.25	13.24
Glass Fiber	1.12	17.50	1.71	20.33
Aluminum Siding	.62	50.10	2.25	52.97
Carpet and Pad	1.61	93.70	2.98	98.29
Plastic Vapor Barrier	.82	96.70	1.48	99.00
TOTAL	8.52	318.91	26.70	354.13
% TOTAL	2%	90%	8%	
MEAN	0.5	19.9	1.7	22.1

(1) Requirements for erection are not included.

Table 6

Capital Depreciation Requirements for Primary Commodities

WOOD-BASED COMMODITIES
(Dollars/Oven-Dry Ton)

COMMODITY	Extraction	Manufacturing	Transport	Total
Softwood Lumber	3.09	3.91	3.25	10.25
Structural Flakeboard	3.13	11.37	2.36	16.86
Lumber Laminated from Veneer	2.42	11.98	3.25	17.65
Softwood Sheathing Plywood	2.44	12.09	3.43	17.96
Underlayment Particleboard	6.72	13.74	2.20	22.66
Hardwood Plywood	3.41	18.37	3.14	24.92
Insulation Board	3.84	24.06	2.29	30.19
Oak Flooring	3.51	26.07	3.14	32.72
Medium-Density Fiberboard	3.21	27.89	2.18	33.28
Wet-formed Hardboard	4.59	48.08	2.18	54.85
TOTAL	36.36	197.56	27.42	261.34
% TOTAL	14	76	10	
MEAN	3.64	19.76	2.74	26.13

NON-WOOD-BASED COMMODITIES
(Dollars/Ton)

Gravel	.19	0	1.17	1.36
Concrete Slab	.19	.80	1.17	2.16
Concrete Block	.19	.80	1.47	2.46
Clay Brick	.19	.80	1.61	2.60
Liquid Asphalt	.17	4.90	1.57	7.24
Gypsum Board	.37	6.23	1.47	8.07
Tar Paper	1.16	5.80	1.57	8.53
Asphalt Shingles	.82	7.40	1.57	9.79
Steel Nails	4.78	16.60	2.68	24.06
Steel Studs	4.78	16.60	2.73	24.11
Steel Joists	4.78	16.60	2.73	24.11
2" Glass Fiber	.96	33.00	1.86	35.82
Vermiculite	.08	34.50	1.86	36.44
Aluminum Siding	2.14	48.60	2.73	53.47
Carpet and Pad	8.11	103.80	2.97	114.88
Plastic Vapor Barrier	6.29	117.40	1.64	125.33
TOTAL	35.80	413.83	30.80	486.43
% TOTAL	8	86	6	
MEAN	2.24	25.86	1.93	30.02

Table 7

Energy Requirements for Primary Commodities

Wood-Based Commodities

Commodity	Gross Manufacturing				Gross total	Avail. residue energy	Net total[1]
	Logging	Electric	Heat	Transport (mill/bldg)			
	Million BTU (oil equivalent)/ton						
Softwood Lumber	0.943	0.786	4.060	1.966	7.755	8.313	2.909
Oak Flooring	1.073	.844	4.847	1.977	8.741	11.388	3.050
Lumber Laminated from Veneer	.740	.144	6.443	1.966	9.293	3.540	5.753
Softwood Sheathing Plywood	.747	.145	6.726	2.081	9.699	3.697	6.002
Structural Flakeboard	.956	.578	6.933	1.314	9.781	8.616	2.270
Medium-density Fiberboard	.783[4]	3.748	5.555	1.146	11.232	2.741	8.491
Insulation Board	.622[3]	4.920	5.619	1.243	12.404	.667	11.737
Hardwood Plywood	1.041	.244	9.998	1.977	13.260	10.629	3.018
Underlayment Particleboard	4.617[2]	2.503	5.598	1.198	13.916	1.529	12.387
Wet-formed Hardboard	.743[3]	9.919	9.743	1.146	21.551	.797	20.754
TOTAL	12.265	23.831	65.522	16.014	117.632	51.917	76.371
% TOTAL (Gross)	10.4	20.3	55.7	13.6			
MEAN	1.23	2.38	6.55	1.60	11.76	5.192	7.64

Non-wood-Based Commodities

Commodity	Extraction	Processing	Transport	Total
	Million BTU (oil equivalent)/ton			
Gravel	0.05	.0	.40	0.45
Gypsum Board	.14	2.73	.65	3.52
Liquid Asphalt	.00	3.20	.73	3.93
Tar Paper	.20	5.00	.73	5.93
Asphalt Shingles	.03	5.70	.73	6.46
Concrete	.52	7.60	.40	8.52
Concrete Block	.52	7.60	.65	8.77
Clay Brick	.57	7.73	.76	9.06
Vermiculite	.04	14.20	.92	15.16
2" Glass Fiber	.62	26.70	.92	28.24
Plastic Vapor Barrier	4.49	25.10	.75	30.34
Carpet and Pad	6.60	28.69	1.90	37.19
Steel Nails	2.45	46.20	1.48	50.13
Steel Studs	2.45	46.20	1.67	50.32
Steel Joists	2.45	46.20	1.67	50.32
Aluminum Siding	26.80	172.00	1.67	200.47
TOTAL	47.93	444.85	16.03	508.81
% TOTAL	9	87	3	-
MEAN	2.99	27.80	1.00	31.80

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[1] Assumes residue energy can be offset only against gross manufacturing energy (but not against logging or transport energy).

[2] Includes energy input in logging plus preparation of particleboard furnish in form of planer shavings, plywood trim and sawdust.

[3] Includes logging plus preparation of forest residual chips.

[4] Includes logging plus preparation of bark-free chips

wood raw materials. Although highly variable, average man-hour and capital requirements for nonrenewable resources exceed those for wood-based materials.

The most notable differences between wood-based and non-wood-based commodities appear in total energy requirements. Commodities based on nonrenewable materials are appreciably more energy intensive than are their wood-based counterparts. Among the wood-based commodities, wet-formed hardboard is the most energy intensive, but, even so, it is considerably superior to metal and petrochemical-derived building materials in this respect.

A Comparison of Manpower, Energy, and Capital Requirements for Some Construction Designs

Manpower, energy, and capital depreciation requirements on the basis of 100ft^2 sections for alternative designs of roofs, exterior walls, interior walls, and floors are summarized in Table 8. Brief design descriptions, are presented in Table 3. These estimates, with few exceptions, include erection of the building.

The most striking difference between alternative constructions is in energy requirements. In roofs, the design incorporating steel rafters requires approximately twice the energy of the constructions that incorporate wood trusses and rafters. Exterior walls sided with brick or constructed with concrete block require seven to eight times the energy of all-wood constructions and exterior and interior walls incorporating metal require approximately twice the energy of counterpart wood-framed constructions. Floors constructed from wood materials require only approximately 10 percent as much energy as the concrete slab construction and the one with steel supporting members.

With the exception of wall constructions incorporating concrete block and brick veneer, which require two to three times the labor man-hours of wood constructions, manpower requirements do not differ appreciably between designs. No clear pattern emerges from capital requirements. It may be observed, however, that wood constructions in floor systems appear to be approximately half as capital intensive as their non-wood counterparts.

For the purpose of comparison, several alternative components serving major functions in the various designs are summarized in Table 9. Values in this table are for the labor, capital, and energy input of each component involved in constructing 100ft^2 of the indicated design. The most striking fact revealed by this table is the very substan-

Table 8

Summary of Requirements for 100 sq. ft. of Construction Including Logging (or extraction), Manufacture, Transport to House Site, and Erection[1]

	Labor man-hours	Net Energy[2] million Btu	Capital Depreciation dollars
Roofs			
1. W-type wood truss with wood shingles	8.96	2.44	6.14
1a. Same but with asphalt shingles	9.04	3.22	6.72
2. Steel rafters (flat roof)	9.17	5.11	6.38
3. Flat roof with LVL[3] rafters and flakeboard[4]	9.36	2.45	6.59
Exterior walls			
1. Plywood siding (no sheathing), 2x4 frame	7.99	1.99	4.15
2. Medium-density fiberboard siding, plywood sheathing, 2x4 frame	9.86	2.54	6.41
3. Medium-density fiberboard siding, 1/2 inch insulation board, and plywood corner bracing	9.26	2.69	6.71
4. Concrete building block, no insulation	18.45	16.53	5.56
5. Aluminum siding over sheathing	9.83	4.95	4.61
6. MDF siding, sheathing, steel studs	9.89	4.79	7.20
7. MDF siding, sheathing, aluminum framing	11.26	5.53	6.91
8. Brick veneer	22.00	17.89	8.37
Interior walls			
1. Wood framing	3.87	0.95	2,17
2. Aluminum framing	3.99	2.25	2.13
3. Steel framing	3.53	1.88	2.25
Floors (all with carpet and pad, except No. 2)			
1. Wood joist, plywood subfloor, and particleboard underlayment	9.15	2.85	7.58
2. Wood joist, plywood subfloor, oak finish floor	8.51	1.19	6.40
3. Wood joist, "single-layer floor"	7.77	2.09	6.32
4. Concrete slab	11.62	22.06	11.81
5. Steel joist, 2-4-1 plywood	11.97	23.26	16.34
6. LVL joist and flakeboard	7.76	2.05	7.23

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[1] For design descriptions, see Table 3.

[2] Energy from wood residues credited only against gross energy requirements of manufacturing phase, not against logging or transport of wood components.

[3] Laminated veneer lumber.

[4] Erection costs unavailable. Approximations based on similar construction.

Table 9

Some Comparisons of Requirements/100 sq. ft. of Construction from Extraction to the Building Site for Selected Alternative Components

Design Incorporating Component (Table 3)	Function and Material	Labor man-hours	Capital Depreciation dollars	Net Energy million Btu
	<u>Floor Joists</u>			
Floor 1,3	Softwood lumber	1.395	1.42	0.404
Floor 6	Laminated-veneer lumber	1.195	1.97	.645
Floor 5	Steel	5.562	10.13	21.134
	<u>Subfloor</u> (Single-Layer)			
Floor 3	Softwood plywood	.997	1.63	.546
Floor 6	Hardwood flakeboard	1.192	1.99	.268
Floor 4	Concrete 3/76	4.469	5.01	19.849
	<u>Interior Wall Studs</u>			
Interior Wall 1	2 x 3 lumber	0.423	0.43	0.123
Interior Wall 2	Aluminum	.376	.39	1.423
Interior Wall 3	Steel	.278	.51	1.056
	<u>Exterior Wall Framing</u>			
Exterior Wall 1,2,3,5	Wood	0.593	0.60	0.172
Exterior Wall 7	Aluminum	.795	.80	3.077
Exterior Wall 6	Steel	.596	1.09	2.264
	<u>Roof Trusses or Rafters</u>			
Roof 1	Lumber (pitched) & plates	1.111	1.17	.457
Roof 2	Steel (flat)	.751	1.37	2.868
Roof 3	LVL (flat)	.789	1.31	.426
	<u>Siding</u>			
Exterior Wall 2,3,6,7	1/2 inch medium density fiberboard	0.728	2.90	0.739
Exterior Wall 5	Aluminum	.795	.80	3.007
Exterior Wall 1	5/8 inch plywood	.997	1.63	.546
Exterior Wall 8	Bricks, 3 1/4 inch	7.688	4.56	15.932
	<u>Flooring</u>			
Floor 2	Oak, 3/4 inch	1.901	4.09	0.381
Floors 1,3,4,5,6	Carpet	2.752	3.22	1.041
	<u>Sheathing</u>			
Exterior Wall 3,5,6,7,8	1/2 inch insulation board plus plywood corners	.548	1.28	.483
Exterior Wall 2	Plywood, 3/8 inch	.603	0.98	.330

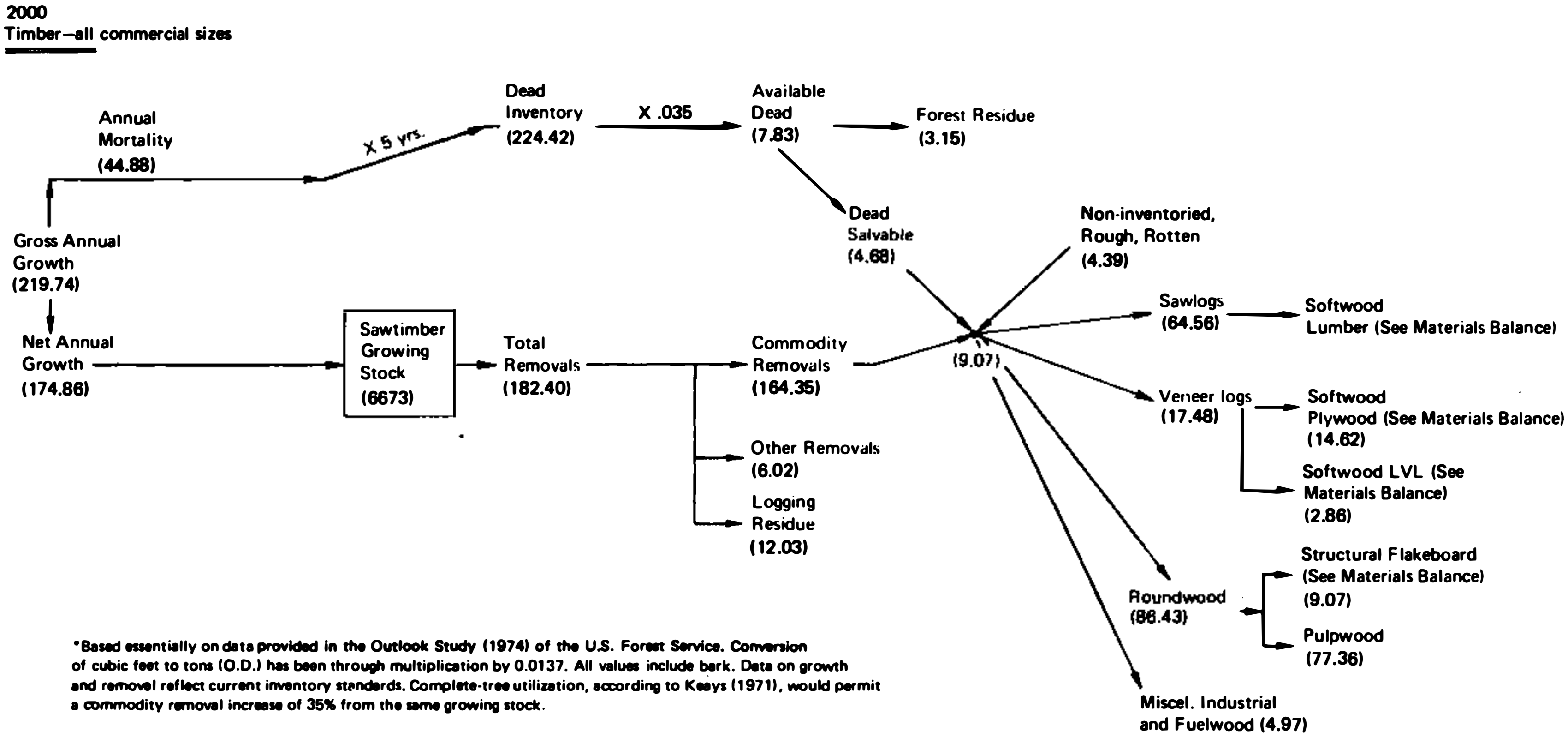
tially lower energy requirements for wood components than for alternative metal ones. Steel floor joists, for example, require approximately 50 times as much energy as do wood counterparts. Aluminum framing for exterior walls is approximately 20 times as energy intensive as wood framing. Energy required for steel framing is approximately two-thirds that for aluminum. Similarly, aluminum and steel studs for interior walls require respectively twelve and eight times the energy of wood studs which perform the same function. Steel rafters exceed wood trusses sevenfold in energy requirements, and aluminum siding requires approximately five times the energy of its plywood and fiberboard counterparts. The energy requirement for brick siding is strikingly high--approximately five times that of aluminum and 25 times that of wood-based siding materials. No clear patterns emerge from labor and capital depreciation requirements. It may be seen, however, that steel floor joists are very substantially higher than wood counterparts in these two requirements, and that brick is more labor and capital intensive than all alternative siding materials in house construction. Similar conclusions with respect to commercial structures may be drawn from a well-documented study by Bingham (1975).

Changing Patterns in Wood Use as a Structural and Architectural Material

Wood is renewable and, as is apparent from the results of this study, has substantial advantages--particularly from the standpoint of energy requirements--over alternative materials. This strongly suggests that it is in the nation's best interest to move positively toward a continued high reliance on wood for building construction. The effect of those factors that influence economic availability and utility of the forest resource as raw material for structural products must be evaluated.

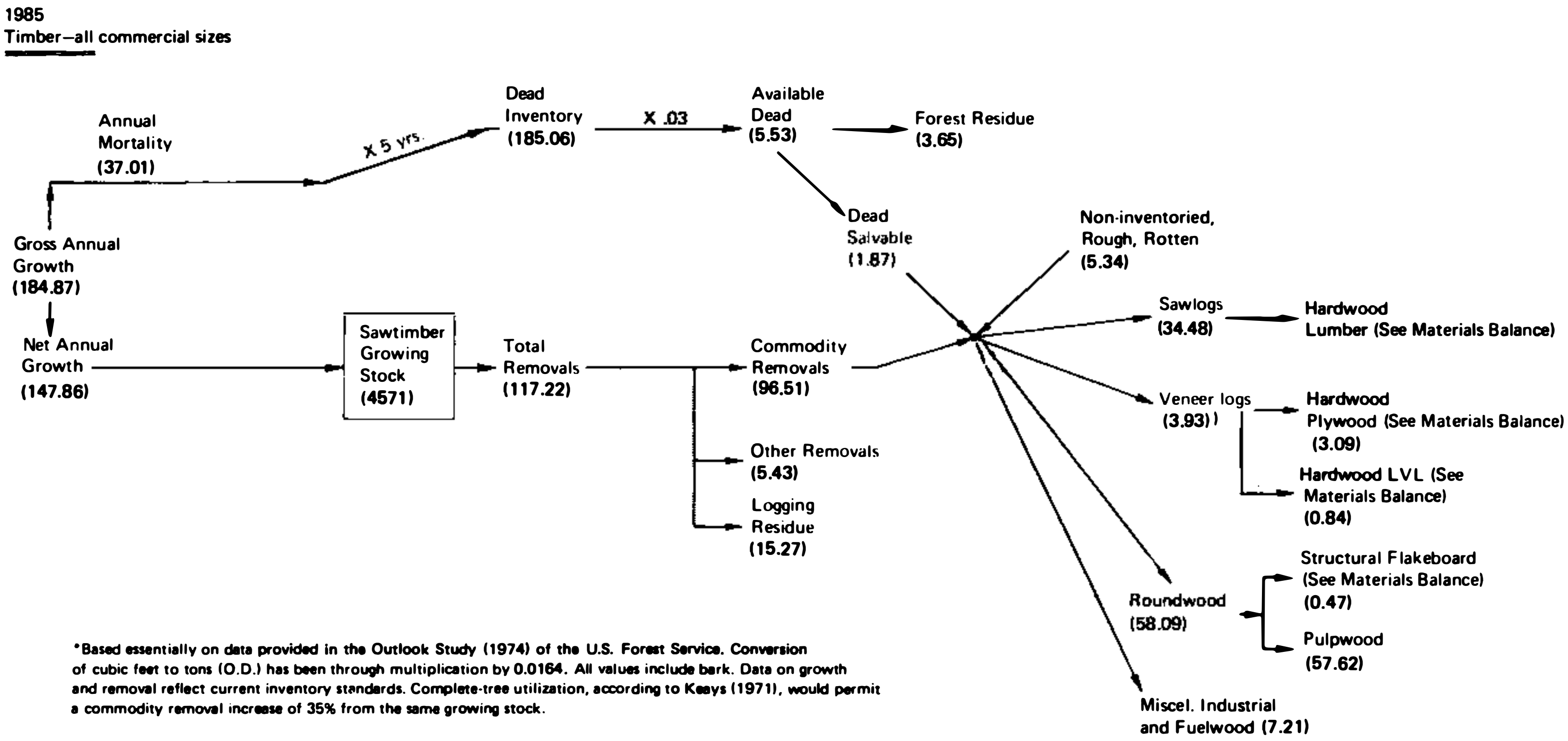
Materials-flow trajectories comparable to those shown in Figure 1 have been developed for 1985 and 2000 based on the Outlook Study data on growth and potential for commodity removals (Figures 6a-6d). In these trajectories, timber in all commercial sizes was pooled in recognition of the fact that sawtimber and pulpwood and polesize timber distinctions have largely lost their meaning. Roundwood totals available for commodities and totals for logging and other forest residues, under the assumptions of the model, are summarized in Table 10.

The continuing replacement of old-growth timber stands with second-growth, managed forests and plantations is resulting in a substantially higher percentage of trees of



*Based essentially on data provided in the Outlook Study (1974) of the U.S. Forest Service. Conversion of cubic feet to tons (O.D.) has been through multiplication by 0.0137. All values include bark. Data on growth and removal reflect current inventory standards. Complete-tree utilization, according to Keays (1971), would permit a commodity removal increase of 35% from the same growing stock.

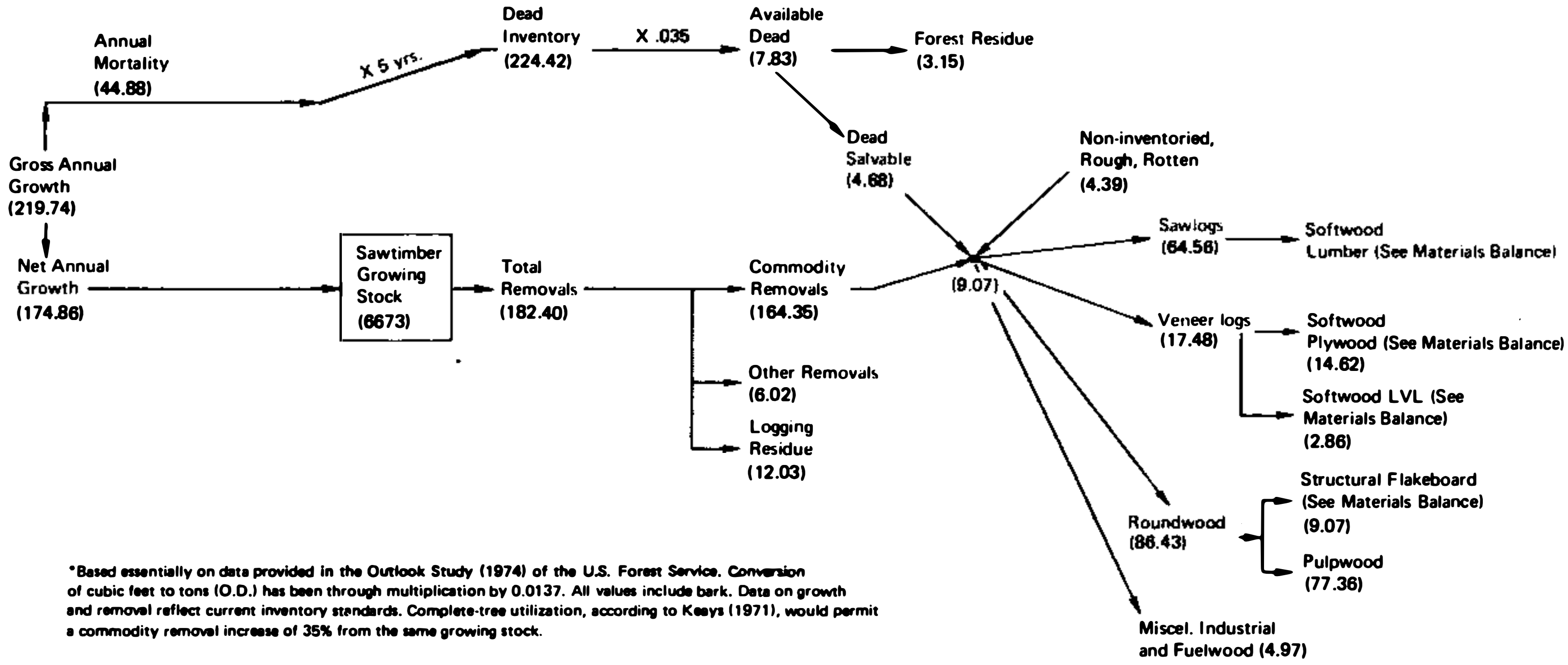
Figure 6c SOFTWOOD MATERIALS FLOW TRAJECTORIES (All data in Millions of Tons, O.D. weight*)



*Based essentially on data provided in the Outlook Study (1974) of the U.S. Forest Service. Conversion of cubic feet to tons (O.D.) has been through multiplication by 0.0164. All values include bark. Data on growth and removal reflect current inventory standards. Complete-tree utilization, according to Keays (1971), would permit a commodity removal increase of 35% from the same growing stock.

Figure 6b HARDWOOD MATERIALS FLOW TRAJECTORIES (All data in Millions of Tons, O.D. weight*)

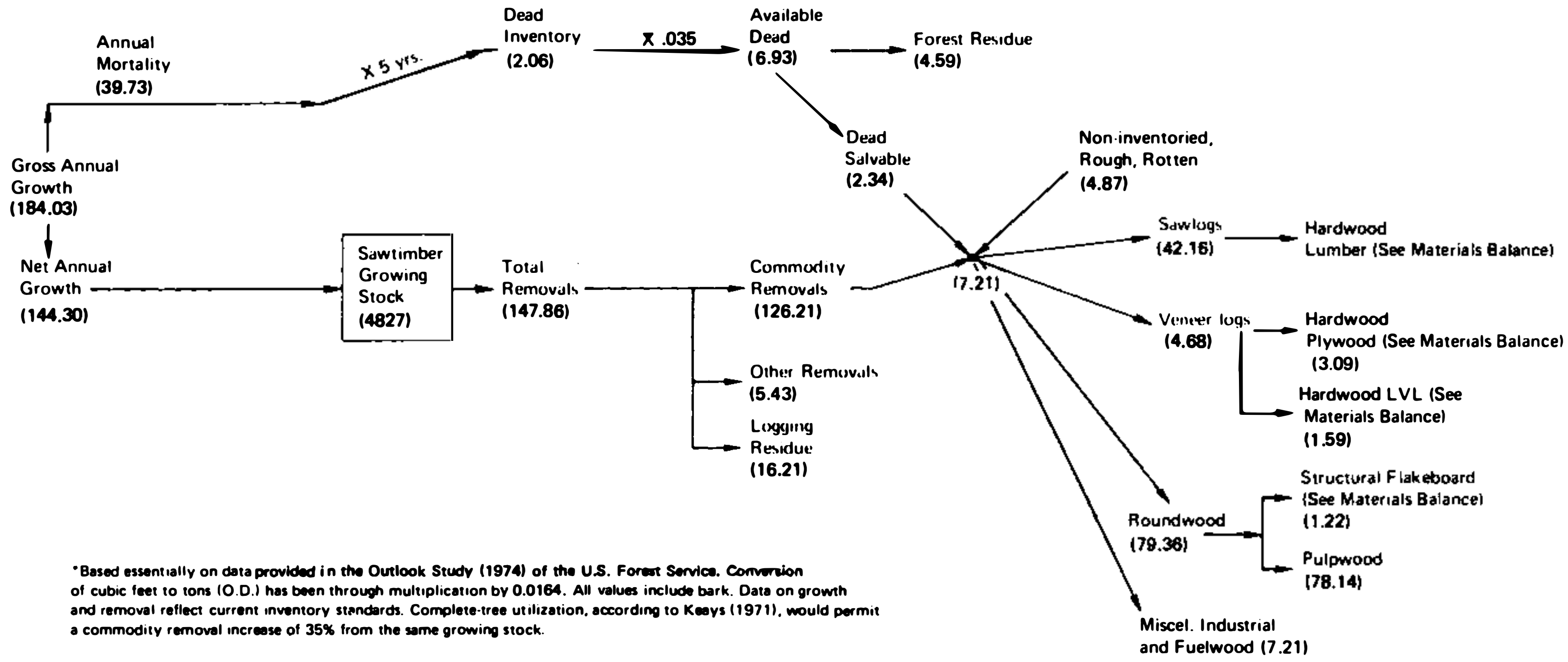
2000
Timber—all commercial sizes



*Based essentially on data provided in the Outlook Study (1974) of the U.S. Forest Service. Conversion of cubic feet to tons (O.D.) has been through multiplication by 0.0137. All values include bark. Data on growth and removal reflect current inventory standards. Complete-tree utilization, according to Keays (1971), would permit a commodity removal increase of 35% from the same growing stock.

Figure 6c SOFTWOOD MATERIALS FLOW TRAJECTORIES (All data in Millions of Tons, O.D. weight*)

2000
Timber—all commercial sizes



*Based essentially on data provided in the Outlook Study (1974) of the U.S. Forest Service. Conversion of cubic feet to tons (O.D.) has been through multiplication by 0.0164. All values include bark. Data on growth and removal reflect current inventory standards. Complete-tree utilization, according to Keays (1971), would permit a commodity removal increase of 35% from the same growing stock.

Figure 6d HARDWOOD MATERIALS FLOW TRAJECTORIES (All data in Millions of Tons, O.D. weight*)

Table 10

Summary of Materials Flow From Gross Annual Growth (Million Oven-Dry Tons)

	Available for All Commodities						
	Roundwood			Logging Residues		Residues from Mortality	
	Softwoods	Hardwoods	Total	Softwood	Hardwoods	Softwoods	Hardwoods
1970	135.3	58.0	193.3	14.6	12.0	1.2	2.8
1985	156.1	103.7	259.8	12.7	15.3	2.6	3.6
2000	173.4	133.4	306.8	12.0	16.2	3.2	4.6

The assessment was that the level of research and development will influence the impact of these forces on manpower, capital, and energy requirements and that most of the change will occur by 1985. Changes in the input requirements under the two levels that can be expected by 1985 are estimated below.

	Man-Hours	Capital	Energy
A. Current level of Research and Development	little change	substantial increase	small decrease
B. Substantial Increase in Research and Development	substantial decrease	small increase	possible substantial decrease

In the judgment of the Committee, substantial additional change accompanying the two research levels is unlikely between the years 1985-2000.

Although it can be assumed that technological advances will move toward increased recovery in the form of primary product, it appears probable that the changing quality of the available raw material will largely offset these gains. Predictably, more accurate sawing in combination with reduced saw kerf will increase lumber yield from a given log size. Improved centering devices may slightly increase veneer yield. Accurate sawing, market acceptance of partially surfaced lumber, and increased application of abrasive planing (as an alternative to surfacing with equipment based on cutter heads) will substantially decrease the loss of lumber in surfacing. In short, improved control in manufacture throughout will help reduce residuals from the primary product. Because of the anticipated decrease in log size and quality, however, it is probable that the materials-flow trajectories that have been developed on the basis of current operations are not likely to change significantly (except in the case of softwood lumber; there a higher yield of primary product can be expected, as shown in Figure 4).

Four scenarios have been developed by the Committee to span a wide range of anticipated demand for wood-based products in the years 1985 and 2000. Although the Forest Service's 1975 assessment report (USDA 1975a) differs from the Outlook Study (USDA 1974d) in several of its underlying assumptions, the projected demands for roundwood are changed very little.) Scenario I is derived essentially from the medium-level projection of the Outlook Study based on constant relative prices for wood-based commodities. A major departure from the Outlook Study assumptions holds dwelling-unit size constant at 1970 levels rather than projecting an increase based on past trends.

Scenario II assumes constant relative prices but at a slower rate of population growth than Scenario I--a population of 266 million by 2000 vs. 281 million as is assumed in the Outlook Study medium-level projection.

Scenario III assumes that prices of nonrenewable substitutes increase by 20 percent relative to structural, and by 30 percent relative to fibrous, renewable resources by the year 2000. Population growth at the same low rate as in Number II is further assumed.

Scenario IV assumes that prices of nonrenewable substitutes increase by 40 percent relative to structural renewables and by 60 percent relative to fibrous renewables by the year 2000. Population growth is again assumed at the same low level as in Numbers II and III.

Results are shown in Table 11. The 1970 level demand for roundwood was 193.4 million tons. Scenario I would project year 1985 demands to be 1.34 times larger and year 2000 demands to be 1.57 times larger than the 1970 level. Scenario II projects 1985 demands to be 1.28 times larger and year 2000 demands to be 1.53 times larger than the 1970 level. The requirement under these scenarios can be readily met under the supply schedule of the materials flow trajectories summarized in Table 10. CORRIM found that, in studying the productive potential of the U.S. forest, application of current technology to the nation's forest land would make a doubling of output quite feasible.

Scenarios III and IV examine the demands if the prices of nonrenewable substitutes increase relative to wood products. This is in contrast to historical trends where wood products prices have generally increased relative to nonrenewables. These scenarios therefore represent a reversal of history. They are conceivable if a major change occurs in the supplies and prices of fossil energy and nonrenewable materials. An example of a situation that would lead in the direction of these scenarios is another oil embargo. Scenario III projects the year 1985 demands to be 1.80 times larger and year 2000 demands to be 2.54 times larger than the 1970 level. Scenario V projects the year 1985 demands to be 2.36 times larger and year 2000 demands to be 3.67 times larger than the 1970 level. These levels stress the projected supply assumed if current technology is

Table 11

Projected Demand for Roundwood and By-Products for Manufacture of Wood-Based Commodities Under Alternative Assumptions

Scenario
No.
1

Wood Requirement

	1970		1985		2000	
	MM O.D. tons		MM O.D. tons		MM O.D. tons	
Commodity	From Roundwood	From By-Product	From Roundwood	From By-Product	From Roundwood	From By-Product
Structural						
1. Softwood lumber	73.41	2.6	80.4	3.5	64.6	4.0
2. Softwood plywood	15.08		17.7		14.6	
3. Hardwood lumber	24.51		34.5	1.4	42.2	1.4
4. Hardwood plywood	2.28		3.1		3.1	
5. Particleboard		2.4		5.3		8.5
6. Med. density fiberboard	.18	.2	0.4	0.4	0.6	0.6
7. Insulation board		1.2		1.9		2.2
8. Wet-formed hardboard		1.1		1.9		2.9
9. Structural flakeboard #1	-	-	3.0[1]		5.1[1]	
10. Structural flakeboard #2 (RCW)	-	-	3.0		5.1	
11. Laminated-veneer lumber	-	-	2.3[2]		4.4[3]	
Fibrous						
12. Paper and paperboard	61.30	24.5	104.2	38.2	154.9	45.1
13. Miscellaneous-industrial and fuelwood	16.62		11.3		12.2	
Total	193.38	31.9	259.9	52.6	306.8	64.7

[1] Yielding flakeboard cores equivalent to veneer from 5.9 MM tons of veneer logs in 1985 and 9.7 MM tons in 2000. These equivalents have consequently been subtracted from projected roundwood demand for softwood plywood.

[2] Of which 1.5 MM O.D. tons is converted to finished softwood lumber and 0.8 MM O.D. tons is converted to finished hardwood lumber.

[3] Of which 2.8 MM O.D. tons is converted to finished softwood lumber and 1.6 MM O.D. tons is converted to finished hardwood lumber.

Scenario
No.
II

Commodity	1985		2000	
	MM O.D. tons		MM O.D. tons	
	From Roundwood	From By-Product	From Roundwood	From By-Product
Structural				
1. Softwood lumber	81.3	3.3	75.1	4.0
2. Softwood plywood	18.2		18.6	
3. Hardwood lumber	29.8	1.4	31.7	1.4
4. Hardwood plywood	3.6		4.3	
5. Particleboard		4.5		6.3
6. Med. density fiberboard	0.3	0.3	0.5	0.5
7. Insulation board		1.9		2.7
8. Wet-formed hardboard		2.0		2.7
9. Structural flakeboard #1	3.0[1]		5.1[1]	
10. Structural flakeboard #2 (RCW)	3.0		5.1	
11. Laminated-veneer lumber	2.2[2]		4.6[3]	
Fibrous				
12. Paper and paperboard	95.3	38.0	139.6	55.6
13. Miscellaneous-industrial and fuelwood	11.1		11.6	
Total	247.8	51.4	296.2	73.2

---

[1] Yielding flakeboard cores equivalent to veneer from 5.9 MM tons of veneer logs in 1985 and 10.0 MM tons in 2000. These equivalents have consequently been subtracted from projected roundwood demand for softwood plywood.

[2] Of which 1.5 MM O.D. tons is converted to finished softwood lumber and 0.7 MM O.D. tons is converted to finished hardwood lumber.

[3] Of which 3.4 MM O.D. tons is converted to finished softwood lumber and 1.2 MM O.D. tons is converted to finished hardwood lumber.

Scenario
No.
III

	Commodity	1985		2000	
		MM O.D. tons		MM O.D. tons	
		From Roundwood	From By-Product	From Roundwood	From By-Product
Structural					
1.	Softwood lumber	124.0	3.9	147.4	5.3
2.	Softwood plywood	20.9		23.9	
3.	Hardwood lumber	45.4	1.7	58.4	1.9
4.	Hardwood plywood	5.5		7.5	
5.	Particleboard		5.4		8.4
6.	Med. density fiberboard	0.4	0.4	0.7	0.7
7.	Insulation board		2.5		4.0
8.	Wet-formed hardboard		2.6		4.0
9.	Structural flakeboard #1	3.6[1]		6.8[1]	
10.	Structural flakeboard #2 (RCW)	3.6		6.8	
11.	Laminated veneer lumber	3.4[2]		9.2[3]	
Fibrous					
12.	Paper and paperboard	123.9	49.4	209.4	83.4
13.	Miscellaneous-industrial and fuelwood	17.1		22.2	
	Total	347.8	65.9	492.3	107.7

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[1] Yielding flakeboard cores equivalent to veneer from 7.1 MM tons of veneer logs in 1985 and 13.3 MM tons in 2000. These equivalents have consequently been subtracted from projected roundwood demand for softwood plywood.

[2] Of which 2.4 MM O.D. tons is converted to finished softwood lumber and 1.0 MM O.D. tons is converted to finished hardwood lumber.

[3] Of which 6.7 MM O.D. tons is converted to finished softwood lumber and 2.5 MM O.D. tons is converted to finished hardwood lumber.

Scenario
No.
IV

		1985		2000	
		MM O.D. tons		MM O.D. tons	
	Commodity	From Roundwood	From By-Product	From Roundwood	From By-Product
Structural					
1.	Softwood lumber	167.4	9.6	220.2	12.5
2.	Softwood plywood	29.6		39.6	
3.	Hardwood lumber	60.2	1.9	91.3	2.3
4.	Hardwood plywood	9.8		12.9	
5.	Particleboard		9.4		18.9
6.	Med. density fiberboard	0.4	0.4	0.8	0.8
7.	Insulation board		3.0		5.4
8.	Wet-formed hardboard		3.2		5.4
9.	Structural flakeboard #1	4.2[1]		8.5[1]	
10.	Structural flakeboard #2 (RCW)	4.2		8.5	
11.	Laminated veneer lumber	4.6[2]		13.8[3]	
Fibrous					
12.	Paper and paperboard	152.5	60.8	279.2	111.2
13.	Miscellaneous-industrial and fuelwood	23.1		34.8	
	Total	456.0	88.3	709.6	156.5

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[1] Yielding flakeboard cores equivalent to veneer from 8.3 MM tons of veneer logs in 1985 and 16.2 MM tons in 2000. These equivalents have consequently been subtracted from projected roundwood demand for softwood plywood.

[2] Of which 3.2 MM O.D. tons is converted to finished softwood lumber and 1.1 MM O.D. tons is converted to finished hardwood lumber.

[3] Of which 10.0 MM O.D. tons is converted to finished softwood lumber and 3.8 MM O.D. tons is converted to finished hardwood lumber.

practiced in forest management. Because of the time element involved in producting forest crops, much more intensive culture would need to be practiced today to have tree crops available at these future dates at these scenario levels. Since this is not being done alternative options available are to make up the differences by reducing levels of inventory in anticipation of future productivity, by complete use of all residues, and by import.

A further consideration requires examination of the prospects of achieving the output levels suggested by these scenarios. Achievement of these levels of output would require a radical social rethinking and scrutiny of how forest lands are to be used in this country. CORRIM has noted (Chapter 4, Table 4) that if forest lands were managed to their inherrent productive (yield table) capacity, output would be approximately 38 billion ft^3. This is on the order of 3 times the 1970 level of output. This yield table potential assumes all forest sites are fully stocked with appropriate species to take full advantage of the growth opportunities of the site. Such a situation would occur only if all landowners, small and large, public and private, were willing to invest in cultural practices to reach this objective. Certainly the higher prices that wood would command under these scenarios would spur such investments, but full achievement of yield table level forestry on all lands may not be possible, particularly in view of other interests of owners and society for forested lands. The yield table potential is only a rough estimate because most conventional yield tables available are applicable only to even aged natural stands. To refine this estimate, more yield table information is needed for mixed age stands and plantations. Furthermore, the conventional yield table values used do not place an upper limit on potential forest output since they do not include dividends from intensive cultural practices such as fertilization and genetic improvement. Also the yield table volume frequently have built into them assumptions concerning the utilization of the forest and as a result the values produced in yield table estimates of potential output may be low.

In conclusion, whereas Scenarios I and II do not use our current forest production capability, Scenarios III and IV would greatly stress our present ability to grow forest crops and our attitudes toward using forest lands for other activities. It would appear that with radical changes in attitudes and extremely extensive investments in forest culture the demand level suggested by these scenarios could be achieved. The questions raised by these scenarios certainly deserve closer study.

The potential of the forest resource to meet realistic demands through the next 25 years is evident, but the realization of this potential presents a challenge to the makers of forest policy, to resource managers, and to the forest-based industries. Much more research in the closer utilization of residues at the mill and in the forest will be needed to achieve the potentials suggested by our scenarios and trajectories.

Apart from the trend toward an increase in overall demand for wood products, the most notable changes that are predictable within the next quarter century will be in the increasing replacement of lumber and plywood with products reconstituted from fibers and small wood components and a trend toward building-up structural members of large dimension from smaller pieces through lamination.

Lumber laminated from veneer, which is now technically feasible and for which trajectories have been developed, holds considerable promise. Even more promising are reconstituted structural products assembled from flakes or strands, which can be derived from essentially all woody components of trees of any species, size, and quality. As in the case of lumber laminated from veneer, technology now exists for such products, and their movement into the market is on the immediate horizon. These products are promising not only as replacements for plywood or veneer in structural panels or panel components, but also as alternatives to lumber in structural supporting members. Reconstituted structural board can be manufactured, for example, from strands from currently unusable defective trees.

In the sphere of improved design concepts, current improvements in wood structural systems promise materials savings of as much as a third without sacrificing structural performance. This is equivalent to a 50 percent gain for this purpose and an overall gain in forest productivity of at least 15 percent.

The long established, but continuously improving, technology of protection of wood from fungi and insects with chemical impregnation can, through more widespread use, reduce substantially the drain from the forest of species lacking in natural durability for use under conditions conducive to decay and insect damage. The effectiveness of such treatment is attested to by estimates that preservative treatment of railroad ties, alone, results in an annual savings of over 2.6 billion board feet of lumber and that some 20 million additional trees would be needed each year for pole replacements (Cliff 1973). Modern, clean preservatives, such as salts or pentachlorophenol, which are now in common use, can provide lasting protection for millwork and other exposed building components without detriment to later surface finishing. More extensive use of these and other preservatives could substantially reduce the 200 million board feet of lumber currently required annually to replace biodegraded building components. Technology is now available for chemical preservation of plywood, particleboard, and hardboard, but additional research is needed in this area.

Chemical impregnation and fire-retardant finishing systems can effectively reduce the flammability of wood in all forms to meet building code requirements and reduce fire damage and loss. More widespread use of the improving technology in this area can increase the acceptability of wood for residential and commercial construction in congested areas in which alternative building materials have, often questionably, been favored. Research is needed to reduce the costs of such treatments and improve the technology of treating composites in primary processing systems.

Assuming a high level of technology (a result of research and development) and assuming an adequate manpower pool, it appears safe to forecast that the nation's needs for structural and architectural materials based on the forest resource can be met, but that they will be met with a mix that is substantially different from that in current use.

Information developed during the course of this study strongly suggests that, on the basis of man-hours, capital, and particularly energy requirements, structural wood products have clear advantages over non-wood alternatives. Large quantities of wood have been used for these purposes for years. There are indications that wood may regain markets that it had earlier lost to nonrenewable materials if the cost of energy continues to increase.

A long established trend toward whole-tree or at least whole-stem use should result in an improvement in the cost of wood relative to the cost of competing nonrenewable materials. This trend should also result in a change in the structural product mix so that reconstituted wood products will make up a larger fraction of the total. Essential to this development is the emergence of improved timber harvesting technology.

If a nonpetroleum-based exterior adhesive can be produced that is competitive with phenol-formaldehyde adhesives in performance and price, the opportunities to conserve petroleum can be enhanced.

The industries that produce structural and architectural materials from wood are in a particularly favorable position to become energy-independent in terms of their own processing requirements. This energy independence will be fostered if improved furnaces are designed to use green wood and bark residues to generate the heat required for kilns, driers, and presses.

Because wood has been a plentiful material, designs using it in structures have tended to be inefficient in terms of weight of material used in a specific application. Improved designs that are structurally more efficient are feasible and will contribute to materials conservation.

CHAPTER 7

FIBERS AS A RENEWABLE RESOURCE FOR INDUSTRIAL MATERIALS

INTRODUCTION

Collectively, the natural fibers provide a major renewable resource for American industry and the national economy. The fiber-based industries form one of the largest industrial groups in the nation, directly affecting the national economy through employment, capital investments, support of chemical and machinery suppliers and other allied industries, and transportation and export of products.

The natural fibers are the basic resource for paper and paperboard products, textiles, leather goods, and fur and feather products. Because of increasing future consumer demand for these materials and developing shortages in some critical nonrenewable resources for industrial materials and for energy, there is great need to analyze and improve our position with respect to renewable fiber resources.

The major materials flows based on renewable fiber resources are outlined in the following simplified flow trajectories (Figure 1). These are: (A) paper and paperboard, (B) cotton textiles, (C) cellulosics, (D) wool and mohair, and (E) feathers, furs, and leather.

PAPER AND PAPERBOARD

Assessment of the Industry

Present Situation

The U.S. paper industry depends on the forest for about 98 percent of its fiber requirements. For total world production, 94 to 95 percent of the fiber used is from wood. The remaining fiber is mainly other vegetable fiber such as cotton linters, bagasse, and flax. Only very minor amounts of nonrenewable fibers (asbestos and glass) are consumed. Some paper products, however, are meeting strong competition from nonrenewable materials, such as plastic films for wrapping and molded plastic containers for milk, etc.

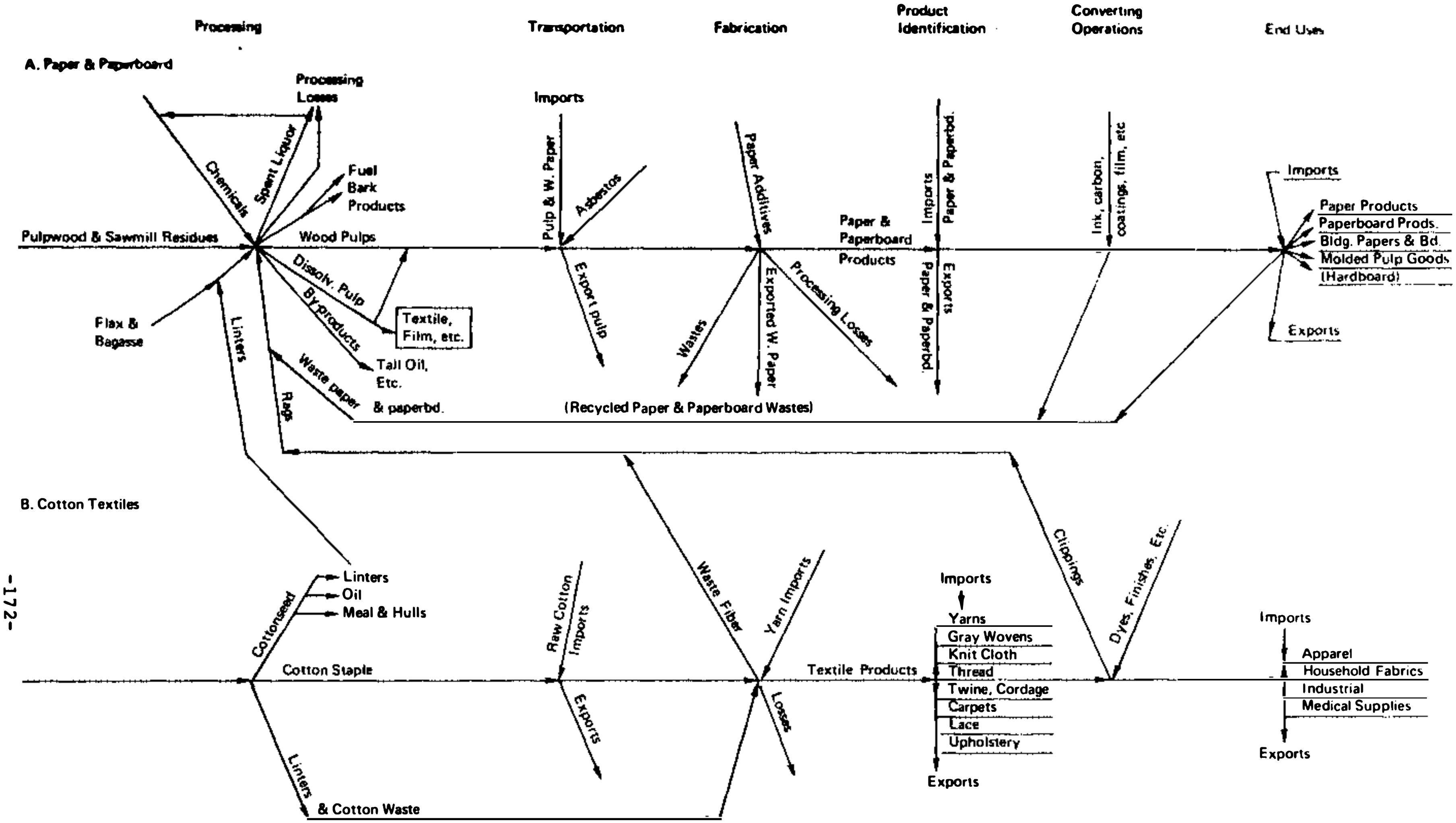
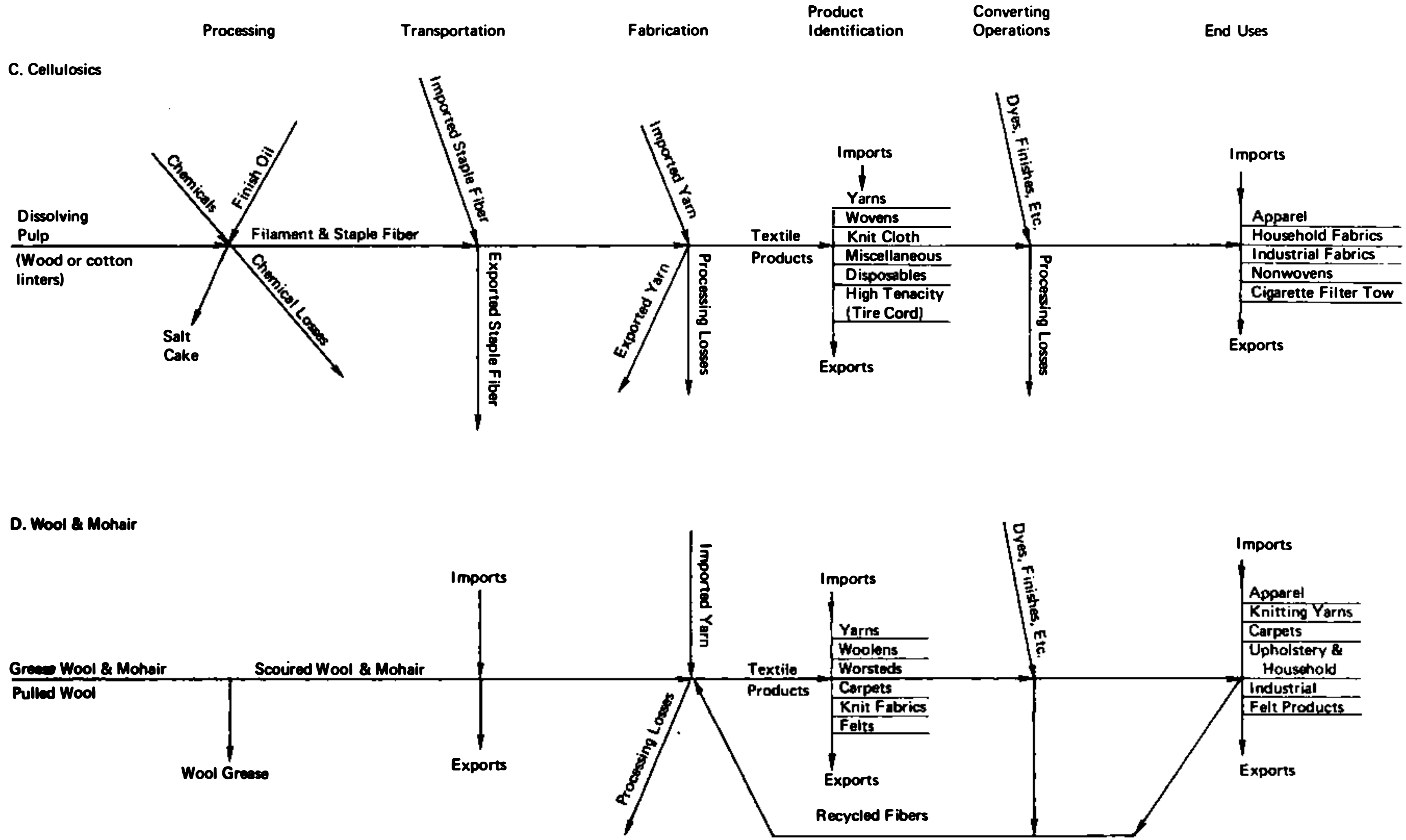
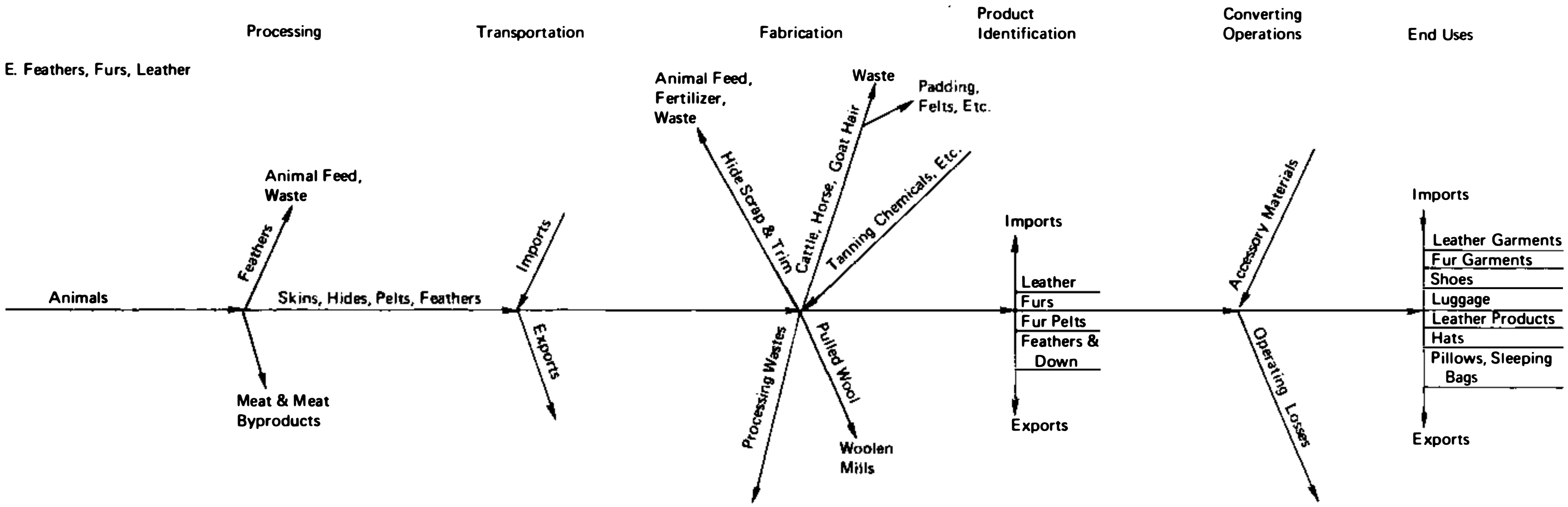


FIGURE 1 SIMPLIFIED FLOW TRAJECTORIES–FIBERS


Processing
Transportation
Fabrication
Product Identification
Converting Operations
End Uses
C. Cellulosics
Dissolving Pulp
(Wood or cotton linters)
Chemicals
Finish Oil
Filament & Staple Fiber
Salt Cake
Chemical Losses
Imported Staple Fiber
Exported Staple Fiber
Imported Yarn
Exported Yarn
Processing Losses
Textile Products
Imports
Yarns
Wovens
Knit Cloth
Miscellaneous
Disposables
High Tenacity (Tire Cord)
Exports
Dyes, Finishes, Etc.
Processing Losses
Imports
Apparel
Household Fabrics
Industrial Fabrics
Nonwovens
Cigarette Filter Tow
Exports
D. Wool & Mohair
Grease Wool & Mohair
Pulled Wool
Wool Grease
Scoured Wool & Mohair
Imports
Exports
Imported Yarn
Processing Losses
Textile Products
Imports
Yarns
Woolens
Worsteds
Carpets
Knit Fabrics
Felts
Exports
Recycled Fibers
Dyes, Finishes, Etc.
Imports
Apparel
Knitting Yarns
Carpets
Upholstery & Household
Industrial
Felt Products
Exports

E. Feathers, Furs, Leather



Statistics for 1972 (U.S. COM 1975a; American Paper Institute (1974) characterizing the U.S. pulp, paper, and paperboard industry (excluding hardboard) follow:

No. of establishments	787
Total no. of employees	221,100
Total production[1]	57,491,000 short tons
Production/man-hour	0.158 short tons
Value added by manufacture	$ 5,364.2 million
Total value of shipments	$11,675.4 million
Capital expenditures	$ 893.6 million
Payroll	$ 2,455.7 million
Cost of materials	$ 5,388.9 million
Cost of electricity & fuel[2]	$ 891.0 million
Purchased fuel, kwh Eq/ton	5,509
Electric energy purchased, kwh/ton	470
Generated less sold, kwh/ton	429
Purchased fuel & electric energy, kwh Eq/ton	5,979

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[1] Excluding hardboard (1,908,000 tons).

[2] Contract and resale was $14.9 million.

The materials input for 1972 (U.S. COM 1975a; American Paper Institute (1974) in the manufacture of paper and paperboard follows:

Pulpwood (incl. harvesting and manufacturing residues)	71,538,000 cords
Wood Pulp (from above pulpwood)	43,628,000 short tons
Waste Paper	11,405,000 tons
Inorganic chemicals, clay, starch, etc.	9,095,000 tons
Non-wood fibers	1,047,000 tons

It is obvious from the above two sets of figures that the American pulp, paper, and paperboard industry is large by any standard and plays an important role in the nation's economy.

The fibers in wood are separated into a pulp by two major procedures: mechanical, by stone or disc grinders; and chemical, by dissolving the lignin matrix by chemicals (usually by the sulfate or kraft process or by the sulfite process) at elevated temperature and pressure. Modifications and combinations of these processes have been developed. The fibers, suspended in a water slurry in the form of a pulp, are washed, screened and mechanically beaten or refined to prepare the pulp for papermaking. The dilute fiber suspension containing such additives as starch, clay, etc., passes over a moving wire screen that separates most of the water and forms a wet web of fibers. This web passes over suction boxes and rolls and then over heated steel drums to remove the remainder of the water to form the dry paper sheet. This then passes through a stack of steel rolls to press and smooth the sheet.

The equipment required for pulp and papermaking and for recovery of the pulping chemicals is large, complicated, and very costly. An average kraft pulp and paper mill coming onto stream in 1975 costs from $90,000 to $250,000 per daily ton of production capacity, depending on the type of product produced. A kraft liverboard mill of 500 tons daily capacity would cost approximately 50 million (1975 dollars), whereas a bleached kraft mill of the same capacity would cost about 2-1/2 times as much. Prices are rising rapidly, however; a mill ordered today would cost much more at time of completion.

Line A of the Figure 1 trajectories shows the materials flow for paper and paperboard.

Statistics for 1972 on production of paper and paperboard are shown in Table 1. The American paper and paperboard industry has experienced rapid continuous growth, amounting to an increase in production of almost 3-1/2-fold over the past three decades. Per capita consumption in 1972 was 616.6 pounds compared to 293.7 in 1942, 368.3 in 1952 and 452.7 in 1962. The export import picture is shown in Table 2.

At the same time that this great growth in production and consumption was taking place, the fiber raw material picture was improving. This is due to better management and use of our forests, to greatly increased use of mill and forest residues, broader use of tree species, and greater efficiency in processing fiber raw materials.

Table 1

Production of Total Paper and Paperboard

Summary
000 Short Tons

	1972	1985F	2000F
Newsprint	3,436	5,350	8,400
Groundwood	1,329	2,020	3,300
Other Printing & Writing	10,958	18,115	29,300
Packaging & Industrial Converting	5,695	7,895	12,000
Tissue	3,977	5,935	9,000
(TOTAL PAPER)	(25,396)	(39,315)	(62,000)
Solid Wood Pulp Paperboard	20,965	32,040	48,330
Recycled Paperboard (incl. Wet Machine Board)	7,686	11,875	18,530
(TOTAL PAPERBOARD)	(28,503)	(43,780)	(66,700)
(TOTAL WET MACHINE BOARD)	(148)	(135)	(160)
Construction Paper and Board excl. Hardboard	3,444	5,130	8,000
Construction Paper and Board incl. Hardboard	5,352	8,015	12,500
TOTAL PAPER AND BOARD excl. Hardboard	57,491	88,360	136,860
TOTAL PAPER AND BOARD incl. Hardboard	59,398	91,245	141,360

F - Forecast trend by American Paper Institute
Real GNP trend 1972 to 2000 -2.580X 28 years 3.5% per year average.

Real GNP:	for 1972	$ 792.5 billion
	for 1985	$1,222.0 billion
	for 200	$2,000.0 billion

Table 2

Statistics and Forecasts for Exports, Imports, Production and New Supply
000 Short Tons

Product	Trend	New Supply[1]	Exports[2]	Imports[2]	Production[3]
			1972		
Paper	40.83	32,356	559	7,520	25,396
Paperboard	33.15	26,272	2,231	---	28,503
Wet Machine Board	.18	146	6	4	148
Construction Paper & Board	4.42	3,503	45	104	3,444
Hardboard	2.82	2,231	34	357	1,908
Total Paper & Board	81.40	64,509	2,875	7,985	59,399
Total Paper & Board (excl. hardboard)	78.58	62,278	2,841	7,628	57,491
			1985		
Paper	40.22	49,140	790	10,615	39,315
Paperboard	33.33	40,730	3,050	0	43,780
Wet Machine Board	.11	140	5	10	135
Construction Paper & Board	4.21	5,145	90	105	5,130
Hardboard	2.59	3,165	70	350	2,885
Total Paper & Board	80.46	98,320	4,005	11,080	91,245
Total Paper & Board (excl. hardboard)	77.87	95,155	3,935	10,730	88,360
			2000		
Paper	39.00	78,000	1,000	17,000	62,000
Paperboard	31.05	62,100	4,600	0	66,700
Wet Machine Board	.08	160	10	0	160
Construction Paper & Board	4.04	8,075	100	175	8,000
Hardboard	2.46	4,925	100	525	4,500
Total Paper & Board	76.63	153,260	5,810	17,510	141,360
Total Paper & Board (excl. hardboard)	74.17	148,335	5,710	17,185	136,860

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[1] Real GNP Times Trend
[2] Projections from Trend
[3] Production = New Supply + Exports-Imports

Real GNP:	for 1972	$ 792.5 billion
	for 1985	$1,222.0 billion
	for 2000	$2,000.0 billion

Forecasts for Demand for 1985 and 2000

All forecasts indicate a continued future growth of demand and production of paper and paperboard both in the U.S. and on a world basis. Forecast projections for U.S. production are shown in Table 1, and for exports, imports, and new supply in Table 2.

Comparative figures for paper and paperboard demand in the U.S. are shown in Table 3.

Table 3

U.S. Paper and Paperboard Demand

	Demand (1,000 short tons)	
Year	Total	(Total excl. hardboard)
1972	64,509	62,278
1985	98,320	95,155
2000	153,260	148,335

The above figures refer to "new supply," which is the sum of production plus imports minus exports. Assuming no change in inventories, new supply is considered to be "apparent consumption."

World demand for paper and paperboard in 2000 is expected to be 456 million tons compared to 155 in 1972. The projected U.S. demand for 2000 is estimated to be 148 million tons or 32 percent of the world consumption. U.S. production in 1985 and 2000 is expected to be 88.36 and 136.86 million tons, respectively (exclusive of hardboard).

Despite this expected growth rate of nearly 50 percent per decade in paper and paperboard production in the U.S. (and even greater on a world basis), there should be sufficient fiber available to 2000 and beyond. This increase in fiber production will be due to continued improvements in forest utilization and will depend upon industry and government investments and policies to fully develop our expertise in managing our fiber resources.

Factors Affecting the Industry

Environmental and Other Regulatory Issues

Federal and state laws and agency regulations relating to land practices, processing, and products have a very considerable impact upon the pulp and paper industry, usually in the form of restrictions and constraints. These include legislation concerning the environment, packaging (generally, packaging is subject to regulations as severe as the food it contains), health and safety (for example, required noise reduction could cost $2 billion), container specifications and constrictions concerning design and performance, tariff rates for preferential incentives (such as to encourage the use of secondary fibers), and consumer protection, which can influence the choice of materials (such as flameproofing).

Meeting environmental regulations is very costly. In 1972 capital expenditures for pollution abatement equipment cost the industry $339 million. Other costs relating to this problem amounted to $243 million. Marked progress has been made by the pulp and paper industry in pollution control, but there is industry-wide concern over its ability to sustain environmental protection expenditures in excess of the $0.5 billion annual level that has been met during the past three years. This includes considerable research expenditures necessary for the development of the best pollution control technology.

Energy Factors

The paper industry is a major consumer of energy with an annual consumption of 320 billion kwh Eq greater than that of the plastics, rolled aluminum, or plate glass industries. However, the energy consumed per ton is less than for any of these other materials. Also the energy cost as a percent of total manufacturing cost (10 to 16 percent) is less than for such nonrenewable materials as plastics or aluminum.

The paper industry now supplies as much as 42 percent of its energy need from its own processing wastes. Therefore, as purchased fuel and power costs increase, the effect on the cost of a ton of paper will be less than the increase in cost of a competitor's product made from a nonrenewable resource. New technology to improve this capability would further increase this advantage and save imported fuel. Research efforts are being made in this direction and should be encouraged.

Other Factors

Environmental and regulatory constraints and energy availability and cost are factors that can greatly affect future industrial operations and production trends. Other major factors are fiber raw material availability (price, quality, ability to produce quality fiber from lowest cost material, integrated use), capital requirements and availability (for growth, updating, and environmental needs), productivity (existing facilities and new facilities for new processes), product changes to meet requirements based on performance specifications, and changes in societal values and new technology. Many of these factors can be impacted by new technological advances (research) and constrained or enhanced by governmental policies and societal values.

Enhancement of Availability and Utility of Materials

Better Use

Since 1960 there has been a decline in the amount of wood used per unit ton of all pulp types from a figure of 1.60 cords per ton to 1.51 cords per ton in 1973. This reduction is partly due to the use of greater percentages of hardwood, but it is primarily the result of technological changes, which have made it possible to use higher yield pulps in the manufacture of packaging papers and paperboard.

Since 1950 there has been a shift, not only to a greater use of hardwoods (about 25 percent of all wood pulped), but to the wider use of sawmill residues, i.e., integrated use. In 1972 and 1973 about 35 percent of all wood pulped was in the form of wood manufacturing residues (30 percent) and logging residues (5 percent), compared to only 17 percent in 1960.

Since 1970 the concept of whole-tree use has resulted in some movement to the chipping of the whole tree and also the recovery of logging residue. This trend is expected to continue and will lead to better forest management and use and increased fiber supply.

Although wood costs themselves will cause a trend toward higher pulp yields, developing technologies lend themselves to higher pulp yields. This is fortunate and will help realize their development and application at an early date.

Product Performance and More Efficient End-Use

Much needs to be learned about the mechanisms of failure in product performance. Performance criteria must be related to controllable factors in the pulp and papermaking operations. Adequate criteria to design paper products effectively for efficient end-use are not available. This results in improper design in many products.

Economic Incentives

Economic incentives take the form of outright grants, investment tax credits, or other special legislation to encourage the adoption of technology and concepts to expand the broader use of the natural fiber resource and improve the products therefrom. Under suitable conditions, economic incentives can speed up acceptance of new technology and operating concepts by as much as five years.

Alternate Use of By-products

Except for tall oil and turpentine, the pulp and paper industry uses most of its wastes (bark and lignin) for fuel. Almost all the lignin and other organic material removed from the wood is converted into heat and energy during the chemical recovery process. Alternative uses will depend on fuel costs and availability.

Increased Recycling

The use of primary and secondary manufacturing wood residues is now well established. Waste wood from urban forestry, construction, demolition, pallets, etc., is another potential source, which is now only beginning to be used.

The recycling of waste paper is expected to increase and peak at some quantity under 30 percent, which is quite reasonable for the U.S. market and quality demands. A sizeable portion of wastepaper will be consumed by major cities in the burning of organic wastes for heat and energy. Only the higher quality and readily collectible clean waste will be recycled to the paper mill.

Technology Transfer

The paper industry maintains several active channels for technology transfer, such as through the Institute of Paper Chemistry, the Empire State Paper Research Institute, the Forest Products Laboratory, and through various joint projects with other institutions. There is also transfer of technology between the paper industry and other industries, such as in computer and instrument applications, etc.

New Technology

New technology resulting from research on tree genetics, continuous pulping, thermomechanical pulping, oxygen bleaching, new forming methods, computer control, to name but a few, has directly enhanced the availability and use of fiber raw material for pulp and paperboard products. Research on whole-tree pulping, high-yield pulping, thermomechanical pulping, and processes with less impact on the environment are now developing technologies that will further enhance the availability and better use of the forest raw material. Research also directly affects the position of paper products in relation to sales and competition with other materials. Based on research on new products, the paper industry expects that about 7 percent of its 1978 sales will be in new products, amounting to $3.89 billion.

Currently the paper and paperboard industry expends about 0.6 percent of its sales dollar (about 9 percent of its capital outlays) for R&D or a 1975 total of $250 million. This is a very low figure in relation to many other industries. The number of R&D scientists and engineers in the paper industry is 4,900, a relatively constant figure since 1967. Increasing this number should be a long-range strategy.

The distribution of planned R&D funds for 1975 is 33 percent for new products, 26 percent for new processes and 41 percent for improving existing products. The amounts budgeted for pollution control research and energy-related research are $28 million and $12 million, respectively. Most research is done by larger companies. In 1972, companies with 10,000 or more workers accounted for 81 percent of all the research.

Product Substitution

Paper and paperboard products have, in the main, resisted invasion by products made from petrochemicals and other nonrenewable materials. There are, of course, a fair number of paper products that have lost most or a share of the market to the nonrenewables. For example, coated paper bread wrap and glassine food packaging have lost most of their markets to plastic films. The blow molded plastic bottle has penetrated 20 percent into the paperboard milk carton market.

These are countered by development of nonwoven fabric from pulp, which is competing with man-made fibers; by composite paper oil can bodies vs. steel or aluminum cans; and by other developments. Paper composites with other materials is a developing area for new paper products.

TEXTILE MATERIALS: COTTON, WOOL, AND CELLULOSICS

Assessment of the Industry

Agriculturally produced renewable fibers receive much of their added value and consumer utility in the processing and manufacturing functions following their production and harvesting. (Simplified flow trajectories defining these various utilization steps are shown for cotton in line B, for cellulosics in line C, and for wool and mohair in line D of Figure 1.) Fibers from both renewable and nonrenewable resources compete in the textile manufacturing functions on the basis of costs of raw materials, and processing, technological capabilities, and quality characteristics that appeal to the consumers. The change in mill consumption of renewable and nonrenewable fibers over the past four decades is shown in Table 4.

Table 4

Fibers, Mill Consumption (millions of pounds)

	Renewable Resources				Nonrenewable Resources		
Year	Cotton	Wool	Rayon & Acetate (cellulosics)	Total	Man-Made Fibers[1]	Textile glass	Total
1942	5,633	604	621	6,858	16	8	24
1952	4,471	466	1,238	6,175	212	41	253
1962	4,192	504	1,392	6,088	944	178	1,122
1972	3,850	247	1,568	5,665	5,586	569	6,155

[1] Other than cellulosics.

Forty-three percent of the fibers processed by U.S. textile mills in 1972 were from renewable resources and 57 percent were from nonrenewable resources, primarily petroleum and natural gas. Fibers from the renewable resources, which are derived from agriculture and forestry, were used in the following proportions:

	Percent
Cotton	30
Wool	1
Cellulosics	12

Fibers from the nonrenewable petroleum and natural gas resources were nylon, acrylic, olefin, polyester, and others.

Products are manufactured of 100 percent cotton, wool, and cellulose fibers of rayon and acetate, as well as blends with other renewable and nonrenewable fibers. The fiber content of products is determined by such factors as fiber cost, strength, efficiency of processing, end product characteristics, and promotional programs.

Textile mills, along with apparel, domestic, and industrial textile products manufacturers, utilize over $30 billion in assets and employ over 2.5 million people to process approximately 12 billion pounds of fibers annually. These textile mills and manufacturers are of great significance to the economic well-being of the U.S. Their economic health and technological capability are equally important to the effective use of renewable fiber resources.

During the decade prior to 1972, the total consumption of fibers in the U.S. increased greatly; but the increase was entirely from the production of fibers from nonrenewable resources. This decade is recognized as a period of exceptionally rapid growth in fiber consumption. Fibers produced from renewable resources decreased 7 percent during this decade, while total fiber consumption was increasing by 64 percent. This clearly illustrates the direction we have been moving in the use of nonrenewable energy resources for fibers. As U.S. petroleum resources near the critical stage of depletion, however, an examination of the fiber resource potentials from renewable resources is required.

Forecasts with brief discussions of the problems and opportunities for cotton, wool, and cellulosics (rayon and acetate) are summarized from the background paper prepared by the Panel on Fibers.

Forecasts for the Years 1985 and 2000

Cotton. Land and other resources for the production of both food and fiber are potentially adequate through the year 2000. [See Report Biological Productivity of Renewable Resources Used as Industrial Materials listed in the FOREWORD.] The future production of cotton will therefore, be determined by demand. It is assumed that production will be equal to the demand.

Projections for cotton demand were estimated for 1985 and 2000 based on three varying levels of economic and population factors resulting in low, medium, and high scenarios (see Table 5). [For details on scenarios, see Report Fibers as Renewable Resources for Industrial Materials listed in the FOREWORD.] The per capita demand for cotton is expected to fall off slightly from the 1972 base year level by 1985, but will increase some by the year 2000.

The increasing population is expected to result in a stable rate of domestic demand through 1985. The projected increases in population and per capita consumption would result in a projected domestic demand increase of approximately 2 million bales by the year 2000.

The above projections are based on reasonable estimates of economic growth, demand price elasticity, and population growth. However, the extent to which this projected demand can be attained or exceeded is dependent very largely on cotton's ability to compete with other fibers in the manufacturing process and in satisfying consumer requirements for functional and aesthetic properties in final products.

The ability of cotton to compete well with fibers from nonrenewable resources is dependent upon the relative costs and availability of such inputs as energy and transportation, as well as fabric-forming systems that can process cotton well. Capital and labor must be available to maintain and expand manufacturing plant capacity. World trade patterns, as well as incentives and regulations imposed by society, will considerably influence the competitive strength of cotton by the years 1985 and 2000.

Wool. U.S. mills consumed 247 million pounds of wool in 1972. This represents a 51 percent decline over the 1962-1972 decade. Though wool has excellent comfort and fashion characteristics, its competitive position has been seriously eroded by man-made fibers. Fluctuating wool prices and lack of availability during periods of high

Table 5

Cotton

		Projection for 1985 Economic Scenario			Projection for 2000 Economic Scenario		
	1972	low	med.	high	low	med.	high
Per Capita Cotton Demand (lbs.)	18	14	16	18	15	17.5	20
Population (million)	209	235	235	235	264	264	264
Domestic Demand (mil. 480 lb. bales)	7.8	6.86	7.85	8.83	8.26	9.64	11.02
Exports (mil. 480 lb. bales)	5.3	4.0	4.0	4.0	5.0	5.0	5.0
Total Domestic Demand + Exports	13.1	10.86	11.85	12.83	13.26	14.64	16.02
Production (mil. 480 lb. bales)	13.70	10.87	11.85	12.83	13.26	14.64	16.02
Cost of Prod. (lb. of lint)	.32	.36	.50	.67	.41	.75	1.28
Cotton Seed Products							
oil (mil. lbs.)	1,355	1,325	1,447	1,565	1,669	1,840	2,015
meal & hulls (mil. tons)	2.97	2.90	3.17	3.43	3.66	4.03	4.42
linters (mil. lbs.)	761	744	812	878	937	1,033	1,131
Cotton Product Production							
weaving and yarn mills (bil. lbs.)	3.8	3.2	3.8	4.4	4.0	4.7	5.3
apparel & garments	1.5	1.3	1.5	1.7	1.6	1.9	2.1
household textile products	1.3	1.1	1.3	1.5	1.4	1.6	1.8
industrial products	.5	.4	.5	.6	.5	.6	.7
other	.5	.4	.5	.6	.5	.6	.7
Energy Consumption							
cotton production, harvesting and ginning[1] (kw. hr./lb.)	3.30	2.78	2.78	2.78	2.58	2.58	2.58
yarn production (kw. hr./lb.)	2.58	2.19	2.19	2.19	1.97	1.97	1.97
gray cloth production (kw. hr./ lin. yd.)	2.96	2.52	2.52	2.52	2.27	2.27	2.27
cloth finishing (kw. hr./lin. yr.)	3.32	2.82	2.82	2.82	2.54	2.54	2.54
Labor Requirements (million man hrs.)							
production and harvesting	307	127	139	150	128	142	155
ginning	11	9.5	105	11	8	9	10

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[1] No energy allocated to cotton seed production.

demand have been partially responsible for serious market losses.

Trend analysis indicates a continuing decline in sheep population to 13.5 and 12.8 million in 1985 and 2000, respectively, yielding 73 and 76 million pounds of clean wool (compared to 83.3 in 1972). The wool increase in 2000 is due to expected continued improvement in clean wool yield from grease wool. Future production will depend on meat demand, wool imports, and wool textile activities. Increased future demand is a good possibility, which could project the wool trend upward.

Cellulosics--Rayon and Acetate. The major base raw material sources for the production of the cellulosics are wood and cotton linters. Theoretically, other types of vegetable fibers could be used, such as straw, reeds, bagasse, kenaf, jute, etc., but harvesting and storage of these raw materials has not been commercially successful, nor have pulping procedures yet produced a cellulose from these materials that is suitable for commercial use. Since the forest offers the largest and most practical source for increasing the supply of chemical cellulose, future emphasis on wood cellulose will continue.

Plant capacity for chemical cellulose (dissolving pulp) was 1,805,000 short air-dry tons in 1972, but had decreased to 1,695,000 in 1975. Estimated capacity for 1980 is 1,465,000 tons.

U.S. consumption of rayon and acetate textile fiber is expected to decrease over the next few years as shown in Table 6.

Table 6

U.S. Rayon and Acetate Textile Fiber Consumption

	Consumption (million lb)		
Fiber	1972	1973	1980
Acetate (staple and filament)	414	320	315
Rayon staple	734	710	630

Man-made cellulosic fiber production is confronted with serious environmental pollution abatement costs, high energy costs, and very large capital expenditures.

Energy and the Environment. Energy is of great importance to our nation's future. A renewable energy resource such as cotton should be a major building block in any national energy policy. The energy problem is a long-term problem and cannot be solved by additional supplies of petroleum or the use of other nonrenewable fuel resources. These finite resources will be depleted in time. It is essential that technology be applied to develop energy alternatives from renewable resources.

Calculations of energy consumption in fiber production based on 1972 census data (see Table 7) show that the production of a pound of cotton fiber requires only a small proportion of the energy required to produce a pound of synthetic fiber. Energy requirements to convert cotton and man-made fibers into textiles are about the same. Therefore, cotton possesses a significant energy advantage through the textile manufacturing process.

Table 7

Energy Consumed as Raw Materials and in Fiber Production Processes

Material	Energy Consumed (kwh/lb of fiber)
Cotton	3.36
Non-cellulosics	16.32
Cellulosics	20.42

Further, material resources and the quality of our environment must be considered jointly. Depletion of reserves and pollution have the same cause, i.e., failure to manage the flow of materials as a cycle or a closed system. The National Commission on Materials Policy (1973) stated, "A national policy for the management of energy and materials is needed to transform this open-ended process of wastage into a substantially closed system." Because cotton is a renewable resource deriving much of its energy from the sun, and because it is biodegradable, cotton fits this "closed system" concept well.

The cost impact of environmental enhancement will affect market price and, therefore, the balance among fibers in the market place. The Commission stated further:

> Some materials will experience price increases as a result of expenditures needed to comply with effluent standards; others will be affected very little or not at all.
>
> Although the trend toward synthetics may continue under current policies, it should be noted that the environmental impact of the industrial processes involved in their manufacture are quite different from those arising from the treatment of natural fibers. Thus environmental concerns may in the future alter the market balance between these fibers. Disposal of synthetic products also is relatively difficult because many resist oxidation or dissolution by natural processes.

The future projections for cotton shown in Table 5 show a 15 percent energy savings in cotton production by 1985 and an additional 7 percent savings by 2000. These savings will be derived largely from improved minimum tillage, the development of earlier maturing plants with greater insect resistance, and yield increases from plant disease reduction.

These energy and environmental advantages of fibers from renewable sources are of significant to our society and must be encouraged by adequate research and by regulatory functions to provide incentives rather than constraints.

Ginning and Marketing. There are opportunities for cost savings in ginning and related operations. In recent years, the charges for ginning a bale of cotton have averaged around $25 throughout the Cotton Belt. This is equivalent to slightly more than 5 cents per pound of lint. Actual costs of ginning vary considerably, however, from gin to gin, and are to a considerable extent volume dependent. While the average number of bales handled by gins is around 3,000 in a normal year, some new high-capacity gins can turn out 5 or 6 times that quantity. While most gins can be operated profitably, it is almost self-evident that those that handle less than 3,000 bales per season, if equipped to cope with machine-harvested cotton, stand a good chance of losing money at prevailing prices for ginning.

It is highly desirable that the cost of producing and processing cotton be reduced not only on the farm, but at every processing stage, from farm to, and through, the spinning mill. One approach to lower cost is through arrangements that increase the volume of cotton available to a given gin. Various methods for accomplishing this have been suggested: central ginning, gin-yard storage of seed cotton, the transport of cotton from greater distances, and high-speed automated ginning. The primary function of these types of changes would be to lower the labor and energy requirements to gin and compress a bale of cotton.

Cottonseed. The cotton crop produces both cotton lint and cottonseed. Cottonseed is one of the major oil seeds of the world. World production of cottonseed reaches 24 million metric tons annually. Oil constitutes the major source of revenue from cottonseed. However, 20 percent of cottonseed is crude protein. Cottonseed protein represents 5 to 6 percent of the world's available protein (Jones 1974). This protein source has largely been unavailable for direct human consumption due to the phenolic toxin, called gossypol, in the pigment glands of the kernel. Historically, cottonseed protein has been used for animal feed.

Progress is being made in both the removal of gossypol from the seed and in the development of glandless seed. Such technological development would not only enhance crop revenue, but also enable cotton to better compete for land at the production stage and with other fibers in the manufacturing processes.

Historically, cottonseed has accounted for 14 percent of the cotton crop revenue, but in 1973 and 1974 cottonseed accounted for 20 percent, due to the increased world demand for oil and protein.

The large potential world demand for protein illustrates an area of excellent payoff opportunities for research and product development.

Fabric Forming Systems. A fiber's consumption at the textile mill level is governed to some extent by the existing capacity of various fabric-forming systems and the fiber's relative processing efficiency on the equipment.

Approximately 75 percent of U.S. mill cotton consumption goes into woven fabrics, about 20 percent into knits, and 5 percent into yarn applications. These consumption relationships become significant when viewed in light of current machine capacities.

During 1973 and 1974, when the U.S. textile economy was strong, weaving capacity was strained. Spokesmen for the textile industry suggested that mill plans for new loom purchases were few and that those were primarily to replace old looms. There are therefore serious capacity constraints on the principal consuming system for cotton.

It seems likely that, in time, consumer demand will make it sufficiently profitable to add weaving capacity; however, in the near term, price competition created by excess knitting capacity may tend to adversely affect weaving profitability and discourage purchasing of new looms.

Knitting accounts for about a fourth of fiber consumption in all yarns. Cotton's chances for improving on its present 22 percent share seem reasonably good. Additional research is needed to improve the processing efficiency of cotton for certain knitting machines and the functional characteristics of cotton knitted products.

New technological developments in textile machinery are in progress and much research is needed to assure that renewable resources fibers can be used efficiently on the high-speed systems, such as open-end spinning and shuttleless looms. Additionally, regulatory and capital incentives are needed to assure that adequate new investments in plant capacity are made.

END-PRODUCT QUALITY REQUIREMENTS

The capability of fibers to fulfill the functional and aesthetic desires of consumers and to enable end products to meet the requirements of governmental regulations have great influence on the proportion of fibers used.

The impact of no-iron textiles on interfiber competition, for example, is unparalleled in recent history. These durable-press blends, many of which contain cotton, are consumed primarily in markets that were once dominated by 100 percent cotton. Competition from durable-press fabrics has cost cotton about 2 million bales (annually) of the domestic market.

Technology to impart high-quality durable-press properties to 100 percent cotton fabrics would improve cotton's competitive position in the domestic market. The potential gain might well approach a million bales.

Presently, a high quality no-iron finish is being marketed for heavy-weight cotton fabrics. This should help cotton hold major markets for heavy fabrics, such as denims and corduroys, and perhaps make some marginal gains. But similar technology will have to be developed for medium and lightweight fabrics if a real competitive impact is to be made.

Flammability may well be to interfiber competition in this decade what durable press was in the previous one. The Consumer Product Safety Commission has promulgated flame retardance standards on a number of textile products, and by 1985, most apparel and home furnishings and many industrial textiles will come under such standards.

When standards were promulgated for children's sleepwear (sizes 0-6X), cotton's market share plummeted from 66 percent to 6 percent in one year. What happens when standards are set for other textile end uses depends on the following:

1. Specific requirements of standards
2. Timing of standards implementation
3. State of flame retardance technology--by fiber or fabric type--at time of implementation

Flame retardance technology--regardless of fiber--is in its infancy. Demand for the property, whether mandatory or voluntary, will almost certainly become enormous. Outstanding success or complete failure of a fiber in the domestic marketplace may well hinge on how well the fiber can compete in this one functional requirement. Continuing research on flammability is essential to maintaining cotton as a viable renewable resource.

FEATHERS, FURS, AND LEATHER

Introduction

Fibrous materials produced by animals include feathers, furs and hides. These raw materials, with the exception of furs, are the by-products of the meat and poultry industries. This fact influences the geographic location of production and leads to a lack of response of supply to changes in demand, with fluctuation in prices.

Leather is skin or hide that is combined with a tanning agent that renders its fibrous protein (collagen) system immune to bacterial and enzyme attack. The tanning agent also prevents the collagen fibers from glueing together on drying, so that the leather remains soft, porous and flexible. The principal commercial tanning agents include: (1) vegetable tannins (from wood, bark, leaves, fruit), (2) mineral agents (complex salts of chromium, aluminum, and zirconium) (3) aldehydes, (4) oxidization oils and (5) synthetic compounds ("syntans").

In this group of materials, hides and leather play by far the major role in production of end uses. Furs are of secondary importance, and feathers are used mainly as a protein source in animal feed.

Feathers

Over 1 billion pounds of chicken and turkey feathers were produced in the U.S. in 1972, which is about current average annual production. Most of these are converted into a protein source for animal feed. Minor amounts of waterfowl feathers and down are used in pillows, quilted apparel, etc., of which over 80 percent is imported. Data are shown in Table 8.

Table 8

SOME PRODUCTION, EXPORT AND IMPORT STATISTICS FOR HIDES, LEATHER, FURS AND FEATHERS YEAR 1972

	U.S. Production		Exports		Imports
	1000 pieces	Million lbs.	1000 pieces	Million lbs.	1000 pieces
Hides					
Cattle	36,080	2,706	17,072		292
Hog		5			
Calf & Kip			2,072		261
Goat & Kid		289			3,355
Sheep & Lamb			5,872		16,852
Total		3,000	25,016	879 (1)	20,760
Leather					
Leather Stock(2)		1,375			
Trimmed Scrap(3)		200-300			
Leather(4)		898		143	
Hair & Wool from Slaughtering					
Pulled Wool		8			
Cattle Hair Available		75(5)			
Cattle Hair Used(5)		7			
Furs					
Mink	3,000				
Rabbit	10,000 est.				
Wild Pelts(6)	9,000				
Feathers					
Chicken		920(7)			
Turkey		187(7)			
Waterfowl Feathers & Down		1.8(8)			8.2 mil. lbs.

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(1) A 75 lb. rawhide, fleshed, trimmed and brine-cured yields 50 lb. cured hide. Other hides converted to cattle hide equivalents on the basis of leather area.

(2) Dry basis, trimmed. Leather stock is trimmed, fleshed, dehaired hides, ready for tanning.

(3) Trimmed scrap, partly used for fertilizer and animal food, but is mostly wasted. It could be a greater protein source.

(4) Tanners Council Projections (4/5/75).

(5) Of a total of 75 million lbs. available at slaughter houses, only 7 million lbs. were used in 1972 for industrial products, such as rug pads, furniture padding, etc. The rest is wasted and adds to stream pollution.

(6) All kinds; 1969-70 data.

(7) Converted and used as a source of protein in animal feed.

(8) An estimated 10 million lbs. were consumed in 1972, of which 8.2 million lbs. were imported.

Furs

Furs, exotic hides, and skins together account for about a third of the world trade in all hides and skins. See Table 8 for production figures.

Animal Hair

Animal hair (mostly cattle) and pulled wool are by-products of the tanning and leather industries. Pulled wool from sheepskins amounted to 8 million pounds in 1972 or 4.8 percent of the total grease wool production of the country.

Cattle hair was produced to the extent of 75 million pounds in 1972 of which only 7 million pounds were used, mainly for industrial products, such as felts, furniture padding and insulation. This represents a wastage of over 90 percent of available cattle hair compared to only 16 percent in 1958. Competition by synthetic materials, such as polyurethane foam and filaments, has caused the decline in use of animal hair.

The hair removal process by caustic soda results in a waste effluent that contributes to stream pollution.

Hides and Leather

Hides and skins are used in a wide variety of end products and rank first among the by-products of the cattle industry. Cattle hides are the major source of leather for shoes, upholstery, luggage, belting, athletic equipment, and harness wear. Calf, goat, and sheepskins also provide leather for garments and a wide variety of products.

Despite a steadily expanding supply of hides, some substitution has occurred in most of its end uses, particularly for shoe soles. As far back as 1958, only a third of the shoe soles in the U.S. came from leather, the majority being made from synthetic polymers (vinyl types). Footwear uppers remains the present major end use for leather and is still largely unaffected by synthetics. However, there is now a challenge by a new synthetic product termed poromerics.

Present Status of Leather Industry

The 1972 status of the hide and leather industry is shown in Tables 8 and 9. Hide production in 1972 was 3000 million pounds, leather stock 1,375 million pounds, and

Table 9

Hide and Leather Production, Exports and Imports[1] with Projections to Year 2000 (Millions of lbs)

	1972	1974	1980	1985	2000
Cattle Hide Production	2,706	2,835	3,450	3,750	4,575
Hog Hide Production[2]	5[3]	15[3]	50	100	500
Total Hide Production[4]	3,000	3,058	3,650	4,000	5,225
Exports, Cured Hides[5,6]	879	922	1,075	1,178	1,539
Leather Production[6]	898	757	1,000	1,096	1,432
Leather Exports[6]	143	210	338	370	484
		(Expressed in millions of $ value)			
Leather Exports[6]	67	101	180	(300)	(500)
Leather Imports[6]	132	111	100	100	100
Leather Production[7]	1,059	890	1,180	1,293	1,690

[1] Projections for hide production, based on cattle and hog slaughter by Dr. Harold M. Taylor, USDA, ERS, stationed at ERRC.

[2] Pulling of hog skins for leather started in 1972 and is predicted to grow. Alternate practice is to leave most of hog skin on meat with balance to gelatin manufacture. Projections by J. W. Harlan, USDA.

[3] Literature and industry sources.

[4] Includes equivalent of sheep, goat, horse and miscellaneous hides which are in static or declining production. Based on data from Tanners' Council Statistical Workshop, 04/05/75.

[5] Basis: A 75 lb. rawhide, fleshed, trimmed and brine-cured yields 50 lbs. cured hide. Other hides converted to cattle hide equivalents on the basis of leather area.

[6] Data for 1972, 1974 and 1980 from Tanners' Council Projections (04/05/75). Projections for 1985 and 2000 made using 1980 ratios of total supply of hides. This assumes a static situation of slow growth. U.S. and/or foreign governmental and environmental activity could shift export/import ratios greatly.

[7] From 1972 Census of Manufactures. 1972 ratio of $/lb. used in projections.

leather 898 million pounds. Exports amounted to 879 million pounds of cured hides and 143 million pounds of leather. Since 1972 there has been a drop in imports and a rise in exports. The future indicates further gains in leather exports.

Energy and the Environment

The total energy consumption in 1972 in the manufacture of salt-cured hides to finished leather was 7,417 Btu/lb raw hide or 30 M Btu/ton leather. To meet 1977 pollution standards, an increase of 270 Btu/lb is estimated and for 1983 standards, 536 Btu/lb. Additional treatment for dissolved solid (salt) would require an additional 7,200 Btu/lb, for an overall energy increase of 107 percent.

Despite the increased energy required for pollution treatment, the future costs for fuel and improved technology will bring about a decrease in future energy requirements to 25 M Btu/ton leather in 1985 and 20 M Btu/ton in 2000. The minimum energy attainable by current technology is estimated to be 22 M Btu/ton leather.

Demand for Leather

Cattle and calf slaughter is expected to increase in the immediate years ahead due to increasing population and meat demand, which will result in an increased supply of hides. The following figures by the Tanners' Council of America (1975) are for the present and near future:

1972	39.2 million hides
1974	41.0 million hides
1975	45.0 million hides
1978	48.5 million hides
1980	50.2 million hides

The domestic production of shoes (444.6 million pairs in 1974) is now considered to have ebbed and is expected to increase. The percentage of shoe imports jumped sharply from 1965 to 1970 and has now levelled off at about 39 to 40 percent of the total market. Leather footwear consumption in the U.S. on a per capita basis is approaching saturation and, consequently, consumption will keep pace with population growth. Greater quantities of cattle hides may be used in leather garments.

If technical improvements are made in the quality of synthetic materials and if production costs are lowered, then these materials might make inroads into the leather market. This would be particularly true if a shortage of hides should develop, which is not expected. Once synthetics penetrate the leather market, it might be difficult for hides and skins to regain more than a part of the lost ground even if falling prices would make hides and skins more competitive again. This is because machinery developed for using synthetics does not lend itself to the processing of leather.

Future Predictions

Total hide production is expected to increase by a third in 1985 and by 74 percent in 2000 (see Table 9). Leather production, however, will increase less, namely by 22 percent in 1985 and by 60 percent in 2000. Exports of both cured hides and of leather will increase appreciably. Imports will decline to a fairly constant level.

CHAPTER 8

CHEMICAL USE OF LIGNOCELLULOSIC MATERIAL

INTRODUCTION

In 1974 the total U.S. production of plastics, noncellulosic fibers, and synthetic rubber amounted to 37 billion pounds (over 18 million tons). About 95 percent of these materials are conceptually (but not necessarily economically) derivable from cellulose, hemicellulose, and lignin. The amount of wood necessary to produce these plastics and chemicals approximates 60 percent of that annually used by the pulp and paper industry. Table 1 categorizes these plastics and chemical products and shows the estimated amount of cellulose or lignin that would be required to produce the 1974 volume of these plastics.

The potential exists to expand the production and applications of cellulose derivatives. Figure 1 shows a schematic potential flow of wood and agricultural, municipal, and feedlot residues for chemical use. Consideration of the potential expanded use of lignocellulosic materials as a basis for the chemical industry involves the relative long-term cost effectiveness, environmental impact, use of capital, energy consumption in production, and difficulties in overcoming technological barriers. Currently, about 6 percent of the nation's total availability of oil and natural gas is used as a raw material for chemicals that form the base of the U.S. plastics and chemicals industry. U.S. domestic petroleum consumption for the manufacture of petrochemicals amounts to 900,000 barrels of crude oil per day.

The argument may be made that petrochemicals should have a high priority because energy needs can be derived relatively readily from other sources, e.g., coal. Also, the chemical industry has a tremendous amount of capital used in petrochemical plants. If such an argument is acceptable, petrochemicals will be produced for many years to come--but their price will be considerably higher as the cost of petroleum escalates. Coal is obviously an alternative raw material for the manufacture of chemicals.

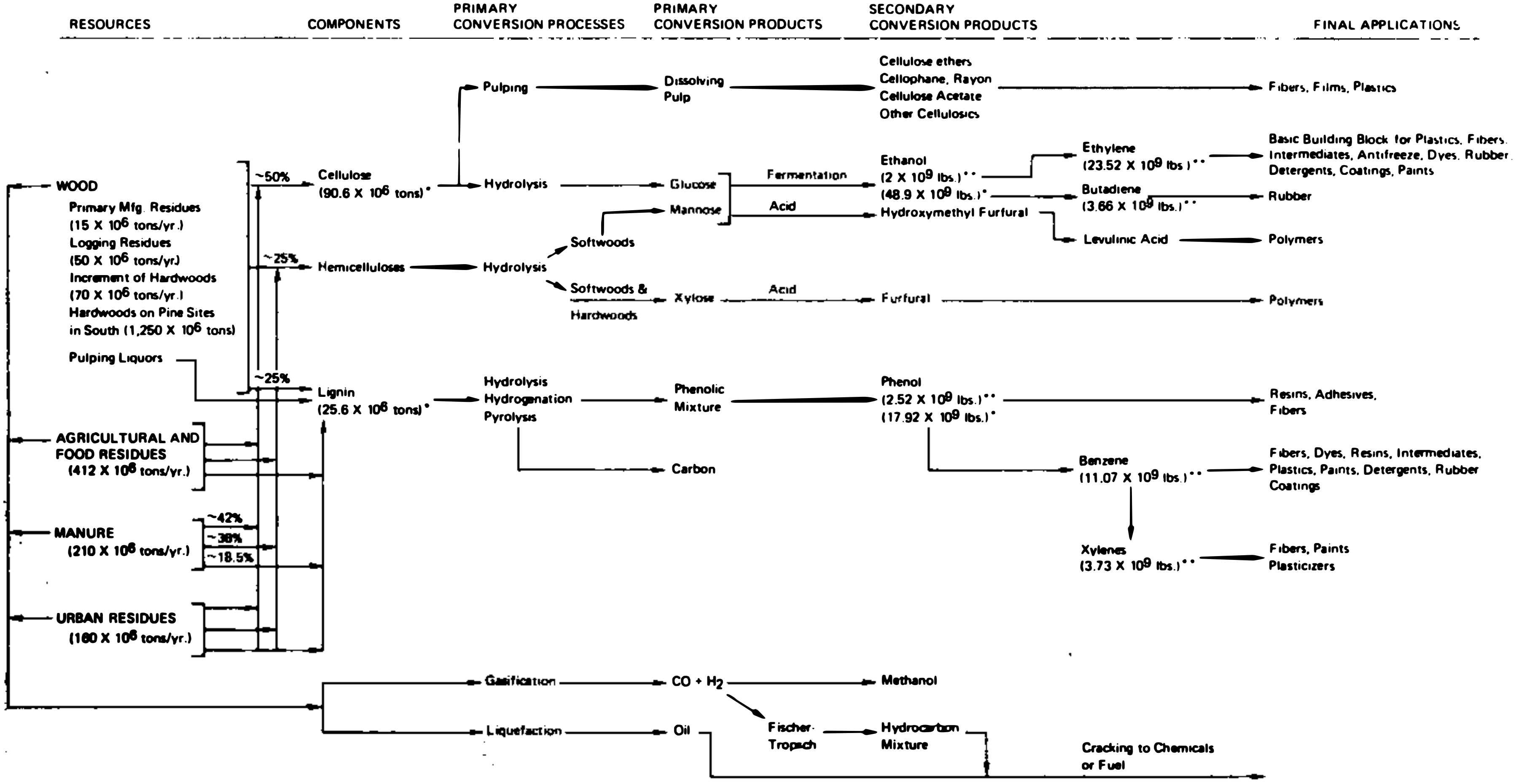
U.S. coal reserves comprise 80 percent of the nation's proven fossil fuel reserves and can, together with shale oil reserves, provide a continuing source of energy for 200 to

Table 1

1974 Production of Plastics, Synthetic Fibers, and Rubber and Estimated Lignocellulose Raw Material Base

	Thousands of Tons	Tons of Lignocellulose Raw Material Required (Thousands)*
PLASTICS		
Thermosetting Resins		
Epoxies	125	355 (L)
Polyesters	455	1220 (L)
Urea	420	
Melamine	80	
Phenolic and other tar acid resins	670	1,915 (L)
Thermoplastic Resins		
Polyamide	100	285 (L)
Polyethylene		
Low-density	2,985	11,940 (C)
High-density	1,420	5,680 (C)
Polypropylene & copolymers	1,125	4,500 (C)
Styrene & copolymers	2,505	7,445 (L)
Polyvinyl Chloride	2,425	4,225 (C)
Other vinyl resins	175	440 (C)
Total Plastics	12,485	
SYNTHETIC FIBERS		
Cellulosic		
Rayon	410	
Acetate	190	
Non-cellulosic		
Nylon	1,065	3,045 (L)
Acrylic	320	640 (C)
Polyester	1,500	4,020 (L)
Olefin	230	920 (C)
Total Non-cellulosic Fibers	3,115	
SYNTHETIC RUBBER		
Styrene-butadiene	1,615	5,700 (C), 1,920 (L)
Butyl	180	1,060 (C)
Nitrile	95	190 (C)
Polybutadiene	360	2,120 (C)
Polyisoprene	100	
Ethylene-propylene	140	825
Neoprene and others	280	
Total Synthetic Rubber	2,770	
Total Plastics, Non-cellulosic Fibers and Rubber	18,370	
Obtainable from Lignocellulose	17,490	58,445
Cellulose Derived (C)		38,240 (C)
Lignin Derived (L)		20,205 (L)

* Estimated from optimistic approximate yields of monomers obtainable.
(C) Cellulose Derived; (L) Lignin Derived.



*Quantity needed for 1974 production of Benzene, Butadiene, Ethanol, Ethylene, Phenol and Xylenes. Cellulose quantity may include Hemicelluloses yielding mannose.

**1974 production (Ethanol and Phenol derived from Ethylene and Benzene instead of vice versa). (Xylenes not derived from Benzene)

Figure 1 Future Potential Flow of Wood and Agricultural, Municipal and Feedlot Residues for Chemical Use

300 years at anticipated rates of consumption. However, problems with coal production are serious in terms of strip mining soil deterioration effects and in water pollution in some areas. Much of the U.S. coal will require a considerable amount of energy to extract, which in some cases could amount to a net loss of energy. Additionally, much of the coal reserves are located in regions where process water is in short supply. The significant sulfur content of the majority of U.S. coal poses major cost and technical problems in the economical use and processing of coal. Finally, coal chemical technology has been neglected in a manner similar to that for lignocellulosic materials because of the more cost-effective petrochemicals technology. It is apparent that coal utilization for energy generation should have a high priority in the nation's search for energy sources. The costs of deriving chemicals and plastics from coal should be compared with costs of obtaining them from lignocellulosic materials to ascertain feasible options.

CONVERSION OF CELLULOSE TO MODIFIED HIGH POLYMERIC DERIVATIVES

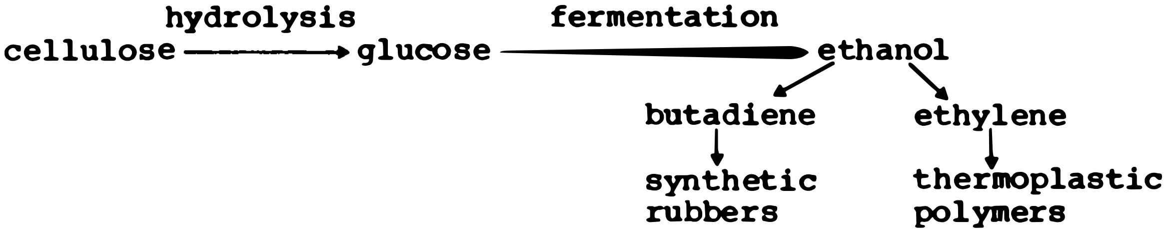
As cellulose is a naturally occurring high polymer, it can be used in that form without degradation and repolymerization. Cellulose is currently used to the extent of about 50 million tons per year--a quantity greater than the total of all synthetic polymers combined. U.S. production in 1974 of cellulose derivatives consumed approximately 2 million tons of dissolving pulp. These derivatives are primarily rayon and cellophane (both regenerated cellulose), cellulose acetate along with the co-esters of cellulose acetate-propionate and cellulose acetate-butyrate, and smaller amounts of ethyl cellulose and carboxymethyl-cellulose.

Excluding fiber use, cellulose derivatives are used primarily in packaging, personal products, protective sheeting, eyeglass frames, decorative automotive parts, and in a variety of pharmaceutical applications. As plastics, these products are characterized by high clarity, gloss, and aesthetic value. However, they have generally been more costly than a number of plastics derived from such fossil fuels as polyethylene, polypropylene, polyvinyl chloride, and polyester. As a result, cellulose derivatives are showing slow growth and little penetration of the markets held by petrochemically based polymers. They are handicapped in processing by the relatively high capital intensiveness of existing dissolving pulp mills, the relatively low yield of alpha cellulose (approximately 25 percent of cellulose is lost), and the capital intensiveness of the regeneration and derivatization process and associated pollution control. There is, therefore, a need to develop new, less capital intensive processes with higher yields of alpha cellulose to improve the overall competitiveness of cellulose derivatives. Additionally, their utility and application could be substantially expanded by structure and property modification processes.

The production of completely new cellulose derivatives should also be encouraged. Another technological need for expanded production of these cellulosics is to develop production processes that are less sensitive with regard to purity of the raw material. Cellulosics offer a real challenge as a substitute for many petrochemically derived plastics and polymers.

CONVERSION TO MONOMERS OR FEEDSTOCKS FOR CONVENTIONAL POLYMERS OR PLASTICS

Of the 18 million tons of synthetic polymers listed in Table 1, 95 percent are derivable from ethylene (47%), butadiene (12%), and phenol (36%). These building blocks are all obtainable in good yields from wood. Ethylene and butadiene can be made from ethanol, which in turn can be made by fermentation of glucose, the product of cellulose by hydrolysis:



Phenol and related compounds are obtainable from the hydrogenation or hydrogenolysis of lignin:

lignin → phenols → phenolic resins, polyesters, etc.

Wood hydrolysis, the conversion of the carbohydrate polymers in wood to simple sugars by chemical reaction with water in the presence of acid catalysts, has been known for 150 years and was practiced on a commercial scale in this country during World War I, in Germany during World War II, and is still in use in the USSR. The simple hydrolytic cleavage to sugars is complicated in the case of cellulose by its crystalline organization, which restricts the accessibility of the dilute acid to the bonds to be hydrolyzed. This resistance to hydrolysis requires the use of temperatures and acid concentrations that cause decomposition of the resulting sugars. Processes must balance rate of hydrolysis against rate of decomposition of the desired products. Glucose yields of approximately 50 percent of the weight of the cellulose have been attained.

Increasing this yield by rendering the cellulose more accessible to the hydrolyzing reagent would provide great economic benefits and warrants a high level of technical activity. The nature of the lignin residue is affected by the catalyst used and the operating temperatures in the hydrolysis. It would be desirable to end up with the most reactive lignin possible to allow its facile conversion to other useful products. The Udic-Rheinau process utilizing strong hydrochloric acid as the catalyst does provide such a reactive lignin.

Fermentation of the glucose solutions to ethanol is readily accomplished in yields of 85 to 95 percent using commercially proven techniques. The further conversion of ethanol to ethylene in 96 percent yield and to butadiene in 70 percent yield are also straightforward and were practiced on a commercial scale in the U.S. during World War II in plants that require much lower capital costs than those based on hydrocarbon conversion.

Biochemical conversion of sugars obtained from both hemicelluloses and cellulose by fermentation can produce a large number of compounds, such as acetic, butyric, and lactic acids and glycerol. Conversion of cellulose to glucose by enzymatic hydrolysis using an enzyme from *Trichoderma viride* is receiving much attention and suggests that sugar may be produced at approximately $.15/lb by this method. Other microbiological conversions may be entirely possible.

Phenolic products have been obtained from the lignin component of wood by various hydrogenolysis techniques. Yields in the neighborhood of 40 percent of monomeric phenols have been reported in pilot plant experiments, but verification on a commercial scale has not been attempted because of unfavorable economic comparisons with phenol production from petroleum.

PRODUCTION OF SUGAR FROM LIGNOCELLULOSE

The calculated maximum yield of ethanol per ton of lignocellulosic material is approximately 80 gallons. The major deterrent to attainment of such yields in practice is in step 1 of the two-step conversion process--hydrolysis of cellulose to sugar. It is here, also, that the major problems with process economics are encountered.

All known processes for cellulose hydrolysis may be grouped into three categories: strong acid, dilute acid, and enzymatic.

1. Strong acid. Only one strong-acid saccharification process, the Bergius fuming hydrochloric acid process, has ever attained industrial significance. The Russians have investigated many variations of a strong sulfuric acid method. The Bergius process was used at a full-scale plant in Germany during World War II to produce some 500 metric tons per month of yeast, although ethanol could have been the primary product if so desired.

2. Dilute acid. Because of lower plant costs, dilute acid processes have received much greater attention than strong-acid methods. Sugar yields, hence ethanol yields, are markedly lower, however, ranging from about 20 gallons of ethanol per ton of wood for a single-stage batch process to about 50 gallons per ton for the Scholler or the Madison percolation process, all based on the use of dilute sulfuric acid.

The reason for the lowered sugar yields is in the extreme hydrolytic resistance of cellulose, a resistance ascribed to the high molecular packing of its crystalline regions. Under comparable conditions, the rate of hydrolytic conversion of cellulose to glucose is only a minute fraction of that obtainable with a relatively amorphous carbohydrate, such as starch. Since sugar yields are governed by the relative rates of sugar production to sugar destruction, sugar yields are high from starch and low from cellulose. Discovery of an effective, yet inexpensive pretreatment for disrupting cellulose crystallinity would constitute a major breakthrough in the use of cellulosic materials for chemical conversion.

3. Enzymatic. With few exceptions, the carbohydrates of whole-wood residue or of newsprint, which is a major constituent of municipal trash and is largely whole-wood fiber, are essentially immune to attack by cellulolytic enzymes. This immunity apparently stems from the close physical and chemical association between cellulose and lignin. Any pretreatment that can "open up" this lignin-carbohydrate complex would thus provide access to the carbohydrate constituents.

Lack of access is not the sole deterrent to the large-scale enzymatic conversion of lignocellulosic materials to sugars; however, as with dilute-acid hydrolysis, the rate of enzymatic hydrolysis of cellulose is only a fraction of the rate of enzymatic hydrolysis of starch, the current industrial process for glucose solutions. Here again, an effective, economical pretreatment for disrupting cellulose crystallinity would be of major benefit.

Pretreatments

A wide variety of physical and chemical pretreatments may be used to make wood carbohydrates more accessible and increase their reactivity. Some of these pretreatments yield only modest benefits; others are capable of radically altering the chemical structure of the raw material.

Carbohydrate accessibility is complete following total delignification by any of the commercial pulping processes, but commercial pulps are expensive substrates for enzymatic conversion. Extensive swelling induced by alkaline reagents provides modest benefits. A more intriguing approach, however, involves disruption of the lignin-carbohydrate complex *in situ*. Treatment of moist wood particles with gaseous sulfur dioxide has been shown to result in a product that is quantitatively convertible by cellulolytic enzymes following neutralization. Good prospects exist for further exploration of optimum processing conditions and use of other reactive agents, making this a rewarding area for additional research.

Reduction of cellulose crystallinity with marked enhancement of both enzymatic and dilute-acid hydrolytic reactivity has been achieved in the laboratory through the use of certain physical pretreatments. Vibratory ball milling was very effective with certain hardwoods, but energy costs make translation of laboratory results into commercial operation doubtful. High-energy irradiation is a simple way to increase cellulose reactivity, but, again, practical application is dependent on reducing irradiation costs.

Other Areas for Hydrolysis Research

Additional areas for development include:

1. New techniques for modification of cellulose fine-structure with realistic cost analysis.

2. New techniques for delignification or disruption of the lignin-carbohydrate complex with realistic cost analyses.

3. Up-to-date assessment of previously studied strong- and weak-acid saccharification processes.

4. Development of techniques for fractionation of lignocelluloses for complete use of major components.

Sugar Production by Pyrolysis

Another method of producing sugar (glucose) from lignocellulose has been less developed technically; it is by pyrolysis. Controlled heating of the lignocellulose decomposes the cellulose to levoglucosan. This volatile anhydride can be collected and readily hydrolyzed to glucose.

Conversion of Glucose to Other Chemicals

The glucose obtained from hydrolysis of cellulose, instead of being fermented into ethanol, can be converted i=to 56hydroxy626furfuraldehyde, which in turn is readily converted to levulinic acid. This material could well serve as an intermediate for a new family of polymers. Levulinic acid, primarily for processing into diphenolic acid, was produced commercially for a time in the 1960s. The re-introduction of levulinic acid into the chemical industry will require extensive development work.

POTENTIAL OF LIGNIN AS A SOURCE OF AROMATIC CHEMICALS

Lignins consist of aromatic components calculated as approximately 40 percent benzene and almost 50 percent phenol. Although actual yields of simple phenols from lignin degradation have been somewhat lower, projected yields of 35 percent pure phenol have been suggested. Benzene has been isolated as a component from lignin hydrocracking, and could be obtained in 25 percent yield on lignin by dehydroxylation of phenol. Conventional petrochemical technology produces phenol from benzene, but if benzene should become unavailable from other sources, the reverse process could be used to provide benzene as an intermediate for styrene and phthalic acids.

In 1974, U.S. production of phenol was 2.32 billion pounds and of cresylic acids about 0.20 billion pounds, for a total of 2.52 billion pounds. About half ended up in phenolic resins, 20 percent in caprolactam for nylon, and 10 percent for epoxy resins. U.S. benzene production in 1974 amounted to 11.07 billion pounds (1.5 billion gallons). This includes that used in the production of phenol, leaving about 9 billion pounds for such other uses as styrene (1974 production--5.94 billion pounds), cyclohexane (1974 production--2.34 billion pounds), etc.

Considering that, in conjunction with the 38 million tons of chemical pulp produced annually, approximately 19 million tons of lignin are obtained in soluble form and are burned or otherwise disposed of, almost the entire amount of lignin required for conversion to phenol and benzene would be available without a need for additional wood, but an alternate fuel for recovery boilers would be required. Another lignin source would be the residues obtained from hydrolysis of lignocellulosic materials.

The primary reason that production of phenols from lignocellulosics has not been commercialized is that until recently, they have been more cheaply obtained from petroleum than the projected cost of obtaining them from lignin. Research should be directed toward process development to increase yield of useful components and to optimize the composition of the products obtained. Additionally, coproducts chemistry and application should be initiated.

Another use of lignin needs a considerable research investment; that is the development of technology to use lignin in as high a polymeric state as possible, for example as a rigid plastic, filler, or adhesive or additive, in lieu of carbon black, for strengthening rubber. Lignin could also be a source of activated carbon.

Currently, vanillin is produced to the extent of approximately 12 to 15 million pounds from lignin sulfonates.

CONVERSION OF HEMICELLULOSES TO CHEMICALS

The components of hemicelluloses--pentoses, such as xyloses, and hexoses, such as mannose, glucose, and galactose--are simple sugars readily obtainable by hydrolysis. These materials can also be obtained by prehydrolysis of lignocellulose prior to any other operation. The hexoses can be processed similarly to the glucose derived from cellulose. The pentoses can be converted to furfural by acid treatment.

Because of the great abundance of xylan available from agricultural residues and wood resources, the potential for furfural is inexhaustible. Furfural is now being produced in limited quantity (from corn cobs and bagasse) because its current price level limits the large-scale use of furfural as a chemical intermediate. Until 1961, furfural was used for the manufacture of nylon when butadiene became available at a lower cost and replaced it. Today, however, furfural may well replace petrochemical intermediates if its production cost can be lowered and the technology of collecting and storing seasonally produced raw materials perfected.

Updating of costs to produce furfural from hardwoods should also be done.

Establishment of an integrated processing scheme for using all of the components of lignocellulose so that raw material costs can be spread over several products is a promising approach to substantially reduce the overall production cost of each chemical produced. Kraft black liquors contain major quantities of carboxylic acids (16 million tons), which are now burned for fuel. Research is needed to capture these materials for a higher valued substitutional use than for fuel. Possible approaches are fermentation treatment or use as chemical intermediates after isolation. Sulfite waste liquors contain approximately 2 million tons of free sugars, principally hexoses, which could be also used for fermentation to ethanol or yeast production.

PRODUCTION OF SYNTHESIS GAS FROM LIGNOCELLULOSE AS A FEEDSTOCK SOURCE

Lignocellulose can yield large quantities of synthesis gas (CO + H) by high-temperature heating.

Synthesis gas can be converted to methanol, ammonia, methane, and to hydrocarbons by the same techniques as synthesis gas from coal. The choice of lignocellulose or coal as a substrate for synthesis gas will depend on local economics. The most likely applications of lignocellulose are use of combustible urban solid waste and possibly, use of large acreages of puckerbrush (low valued wood vegetation).

An Integrated Lignocellulosic Chemical Plant-- A Possible Production System

An approach that will allow lower unit product cost is the use of a multi-product manufacturing process that uses all of the components of the available lignocellulosic raw material. Obvious examples of similar total use are the oil, meat packing, and coal for chemicals industries. Applied to lignocellulosic materials, a sample scheme of an integrated plant is shown in Figure 2. It is recommended that in-depth engineering and economic analyses be made of such schemes and evaluated in comparison with chemical production from coal and petroleum over a range of raw material costs. If such a comparison shows potential utility, then it is recommended that a pilot plant study be made.

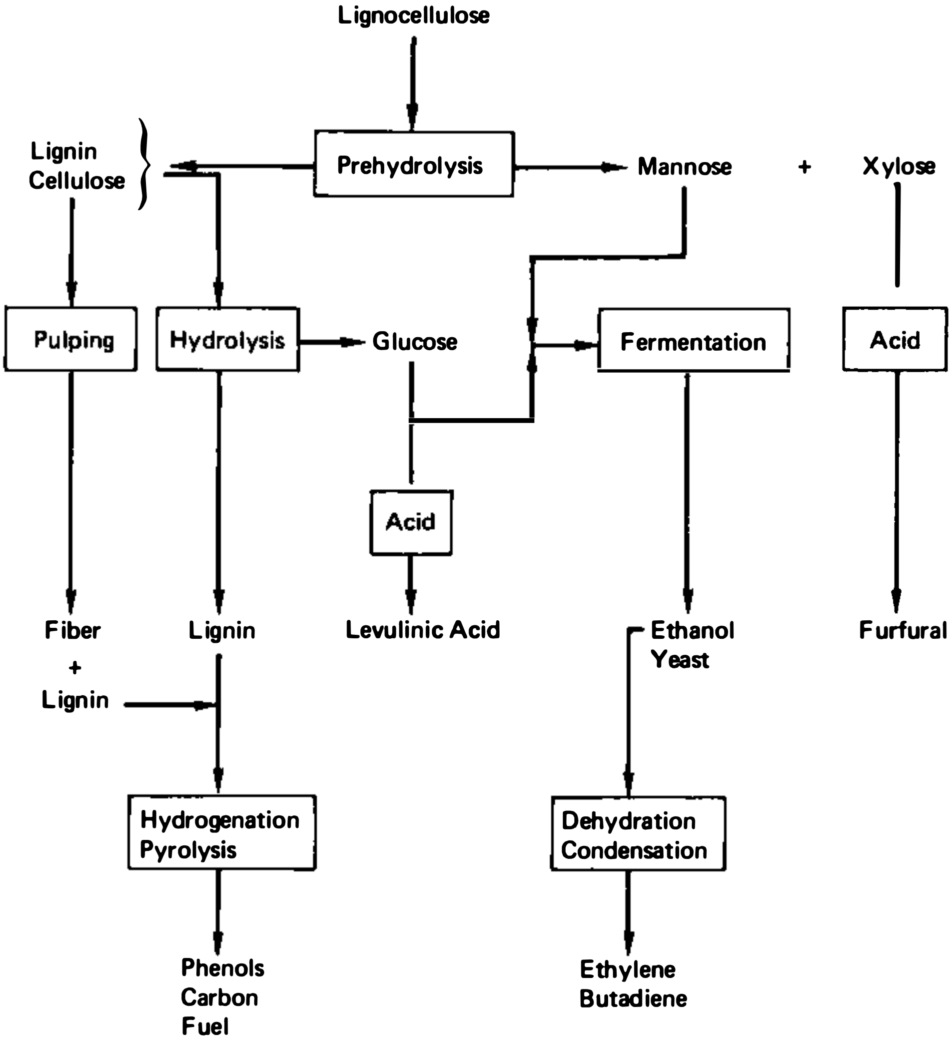


Figure 2 Schematic Flow Chart of a Sample Lignocellulosic Chemical Plant

CHAPTER 9

FUEL FROM BIOMASS

INTRODUCTION

The recent oil embargo and subsequent dramatic increase in the price of petroleum has rekindled an interest in the potential of biomass, particularly wood, for use as fuel. Fuel is one of the oldest uses of wood and, in fact, about half of the wood harvested in the world today is used for fuel (Food and Agriculture Organization of the United Nations 1973 [referred to after this as FAO]). Originally wood was the most important fuel material used in the U.S. until it was largely supplanted in this use, first by coal and then by petroleum and natural gas. Annual consumption of wood for fuel increased from the early colonizing period until 1880 when it reached a maximum consumption of about 12.4 billion cubic feet (Panshin et al. 1962). Per capita consumption of wood for fuel had peaked earlier at about 382 cubic feet in 1860. Use of wood for fuel in the U.S. has declined since 1880 to about 1.2 billion cubic feet in 1970.

Even though wood has declined as a general fuel in the U.S., it is not necessarily true that it is unimportant in industrialized countries. Sweden now gets 8 percent of her energy from wood and Finland 15 percent. In the U.S., wood and wood-based materials are used by industry to generate more power than is produced by nuclear power stations. This is because segments of the wood products industry are large consumers of power and use wood residues including bark as fuels to meet these power needs. For example, the American Paper Institute reported that the paper industry annually consumes 2.35 quads [1 quad (q) = 10^{15} Btu] of energy of which 37 percent is provided by the burning of wood and its constituents. In 1972 the southern paper industry obtained about half of its energy from process waste. Energy sources in U.S. pulp and paper manufacture for 1971 are shown in Table 1.

Table 1

Energy Sources in U.S. Pulp and Paper Manufacture, 1971

Source	Energy Equivalent (quads)[1]	Percent of Total
Spent cooking liquor (recovery furnace)	0.667	28.5
Bark and wood (power furnace)	0.197	8.5
Natural gas (power furnace)	0.569	24.0
Oil (power furnace)	0.440	19.0
Coal (power furnace)	0.374	16.0
Purchased electricity[2]	0.094	4.0
Total energy[3]	2.341	100.0

[1] 1 quad = 10^{15} Btu

[2] Equivalent to 27.6 billion kWh at 3,413 Btu/kWh

[3] Equivalent to nearly 43 million Btu of energy per ton of paper produced (or 27 million Btu of purchased energy, which amounts to about 2 percent of the U.S. total)

Source: Grantham, T.B. (1974) Status of Timber Utilization on the Pacific Coast, U.S. Department of Agriculture Forest Service.

Similarly, the sawmilling industry uses wood to generate a portion of its required energy. Residues developed in the manufacture of softwood and hardwood lumber and structural flakeboard, however, can produce more than sufficient energy to satisfy production energy needs. Historically, at the turn of the century wood-based industries depended primarily upon wood materials to generate power for plant operation, chiefly through steam production using fuelwood. With the advent of relatively cheap electricity, coal and oil, these manufacturing plants substituted fossil fuel power. Now the trend back to power generated from wood and agricultural residues is receiving added emphasis.

If this trend in use of wood for fuel is to accelerate, it is likely to be in response to a significant change in the price of wood relative to competitive fuel materials. As the oil embargo demonstrated, the U.S. does have a serious problem with respect to present and future supplies of fuel. Whether substantial increase in the use of wood for fuel constitutes a rational response to this materials supply problem was the subject of study by CORRIM. During periods of critical shortage of fossil fuels, the industrial countries have often turned to wood as a substitute. This occurred, for example, in several European countries during World War II. After the crisis, the normal pattern was for the fossil fuels to again substitute for wood. CORRIM's examination of the opportunities for substitution of wood for fossil fuel focused on the prospects for long-term continuing substitution rather than short-term emergency substitution. There is clear evidence that the supply of petroleum and natural gas is a long-term rather than a short-term problem. As Risser (1970) has pointed out, "although the present energy crisis and related environmental problems may appear to have arisen quite suddenly, they have actually been in the making for many years, and their solution, too, will require time."

The U.S. is the greatest consumer of process energy among the nations of the world. According to NCMP (1973) the flow of energy through the U.S. system originating from fuel and other sources was of the order of 65 quads in 1970. Nonenergy uses of fuels, primarily for petrochemicals, brings this figure up to about 68 quads. Of this quantity about 76 percent was based on petroleum and natural gas and an additional 20 percent was based on coal. Hydropower accounted for about 1.5 percent, as did burning of fuelwood and waste products in the forest industry. Nuclear power sources accounted for about 1 percent of energy production. Projections of energy requirements for the year 2000 suggest consumption on the order of 167 quads.

The potential substitutes for petroleum and natural gas as fuels are coal, oil shale, tar sands, nuclear power sources, and biomass. Nonfuel sources of energy that might be substituted for petroleum and natural gas for energy supply are hydro, geothermal, solar, and wind power.

NONBIOMASS SUBSTITUTES FOR PETROLEUM AND NATURAL GAS

Coal

Coal looms as an important prospect for substitution in the U.S. energy system. It already provides a substantial fraction of the nation's fuel requirements. U.S. reserves of coal are so large that they offer the opportunity to delay the problem of critical raw material shortage for many decades. According to Schmidt (1972), about 370 billion tons of the remaining coal reserves are recoverable using current technology. Using a heat value of 13,000 Btu per pound it is estimated that this material will yield 9,600 quads. This is approximately 148 years of energy requirements based on 1970 consumption rates. Coal is, however, a nonrenewable resource.

Coal deposits are concentrated, but the principal coal reserves are located west of the Mississippi River far from the major population concentrations and centers of energy use. Coal exploitation also involves critical environmental problems that may inhibit its use under today's laws, problems related both to extraction and to use. In the domain of extraction, the disorganization of land either in subterranean mining or surface mining and the pollution of streams flowing from the mining sites are often in conflict with current environmental laws and regulations. In use, coal often develops serious atmospheric pollution; it is a major source of sulfur oxide emissions into the atmosphere. Eastern coal, which is most accessible, is also much higher in sulfur content than the remote western coal. Coal is also an important source of emission of particles and nitrogen oxides.

Oil Shale

Oil shale, like coal, is a nonrenewable fuel resource with very large reserves. Oil can be recovered from the important deposits of oil shale in Colorado, Utah, and Wyoming. According to Abelson (1976) the total potential yield of oil from the shale deposits of the Rocky Mountains "is considerably greater than the known reserves of the Middle East." Schmidt (1972) estimates 1.8 trillion barrels, but notes that all of this is not recoverable with current technology. The National Petroleum Council estimates the currently recoverable reserves to be about 80 billion barrels. The cost of recovering oil from shale using current technology is far greater than the cost of recovering liquid petroleum from existing wells. Oil shale development is inhibited by environmental problems that are the same or similar to those that confront coal exploitation. The land disorganization problem is greater. Abelson (1976) points out that the amount of shale processed per unit of oil output is very large, about 1.3 tons of shale for every barrel of oil produced. In addition to the land disorganization problem, there is a water pollution problem associated with the disposition of spent shale. Water flowing through these shale wastes is highly akaline. The oil produced from shale has the same air pollution problems in use as does petroleum and the other fossil fuels.

Other Nonbiomass Sources

Unlike Canada, the U.S. has relatively modest recoverable reserves of tar sands. Nuclear power, geothermal power, and solar power are all processes with uncertain potential in terms of the current level of technology, long development lead times, and, in the case of nuclear power, very severe environmental limitations due to uncertainty concerning generation plant safety and feasibility of safe large-scale waste disposition.

BIOMASS SUBSTITUTES FOR PETROLEUM AND NATURAL GAS

Biomass as a fuel can originate from several different sources. These sources are:

1. Nonused residues from plant and animal production activities
2. Plant crops grown specifically for fuel
3. Residues of plant and animal materials that have already provided for their primary use.

Nonused Residues from Plant and Animal Production Activities

Nonused residues are by-products of the production of plants and animals for food and fiber. These include such resources as timber harvest residues in the form of limbs, tops, stumps, etc. left in the woods following logging; stalks, husks, straw and other similar residues of agricultural field crops; and manure from livestock feedlots.

According to Grantham and Ellis (1974), logging residues from growing stock in 1970 represented 1.595 billion cubic feet. According to the Outlook Study (USDA 1974d), residues from nongrowing stock are approximately equal to that from growing stock. Excess of growth over harvest, a potential fuel pool, was 1.1 billion cubic feet for softwoods and 3.5 billion for hardwoods. Logging residues from excess of growth over harvest would be 0.11 billion cubic feet for softwoods and 0.35 billion cubic feet for hardwoods. Residues from manufacturing in the form of bark and wood amount to 1.52 billion cubic feet. This yields a total of nonused residues from forestry production of 9.87 billion cubic feet, which would convert to approximately 2 quads of energy. This production would be an annual yield based on 1970 levels of forest management and use efficiency.

As noted in Chapter 4, over 300 million tons (dry weight) of plant crop residues are left in the field and could be made available for fuel. In addition, some 26 million tons of dry manure solids are produced annually from the largest poultry and hog production operations and from cattle feedlots of at least a thousand head. The total production of animal wastes, principally from cattle, poultry, and hogs, is on the order of 356 million tons (dry weight), but only the above quantities are produced at large operations where collection may be feasible. It is estimated that another 23 million tons of organic residues are generated in the largest processing facilities, such as canneries, mills, slaughterhouses, and dairies.

The total of residues from agricultural and forest operations at 1970 levels of production and use efficiency would be of the order of 6.74 quads. This would represent 11 percent of 1970 energy requirements. Green (1975) has suggested that, based on Wittwer's calculations, U.S. food production could be doubled in the next 20 years and that this would result in a doubling of agricultural residues that could be used as fuels.

The Outlook Study (USDA 1974d) indicates that current forest production represents only half of the biological potential of U.S. forest land at current low levels of silviculture. The Outlook Study defines the biological potential of forest lands in terms of normally stocked natural stands and current use standards. The production potential could be substantially increased under intensive silviculture and more complete use of the trees produced. The addition of a substantial fuel market that was relatively indiscriminate with respect to tree species and wood quality might contribute to the economic incentives to practice intensive silviculture and thus increase forest productivity and accordingly residues available as fuel.

Plants Grown Specifically for Fuel

The biomass fuel sources discussed so far have represented either the residues of production processes whose primary objective is to obtain other food or fiber crops or the natural growth of unused plants on wild lands. Under favorable economic circumstances, it is entirely feasible to grow plant crops deliberately for the production of fuel. This is the essence of the proposals recently advanced (Kemp et al. 1975, Evans 1974) for the development of "energy plantations" or "biomass plantations." The deliberate production of wood for fuel is not a new concept. The coppice method of silviculture widely practiced in Europe during the last century was a form of energy plantation. In many areas of the tropics mangrove has been cultivated and managed as a fuel plantation species.

Annual crops, such as grasses, can be grown for fuel. Kemp et al. (1975) have examined a variety of field and forest crops as candidates for energy plantations. Their studies of biomass fuel production were based on data obtained from the production records of field crop and forest plantations grown for other products. These data suggested that annual field crops had a production advantage over forest plantations. They noted that "the cost of fuel value produced by conifers appears to be nearly three times that from annual crops such as corn or sorghum." These authors nonetheless concluded that:

> The advantages offered by perennials over annuals, however, are crucial to the feasibility of Energy Plantations. Perennials can be harvested essentially throughout the year in response to the demand for fuel, whereas annuals must be planted and harvested on nature's schedule. This means that in those localities where only one annual crop per year is possible, which is the case for most of the United States, a harvested product inventory equivalent to at least a year's supply of fuel will have to be established at harvest time if the Btu Bushes are annuals. Storing and preserving such an inventory would be a substantial and costly proposition. Perennials, on the other hand preserve themselves until they are reaped.

Most of the energy plantation analyses reported in the literature have been directed at providing the fuel for a thermal electric power plant. As noted by Scholl et al. (1976), costs of land, harvesting, and transportation of fuel are crucial to the economic feasibility of energy plantations. In most biomass for energy analyses emphasis has been placed on the determination of the number of acres of land required to provide a continuous supply of fuel for a plant of a prescribed capacity.

These calculations can be made using the following formula derived from the procedures of Evans (1974)

$$A = K \frac{CL}{BEY}$$

where C = capacity of energy installation,

L = installation average load factor,

B = heat value of fuel Btu/OD ton,

E = installation conversion efficiency,

Y = plantation yield, OD tons/acre/year, and

K = constant Btu/MW year = 2.99×10^{10}.

Evans (1974) studied the potential for energy plantations in Canada on this basis. He evaluated production options in terms of the land area required to fuel a 150 MW thermal-electric power plant. On the basis of his analysis he concluded:

> On the basis of available forest-productivity (biomass) data, the energy-plantation concept has dubious promise for most regions of North America. On short rotation, productivities of six or less dry tons per acre per year for most wood species would require management of very substantial plantation areas to provide continuous fuel for a power plant of reasonable size.
>
> However, red alder on the Pacific Coast appears to have exceptional productivity, averaging somewhere between 4 and 33 dry tons per acre per year.

Using a similar analysis, Resch (1975) concludes that 40 square miles (25,600 acres) of red alder plantations would provide the fuel required to supply a 150 MW thermal-electric power plant.

Kemp et al. (1975), basing their calculations on estimates of solar energy conversions to fuel value, conclude that an area of about 224,000 acres would supply a 400 MW thermal-electric power plant on a continuing basis.

The factor that accounts for most of the variability among the estimates of land requirements per unit of power production is the assumption concerning land productivity. As noted earlier in this report, most of the information available on forest productivity on a macro-area basis derives from normal yield tables and include use assumptions. Data on wood production from intensively managed forest plantations in terms of whole stem volumes are not available from the forest survey. Experimental evidence provides some guidance in estimating large-scale plantation production of fuel, but it is inconclusive.

The evaluations of energy plantation potential have usually assumed single product (fuel) objectives of the cropping operation and have been based on the growth of a single plant type. Furthermore, the majority of these studies have been based upon the assumption that biomass would be used to generate electricity. The options available are much more extensive. Fuel can represent one of the products in a multi-product agricultural or forestry enterprise. Residues of farm and forest production and agricultural and forest product manufacturing operations can be combined with partial output of integrated plant production and the yield from single-crop operations to provide the raw material for a fuel supply enterprise. The biomass can be directly fired or modified into a more useful solid, liquid, or gaseous form. Urban wastes that commonly consist very largely of already used biomass products can be combined with new biomass production. Such integrated systems are much more complex and difficult to analyze than the single-crop biomass for fuel operation, but they may be more economically feasible in the long run. Such combinations offer the possibilities of combining the high biomass productivity of annual plants with the storage characteristics of perennial plants. They also may obtain needed energy while contributing to the solution of environmental problems related to waste disposal. Methanol produced from biomass used for fueling internal combustion engines may reduce harmful emissions, even though it is more expensive than gasoline.

Plant and Animal Solid Wastes

Refuse from discarded materials after they have performed their primary function is another large potential source of biomass material for fuel. A major source of this material is urban and municipal solid waste. Commonly urban solid waste has been used as landfill, but landfill opportunities are rapidly diminishing and costs of these operations are increasing. Concurrently, systems are being developed to segregate metals, ceramics and minerals, and paper and other biomass components of solid waste. More than half of urban solid waste is composed of biomass materials, such as building materials, paper and packaging products, and other vegetation matter. This biomass material represents about 160 million dry tons per year.

Biomass solid waste probably is the lowest cost material of its type and, in the larger urban areas, should be available in quantities to support feasible scale operation. Initially it may be available at negative cost because it costs the city to dispose of it, but undoubtedly its value will rise as technology evolves efficient separation and sorting processes, as recycling of materials gains momentum, and its use for energy production becomes more financially attractive.

CONVERTING BIOMASS FOR FUEL

Of all of the plans for the use of biomass for fuel, the one that is easiest to implement is that of using forest-based material to provide the fuel for processing forest products. There is a long history of use of wood for fuel by the forest industries. Many of them are now substantially energy independent, and since the oil embargo there is a growing effort to achieve energy independence on the part of many others. An increasing number of such factories may be able to meet their own needs for processing energy and provide surplus quantities to other users. The wood-using industries are particularly well-adapted to the use of wood for fuel. Often the collection system that provides the raw material for primary products can quite easily be adapted to the collection of more material for fuel. The combination of energy uses that characterize wood processing industries are well-adapted to the use of biomass energy. As Grantham and Ellis (1974) have pointed out, "Large manufacturing centers, such as pulpmills, use much process steam and electricity. Thus steam generated from wood or bark can power a steam turbine-electric generator set and exhaust to process steam rather than to a condenser. When an industry has such a desirable combination of steam and electrical power demand, the relative efficiency of heat recovery from steam can be almost 75 percent compared to the 38 percent at a modern facility generating electricity."

Biomass may be used in a variety of ways to convert solar energy. Among these conversion methods are the following:

1. Direct combusion of biomass
2. Gasification to produce low Btu gas and/or methanol
3. Pyrolysis to form low Btu gas and charcoal
4. Liquification to produce oil and hydrocarbon fuels
5. Anaerobic fermentation to produce methane

6. Enzymatic or acid hydrolysis to sugars for fermentation to ethanol.

On a dry weight basis the heating value of biomass is substantially less than that of the fossil fuels. According to Green (1975), corn, wheat, oat, and other field residues yield 7,500 Btu per pound.

The higher calorific value for wood and bark ranges from 8,000 to 10,000 Btu per pound oven dry. This compares to 18,000 for No. 6 fuel oil, 13,500 for bituminous coal, and 18,550 for natural gas. Biomass is much lower in density than coal and therefore more volume must be moved to provide the same heating value. Biomass in its original natural form is usually high in moisture content, although it is often air dry at the time of use. A pound of wood with a higher calorific value of 8,600 Btu/lb would yield 6,011 Btu at 15 percent moisture content. Some agricultural residues have much higher original moisture contents than wood, and some woods have higher calorific values than others because of their extractive contents. The resinous conifers and woods with significant oil content, such as the cedars, are in this latter category. Resch (1975) gives a higher heating value for Ponderosa pine of 9,100 Btu per pound and for western red cedar of 9,700 Btu per pound.

Wood is usually used in direct combustion in the form of sawdust, shavings, chips, or hogged particles.

By partial combustion in the presence of limited quantities of oxygen, lignocellulosic materials can be converted into gas streams consisting chiefly of carbon monoxide and hydrogen (synthesis gas). This can be burned directly as a low Btu gas (150 to 300 Btu per cubic foot) or converted to methanol after correcting the H_2 to CO ratio. Gasification of wood requires less oxygen than gasification of coal, has essentially no steam requirement, lower shift cost requirements, and appreciably lower desulfurization costs. This system could have application, not only for municipal energy generation, but also for industrial consumption.

It has been established in Europe and in the U.S. that methanol can be blended to the extent of 10 percent in gasoline in unmodified automobiles. It can be used in modified internal combustion engines as the sole fuel. At current price levels, methanol is still more expensive than gasoline as an automotive fuel. But when used as a 10 to 15 percent blend with gasoline, there is no mileage penalty at all on a gallon basis because of higher efficiencies.

The distinctive distillation of lignocellulose in smaller quantities of oxygen than for total gasification, provides lower yields of synthesis gas but about 20 percent yield of charcoal. Charcoal could be used industrially in place of coal, especially in metallurgical operation or for the production of activated carbon.

Lignocellulose may be converted into high viscosity liquid fuels by two routes: the material may be reacted with CO and water at high temperature and pressure to give oil yields of 40 to 50 percent. A current economic study produced for the Bureau of Mines indicated with 1973 costs that production costs would approximate $7/barrel (Blaw-Knox 1973). If wood costs were $20/ton, the cost per barrel would increase to $16. Therefore, current economics are not now attractive. A second liquefaction route is the Fischer Tropsch conversion to hydrocarbons of the CO and H produced.

Large-scale methane production from plant materials, agricultural wastes, and sewage is economically attractive because a great many biological organic compounds are microbially converted to methane with a theoretical fuel energy recovery of over 90 percent. The fermentation can be carried out on almost any scale, depending on the amount of organic material available.

Disadvantages in using biological methods for methane production include the following:

1. Highly lignified wood and possibly some other plant materials cannot be readily used

2. The rate of methane formation from some polymeric substrates is relatively slow and relatively large fermentation vessels and long holding times are required.

In general, methane fermentation is most suitable for organic materials of high water content or for relatively small-scale operations. Knowledge of methane-producing bacteria using various substrates under a variety of conditions is still fragmentary. Further biological and physiological studies of methane-producing bacteria are needed to determine the range of existing types and the possibility of finding types that can produce methane from various substrates at higher rates.

Ethanol has also been suggested as an additive to gasoline to augment available supplies. A fleet test in Nebraska using 10 percent ethanol has been very satisfactory at the million mile mark.

The conversion of cellulose into ethanol involves a two-step process: (1) hydrolysis of cellulose to glucose by enzymes or acid, and (2) fermentation of glucose to ethanol. The hydrolysis step is limiting with present technology because of the difficult accessibility of acid or enzymes to the crystalline or lignified cellulose. Increasing the yield of glucose by enhancing accessibility would significantly improve the economics and warrants a major research effort.

International Aspects

Since the supply of fuel is a world problem as well as a U.S. problem, it is appropriate to examine the use of biomass for fuel in an international context. As already noted, such countries as Sweden and Finland that are important producers of forest products rely much more heavily upon wood as a fuel than does the U.S. In most of the world the price of fossil fuels is much higher than in the U.S. Surplus wood, however, is a common worldwide phenomenon. Whereas softwood is in great demand in the industrialized countries hardwoods are in long supply almost everywhere. Many of the tropical countries have huge stands of hardwoods that are unused. In many of these countries, the ratio of biomass in the forest to biomass that is merchantable is of the order of 10-1 to 40-1. These use efficiencies apply to forests being exploited. There are many billions of acres of tropical forests that are not used for materials at all.

According to Sanchez (1973), the total biomass of the indigenous tropical forest is in the range of 80 to 160 tons per acre and that 90 percent of the total jungle regrowth occurs within eight years of clearing. Johnson (1976) reports biomass growth in tropical forest plantations on eight year rotations that are consistent with Sanchez' observations on natural tropical forests. For forests of this type about 325 million acres would annually produce the 1970 total U.S. consumption of energy from all sources.

Environmental Aspects

Wood and some agricultural residues have some unique advantages over fossil fuels and nuclear power sources in terms of environmental impact. Among these are:

1. Sulfur content is low or nonexistent

2. Harvesting of biomass does not cause the land disorganization associated with extraction of coal or oil shale

3. Residues from wood fuel combustion are easily disposed of; wood ash can be used as a fertilizer.

The burning of biomass fuels introduces some environmental impacts.

1. Particulate emission is often high

2. Harvesting of biomass causes change in the appearance of the land area

3. Organic residues increase BOD in receiving water reservoirs.

In general, the environmental impacts associated with the production and use of biomass for fuel are much less severe than are those resulting from the use of fossil fuels and nuclear power in terms of duration of impact or effect upon human health or welfare. Environmental laws and regulations, however, rarely evaluate environmental impact with any objective measure of comparative severity of impact. In the past several years the gaseous discharges from wood-burning furnaces have been restricted much more than the gaseous discharges from hydrocarbon burning internal combustion engines.

CONCLUSION

The uncertainties associated with the future price of petroleum and its availability and similar considerations related to coal, oil shale, and nuclear power sources discourage large-scale investment in facilities to produce and convert biomass for fuel. If it is in the national interest to undertake a larger scale biomass for energy program, the opportunities are available but government intervention will probably be needed to provide incentives. These incentives might take the form of:

1. Support of research and resource inventory

2. Pilot scale experiments on biomass production on federal forest lands

3. Support of capital investments in conversion facilities

4. Guarantee of a market for fuel at an adequate price.

CHAPTER 10

EXTRACTIVES AS A RENEWABLE RESOURCE FOR INDUSTRIAL MATERIALS

INTRODUCTION

In addition to lignocellulosic materials and proteins, most plants and animals contain small amounts of extractives, which in the past have been extensively used as components in the manufacture of industrial goods. Oleoresins and fatty substances belong to this group. They are obtained in large part as by-products from the chemical processing of wood or the production of food, feed, or non-wood fibers. Their supply is thus contingent upon the production of such commodities as paper, beef, fish meal, and certain animal crops. Production and consumption for industrial materials is summarized in Table 1. In 1972, production amounted to approximately 23 billion pounds, with the bulk (70%) coming from vegetable oils, followed by tallow (22%), and wood (6.4%). Imports and stocks carried over from 1971 increased this amount to 25 billion pounds, the total available for export and domestic consumption. Of this, about 25 percent (5.9 billion pounds) as processed into industrial materials; the rest was exported or consumed for food and feed applications. Assuming an average value of about 8 cents per pound, the market for oleoresins and fatty materials consumed for industrial uses amounted to a total of about $450 million. Roughly 50 percent of these materials came from tallow, and 25 percent each from naval stores and vegetable oils. The analysis of current trends in production and consumption of renewable extractives has led to the projections summarized in Table 2.

The availability of vegetable oils for use in industrial materials will increase slightly following population increases expected for 1985 and 2000 (Table 2). The increases arise from the fact that most of the products devoted to industrial uses are from soapstock, which is a by-product of refining processes for making edible oils and which represents 4 to 6 percent of edible oil production. If petrochemical prices accelerate more rapidly than do those for extractives, industrial usage of extractives can be expected to grow more sharply.

Table 1

U.S. Production from Domestic and Imported Materials, and Disappearances for Nonfood Uses of Extractives in 1972 (In 1,000 lbs.)

Material	Production	Disappearance for Nonfood Products	Total Nonfood Uses,
I. Bark	45,000,000		
II. Turpentine, total	203,900		
Gum	9,500		
Wood	27,400		
Sulfate	167,000		
Rosin, total	846,200		
Gum	46,200		
Wood	364,000		
Sulfate	436,000		
Tall Oil Fatty Acids	428,874		
Citrus Peel-Limonene	10,457[1]		1,489,431
III. Vegetable Oils			
Soybean Oil	8,084,000	446,000	
Cottonseed Oil	1,355,000	110,000	
Coconut Oil[2]	215,000	434,000	
Corn Oil	507,000	38,000	
Linseed Oil	440,000	223,000	
Peanut Oil	258,000	12,000	
Castor Oil	-	140,000	
Others	5,187,000[3]	174,000	1,577,000
IV. Inedible Animal Fats	5,076,000	1,650,700[4]	1,650,700[4]
V. Fish Oils	188,000	100,000	
Seaweeds	2,205		102,000

[1] Includes approximately 1 million lbs. estimated for California; rest Florida; 1971-72 growing season.

[2] Oil produced from imported copra.

[3] Includes oil equivalent of exported domestic oil seeds.

[4] From "Current Industrial Reports, Fats and Oils" Series M20K (72)-13 U.S. Bureau of the Census, 1973, excludes animal feed.

Source: Navel Stores Annual Report, USDA, April 1973 - March 1974; Statistical Reporting Service, USDA (1974); Floride Canners Ass. Statisical Summary 1973-74. Kromer, G.W. 1974 "Economic Aspects of the Vegetable Oils and Fats Industry in the U.S.," paper presented at the International Trade and Development Conference, U.S. Economic Commission for Asia and the Far East, Seattle Washington June 10, 1974.

Table 2

Projected Use of Extractives for Industrial Materials in the U.S. for the Years 1985 and 2000
(In million pounds)

	Used for Industrial Purposes 1972	Projection for 1985		Projection for 2000	
		high	low	high	low
Turpentine	203.9	1070.0[1]	255.0	5090.0[1]	30.0
Rosin	846.2	3210.0	555.0	15270.0[1]	44.0
T.O. Fatty Acids	428.9	515.0	450.0	550.0	480.0
Cottonseed Oil	110.0	150.0	135.0	200.0	150.0
Soybean Oil	446.0	600.0	500.0	700.0	560.0
Coconut	434.0	600.0	510.0	700.0	575.0
Corn Oil	38.0	45.0	43.0	50.0	48.0
Linseed Oil	223.0	260.0	250.0	300.0	280.0
Peanut Oil	12.0	15.0	13.0	17.0	15.0
Castor Oil	140.0	175.0	157.0	200.0	176.0
Others	174.0	200.0	195.0	225.0	219.0
Citrus Peel Limonene	10.5[2]	25.0[3]	15.0[2]	60.0[3]	30.0[2]
Tallow	1650.7[2]	3500.0[3]	1900.0[2]	4300.0[3]	2100.0[2]
Marine Oils and Fats	42.0	50.0	35.0	35.0	7.0
Seaweed	1.0	4.0	2.0	8.0	4.0
Total	4767.1	10000.0	5000.0	27000.0	5000.0

[1] In case paraquat treatment is approved and widely applied.

[2] Does not include animal feed. Projection based on population increases.

[3] Includes animal feed. Projection based on article in Fats and Oils Situation, FOS-260, November, 1971, p.17, Economics Research Services, U.S.D.A. and on the assumption that 50% of tallow produced goes into industrial uses.

The question of whether or not there will be major increases in tallow supplies is problematic and it is not resolvable for the present.

Production of inedible tallow and greases more than doubled in the period 1950-1971. This rate is not likely to continue as more cattle are range fed to produce lean meat and as meat consumption decreases along with increased consumption of vegetable protein products. Probably the best estimate is that tallow supplies will also follow population increases.

Naval stores availability will increase gradually with the kraft pulp industries' heavier reliance on pines as principal raw materials, as well as through whole-tree use and shorter storage times of unprotected chips. The recently discovered stimulation of oleoresin formation of pine trees by injecting small amounts of a herbicide into the cambium of the standing tree may create up to a twenty fold increase of naval stores over 1972 supplies. However, too little is as yet known about the cost of this treatment to be certain that its use will be commercialized.

Currently, extractives are used for an almost endless list of products, some of which are manufactured in very small quantities. Turpentine is used mainly for pine oils (48%) and to a lesser extent, for polyterpene resins for adhesives (16%) and insecticides (16%). Rosin currently has three major uses: rubber additives (40%), paper size (36%), and resins for adhesives, coatings, and printing inks (20%). It should be emphasized that consumption of rosin in the U.S. has not exceeded production and, in fact, the U.S. has always been a major net exporter of rosin.

Nonfood uses of fats and oils is in fatty acids (40%), animal feeds (21%), soaps (12%), drying oils (11%), and others (16%). Fatty acid production has nearly doubled during the past two decades. Inedible tallow and tall oil comprise about 90 percent of the total raw materials used in fatty acid production; coconut oil and vegetable oil foots and soap stocks account for the remainder. Fatty acids and their chemical derivatives are used in almost every segment of today's industry in a wide array of products, such as soaps and detergents, protective coatings, textile processing, rubber manufacture, lubricants, pharmaceuticals, cosmetics, plastics, and many chemical intermediates. In addition to fatty acids, many oils as such (e.g., soybean, linseed, and tung oils) go into industrial uses. For example, 575 million pounds of drying oils were used in 1972. Another example is epoxidized soybean oil, a valuable plasticizer/stabilizer, production of which has doubled in the last 10 years to 85 million pounds. In spite of the inroads made by petrochemicals into end uses formerly dominated by fatty acid-derived products, the latter still occupy significant portions of some major markets; 40 percent of binders for coatings, 38 percent of surface active agents, and 15 percent of plasticizers. The use of industrial fats and oils in animal feeds has grown from 0.1 billion pounds in 1954 to 1.1 billion pounds in 1972. Tallow and greases are the major suppliers of this market. However, it must be recognized that about half (47% in 1972) of the available inedible tallow is exported. Much of this material is refined overseas, and used for food products. Japan and Western Europe are major consumers.

Extractives from plants and animals will continue to be available as by-products and co-products from the processing of forest, agricultural, and marine products. Their overall supply will largely be tied to the production of paper, cotton and flax, vegetable protein, pork, beef, and the harvest of marine animals. In order to insure their continued and expanded use for industrial materials, certain considerations will have to be emphasized.

EXTRACTIVES AS FUTURE RAW MATERIALS

Industries considering replacement of depleting nonrenewable resources by renewable resources as raw materials have certain constraints. The most critical is an assured supply. This means that many corporations will try to obtain a captive supply by ownership or contract, as paper companies do now with trees. Chemical companies will also prefer supplies with little waste for both environmental and economic reasons. Natural products are rarely pure. Often this impurity is useful as in fats, where a mixture of triglycerides has a lower melting point than a pure compound, or in rosin, where the mix remains tacky and does not crystallize. For new chemical uses, however, purification may be more important. This puts a potential premium on sources that have high concentrations of single compounds. At the least, standardization of properties, including properties not now considered important, will be necessary. In the case of annual crop seed oils, such standardization is partly an agronomic problem, but it will also affect the choice of sources and the processes adapted to new sources.

Supply and Use

New ways to supply and use natural oils and fats need to be found. New crop screening should be accelerated; the present effort is quite small and slow. Only a few crops have successfully been introduced; soy is the most prominent example. Crambe, jojoba, and kenaf are nearing introduction. New crop introduction is complicated and time consuming; domestication and breeding efforts are needed to aid adaptation to particular soils, climates, and hazards. Problems include pests, poor seed handling, uneven seed maturing, and inadequate yields. Basic research could be fruitful in finding ways to accelerate desirable genetic changes.

For any crop, research is needed on all by-products. Risks must be taken by innovators in the field. Plants will not be built until a supply is assured; and crops are not planted unless an outlet exists. Some corporations could assume the entire risk, but government may need to help if the scheme is to succeed. Tax credits on poor quality site lands for growing raw materials might be useful.

Tallow

Tallow supplies will continue to advance with beef production. Research should be conducted with the aim of using modified tallow fatty acids since tallow will continue to be in sufficient supply as the cheapest fatty material worldwide. The large quantities currently exported seem to guarantee excellent opportunities for domestic conversion into industrial products.

By-products from Wood

Extractive by-products from wood sources hold promise for expanded use in industrial materials as well. Sulfate turpentine from the kraft pulping of pines has been in short supply for many years. Rosin and fatty acids recovered from tall oil skimmings of the black liquors of kraft pulp mills could serve as chemical raw materials for a wide variety of products. Efforts aiming at the optimization of tall oil recovery should be intensified through technological refinements and modifications of the recovery process, and through reduction of the storage time of harvested wood, especially in the form of open chip piles. Direct delivery to mills, and immediate use of forest-chipped whole trees may be the most promising approach to an increased recovery of tall oil.

Although increased supplies of unsaturated fatty acids from tall oil refining are expected to find ready acceptance by markets for industrial products, such expanded markets will first have to be developed for resin acids (rosin). Increased research efforts should be carried out to find new uses for rosin that show advantage from the unique chemical characteristics of these diterpenes.

Therefore, when one considers how rosin can best be used to replace products from nonrenewable resources, one must examine rosin's major uses and the possibility of expanding them at the expense of the low-molecular-weight hydrocarbon resins with which they are more or less interchangeable and directly competitive. These petroleum resins are largely derived as by-products from the cracking of petroleum. In spite of an almost unlimited supply, the market for these products has never been as high as 50 percent of the rosin consumption.

The major use of rosin is in rubber production, especially in SBR polymerization, which accounted for about 200 million pounds per year. Here, rosin has little competition and therefore very limited opportunity, except where rosin and/or hydrocarbon resins are used as softeners or plasticizers. In paper size, the second major use, rosin consumption has been declining. To a minor degree, this has been the result of replacement of rosin by synthetic sizes, such as styrene-maleic anhydride resins. When this has occurred, special properties obtained from these much more expensive, but yet much more efficient, sizes has been the predominant factor. The major cause of decreasing rosin consumption has been the more efficient use of rosin size by the paper industry and the great decrease in the consumption per ton of paper. Despite a great deal of effort over many years, hydrocarbon resins have not been at all successful in replacing rosin in paper size.

This leaves the general area of resins, used principally in adhesives, coatings, and inks, as opportunities for rosin to replace products from nonrenewable resources. In recent years, particularly in 1974, when rosin prices reached an all-time high, the reverse was true; the usually cheaper hydrocarbon resins were replacing the more expensive rosin-based products. With few exceptions, rosin-based materials could replace all the hydrocarbon resins used here. Whether they will depends primarily on demand, supply, and price. In order to make serious inroads in hydrocarbon resin use, more rosin would have to be available. Without innovative harvesting technology, there seems to be little chance of increased domestic production of gum or wood rosins. Therefore, the increase must come from other sources. For a variety of reasons, production of tall oil rosin <u>per se</u> has not increased in recent years. Better technology in the recovery of tall oil soap, the precursor of tall oil rosin, from kraft pulping is possible and is being studied in both industry-wide sponsored work under the auspices of the Pulp Chemicals Association and by producing companies. Some modest increase, possibly 100,000 tons could result. These efforts should be supplemented by research aimed at achieving constant and upgraded rosin quality.

A second possibility for obtaining greater tall oil yields presents itself through the "paraquat" induced stimulation of rosin in living trees. Although this treatment is under intensive investigation, much is as yet speculation as to the potential of this development. A conservative estimate is that increased rosin from pulp wood (some of which might be recovered in wood rosin extraction plants) could equal that of current domestic tall oil production, or about 400 to 500 million pounds. Some very optimistic estimates indicate the potential is several times as great.

Another opportunity to replace oil-derived hydrocarbons in industrial products is the greater recovery and use of non-pinene monoterpenes, such as 3-carene and phellandrene which are principally found in western conifer species. The current low use potential of these hydrocarbons has generally kept west coast pulp mills from optimizing their sulfate turpentine recovery systems.

CHAPTER 11

INTERNATIONAL TRADE IN RENEWABLE MATERIALS

INTRODUCTION

The position of the U.S. with respect to international trade in renewable materials varies with the commodity. The primary agricultural materials, such as cotton and wool, move across international boundaries either as raw materials or finished products in rather large volumes. Secondary agricultural materials, i.e., the by-products or residues of food production have little international mobility, normally being used in the country of origin. Forest products move in international trade extensively. Just as these products represent the overwhelming tonnage of renewable materials domestically, so do they also represent the major component of renewable materials in world trade.

INTERNATIONAL TRADE IN TEXTILE MATERIALS

Worldwide, the consumption of textile fibers has increased very rapidly over the past several decades. Most of this increase in textile use has been provided for through expansion of the production of fibers from nonrenewable resources. Nonetheless, the world consumption of cotton has continued to increase by 1 to 1 1/2 percent in recent years. Historically, cotton has been a most important commodity in world trade.

The U.S. has been and continues to be a net exporter of cotton. This export has been important to the U.S. balance of trade and, in addition, has supported some 5 million people involved in production, processing, and manufacturing.

The volume of exports from the U.S. depends on the levels of production and consumption in many cotton producing and cotton consuming countries. Frequently, decisions on the import or export of cotton by other countries is made politically to enhance the economic opportunities of the countries involved. In this domain, efforts are commonly made to channel resources into production of commodities that will generate foreign exchange earnings or save foreign exchange costs. Foreign political decisions and economic circumstances can considerably change the levels of cotton and textile exports.

Major restrictions on the importation of cotton from the U.S. by large textile-consuming countries could induce short-term economic stress. Since much of the land devoted to cotton production can be used for the production of food or timber and since cotton is an annual crop, shifts in land use between commodities would probably relieve this stress in the long run, although not without some serious short-term economic dislocations.

On the other hand, increases in the availability and price of fossil materials could substantially increase the demand for renewable textile materials in both U.S. and foreign markets. The potential for reversing the trend from nonrenewable to renewable materials in the domestic market may depend upon a variety of technological and institutional factors. Consumer acceptance of cotton as a substitute for nonrenewable textile fibers may depend substantially on the development of technologies that permit maintenance of durable press properties in all cotton fabrics or in fabrics with greater cotton fractions. Rapid development of flame retardance technology may also significantly influence consumer acceptance of substitution. Government mandated environmental restrictions can influence the direction and rate of substitution between renewable and nonrenewable textile fibers. Such restrictions can influence both renewable and nonrenewable fiber production. Since such restrictions are typically process-specific and developed ad hoc without serious evaluation of environmental trade-offs, their potential introduces important elements of uncertainty into materials supply analysis.

INTERNATIONAL TRADE IN FOREST PRODUCTS

The situation with respect to international trade in forest products is different. World trade in wood involves a mixture of the products of natural and managed forests in the international market. Products originating in natural forests usually do not reflect the costs of growing the trees. On the other hand, extraction, transportation, and conversion costs are sometimes very high for natural forest products. The match between the forest resource and the use system for natural forests is usually much poorer than for managed forests. A larger fraction of the biomass of managed forests is marketable as material than is the case for natural forests. These trade-offs between natural and managed forests output commonly influence the direction of flow of forest products in the world market. This cost directed flow is, however, biased by nationally imposed protective tariffs and other forms of institutional constraints.

The U.S. has been active in international trade in wood throughout its history. Originally a supplier of wood to the world, the nation has been a net importer of wood for over 60 years. It continues to be a net importer since it uses and maintains a relatively inefficient forest production system in terms of achievement of anything like its forest-based materials' potential. While its forest-based materials' potential is great, its supply of concentrated and cheaply exploitable nonrenewable resources has also been great. In the short run, exploitation of domestic nonrenewable resources has presented more attractive investment opportunities than exploitation of domestic forest resources. The easy availability of nonrenewable resources encouraged major investment in the technology associated with the conversion of these resources to essential materials. As the first order supply of these resources became limiting, it was easier and cheaper to seek inexpensive foreign sources of the nonrenewable resources than to create the technology required to shift to domestically available sources of alternative renewable resources. These decisions stemmed very largely from an assumption that the trade-off was essentially an economic one within the context of worldwide free trade.

The U.S. has had some self-imposed restrictions on the use of its forest-based renewable resources that encouraged this trend. Its most productive forest land is located in the Southeast and the Northwest. Its greatest population densities are in the Northeast, the Southwest and the northern Midwest. Movement of its forest-based material resource from production centers to consumption centers requires an effective and inexpensive transportation infrastructure. The nation's long haul railroad transportation system, originally imaginative in its development has degenerated in the past 30 years. The quality of its roadbed and rolling stock facilities has declined. The federally regulated railroad rate structure has not encouraged long haul transportation of wood. Alternative water transportation of wood from production site to consumption site has been inhibited by the Jones Act, regardless of its social value. This legal restriction has essentially eliminated what was once a flourishing intercoastal waterborne timber trade. It has discouraged the movement of southern wood to the markets of the Northeast and the movement of northwest wood to the markets of the Southwest and the Northeast. It has effectively denied to the markets of the contiguous 48 states of the country, on an economic basis, the materials of the forests of Alaska.

This country has engaged in international trade in forest products from the early days of its colonial history. Timber from the east coast was one of the commodities exported to Europe during the seventeenth and eighteenth centuries. The first sawmills established in the Northwest produced wood products not only for domestic markets but for the markets of western South America, Australia, and China as well. Federal legislation implies that it is national policy to achieve a balanced wood budget. References to a balanced timber budget in the McSweeney-McNary Act imply such a national policy [16 USC 581 (1970)]. It is not clear whether these references to a balanced timber budget infer an internally balanced budget or an externally balanced budget. In any case, since the Act was passed in 1928 the country has never achieved a balanced timber budget either internally or externally nor has it made significant efforts to move toward either type of budget balance.

Table 1 from the PAPTE (1973) indicates the level of U.S. production, consumption, and level of net export or import annually since the beginning of this century. Since 1914 the nation has been a net importer of wood and the percentage of national consumption represented by imports increased from 0 to 12.2 through 1971.

U.S. IMPORT AND EXPORT OF WOOD

According to Cliff (1973), in 1971 the U.S. importation of wood and wood products amounted to 2.75 billion cubic feet roundwood equivalent while exports totaled 1.18 billion cubic feet on the same basis. This yielded a net importation of 1.57 billion cubic feet roundwood equivalent.

The Forest Service (USDA 1974d), estimates that the nation will continue to be a net importer of wood and that it will continue to participate in the world wood market as both an importer and an exporter. Given the transportation problems that inhibit matching wood production with wood consumption internally it would seem that it is more feasible to set as a national objective an externally balanced wood budget rather than an internally balanced wood budget.

Table 2 shows the import/export status of individual forest product commodities for 1972 in roundwood equivalents. In hardwoods where the U.S. produces substantially more than it harvests, the only commodity that shows a substantial excess of imports over exports is hardwood veneer and plywood, almost entirely in the form of tropical hardwoods shipped in from Southeast Asia. This is

Table 1

U.S. Production, Consumption, and Net Imports of Industrial Wood Products, 1900-1971

[Volumes in billions of cubic feet]

Year	Production	Net imports	Consumption	Net imports as percent of consumption
1900	7.3	[1]0.1	7.1	[1]1.4
1901	7.6	[1].1	7.5	[1]1.3
1902	7.9	[1].1	7.8	[1]1.3
1903	8.2	[1].1	8.1	[1]1.2
1904	8.5	[1].2	8.3	[1]2.4
1905	8.6	[1].1	8.5	[1]1.2
1906	9.2	[1].1	9.1	[1]1.2
1907	9.5	[1].1	9.4	[1]1.2
1908	8.7	[1].1	8.6	[1]1.2
1909	9.3	[1].1	9.2	[1]1.2
1910	9.3	[1].1	9.2	[1]1.1
1911	9.0	[1].1	8.9	[1]1.1
1912	9.3	[1].1	9.2	[1]1.1
1913	9.2	[1].2	9.0	[1]1.1
1914	8.6	0	8.6	0
1915	8.0	.2	8.2	2.4
1916	8.5	.2	8.7	2.3
1917	8.0	.2	8.2	2.4
1918	7.3	.2	7.5	2.7
1919	7.7	.1	7.8	1.3
1920	7.8	.2	8.0	2.5
1921	6.6	.1	6.7	1.5
1922	7.6	.3	7.9	3.8
1923	8.6	.3	8.9	3.4
1924	8.3	.3	8.6	3.5
1925	8.4	.3	8.7	3.4
1926	8.2	.4	8.6	4.7
1927	7.8	.3	8.1	3.7
1928	7.7	.3	8.0	3.8
1929	8.1	.3	8.4	3.6
1930	6.4	.4	6.8	5.9
1931	4.7	.3	5.0	6.0
1932	3.4	.3	3.7	8.1
1933	4.1	.3	4.4	6.8
1934	4.4	.3	4.7	6.4
1935	5.1	.4	5.7	7.0
1936	6.0	.6	6.4	9.4
1937	6.4	.6	6.6	9.1
1938	5.6	.5	6.0	8.3
1939	6.4	.5	6.9	7.2
1940	7.0	.4	7.9	5.1
1941	8.1	.7	8.6	8.1
1942	8.1	.7	8.8	8.0
1943	7.6	.6	8.8	6.8
1944	7.5	.6	8.2	7.3
1945	6.6	.7	7.6	9.2
1946	7.7	.8	8.3	9.6
1947	8.1	.8	8.6	9.3
1948	8.4	1.1	9.1	12.0
1949	7.4	.9	8.6	10.5
1950	8.5	1.4	9.1	15.4
1951	8.7	1.2	10.0	12.0
1952	8.8	1.2	9.9	12.1
1953	8.8	1.2	10.0	12.0
1954	8.8	1.2	9.9	12.1
1955	9.2	1.3	10.5	12.4
1956	9.6	1.3	11.0	11.8
1957	8.6	1.2	9.7	12.4
1958	8.5	1.2	9.7	12.4
1959	9.4	1.3	10.7	12.1
1960	8.9	1.2	10.1	11.9
1961	8.7	1.2	10.0	12.0
1962	9.0	1.4	10.4	13.5
1963	9.6	1.4	10.9	12.8
1964	10.2	1.3	11.5	11.3
1965	10.5	1.4	11.9	11.8
1966	10.6	1.4	12.1	11.6
1967	10.4	1.2	11.6	10.3
1968	11.0	1.3	12.2	10.7
1969	10.9	1.4	12.3	11.4
1970	11.0	1.0	12.1	8.3
1971	11.5	1.6	13.1	12.2

[1] Values are net exports.

Source: PAPTE (1973) Report of the President's Advisory Panel on Timber and the Environment, U.S. Government Printing Office.

Table 2

U.S. International Trade in Forest Products, 1972
(Million cubic feet - roundwood equivalent)

		Import	Export	Net Export
Logs	softwood	2.5	475	475
	hardwood	5	20	15
	Total	5	495	490
Lumber	softwood	1,340	175	-1,165
	hardwood	70	40	- 30
	Total	1,405	215	-1,190
Veneer and Plywood	softwood	10	20	10
	hardwood	255	5	- 250
	Total	265	25	- 240
Pulp Products	softwood	1,250	510	- 740
	hardwood	115	230	115
	Total	1,365	740	- 625
Total	softwood	2,595	1,180	-1,415
	hardwood	450	295	- 155
	Total	3,045	1,475	-1,570

Note: Totals may not add due to rounding.

Source: Phelps, R.B. (1975) The Demand and Price Situation for Forest Products, U.S. Department of Agriculture Forest Service, U.S. Government Printing Office, Washington, D.C.

almost the only major item of international trade in wood that represents a commodity that cannot be produced in the U.S. from domestic forest products supply. The importation of tropical hardwood veneer and plywood is responsive to price. It reflects U.S. consumer preference for the appearance of tropical wood panels as compared to competitive domestic materials. Trade across national boundaries in other hardwood items is relatively minor. The U.S. is a net exporter of hardwood logs and hardwood pulp products, and a net importer of hardwood lumber though the balance of trade in each of these commodity items is relatively minor in terms of value and volume.

On the softwood side, the nation is a net exporter of logs and plywood and a net importer of lumber and pulp products. These international trade movements reflect economic trade-offs that very largely reflect U.S. transportation restrictions. The largest import volume is softwood lumber from Canada in the amount of 1.165 billion cubic feet. This was predominantly Douglas fir from British Columbia moving into the northern markets of the midwest and eastern United States. Douglas fir is the principal species produced in the states of Washington and Oregon.

The other major softwood import items is pulp products. As in the case of softwood lumber, this very largely reflects importation from Canada, with the largest component being newsprint from central and eastern Canada. This too is a commodity that is produced in the U.S., where preference for imported materials is largely a matter of price.

Logs represent the only major softwood export item. These are shipped from the northwest states, Washington, Oregon, and Alaska. They go almost exclusively to Japan. In 1972, over 70 percent of this export was from Washington. Most of the production of export logs originated from forest lands in private-ownership and from state owned forest lands in Washington. The federal government and the states of Oregon and Alaska have imposed restrictions upon the export of logs originating from their ownerships. This has sometimes resulted in the artifact of splitting logs into large cants to avoid the export restrictions on logs. The softwood logs exported include Douglas fir, cedar, and such white woods as hemlock, spruce, and the true firs. The Japanese log export market is attractive to northwest log producers because of the transportation problems associated with movement of lumber and other softwood forest products to major U.S. consuming centers and because Japan generally converts white softwood logs to higher value products than does the U.S. In the past, Japan has preferred to buy softwood logs rather than finished products for a variety of reasons. The Japanese construction industry uses lumber and timber sizes that are different from standard U.S. lumber sizes. The Japanese lumber industry typically obtains much larger yields from a log than does the U.S. sawmill. The Japanese construction industry is partial to white woods, such as hemlock, and the true firs; species that in the U.S. typically go into lower valued pulp products.

Recently the Japanese construction industry has moved significantly in the direction of adopting U.S. stud wall construction methods. This makes standard U.S. lumber and structural plywood items more acceptable and competitive in the Japanese construction market. If this trend continues the potential for the export of west coast softwood products will improve and current restrictions on the export of softwood timber in log form will be less significant.

Since the U.S. operates essentially in the context of a world wood budget rather than a national wood budget, it is appropriate to examine the potential of world wood supply as it relates to U.S. demand and supply of wood in the long run.

WORLD WOOD SUPPLY

Softwood

Softwood species are preferred worldwide for many uses. They are the principal sources of renewable structural materials in the form of lumber, plywood, and such composites as structural particleboard. The structure and properties of softwoods make them more adaptable to structural uses than hardwood species. A similar situation exists with respect to fiber products. The long fibers that characterize softwood species make them preferred raw materials in many fiber uses. Supplies of these species originate primarily from the temperate regions of the world. The principal softwood producing areas are the U.S., Europe, Canada, the USSR, and Japan, in the northern hemisphere. Smaller quantities of softwood originate in Mexico and northern Central America. Australia, New Zealand, Chile, Argentina, and Brazil are the major producers of softwoods in the southern hemisphere, although these sources are much smaller suppliers than are the northern hemisphere sources.

Canada has very large areas of natural softwood stands located principally in British Columbia. These forests carry the very large standing volumes typical of virgin forests, but located as they are in the northern portion of the north temperate zone, many of them have low production potential compared to the highly productive forests of the

U.S. in the Southeast or Pacific Northwest. Based on its large timber reserves, Canada is likely to be a major supplier of softwood to the world for many years. Only a portion of Canadian forest land has been inventoried and growth data on much of it is very sparse. Nonetheless, conservative estimates based on these limited data indicate that less than half of its sustainable harvest is currently being removed. Canada is a major exporter of wood. In 1966 Canada exported 70 percent of its paper production and 60 percent of its lumber production (Manning and Grinnell 1971). Ninety percent of forest products exports are shipped to the U.S., United Kingdom, and Japan. The U.S. is the major customer accounting for more than 75 percent of exports. Historically, wood has moved relatively freely across the Canadian-U.S. border. Canada does, however, allocate its resources to its own advantage and can be expected to serve as a reservoir of wood for the U.S. only to the extent that it is perceived to be its most profitable market. The U.S. tariff position has encouraged importation of forest products from Canada. The Kennedy round of tariff negotiations resulted in either removal of tariffs or sharply reduced tariffs on all major forest products. This position could be modified in the upcoming General Agreement on Tariffs and Trade (GATT) negotiations. Currently, the U.S. so depends on Canada as a source of softwood lumber and newsprint that any major restriction in price or volume could create a significant materials supply problem for this country. Canada's future relationships with its former commonwealth trading partners and with the European Common Market may influence the availability and price of Canadian softwood to the U.S.

A very large reservoir of softwood timber exists in the USSR. Like Canada, much of its forest land is in the far north where productivity is likely to be low. Nonetheless, the large quantities of wood in the present natural stands represent a reserve that is apparently being drawn down at a low rate. Like the U.S., the USSR does not have a good match between its forest resources and its wood products consumption areas. Inadequate transportation, labor, and equipment infrastructure denies to its major population centers the resources of its remote eastern forests. The markets of Japan are much more accessible to these eastern forests.

The USSR has been a net exporter of wood for the past 20 years. Its exports are made to develop foreign exchange for the purchase of other commodities and to achieve political objectives. It is apparently removing more than its sustainable harvest from some of its readily accessible western forests, and the principal source of its exports are these forests. The manufacture of forest products in the

USSR has steadily increased over the past several decades, although this increase has fallen substantially short of planned targets, particularly in fiber production (Solecki 1975).

One of the problems in wood use in the USSR for both domestic and export purposes is that a substantial fraction of its forest inventory is larch. This species is preferred neither in the world market nor, apparently, in the domestic market. Approximately 38 percent of the nation's forest land is occupied by larch and 51 percent of its coniferous forest land produces larch. Thirty-six percent of the country's timber inventory is larch, and this accounts for 43 percent of its softwood inventory (Medvedev 1970).

In its priorities for capital investment the USSR has not emphasized the capital dedication to forest products exploitation required to develop its inaccessible forest reserves, principally those represented by its eastern forests. It has been an exporter of softwood to Europe--primarily eastern Europe--and, in the case of fiber products, to selected less developed countries. The USSR supplies some wood to Japan, its most rapidly expanding export market for wood. It is not likely to be an important source of softwood for the U.S., but if it elects to develop its opportunities for export it could become a major factor in the world softwood market and thus indirectly influence the U.S. position in international trade.

Europe is a major producer and consumer of softwoods. Most European forests are intensively managed by U.S. standards. Eastern Europe, other than the USSR,[1] is a net importer of forest products; its principal external source of supply is the USSR. The most recent European timber appraisal indicates that western Europe has a nearly balanced timber budget (Nagle 1975). Table 3 shows annual consumption and removals for the 1970-1972 period for western Europe. The western European timber budget though nearly in balance is in fact externally balanced with substantial imports and exports. It will be noted that the EEC countries[2] produce about 44 percent of their requirements on a roundwood equivalent basis. The central European countries[3] have an excess of removals over consumption of 14 percent and the southern European countries[4] a similar excess of 66 percent.

The Nordic countries[5] have a removal rate that is 3.73 times their consumption rate. These northern European countries are important producers of softwood and manufacturers of softwood forest products. Since European forests are intensively managed, for the most part, they are not in the position of Canada, the USSR, and western U.S. of drawing down inventories in natural overmature forests. Because their silviculture and forest management is much more intensive than that of the other major producers of softwoods, they are growing forests at much nearer their biological capacity than are the other major softwood producers. These countries are major exporters of wood products to the rest of Europe and to the U.S. There is some evidence that their capacity for manufacture exceeds their capacity to grow wood, and they have been aggressively seeking other supplies of softwood raw material recently in the U.S. and in other parts of the world.

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[1] The eastern European countries include Bulgaria, Hungary, East Germany, Poland, Rumania, and Czechoslovakia.

[2] The European Economic Community includes Belgium, Denmark, France, West Germany, Ireland, Italy, Luxemburg, Netherlands, and the United Kingdom.

[3] The central European countries include Austria and Switzerland.

[4] The southern European countries include Greece, Portugal, Spain, Turkey, and Yugoslavia.

[5] The Nordic countries include Finland, Norway, Sweden, and Iceland.

Table 3

Western European Roundwood Consumption and Removals, 1970-1972
(Million cubic meters - roundwood equivalent)

	Consumption	Removals
NORDIC	30	112
EEC	180	79
Central	14	16
Southern	35	58
Total	259	265

Source: Nagle, G.S. (1975) Wood Supply and Demand in Western Europe; Preprint - 66th Western Forestry Conference, Vancouver, B.C.

The U.S. has been able to buy softwood at reasonable prices from the softwood exporting countries and has been content to fill out its softwood needs beyond its own production through importation. This is a viable position, provided that the sources of supply are dependable in the long run and that the U.S. can afford a trade deficit in these commodities. Growing demand for softwood worldwide suggests that this position needs to be carefully evaluated, however. The per capita use of softwood is increasing in all of the industrial nations of the world. Modest increases are also apparent in the less developed countries.

Canada and the USSR are the principal sources of unexploited natural softwood reserves available to meet these greater demands. If the U.S. also goes to these sources to meet its growing needs as projected by the Outlook Study (USDA 1974d), it will have to compete with the other importing industrial nations for this supply. This would place the country in a somewhat vulnerable position were these foreign sources to change their marketing policies and practices in the pattern of the petroleum and natural gas producers. Among the importing industrial nations, the U.S. is the only one that has a major undeveloped softwood production potential. It clearly has the opportunity to avoid softwood supply vulnerability in the long run, but this would require a change in priorities for forest land use, particularly at the federal level, and for the development and use of its long haul transportation systems.

Hardwoods

A major enigma in the future world timber supply picture is the role of hardwoods. In most of the industrial countries substantial areas of natural forest are occupied by hardwoods and, for the most part, the wood produced on these lands is underused. In the tropical areas of the world all but a very small fraction of the forests consist of hardwood stands. Over half of the world's standing volume of timber is in tropical hardwood forests. Most of these forests are all aged, multi-species stands. In the tropics the hardwood forests are extremely diverse with respect to tree size and quality and the properties of the wood. They commonly include several hundred tree size species in a few acres.

Most production systems for wood processing are based on rather rigid requirements of species or general, size, and quality of raw material. Thus, when the forest resource is extremely heterogeneous, the useful material from a unit of land area is likely to be very small. Many tropical hardwood forests--characterized by high species diversity--may contain 4000 to 5000 cubic feet of biomass per acre in the form of trees of which only 1 or 2 percent could be converted to industrial materials in economical manufacturing systems. Only under unusual site conditions are naturally occuring hardwood forests sufficiently homogeneous to yield a high enough percentage of usable raw materials per unit of area for extensive materials production. Stands of alder and aspen in temperate North America are examples of this condition. In the tropics the dipterocarp forests of Southeast Asia yield reasonably good volumes of product per acre and are being used extensively. The Catixo forests of central and northern South America are other examples. The use of wood for fuel is relatively indiscriminate with respect to species, size, and tree and wood quality. Production per acre from mixed hardwood stands sometimes becomes economically feasible, when harvest for fuel is combined with harvest for industrial materials supply. Such fine cabinet woods as mahogany, walnut, and rosewood are so valuable that it is economically justifiable to harvest the occasional tree as a high grading selection process. The vast majority of hardwoods, however, both in temperate and tropical regions, do not command prices that justify this type of use. The result is that in many hardwood forests the majority of trees are weeds from an industrial materials production standpoint. This situation leads to the common practice of simply destroying large numbers of trees in shifting agriculture or in large land-clearing operations and changing land use to roads or agricultural crops. It also leads to high grading of natural forest stands resulting in their degradation from a materials supply standpoint.

The solution to this problem seems to be in either simplifying the forest resource system to achieve a better match with the materials production system or in diversifying the materials conversion system to match the diversity of the forest. The first solution is the one being used in many tropical areas where diverse natural stands are being replaced by even-aged plantations comprised of single species. The teak plantations of Java and Sumatra and the Monterey pine plantations of Australia and New Zealand are examples. When this practice is undertaken, the species selected are frequently exotics and as often as not are softwoods. Many biologists deplore the conversion of all-aged multispecies hardwood forests to even-aged single species plantations on grounds of loss of gene pools, dangers inherent in monoculture, loss of game habitat, reduction in site quality, and loss of aesthetic values. The evidence in support of many of these alleged dire consequences is limited and inconclusive in most cases. In any case the alternatives currently available do not seem to be generally feasible.

Efforts to construct a materials production system that will match the diverse all-aged, multispecies hardwood forest resource confront some serious problems. Such a manufacturing installation must usually be very large and costly and be supported by an extensive and expensive transportation infrastructure. The capital required for such an installation is usually not available in the tropical countries that have political custody of these forests. In many developing countries the natural forests are owned by the national governments and land use and land tenure commitments are nebulous or transitory. Often it is not clear whether the land will be permanently allocated to forest production or whether the natural forest simply constitutes a reservoir of wood on currently unallocated land, which ultimately will be allocated to other uses. Small and relatively inexpensive conversion facilities can often be justified on the basis of natural forest liquidation, but the allocation of large amounts of capital to elaborate integrated use manufacturing facilities usually depend on an assured long-term wood supply.

Another factor that inhibits the effective use of tropical hardwood resources for industrial materials is the lack of information about the potential utility of many of the species. The research required to illuminate these potentials simply has not been accomplished. Most wood and fiber technology research is performed by scientists in the industrial countries of the temperate regions, and they concentrate on endemic species. Wood is a bulky material that is difficult and costly to transport long distances; hence there is a real advantage to pursuing the required wood technology research in the countries of origin. The financial resources required to accomplish such research and the supply of scientific and technical talent demanded is usually in short supply in these regions. Incentives to encourage appropriately qualified research manpower to move from the industrial countries to less developed countries for this purpose have generally been lacking.

Despite these problems, it would be unwise to ignore the potential role of tropical countries in meeting world needs for renewable materials. In many of the developing countries the trend toward conversion from wood and charcoal to petroleum as a heating fuel has been reversed as a consequence of the increased cost of petroleum. The conversion of wood residues to liquid and gaseous fuels still seems to be a marginal undertaking in most circumstances in the U.S. where residues, once accumulated, often have higher values for other uses. Such conversion may be a much more viable enterprise in tropical hardwood-rich countries that do not have the options of large-scale hydroelectric developments, and exploitable oil, gas, and coal resources. In forests where more than 90 percent of the standing biomass is comprised of weeds from a materials standpoint, such concentrations of raw material may make the production of liquid and gaseous alternatives to petroleum feasible, at least during the period of conversion from natural forests to managed forests or from natural forests to non-forest use. Such processing opportunities might also make harvesting the usable portion economically feasible. Such developments could influence U.S. materials supply problems by reducing the worldwide demand for petroleum, thus easing the position of the U.S. as it competes in the world market for fossil fuels.

Another development that could ease the pressure on softwood timber supply in the long run is the conversion of native tropical hardwood forests to introduced softwood species. Such conversion has been successful in many temperate zone hardwood areas in Europe, the U.S., Australia, New Zealand, Chile, and Argentina. It is much more difficult and costly to convert from hardwoods to softwoods and to maintain the conversion in the tropical regions of the world, but experimentation with this type of conversion is widespread throughout the tropics. It would probably be more technically feasible and less expensive to convert more hardwood areas to softwoods in the U.S. than to do the same thing in the tropics. However, this is becoming less acceptable from a social standpoint in many industrial counries, including the U.S., where hardwood forests are prized for their recreation and aesthetic values. These social inhibitions have not yet represented serious restrictions in most of the less developed countries of the tropics.

U.S. PROGRAMS

If the U.S. is to accept long-term dependency on foreign sources of wood, it would be wise to develop relationships with potential suppliers that will foster a favorable long-term climate for trade. This may involve participation in the research essential to the development of the utility of the forest resource. Given the great potential of the tropics in the long-term timber supply picture and given that the U.S. has long accepted a dependency on foreign wood resources, it is surprising that this country has very largely ignored the opportunities for bilateral cooperative programs with potential wood suppliers in the tropics. Many U.S.-based corporations are very active in tropical regions, but the federal government has been inactive. The U.S. foreign assistance programs have never had a strong forest resource thrust. Those programs that have been undertaken at the request of less developed countries have been ad hoc, intermittent, and--lacking central planning--often ineffective. This is a mistake that is not being made by the other major industrial countries whether exporters or importers. While most bilateral research, development, and education programs have as their central purpose the advancement of the recipient country, many of the best of these foster the mutual interests of the two countries involved.

CHAPTER 12

INCREASING THE PRODUCTION AND USE OF RENEWABLE MATERIALS

INTRODUCTION

The U.S. has unique opportunities to increase the use of renewable resources as industrial materials. These resources derive from the growth of living organisms, plants and animals, using a large and very productive land base. Within U.S. borders are included some of the most productive lands in the world for the production of biologically based resources. The nation has elected to emphasize the use of much of this highly productive land base for the effective production of food. It has not had the same national commitment to the production of renewable materials.

The renewable resources for industrial materials are overwhelmingly forest based. Forests now account for about 96 percent by weight of the nation's current production of renewable materials. A great variety of renewable materials are also available as primary or secondary products of agricultural production even though the tonnage of these is relatively small compared with the tonnage of forest products. Renewable materials can be substituted for nonrenewable materials in a great many situations. Such substitution often results in a saving in the requirement for energy added in manufacture. It provides opportunities to reduce dependence upon foreign materials and to produce surpluses for export. It can be accomplished with modest environmental impacts. Every recent study of the potential for increasing the domestic supply of renewable materials, including this one, has indicated that it is technically feasible. What is not clear is whether it is socially feasible in the contemporary political climate. Lack of a well-defined and aggressively implemented national policy for increasing production of renewable materials places the outcome in doubt. National preoccupation with food production has resulted in an agricultural policy that very largely ignores materials production. Clawson (1975) has discussed the deficiencies in national forest policy as follows:

> . . . there is no organization to look at all forests in all their uses and in all their aspects. Forest policy is an incidental objective or purpose of many

> organizations; it commands neither the full time nor the full attention of the ablest men. The input on forest policy from many organizations, both public and private, is relatively small in many cases and often overlooked as forest policies are actually formed. In short, it is a weak policy-forming process.

It is not the purpose of this study to explore the social or political feasibility of the development of an effective national policy that will enhance the production of renewable materials. Clawson (1975) has discussed these issues as they relate to the forest resource in some detail. This study examines the technological efforts that must be made if there is a decision to foster such a national policy. They are not unrelated, however, to the nature of a national policy if it is established.

AGRICULTURE RESOURCE BASE

In the agricultural sector, the resource production base is the land and it is in many thousands of separate private ownerships. In recognition of this diverse and dispersed land ownership pattern and of the importance of agricultural production to the nation, this country has developed and maintained a large research and education program in agriculture as a cooperative undertaking involving the U.S. Department of Agriculture (USDA) and the schools and colleges of agriculture of the land grant universities. This well established cooperative research and education program has been extremely effective in providing the technical backup for the most effective food production system in the world. This cooperative program has been predominantly devoted, however, to the production of primary agricultural products. With the exception of a few primary agricultural materials such as cotton, wool, and tobacco, this research and education effort has been primarily directed at food supply. Very little research and education effort has been devoted to the creation of new knowledge or the development of scientific and technical manpower in the area of secondary agricultural products useful or potentially useful as industrial materials. As a result, the full potential of these sources of renewable materials is substantially underdeveloped.

If the potential for the development of these resources is to be exploited, it can probably be most efficiently accomplished through an expansion of the existing federal-state cooperative research and education program in agriculture to include significant new efforts devoted to the development of methods of utilizing agricultural residues for industrial materials. The landowners that produce the primary agricultural products will also produce the secondary products that are candidates for materials production. These represent the natural and traditional constituency of the federal-state cooperative agricultural program.

FOREST RESOURCE BASE

An effective national effort to foster an expanded forest-resource-based materials supply system faces more difficult problems. Lacking a traditional national policy in this domain, there is no well organized system that can be utilized to develop and implement the essential technology.

As is the case of agricultural production, forest-products-based materials also involve a multiplicity of land ownerships. Unlike agriculture, the largest single custodian of forest land is the federal government itself. Large areas of forest land are also owned and managed by several of the states. Over one quarter of what is currently classified as commercial forest land is in federal and state ownership. The balance between public and private ownership varies widely among regions of the country with the major component of publicly owned commercial forest land located in the western states. The fact that federal and state governments are the custodians of forests as well as the regulators of forests creates a climate that is different from that in which food is produced.

Federally Supported Research and Education

There is no real counterpart in the forestry sector to the federal land grant institution cooperative research and education program in agriculture. This results in part from the lack of a well-defined national policy on forest-based materials supply, partly from the historical dual role of the federal government as a landowner and manager and as a regulator and supporter of the whole forest resource enterprise, and partly from the different tradition in forestry education. Whereas agricultural education at the university level emerged very largely in the land grant institution tradition originally under the aegis of the Morrel Act, forestry education began at the turn of the century in quite a different pattern. Some of the earliest forestry education was initiated at private universities and at non-land grant state universities and most of these are still important centers of forestry research and education. In some land grant institutions, forestry education and research is fully integrated with agricultural education and research, but at many others the forestry programs are independent. The McIntire-Stennis program has some of the features of the cooperative federal-state research and education program in agriculture, but it is a relatively small program and because of the structure of forestry education in the universities, its support is fragmented among many institutions. Forestry programs in private institutions are excluded from the McIntire-Stennis program.

The major part of the federally supported research in forest-based materials has been conducted by the Forest Service's Forest Products Laboratory at Madison, Wisconsin. While it is one of the largest forest products laboratories in the world, it has operated in considerable isolation. It is geographically remote from the major forest-based materials regions of the country. The research effort at this laboratory has been declining in recent years, and its thrust has been increasingly away from basic materials research. It has undertaken very little cooperative research effort in collaboration with the centers of academic research in forest-based materials.

University Research and Education

There is a long history of research and graduate study in wood science and technology at a small number of the schools and colleges of forest resources. The two Forest Service forest product laboratories preceding the Forest Product Laboratory at Madison, Wisconsin, were located on the campuses of Yale University and the University of Washington where they were closely associated with academic research. But when these laboratories were closed over 50 years ago in favor of development of the central facility at Madison, close collaboration with universities became more difficult and was gradually reduced to the present status. Immediately following World War II, several universities expanded their research and teaching activities in the field of forest-based materials. This small number of schools and colleges of forestry have been the principal sources of wood and fiber specialists in the forest resource field. With a few exceptions, these have been small programs involving a very limited spectrum of faculty talent and limited output of students educated at the advanced materials level. During the past decade several of these universities with traditions of advanced education in the field of wood science and technology have phased out their programs, presumably due to lack of support. In the judgment of CORRIM there are no more than eight universities with programs of teaching and research in wood science and technology that represent sufficient breadth of faculty talent and adequate physical facilities to justify identification as important forest-based renewable materials research and education centers.

If there is to be any major effort to increase the use of renewable resources from the forest base as substitutes for nonrenewable resources, the inadequacy of an academic foundation must be remedied.

Industrial Research

The major source of renewable resources from the forest is the research laboratories of the largest forest products corporations. There are only a few firms among the forest products industries that are large enough to justify significant investment in research. These few do research that is comparable to the best in the world. However, unlike the situation in many of the nonrenewable materials fields, industrial production is not concentrated in a few large corporations. There are more than 10,000 separate firms engaged in the manufacture of forest products. Most of these are manufacturers of lumber. According to the President's Advisory Panel on Timber and the Environment (PAPTE 1973), "Nationally, the five largest firms in 1972 together accounted for approximately 17 percent of total production." Nonetheless, the largest single firm produced less than 8 percent of the national lumber output. There is little incentive for most manufacturers to conduct research unless the results can be protected for their exclusive use through patents or the exercise of proprietary secrecy. Most of the companies are so small that they cannot justify the expenditures required to pursue an effective research program. The major part of R&D expenditures in the wood products field represents investment in the fiber component and by a relatively small number of firms. According to an NRC (1974) report <u>Materials and Man's Needs</u>, in 1970 the total of federally financed industrial R&D expenditures for all wood products represented about 0.02 percent of such investment in all manufacturing. The total of industrial R&D expenditures for forest products represented less than 1 percent of national R&D expenditures in the forest products field, 17 percent of the total industrial R&D expenditures in the forest products field, 17 percent related to solid wood products and the remainder to pulp and paper.

Where corporations are willing to place the results of their more fundamental research in the public domain they have contributed substantially to advancement of science and technology related to production and use of renewable resources. The action of the Weyerhaeuser Company in releasing to the scientific community their very extensive soil evaluation research is a good example. If the federal government were willing to share in the cost of broadly applicable industrial research it could broaden the base of research leading to generally available new knowledge.

RENEWABLE RESOURCE BASE

The federal government has recently accelerated its research efforts in the nonrenewable materials field in a number of ways, and much of this new effort has been directed at strengthening university research and education. It has provided block funding for a significant number of materials research laboratories and centers in universities with a history of academic excellence in materials science. The U.S. Department of Defense, NASA, AEC, and NSF have provided this basic and continuing support. No similar effort has been made in the renewable materials field where the nature of the materials production and conversion system is so diffused as to make a substantial nonfederal research program unlikely.

The development of a strong renewable materials production base is peculiarly dependent upon federal government action. As previously indicated, the federal government has custody over a large fraction of the nation's forest land. This forest land serves many purposes in addition to materials supply. In recent years the management of government owned forest land has been much more responsive to pressures for nonmaterials use than to materials use. Federal legislation is particularly confusing in this domain. The Forest Service has a federal mandate (USDA 1964) to manage the property in its custody in accordance with the principles of a land use policy identified as multiple use. In spite of this general mandate, additional specific federal legislation (USDA 1964) fosters the identification of large federally owned forest land areas where materials supply is excluded or made infeasible, thus excluding them from the general multiple-use mandate. The remaining federally owned forest land is subject to the general multiple-use mandate, and materials production emphasis is negotiable within the context of a broad spectrum of uses. Decisions related to forest land use in the federal domain have little relationship to forest-based materials productivity. Over 17 percent of the identified commercial forest land of the country that is in Site III productivity class and better is in the National Forests. Nonetheless, there is no federal legislation specifically dedicating highly productive federal forest land as a materials supply base where materials production has a mandated primary goal comparable to the mandated primary goals identified with other forms of federal forest land use. In the presence of such indifference to materials supply on the part of the federal government with respect to its own forest land, it is not surprising that forest-based materials research has had a low priority in the research programming of the federal land management agencies or that they have been indifferent to the need to foster research and education in this field at the universities.

The Public Land Law Review Commission (1970) recommended a materials production priority identification of certain areas of public forest land. PAPTE (1973) also recommended a deliberate effort to concentrate materials supply production activities on the most productive federal forest land. Neither of these recommendations has been implemented by congressional action.

Recent federal court decisions invoking a very restrictive interpretation of the Organic Act establishing the Forest Service (USDA 1964) have in effect directed the Forest Service to return to its custodial role of the turn of the century. These legal restrictions apply at this time to the national forests of the mid-Atlantic area and Alaska. If they are extended to the large federal forest holdings of the West and if they are not modified by congressional action, the federal forest land, even where it represents high site quality, is likely to be of minor importance as a materials supply resource.

Such a development could substantially reduce the potential for timber supply projected by PAPTE (1973), the Outlook Study (1974d), and this study. The effect of such materials supply regression might be modified by a deliberate policy of exchanging forest land between federal agencies and private industry to concentrate high site land in private ownership and low site land in federal ownership. Federal support of R&D programmed to advance the use of forest-based renewable materials would need to reflect such a materials supply policy whether it is implicit or explicit.

Fifty-nine percent of all identified commercial forest land is in nonindustrial private ownership. In this ownership class over 32 percent of the area is in Site III land and better. This represents over 19 percent of all U.S. commercial forest land and over 57 percent of the national pool of Site III and better forest land. Little is known about the utilization objectives of these owners. Some clearly own the land for speculative purposes. Others own the land for use as private parks for personal recreation. Some will sell timber from these lands when the price is high or when they have a need to liquidate personal capital. Others own and manage the land for the production of timber but the incentive for such owners to engage in any forest practice other than harvesting and in some cases legally required post-harvest regeneration is very low. Government could change these incentives through the use of its taxing, zoning, and regulatory powers, but these are policy issues outside of the scope of this study. It is essential, however, to consider the potential use of these lands in any serious assessment of materials supply. At a minimum some research effort ought to be devoted to an analysis of nonindustrial forest land in terms of ownership objectives with particular reference to materials supply and to incentives and restrictions that influence such objectives. Given the nature of these ownerships, it is highly unlikely that the owners will engage in much materials research. If it is to be national policy to encourage any significant fraction of nonindustrial forest owners to function effectively in the materials supply base, the research fundamental to such a policy will need to be government supported.

Many forest products are used in a manner that does not encourage materials conservation. Dimensions and tolerances were established for the most part over 50 years ago when basic materials values were low and when raw material supply was plentiful. These standards have become established in custom and marketing practice. They are included in countless government specifications and commercial standards. They are reflected in thousands of building codes. Since the forest products industry is made up of thousands of independent producers and since its standards have been highly institutionalized, they have remained essentially unchanged since they were first developed. Under the restrictions of building codes, wood used in structural design usually trades large factors of safety and a low level of industry-wide quality control for materials conservation. The prospective early change from English to metric units of measurement will require that the standards and codes be modified in any case. This provides an excellent opportunity to make other changes in the cumbersome standards sector that could reflect improved design and manufacturing technology which would result in significant materials conservation provided that the necessary backup research has been accomplished.

The opportunities to increase the production and use of renewable materials in the U.S. are many. It is a social and political decision whether it should be national policy to exploit these opportunities. If the nation is to maintain an option to exploit these opportunities, it will need to develop an appropriate base of research and a supply of technically educated human talent it does not now have.

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