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World Developments in Increased Forest Resources for the Pulp and Paper Industry

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RESUMÉ

The present report reviews major trends in utilization of world forest resources for conversion to fiber products: pulp, paper, paperboard, composition board and fibreboard. Trends are reviewed from 1930 to the present and cover anticipated extension of these trends to the year 2000.

World production of wood-fiber products tripled from 1940 to 1970, and is expected to triple again by 2000, reaching a demand level of something more than 400 million metric tons for paper and paperboard alone. Since 1930, the increase in wood-fiber production has been accompanied by:

- the development of new pulping processes (refiner groundwood, neutral sulfite semichemical, cold soda, chemi-mechanical);
- the utilization of an increasing number of wood species (southern pines, *Pinus radiata*, the eucalypts, hardwoods generally);
- the utilization of material once considered waste (sawmill residues, plywood wastes);
- a closer utilization of forest resources (smaller trees, decreased top diameter, use of thinnings, weed trees, cull logs).

In spite of the work which has gone forward in the past to protect and sustain the world's forests, there is a great and growing need on a world-wide basis for increased afforestation:

- for industrial plantations;
- for reclamation of spoil banks and swamps, for shelter belts and avalanche or erosion control, for riverine protection;
- for reclamation of deserts and sub-marginal lands and to prevent their catastrophic spread.

Over the next 30 years, the raw material for wood-fiber products will be augmented by:

- exploitation of all available coniferous forests;
- an increase in the use of plantation wood from its present 1-2% to 4-5% of the pulpwood supply;
- a much closer utilization of forest resources everywhere;
- the use of practically all materials "wasted" from logging or wood processing;
- an increasing application of the complete-tree utilization concept, that is, use of tree components other than boles for pulping.

The following trends are expected to dominate in fiber use and conversion:

- a major increase in the consumption of composition board and fibreboard;
- a decrease in the production of sulfite pulp from 25% of total pulp to 10% or less;

- an increase in the production of conventional or modified kraft pulp to 50% or more of the total;
- a relatively constant production of neutral sulphite semichemical and dissolving-grade pulps at 5% of total production each;
- an increase in mechanical pulp production from 20% to 30% of the total; processing will include conventional grinding, disc refining of a variety of raw materials, with some chemical pretreatment. An increasing amount of pulp will be produced from hardwoods in the 85-90% range, with chemical pretreatment followed by disc refining and brightening or bleaching;
- an increasing number of bleaching reagents available for use on an industrial scale.

1. INTRODUCTION

One commanding reason exists for continuing world-wide interest in the development of forest resources for the pulp and paper industry; fiber products, in the form of pulp, paper, paperboard and fibreboard, currently represent more than 40 percent of the total value of wood products consumed (68). It is estimated that by 1975 the percent will exceed 50 and the primary sales value will approach 60 billion dollars.

World production of wood fiber products has tripled over the past 30 years, and will more than triple again by the year 2000. The primary objective of forest utilization for the manufacture of fiber products is production of an optimum yield of saleable products per year from forested or forestable land. This yield can be increased by:

- utilization of wood species not presently used;
- utilization of small diameter trees;
- harvesting on a short rotation cycle;
- close utilization of forest resources;
- increased forest area of plantations;
- conversion of processing wastes from sawmills, veneer plants, and wood-working plants generally;
- utilization of parts of trees not presently used, as tops, branches, and root-stump systems;
- raising yields of pulp across the digesters;
- manufacture of stronger pulps, so that the basis weight of a given product can be reduced, or higher yield pulps can be used for a given product at the same basis weight.

The present review deals directly or indirectly with these various possibilities for increasing the dimensions of the raw material base for the pulp and paper industry, and covers changing patterns in the use of forests as a raw material for pulp manufacture. The technical literature reviewed falls into broad categories: research studies aimed at increased forests and their utilization, and reduction to practice of research results. The changes indicated in Table I for pulp production from 1937 to 1967 are reflected in the technical literature of the period, and indicate the general pattern of change in forest utilization which can be expected in the following 30-year period, from 1970 to the year 2000 (see Section 10).

The technical literature relating to the preparation of wood fiber for paper, paperboard and fibreboard is vast, bewilderingly complex, and suffers from a lack of consistency in evaluative procedures and methods of reporting. In the following section, only those studies or reviews are included which cover a number of wood species, or which are considered to have broad implications for present or future forest utilization.

One of the most extensive reviews of pulping published to date has been prepared by Rydholm (436) in his comprehensive book Pulping Processes. World production of pulp and paper has been summarized from time to time by the United Nations'F.A.O. (20, 24), and a recent F.A.O. publication gives a detailed analysis of world needs for all major wood products to 1975 (68). Regression analyses have been used for the projection of trends in demand for paper and paperboard in the United States to 1985 (28). Present world production of fibreboard, and future demand, have been reviewed (28, 47). Pulp and paper production requirements and prospects for Latin America (25), Asia (35, 37), Africa and the Near East (62), and the long-term pulp needs for South Africa (310) have

TABLE I

WORLD PRODUCTION OF VARIOUS TYPES OF WOOD PULP: 1937, 1967 AND 1960[a]

	North America (75)		Western Europe (75)		Asia, Africa and Pacific (75)		Latin America (75)		U.S.S.R. (75)		World Production (436)
YEAR	1937	1967	1937	1967	1937	1967	1937	1967	1937	1967	1960
otal Pulp Production in millions of short tons, air-dry weight)	11.8	51.3	12.1	24.2	1.0	8.6	Negligible	1.7	0.9	6.1	65.3
ulp Types as a percentage of total wood pulp production)									55.6[c]	72.1[c]	
Kraft[b]	21.2	54.3	16.5	34.0	10.0	48.9		41.1			36.0
Sulfite[b]	25.5	10.7	41.3	22.7	40.0	5.8		11.8			22.0
Soda	4.2	0.4	-	-	-	1.2		5.9			1.0
Dissolving grade	4.2	3.7	5.0	5.8	10.0	9.3		5.9			6.0
Semichemical	0.8	6.8	-	4.1	-	5.8		5.9			4.0
Mechanical	42.4	21.4	36.4	28.9	40.0	26.7		23.5	44.4	27.9	25.0
Defibrated & exploded	1.7	2.7	0.8	4.5	-	2.3		5.9			6.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0		100.0	100.0	100.0	100.0

(a) The values shown represent more than 95% of total world production of wood pulp.

(b) Not including dissolving grade pulp.

(c) Total chemical pulp.

been examined in various studies. Prospects for the pulp and paper industry of western Europe (480), and the ability of this area to meet its wood requirements, have been studied (60). The present and future use of hardwoods in Europe, Japan and North America have been reviewed by Volkov (503).

At an international meeting in Geneva, the future pulp and paper prospects for India, the Sudan and Mexico were considered in depth (35). The raw material base for the future pulp and paper industry of the Soviet Union has been examined in terms of forest resources, logging, the forest-industrial regions of the U.S.S.R. (278) and the economics of fiber use (193). Two reviews dealing with the pulping field have been published in *Forestry Abstracts:* The Paper Making Materials of the British Empire (213), and Pulp and Pulping in Notes on Progress in Forest Science, Part II (52). A number of papers relating to the development of new pulp fiber sources in various parts of the world were presented at the Fifth World Forestry Congress held in 1960 in Seattle, Washington (42).

Bibliographies have been compiled on pulping research in the United States (11, 34, 59). Some of the reviews in the field cover a wide range of raw materials, such as an examination of 208 monocotyledonous and dicotyledonous species as possible sources of pulp fiber in the southeastern and western United States (379). Summaries have been prepared on the application of the conventional pulping processes to wood species of the northeastern and Great Lakes areas of the United States (352, 448), on the neutral sulfite semichemical (NSSC) pulping characteristics of 29 hardwoods and 10 softwoods (144), and on the preparation of kraft and sulfite pulps from 17 North American softwoods and 53 hardwoods (58). Various pulping processes were applied to southern hardwoods and softwoods for the preparation of insulating boards, hardboards, and high-yield pulps (194). Pulping characteristics have been determined for wood species from a number of North

American regions, including the Rocky Mountain area (497), Pacific Coast (243), Inland Empire (369), southern United States (142, 449), and Alaska (48).

Extensive pulping research at Dehra Dun, India, over the past 50 years has been summarized (1, 105, 468). Pulping studies covering hundreds of Asian wood species have been carried out in Japan; a bibliography listing over 400 of these studies, dating from 1925 to 1956, has been prepared (286). The fiber geometry of 135 wood species from the Congo has been summarized (137, 259). Based on a microscopic examination of 400 wood species from the Congo, some 100 were considered to be suitable for conversion to pulp (1). One review of South American forests covers the pulping characteristics of major species (438), and another gives an analysis of the pulping characteristics of 109 species (149). Pulping research has been carried out on material from the forests of Argentina (493, 494), Taiwan (465), Indonesia (90), and Portugal (457).

2. AFFORESTATION

(a) General -- Many countries are carrying out programs in afforestation, some on a massive scale, and reports on these programs number into the thousands. Some concept of the magnitude of the world problem can be gained from needs for afforestation in the Soviet Union (499). Based on a review of long-range forest needs of the U.S.S.R., and on the assumption that the degree of forest cover should range from 5 to 10 percent in the treeless areas to 40 to 50 percent in the densely forested areas, it is estimated that realization of this degree of forest cover would involve afforestation of some 120 million hectares, which is approximately the total forested area of Europe excluding the U.S.S.R.. The present rate of forest plantation in the Soviet Union is approximately 1.2 million hectares per year (381).

The literature of afforestation includes historical reviews for a number of countries. In **Reclaiming Derelict Land** (391), Oxenham discusses afforestation of derelict lands in terms of methods, species and costs. An account of afforestation in Pennsylvania alone (172) describes 198 separate forest plots. Reports have been prepared on afforestation in Spain since 1940 (283), in Portugal over the centuries (176), in Denmark since 1788 (267), in Belgium since 1906 (177), in the Karst region since 1842 (498), and in Rumania since 1950 (495). A German publication covers plantations on railway embankments, rubbish heaps, slag dumps, and spoil lands generally (232). The 1951, No. 21 issue of the *Journal of the South African Forestry Association* was devoted entirely to afforestation in southern Africa (290).

Success in afforestation has varied widely, from the high level of success with *Pinus radiata* in Australia-New Zealand (354) to the very limited success with various maquis, gaugue, chapparal, and savannah areas (225).

(b) Industrial Plantations -- Industrial plantations have a long history, going back to 1844 for teak plantations in India, and to origins lost in the mists of time in Java (506). A substantial part of the forest-products industries in a number of regions (Table II) are based on plantation wood.

Plantations for industrial use have been considered for the recovery of destroyed forest land in Greece (155), sub-marginal lands and landslide protection in Switzerland (132) and for degraded, derelict lands and erosion protection in Czechoslovakia (53, 320, 442). In Ceylon, planting of some 37 tree species has been investigated for the development of forest industries generally (413) and for the pulp and paper industry specifically (257). Afforestation of poor soils in arid regions of the Negev in Israel (271) and in Java (108) have been reported. In Israel, plantations are planned for sand-dune stabilization, shelterbelts, and a balanced forest-products industry (441).

TABLE II

FOREST PLANTATIONS IN SELECTED REGIONS OR COUNTRIES

Region or country	Approx. area of plantations in 1000s of ha.[a]	Principal wood, genus or species	Reference
China	30,000-60,000	*Pinus, Larix, Populus, Eucalyptus*	(68)
United States	11,000-12,000	*Pinus, Picea, Larix, Populus,* etc.	(8, 128, 236, 408)
U.S.S.R.	11,000	*Pinus, Picea, Larix, Populus,* etc.	(317, 499)
Japan	7,000-8,000	*Pinus, Larix, Cryptomeria*	(70, 486)
South Africa	1,600	*Pinus, Eucalyptus*	(109, 140, 179, 189, 268)
Indonesia	1,200	*Pinus, Tectona, Acacia*	(68, 108)
Australia New Zealand	1,000	*Pinus, Pseudotsuga menziesii*	(13, 284, 389, 411, 512, 354)
Southern Europe	700	*Pinus, Populus, Eucalyptus*	(49, 68, 166, 283, 103, 223)
Brazil	700	*Pinus, Populus, Eucalyptus*	(10, 358)
Chile	500	*Pinus, Populus, Eucalyptus*	(68)

(a) Based on 68.

Pulpwood is recovered or planned from plantations in Morocco (228), India (63), Argentina (27, 502), and the Congo (399). A detailed feasibility study has been made of the possibility of producing pulp and paper from the 160,000 acres of *Chamaecyparis* and *Pinus* plantations in Kenya (471). In Venezuela, exotic conifers are being introduced in the Andes for additional pulpwood supplies (307) and, in Spain, plantations of *Eucalyptus* and *Pinus* are providing fiber for two pulp mills (49, 481). Of the Brazilian plantations of *Araucaria angustifolia, Eucalyptus, Populus* and *Salix* spp., only 5 percent are presently used in pulp manufacture (357). The danger inherent in extrapolating plantation experience from one region to another is indicated by the fact that *Pinus insignis,* which proved so successful in Chile, has given almost completely negative results in Brazil and Argentina (438).

(c) Reclamation of Desert and Submarginal Lands -- Much of the afforestation work in various regions of the world has been directed at the recovery of desert, arid, or semi-arid lands. The problem of existing and spreading desert is a serious one in large areas of Asia and Africa, and by some is thought to be growing increasingly serious (106, 164, 88, 97) with increasingly heavy population pressures. A combination of centuries of shifting agriculture on a large scale, indiscriminate grazing of already impoverished land, ruthless exploitation of forest and field, with some help from fire, disease and insects, have degraded large areas of Africa and Asia to the point where wind and water could complete the conversion of potentially or once fertile lands to desert. This type of land use and misuse has destroyed perhaps as much as 50 percent of the original forest cover of the world. It has been suggested (106) that in some areas it will be necessary to control sand drift in order to reduce nomadism, or people drift, which is in itself a major factor in the creation of new deserts. The picture is a particularly bleak one in parts of Africa, where it is reported that lake levels are falling, rivers are drying up, springs are disappearing, water tables are falling, and deserts are spreading (164). Much afforestation work appears to be haphazard and Dawkins (175) makes a strong plea for a world-wide forestry policy.

Studies on sand-dune fixation by means of afforestation have been reported for the sand hills of New Zealand (54), drifting dunes of Korea (312), coastal dunes of the Mediterranean and the Black Sea regions (86) and sand dunes of Anatolia (87). Tree planting has been used for stabilization of sandy soils in Uruguay (134), China (321) and Spain (94, 364). In Tunisia, the use of an oil spray has proven particularly effective in planting coastal dunes (6). Successful planting developments include deep plowing and intensive profiling, with ridge heights up to 70 cm. in steppe afforestation, and the use of large plants, up to one meter high and with approximately half the plant above ground, in sand dune fixation (225), and the use of perforated polyethylene planters (361). *Pinus sylvestris* and *P. nigra* have been recommended for afforestation of the continental sands of Rumania (200) and various *Populus* species for submarginal land in Poland (300). A special issue (46a) of *Revue forestière francaise* was devoted to the fixation and afforestation of sand dunes in France, Morocco and Tunisia.

The problem of developing techniques for recovery of deserts and near deserts is world wide. In Argentina, for example, it is estimated that 75 percent of the total land is arid or semi-arid (203). The dimensions of the problem of desert recovery in the Soviet Union are indicated in a number of publications: by Leont'ev in his book The Sandy Deserts of Soviet Central Asia and Their Reclamation by Forests (317), by Buchholz and Maydell in a long review Afforestation in the Arid Regions of the Soviet Union (130), in a detailed report on Russian experience since 1841 in the Kara-Kum desert (249), in a report on the use of numerous exotic species in Kazakhstan (92), and in a section of Tseplyaev's monumental work The Forests of the U.S.S.R. (499). In an extensive review on afforestation in Kazakhstan (464), it was stated that 700 species of trees and shrubs have been introduced into the Kazakhstan S.S.R. and 1200 could be used effectively. Some 250 species have been found suitable for various arid regions in India (89).

(d) Shelterbelts -- The use of shelterbelts, particularly on prairie or steppe lands, has been reviewed in *Forestry Abstracts*, in Notes on Progress in Forest Science (66). Logginov (327) has described the use of shelterbelts in the steppe and forest-steppe regions of the U.S.S.R., and E.J. George has compiled a bibliography of world literature to 1960 on the effect of shelterbelts on crop yields (219). Reviews have been published on shelterbelt erosion control in Japan (374), the Ukraine (285), Korea (463) and Bulgaria (282). It is a commentary on the magnitude of the general problem of soil erosion and its prevention that some 300 species have been tried over a 100-year period in the Kuibyshev region of the Soviet Union (380).

(e) River Bank Protection -- The protection of river banks by afforestation has received widespread study, as in Spain (365), Rumania (161) and the Ukraine (224). The use of *Populus* plantations along water courses, frequently combined with intercropping as in Italy (225), can yield as many as 40 cubic meters of wood per hectare per year. In the Soviet Union, somewhat more than a million hectares of the Upper Don riverine are in need of protective cover (214). Large-scale studies have been made on plantation of the floodplains of the Volga-Don (496), the Middle Don (504) and the Chir rivers (337). Along the sandy terrain of the Don, some 90 years of afforestation, chiefly with *Pinus sylvestris*, have achieved little in the way of success (188), indicating the extremely long-range nature of afforestation studies.

(f) Spoil Banks -- A great deal of attention has been given, and in increasing amounts, to provision of cover for spoil banks from strip mining, slag heaps, power-station spoil banks, and industrial spoil lands generally. Space permits mention of only a few of these extensive and widespread studies. Major reviews on the subject include a general review by Funk (212), survey of the literature by Limstrom (323) and summary of studies in the United States, Denmark, Czechoslovakia and Germany (295, 296).

Crowl (170) lists 23 states in which strip mining is practiced, yielding 25 percent of the coal produced in the United States. He estimates that 95 percent of the stripped land (representing less than one percent of the total land in the states concerned) will ultimately be restored to productive use, some of the plantations yielding pulpwood in 20 to 30 years.

The importance of these studies can scarcely be overemphasized, dealing as they do with land contamination and spoilation, the elimination of unsightly wasteland (43) and, in time, the conversion of ugly and sometimes dangerous spoil mounds to parks and a source of additional wood fiber.

(g) Miscellaneous Studies -- In addition to the recovery of deserts, river bank protection, provision for shelterbelts, and reclamation of industrial wastelands, plantation programs have been carried out for a number of miscellaneous purposes. These studies include the extension of forests northward (385a); introduction of high-value wood species, such as teak, into India and Burma (506); as part of malaria control (478), in sea reclamation (246) and as part of avalanche control in Germany (452).

The economics of flood, avalanche and soil-erosion control in Australia have been analyzed (238). Soil-erosion control by means of plantations has been practiced in Spain, where erosion is particularly severe on Mediterranean slopes (444), in Japan (386) and in the Himalayas (270).

One of the major objectives of long-range afforestation is swampland reclamation. Some 300,000 hectares of worked-out peatlands and 1,200,000 hectares of peat bogs under exploitation in the Soviet Union are to be afforested (499). Of even greater long-range importance to the economy of the U.S.S.R. is the recovery of swampland, which constitutes some 12 percent (or 37 million hectares) of the area within the Forest Reserves (499).

3. INCREASED USE OF SOFTWOODS IN PULPING

Over the past 30 years there has been appreciably less research on the pulping characteristics of softwoods than of hardwoods. This difference arises from the smaller number of softwood species; the fact that many softwoods (*Pinus, Picea, Tsuga, Abies* species) have been used for many decades on a world-wide basis for pulp production and, in consequence, their pulping characteristics by the conventional pulping processes are well known. Definitive reviews have been published on a few coniferous species, including *Pinus contorta* var. *latifolia* (196) and *Larix sibirica* (61). It is understandable that a major research effort would be made on *Larix sibirica,* since the forest reserves of this species are estimated to be 30 billion cubic meters (499), approximately equal to the total forest reserves of North America. A number of disadvantages have to be overcome before it will come into large-scale industrial application.

Pulping research has been extensive on those conifers which are plentiful in supply, but which have not been widely used in pulping practice because of specific characteristics which render them unsuitable for one or more of the conventional pulping processes. *Pseudotsuga menziesii*, for example, is one of the major wood species in western North America, but it has not been a suitable species for conversion to pulp by the mechanical or sulfite processes, and a number of investigations have been directed at extending the use of this species as a raw material for pulp manufacture. Research has included pulping by a variety of processes, including conventional calcium-base (122), ammonia-base (443) and soluble-base sulfite (102, 234).

Thuja plicata, once considered undesirable as a pulping species because of high extractives content and low specific gravity, resulting in a low yield across the digesters (514), has proved capable of yielding a high-quality kraft pulp (372). *Pinus banksiana*, which does not pulp satisfactorily by the conventional calcium-base process, can be pulped readily by the ammonia or soluble-base sulfite process (475). In a recent study (392), the pulping characteristics of *Pinus caribaea* from Fiji were reported. Investigations have also been carried out on the pulping potential of *Podocarpus parlatorei* native to Argentina (303).

The single most important development over the past 30 years in extending the use of conifers has been in the development of processing suitable for the conversion of U.S. southern pines into market pulps, papers and paperboard. In 1938 it was questioned whether southern pines could give a newsprint which would be competitive with Canadian newsprint (210). The first newsprint mill utilizing southern pines (23) started in 1940 and, it is estimated, in the near future the southern United States will be self-sufficient in all types of paper, including newsprint. Similarly, industrial processing has been developed for the use of exotic *Pinus radiata* in Australia and New Zealand (18) and in South America (68).

4. INCREASED USE OF HARDWOODS IN PULPING

It is not possible in brief compass to review more than cursorily the mass of research on the utilization of hardwoods in the pulp and paper industry.

In the period under review, studies have been made on the quality of various types of pulp prepared from thousands of hardwood species and species mixtures by conventional, modified and new pulping processes. Only the more important of these studies have been included in the present review, where importance is considered in terms of present or potential contributions to pulping practice.

A few hardwood species, including *Fagus sylvatica* (67) and *Populus tremuloides* (see end of this section) have been reviewed in depth. The Third International Fundamental Research Symposium, held in Montreal in 1958 (29), covered the availability and distribution, fiber morphology, and genetic improvement of hardwoods, and the characteristics of N.S.S.C. pulps prepared from them. Table III lists selected pulping studies relating to hardwoods from various regions.

The largest forest reserves in the world, those in South America (438), have an extremely low coefficient of use. A number of formidable problems, both technical and economic, must be overcome before these vast forest reserves come into widespread use as a raw material for pulp manufacture. One of the most serious problems arises from the number of species making up the South American forests. In Amazonia, for example, it is estimated that the forests contain at least 2,500 species (515), including more than 170 major species (433). The problems of utilizing South American hardwoods has been discussed in detail by Rys (437, 438). There are more than 700 million hectares of hardwoods in South America, and the number of species may be as many as 100 on a single hectare. Rys examined 126 wood species from the Parana region, and found an extreme range in extractives, bark content, chemical composition, fiber geometry and pulp strengths. Difficulties in the development of tropical forests generally (305, 341) include lack of markets and integrated or efficient utilization (215),

TABLE III

SELECTED STUDIES RELATING TO THE PULPING OF HARDWOODS

Study or Review	Hardwoods	References
Present and future of hardwood pulps	General	(445, 482)
Pulping studies	Tropical Am. sp.	(508)
Relationship between fiber characteristics and pulp-sheet properties	15 U.S. and tropical Am. hardwoods	(485)
Mechanical pulp for book, magazine and newsprint papers	7 American sp.	(449)
N.S.S.C., sulfate, and semichemical pulps	9 American sp.	(111)
Use of hardwoods since early 20th century	Am. sp., gen.	(113, 263)
Strength of bleached kraft pulps	11 southern U.S. sp.	(333)
Pulps for conversion to stable papers	Hardwoods, general	(420)
Use hardwoods for increased pulpwood needs	Hardwoods, general	(347)
Hardwoods pulping in Sweden, Germany, and the United States	Eastern U.S. sp.	(12)
Suitability conventional pulping processes	N.E. U.S. sp.	(348, 401, 419)
Sources, availability and procurement of hardwoods, and pulping processes	N.E. U.S. sp.	(22)
Kraft, high-yield kraft, and N.S.S.C. pulps	4 Connecticut sp.	(79)
Hardwoods in mechanical pulp manufacture	North American sp.	(145, 331)
High-yield sulfite, semichemical pulps	7 southern U.S. sp.	(114)
Sulfite pulp quality	Southern U.S. sp.	(350)
Kraft pulp for linerboard	Southern U.S. sp.	(338)
Increased use of hardwoods	Southern U.S. sp.	(345)
Properties of kraft pulps	59 southern U.S. sp.	(209)
Mixtures of hardwoods and softwoods in mechanical pulp for newsprint	Mixed southern U.S. hardwoods, *Pinus* sp.	(450)
Pulping characteristics of hardwoods, gen.	Various sp., France	(421, 440, 488, 501)
Pulping characteristics of hardwoods, gen.	Various sp., Africa	(151, 211, 398, 430, 431)
Pulping characteristics of hardwoods, gen.	Various sp., Gr. Britain	(425)
Pulping characteristics of hardwoods, gen.	Various sp., Sweden	(235)
Pulping characteristics of hardwoods, gen.	Various sp., Hungary	(315, 316)
Pulping characteristics of hardwoods, gen.	Various sp., Portugal	(456, 457)
Pulping characteristics of hardwoods, gen.	Various sp., Mozambique	(384)
Pulping characteristics of hardwoods, gen.	Various sp., Equatorial West Africa	(360)
Studies on pulping characteristics	Nigerian sp.	(169)
Pulping characteristics	100 Congo sp.	(136, 260, 261, 400)

variable land tenure (226) and high cost of forest management (98). Reports on South American woods cover general reviews on 100 species (538), pulping of woods from Chile (467) and Mexico (256), pulping characteristics of 48 and 125 species from Venezuela (426, 427), of 31 species from Colombia (100, 150, 424) and of various woods from British Honduras (38, 153), Argentina (500), and the Yucatan Peninsula (247).

Some concept of the complexities involved in pulping tropical hardwoods is shown in investigations undertaken on Philippine hardwoods, which include pulping research on 141 species (45), on 10 commercial hardwoods (362), on 192 hardwood species (484), and on 250 hardwoods and 10 softwoods (363).

The *Eucalyptus* of Australia and New Zealand are unique in that, despite the large number of species, pulping methods have been developed for the utilization of many of them, and a substantial industry has been built up around their use. Numerous individual studies have been made on the pulping characteristics of Australian or New Zealand *Eucalyptus* (65, 109, 129, 173, 313, 439, 487, 509). An excellent review has been prepared on the prospects for kraft, soda, cold soda, and mechanical pulps from Australian *Eucalyptus* (482). Research has involved theoretical studies, as well as the practical aspects of developing a pulping technology for *Eucalyptus*.

The pulping characteristics of Asian hardwoods have been reported for hardwoods from Borneo (359), Indonesia (91, 373), New Guinea (404), 51 species from Thailand (410, 462), 21 species from Taiwan (141), and various species from Malaya (393, 394). Multiple hundreds of pulping research studies have been carried out during the period under review on the application of conventional pulping processes to individual wood species. Space does not permit review of all of this work, but many individual investigations could be quite important.

For example, a number of investigations have been made on the properties of pulps from mangrove species (298, 431) and rubber wood (394, 395); the Japanese pulp and paper industry is now importing these woods in order to supplement its pulpwood supply.

Populus generally, and *Populus tremuloides* in particular, fall in a special category of hardwoods by virtue of the attention they have received. *Populus* sp. are widely distributed throughout the world, grow rapidly, give a high yield per hectare, and are extensively used for a wide range of end products. They are unique in the amount of research devoted to their growth, composition, conversion and use; there have been more publications relating to *Populus* than to any other genus and more to *P. tremuloides* than to any other wood species during the period under review. The literature on *P. tremuloides* (aspen) as a source of pulp fiber is so extensive that only the more comprehensive bibliographies will be mentioned, such as those on the constitution and pulping of aspen and poplar wood (124, 429); the characteristics, properties and uses of *P. tremuloides* (306); biology, silviculture, harvesting, protection, mensuration and utilization of *P. tremuloides* (466); on *Populus* sp., with emphasis on *P. tremuloides* (412), and on the growth and utilization of *Populus* in Canada (336).

It is of interest that, in spite of the vast amount of research work done on the pulping of *P. tremuloides* and related *P. tremula* of northern Europe, no satisfactory method has been developed for utilization of the massive reserves of low-quality *Populus* distributed throughout the northern hemisphere, particularly in Canada. The poplars, thus, come in the same general category as tropical hardwoods, of which the same can be said but for somewhat different reasons.

5. INCREASED USE BY NEW PULPING PROCESSES

(a) Neutral Sulfite Semichemical Pulping -- The following brief commentary on new pulping processes has been included in the present review because the development of these processes has been critically important to expanded use of the world's forest resources.

One of the major developments in the utilization of hardwoods for pulping has been the neutral sulfite semichemical (N.S.S.C) process developed by the U.S. Forest Products Laboratory in Madison, Wisconsin (171), and in use since 1926 (112). The development of this process has had a major, world-wide influence on increased utilization of hardwoods (40); N.S.S.C. pulping has shown the highest percentage increase in production since 1940 of any type of pulp. A large number of installations have been built throughout the world to use this process, including mills in Canada (204), United States (158), United Kingdom (180) and Tasmania (371), to name only a few. The process is used in all countries with a pulp and paper industry of any significant magnitude.

The process has been found to be highly suitable for the conversion of hardwoods to pulps which can be processed to a wide variety of papers (367, 397), particularly to corrugating medium for combined board. As a consequence, and because of its widespread use, the N.S.S.C. process is now a conventional pulping process, joining the older soda, sulfite, kraft, and mechanical pulping processes. It has been applied to a wide variety of wood species, as in Hungary (314), Rumania (272), United States (143, 202, 334, 414) and British Honduras (33), to some 40 wood species in the Belgian Congo (366), to many wood species in Japan (522) and Tanganyika (57), and to wood species in a number of countries which have extensive hardwood resources -- Australia (407), Malaya (396) and the Philippines (4).

Not all efforts to obtain usable pulps from various hardwoods by the N.S.S.C. process have been successful, as shown by studies on wood species from Nigeria (162, 163, 168).

(b) Chemigroundwood -- In the chemigroundwood process, developed at Syracuse, New York (17, 322), grinder blocks are impregnated with a mixture of sodium sulfite and sodium carbonate and then ground conventionally. The process has been used commercially in a large American newsprint mill (178) and in the Soviet Union (273, 274); it was first used in Europe at Corbeham, France, and in Asia at the Khulna newsprint mill in East Pakistan (482). The process has been tested on *Populus* sp. in Germany (119), on a number of wood species from New Guinea (405), and in pilot-plant studies in Czechoslovakia (469). The G.I.B. process, developed in Australia, involves impregnation of grinder blocks with sodium hydroxide and is reported to give a high quality groundwood (198). In the A.L.B.-Semicell process, developed in Austria (239), hardwood grinder blocks are impregnated with sodium sulfite.

(c) Cold Soda Mechanical Pulp -- The process, developed by the U.S. Forest Products Laboratory in Madison, has found wide application. In this process, chips are impregnated with dilute solutions of sodium hydroxide at low temperature and the impregnated chips are then refined. The advantage of the cold soda process lies in the fact that it gives a stronger refiner groundwood than would otherwise be possible. A number of studies have been made on application of the cold soda process to North American hardwoods (125, 126, 133, 231). By 1960, installations using the cold soda process included mills in the southern United States, Australia and Japan (482).

(d) Refiner Groundwood -- Perhaps the single most important pulping process developed during the past 20 years has been the refiner groundwood process (81, 182, 217, 218, 250, 288, 332). Disc refiners have long been used in refining of screen rejects (491) and high-yield pulps (93, 104, 195, 308) and their use is integral to the cold soda and the N.S.S.C. processes. They are applicable to chips without chemical pretreatment (157, 377, 378) or to impregnated chips (95, 147, 167, 242, 385) in what is sometimes termed the chemi-mechanical process. Refiner groundwood from chips can be appreciably higher in strength than conventional stone groundwood from the same species (157) and permits use of a wide range of materials which do not respond well to the stone groundwood process (217, 250), including crooked trees, short lengths and small-diameter tree components.

The chip groundwood process has expanded rapidly over the past 10 years, from pilot-plant installation in British Columbia and Washington, to partial mill installations, to small mills (69, 71, 72, 73) and finally to large-scale units. The Oji Paper Company in Japan uses up to 50 percent of refiner groundwood from hardwood chips in newsprint furnish (388). One of the new, large newsprint mills in the western United States uses refiner groundwood only, both from chips and from sawdust (293). A recent publication (69) gives the number of operating refiner groundwood mills throughout the world as 32 located in the United States, Canada, Japan, Sweden, Finland, Norway, Korea, Germany, England and New Zealand.

The refiner groundwood process can also be used to convert sawdust or shavings to acceptable newsprint groundwood (293, 461, 476) and a number of mills, particularly in western Canada and the United States, utilize sawdust and shavings for this purpose. The development of a process whereby sawdust and shavings or other mill wastes can be converted to a newsprint grade of groundwood of acceptable strength has massive implications for future complete utilization of forest resources. The disc refiner process, with or without chemical pretreatment of the refiner feed, provides a versatile and powerful tool for the utilization of the world's forests, for the processing of wastes, upgrading low-quality fiber, extending pulping to tree components other than boles, and in general offering promise for a massive extension of world forest resources.

While all of the original studies on refiner groundwood developments were highly empirical in nature, and a great number of unknowns remain to be investigated (157), a fundamental study of the refiner groundwood process has been undertaken in Canada (83, 84, 85).

6. INCREASED UTILIZATION OF FORESTS

There are a number of ways in which the yield of usable fiber from present forest resources can be increased: by the use of thinnings and wood species presently considered scrub or waste, by harvesting on a shorter rotation cycle, and by the use of logging salvage and smallwood. The amount of forest wastes vary from a small percent, with close utilization, to 30 to 50 percent of the volume of mature hardwoods logged (417).

(a) Thinnings -- Publications have dealt with the general aspects of thinnings use, including their conversion to pulp (56), and on the estimated amounts of smallwood and coniferous thinnings available for pulp production (154). The utilization of thinnings was one of the subjects reviewed at the Fifth Forestry Congress (39). In the United States, the use of thinnings and logging wastes has been the subject of a variety of studies, relating to wood species in the Northwest (346), to 23-year-old *Pinus resinosa* (344, 479), to *P. banksiana* for pulpwood (205), to logging wastes and thinnings in the Lake States (252), to *Larix* in New York (159), to *Pinus taeda* for kraft pulp (206, 370), to *Picea mariana* (539) and *Pinus ponderosa* (447). The possibility of going to thinnings management in young *Pseudotsuga menziesii* stands in the Northwest has been discussed (516). The utilization of wood wastes and thinnings has been investigated in Finland (511) and Norway (474). Consideration has been given to the possibility of manufacturing kraft and/or N.S.S.C. pulps from thinnings of three softwood species from Kenya (36) and of softwoods and hardwood in Australia (50, 51, 402) and Chile (355). Thinning practices in New Zealand have been reviewed (46).

(b) Short Rotation Cycle -- The use of short rotation cycle is associated in general with plantations. This fact is indicated by noting those areas where short rotation cycles are in use, or being considered, as in the case of 15- and 25-year-old *Araucaria angustifolia* (292, 437), 13- to 16-year-old *Pinus radiata* thinnings (123), the use of short rotation cycles in South Africa (96), 4-, 6- and 8-year-old *Eucalyptus saligna* (21), 15- to 16-year-old *Pinus patula* (254, 383) and 8-, 13-, 18- and 24-year-old *Pinus elliottii* from Queensland plantations (537). Studies have been made on the quality of kraft pulp from 5- to 15-year-old *Salix* in Germany (264), kraft pulp from 4-year-old *Pinus radiata* in Bolivia (458), pulp from 6-year-old *Eucalyptus saligna* in Brazil (135), kraft from young *Araucaria klinkii* from New Guinea (403, 406), and pulp from 3- to 4-year-old *Gmelina arborea* in Nigeria (152). Canadian research on second-growth plantations includes studies on a 15-year felling cycle for hardwoods (197) and a 30-year cycle for exotic *Picea abies* in Quebec (329).

(c) Salvage Logging -- Low-grade wood is variously defined; in general, it is made up of undesirable wood species, of trees that are crooked, broken, of small diameter or short length, or that are defective because of inherent growth characteristics, decay, insect attack, fire kill, or wind throw. The problem of utilization is always difficult. It is particularly difficult where a total forest area is made up of low-quality wood, and there is no high-quality wood to bear a share of extraction costs (297). Much of the world's forests, in Asia, Africa, South America, central and eastern Canada, and parts of the Soviet Union, fall in this category, and these forests must be used as they are, or not used at all.

Salvage logging has a long history, and is related to closer forest utilization, which in turn results from economic pressures and the need for more pulp fiber. The utilization of logging wastes in the U.S.S.R. has been discussed in detail by Kacelkin in his book *Utilization of Logging Waste*. United States and European practices in salvage logging, and the use of sawmill wastes, have been reviewed by Brown (127). Extensive field trials in British Columbia (121, 330) in 1943-44 set the pattern for closer utilization of forests in that region. A number of studies have been made on the utilization of logging wastes in the western United States (115, 187, 229). Salvage logging is sufficiently widely practiced that there has been concern over the limits of slash retrieval, that is, the danger of leaving too little slash, balanced against the cost of leaving too much, as discussed by Allen (3). Analyses have been made of the character and volume of logging wastes in various parts of Canada (183, 185, 190, 459), of *Eucalyptus* logging wastes in Australia (453) and of forest wastes in Slovenia-Croatia (156). It was estimated that in Norway (294) approximately 65 percent of the recoverable logging waste was not recovered in 1958. In Venezuela (520), manufacture of wood wool and building slabs from hardwood species has been studied; the study indicated that the volume of annual wastes in Venezuelan forests was 384 million (*sic.*) cubic meters per year.

(d) Smallwood -- In a number of countries, field studies have been made on the utilization of smallwood for a variety of pulps and fibreboards. Smallwood is less than 3 to 4 inches in diameter by European use standards (417), but can be larger in other regions, as in British Columbia (330). The use of smallwood continues to be a widespread and serious problem, since costs of extraction, transport and processing are likely to be high, and markets are declining for all uses other than pulping (417)

Research on smallwood use has included the production of wallboards from smallwood and slabs (241), chip groundwood from smallwood and sawmill wastes (289), pulp from low-quality woods in Norway (428), chemigroundwood from pine and birch smallwood in Finland (266), groundwood from woodlot species in the northeastern United States (446), N.S.S.C. pulp from *Carya tomentosa* and *C. glabra* in the United States (351), kraft from small diameter *Pinus elliotti* (353), pulps from various species in the southern United States (220), and kraft pulp from smallwood in Sweden (328). The general use of smallwood for pulp and paper manufacture has been reviewed for the wood species of Germany (451), Poland (44) and Canada (121, 138, 197, 330, 432). The quality characteristics of pulp have been determined for wood from dead standing *Pinus banksiana* (245) and for insect-killed *Pinus contorta* var. *latifolia* (349). The use of coppice for pulp has been reviewed for France (415), Portugal (160) and Europe in general (30).

7. UTILIZATION OF WOOD PROCESSING WASTES

(a) Introduction -- Probably the greatest single advance during the past 30 years in increasing pulp fiber supply beyond the forest has been the recovery of fiber from sawmill, veneer, and plywood plant wastes, involving material not previously utilized (41). It has been estimated (222) that every 1,000 board feet of lumber generates sufficient waste material to give one ton of chemical pulp and that the total sawmill residues in 1960 amounted to 200 million cubic meters (470), representing 75 percent of the world's total wood requirements for pulp. The percent recovery varies widely, from nearly complete utilization of sawmill residues in Norway, to 50 percent in the western United States, to 14 percent for the United States as a whole, to zero for most of Africa, Asia and South America (470).

The use of wastes from wood-processing industries is now well advanced in the southern and western United States (77, 253), Canada (15, 84, 185, 190, 207, 434, 459), Scandinavian countries (291, 470) and Australia. Wood-processing wastes have been examined on a basis of their possible conversion to insulating boards (14, 507) and fibreboard (82, 227, 319, 423, 455). The use of wastes in general has been reported for Great Britain (181), Germany (248), Denmark (32), Italy (139), Switzerland (255), and India (375).

(b) Sawmill Residues -- The greatest single source of recoverable waste fiber for pulp is from the sawmilling industry. The number of sawmills has been estimated at 35,000 in Europe, 41,000 in the U.S.S.R., 36,000 in North America, 19,000 in Latin America and 43,000 in the Asia-Pacific area (68). These mills produce approximately 360 million cubic meters of sawnwood per year. Since without recovery approximately as much wood is wasted as is converted to sawnwood, the total waste without recovery would be of the order of 300 million cubic meters annually, equivalent to more than 50 million tons of chemical pulp. Sawmill residues obviously offer a vast source of raw material for pulp and their sale can have a marked effect on the economics of sawmilling (77, 207). The potential return from the use of sawmill residues is of the order of billions of dollars, providing economic incentive for the numerous studies that have been carried out on the pulping of this material, and on the development of processes, plant, and equipment for its use. A number of broad, general reviews on the utilization of sawmill residues have been published, including a review by *Forestry Abstracts* (240), The Utilization of Sawdust and Wood Chips. Data have been compiled on the amounts of sawmill residues available (77, 190, 253). The amounts of sawmill wastes available have been reported for New England (80), the Maritime Provinces of Canada (459), southern coastal regions of British Columbia (233) and for various wood species of eastern Canada (99, 190). Reviews have been prepared on conversion of sawmill residues to wallboard (16, 186), hardboard (165, 422), chemical pulps from a number of woods of the southern United States (519) and to viscose pulp from *Liquidambar styraciflua* and *Pinus taeda* (309). The pulping potential of sawmill residues has been determined for various pulping processes, including kraft (518) and cold soda (230), results of which indicated that sawdust from hardwood compares favorably with chips for the production of high-quality corrugating medium and refiner groundwood for newsprint (460). Within the past 30 years, the use of sawmill chips has become standard practice and a large part of the world's pulp is manufactured from material that formerly was wasted.

In another major development, techniques have been devised for the use of disc refiners for the conversion of sawdust and shavings to groundwood for newsprint manufacture [see section 5(d)]. It is of interest that in a review made in 1941 on the use of sawdust (9), its potential use for pulp was not mentioned and, in a later review (434), it was stated that sawdust could not be used for pulp manufacture. Through research and the development of pulping equipment and centrifugal cleaners, as well as techniques and processing, large amounts of sawdust, totalling perhaps several thousand tons a day, are now used in groundwood manufacture, or in the manufacture of chemical pulp (55, 107, 521). The first mill installation using sawdust for chemical pulping was started up in 1953 at the Potlatch Forests Inc. mill in Idaho (325). The amount of sawdust and shavings available from sawmilling operations is highly variable; one estimate quotes 18% for a western United States sawmill (253).

(c) Veneer Plant Wastes -- Considerable success has been achieved in converting veneer wastes to pulp. These wastes are not as extensive as sawmill residues, but they are still substantial. In the United States, for example, it has been estimated that more than 25 million board feet of logs per year are saved by the use of veneer waste chips for pulping (244). Publications in the field include reviews on pulp from veneer wastes in Japan (490), the use of birch veneer wastes in Finland (265), the maufacture of wallboard and kraft pulps from veneer plant wastes in the United States (19, 199, 324) and, in Australia, the conversion of *Araucaria klinkii* veneer wastes and bolt cores to sulfate pulps (26, 403).

8. USE OF TREE COMPONENTS OTHER THAN BOLES

Traditionally, the bark-free tree bole has served as sole source of pulp fiber; the stump-root system has remained in the ground, foliage, branches and unmerchantable tops have been left in the forest as slash, and bark has been burned at the mill or otherwise disposed of. There is usable fiber in tree components other than boles, and increasing effort is being made to determine what part of this fiber can be recovered economically.

(a) Foliage -- A great deal of research has been carried out on the extraction of vitamins, cattle fodder supplement, and a variety of pharmaceutical mixtures from foliage (492). One reference concerns the use of foliage of *Pinus pinaster* for insulating fiber (208), but in general research on foliage does not come within the context of the present review.

(b) Unmerchantable Top of Boles -- The amount of unmerchantable top left at the felling site is a function of logging practice and, in general, tends to decrease in amount with increasing wood costs and closer forest utilization. Good kraft pulps have been prepared from the tops of U.S. southern *Pinus* sp. (117, 120, 505), *P. banksiana* (146), *Pseudotsuga menziesii* (118), various conifers (262), and *Pinus* sp. of Australia (416). Tops and branches have been used for the production of soda pulp in Japan (523) and of high-yield calcium-base pulps from *Pseudotsuga menziesii* (148, 335), *Picea* species and *Abies balsamea* (287). The economics of using unmerchantable tops has been analyzed for spruce and fir in Germany (5) and Norway (428), and spruce (7) and *Abies amabilis* in the United States (116). In general the unmerchantable top of boles, compared with merchantable boles, tend to give pulps in slightly lower yield and with 10 to 20 percent lower tear strength (275).

(c) Branches -- Specific studies relating to the utilization of branches for fiber have been carried out in those countries which are particularly deficient in forest resources, but which have an established pulp and paper industry. These countries include Czechoslovakia (301, 302), Hungary (311), Yugoslavia (101), Spain (131) and Japan (523). Branches have been used in the U.S.S.R. for the manufacture of building blocks (258, 489) and in Finland for groundwood (510) and kraft pulp (2). Variable results are reported for the quality of pulp from branches, compared with pulp from comparable boles; as a general rule it would be expected to be appreciably lower. Bark removal is likely to be a problem.

(d) Stump-Root System -- Although stumps have long served as a source of naval stores, with recovery of fiber following extraction of chips, little consideration has been given to the use of stumps and roots *per se* as a source of pulp fiber. The most extensive study on the pulping characteristics of stumps has been made on kraft pulp from *Pinus sylvestris* stumps (342) and kraft pulp from the tops, branches and stumps of *Picea excelsa* and *Pinus sylvestris* (2). In both cases, the pulp from stumps was not appreciably different in quality from that of the bole pulp. In the southern United States, pine stumps which had been solvent extracted produced an inferior pulp (299). Studies have been carried out in Germany (251) and Poland (390) on the manufacture of fibreboard from stumps and/or roots. Reported results on the quality of pulp from stumps and roots are highly variable and difficult to interpret. In general, stump-root systems, compared with boles, would be expected to give pulps with somewhat higher tear and lower burst and tensile strengths; pulp strength would depend in large part upon the wood species and method of chipping, and yield would depend upon the extractives content of the stump-root system. Bark removal and chipping are likely to pose formidable problems.

(e) Bark -- Although little success has been achieved in the extraction of usable fiber from bark, a great number of studies have been made on the possibility of using bark as a source of pulp fiber. In one of the first mill trials on the processing of bark as a source of fiber, a wrapper containing a high percent of bark was manufactured on a trial basis in Canada (237). Another possibility of utilizing bark as a source of fiber is to pulp chips prepared from unbarked logs, good results being obtained in the case of N.S.S.C. pulps (435). In the case of southern United States pines (339), however, tolerance in the amounts of bark that could be added to bole pulp was low (8 to 11 percent). Bark has been studied as a source of raw materials for fibreboard (110, 387, 454), but in general the product is not competitive with comparable conventional products. Barks of *Eucalyptus* sp. and *Shorea robusta* have been studied for the manufacture of building board in India (376), and the yield of pulp from wood with up to 25% barks of *Populus* sp., *Carya* sp. and *Pinus caribaea* has been determined (279). *Sequoia* sp. bark has been used for insulating boards (318). It is possible that some wood species, such as *Thuja plicata* or selected *Eucalyptus* species might give bark with a relatively high content of usable fiber. These species would be very much the exception, however, and in general pulp from bark of most wood species,would be extremely low in yield and unusable in quality.

9. COMPLETE-TREE UTILIZATION

The concept of complete-tree utilization (C.T.U.) is closely associated with Professor Young of the University of Maine, who has carried out the most complete studies to date in this field, and who has published a number of articles on the subject (524, 526 to 529, 532 to 535). Table IV gives a list of studies

TABLE IV

COMPLETE-TREE UTILIZATION STUDIES

Species	Pulping Process	Author	Reference
Picea excelsa, Pinus sylvestris (probably)	Sulfate	Alestalo and Hentola	(2)
Thuja occidentalis	Sulfate	Dyer	(191)
Alnus rugosa, Salix babiana, Vaccinium carymbosum	Sulfate	Dyer, Chase and Young	(192)
Pinus palustris	Sulfate	Gleaton and Saydah	(221)
Tsuga heterophylla	--	Kellogg and Keays	(280)
Picea rubens	Ammonia-base sulfite	Kenniston	(281)
Picea rubens	Nitric acid	Kurrle	(304)
Acer rubrum	Sulfate	Martin and Hanson	(340)
Acer rubrum, Betula papyrifera	Sulfate	Michaud and Smith	(356)
Pinus caribaea, Pinus palustris	Sulfate	Sproull, Parker and Belvin	(473)
Picea rubens, Acer rubrum, Abies balsamea, Pinus strobus, Tsuga canadensis, Betula papyrifera, Populus sp.,*Pinus echinata*	Various (review)	Young	(525)
Acer rubrum, Betula papyrifera	Kraft	Young and Chase	(531)
Picea rubens, Acer rubrum, Abies balsamea, Pinus strobus, Tsuga canadensis, Betula papyrifera, Populus sp.	--	Young and Chase	(530)
Picea rubens, Acer rubrum, Abies balsamea, Pinus strobus, Tsuga canadensis, Betula papyrifera, Populus sp.	--	Young, Strand and Altenberger	(536)

which involve determining the amount of fiber available and the quality of pulp produced from the component parts of whole trees.

The concept of C.T.U. is a bold one, with far-reaching consequences to forest practice and to the extraction, transportation, and processing of component parts. In very broad terms, C.T.U. involves conversion and use of total trees: foliage, unmerchantable tops, branches, stumps and roots, as well as boles. Very approximately, C.T.U. could increase the world's fiber supply by 35 percent (5 percent from tops, 10 percent from branches, and 20 percent from root-stump systems). The concept is in embryo stage, and a great many problems including methods of extraction and processing, soil depletion and land erosion, must be solved before C.T.U. reaches a large-scale dimension in use.

Two phases of C.T.U. on which a great deal of research must be done are in determining the amount of material available from various tree components, as a function of species and growing conditions; the type of pulp which can be prepared from each component by conventional, modified or new pulping processes. The present author has put forth a rationale and procedure for determining the amount of fiber available from tree components (277). It is urged that attention be paid to standardization of procedures and methods of reporting the results in all tree-component biomass studies. With respect to information on the amounts of fiber available from component parts, there are no firm data on the amount of oven-dry, bark-free fiber available from any wood species or any tree components as a percent of oven-dry, bark-free boles. There are only scattered and inconsistent data available on pulping quality as a function of pulping process, tree components, tree species, and growth conditions.

The potential return on complete-tree utilization is massive, but so also is the amount of research which remains to be done on all aspects of C.T.U. before increasing amounts of the potential can be realized.

10. SUMMARY AND PROJECTION

A number of studies have been made on future world demands for pulp fiber (31, 64, 68, 76, 236, 326, 513, 472, 477, 517). F.A.O. predicts (68) that the world production of paper and paperboard will be 178 million tons by 1975, against a world production of 119 million tons in 1967 (74); this trend amounts to an annual compounded increase of approximately 5 percent per year. At an average compounded increase of approximately 3 percent per year for the years 1975 to 2000, the total world production of paper and paperboard by the year 2000 would be 375 million tons. The present author using the concept of "critical year" (216), estimated a world production of paper and paperboard in the year 2000 of 310 million tons (excluding fibreboard) at a growth rate of 4% and 400 million metric tons at a growth rate of 5% (276). A more detailed analysis indicates a total world demand for paper and paperboard by the year 2000 of 410 million metric tons per year.

Space does not permit discussion of the various factors relating to future world needs for fiber products, but a reasonably conservative estimate for world demand for pulp (for dissolving grade, paper, paperboard, and a range of fiberboards) is considered to be of the order of 400 to 450 million tons per year by 2000, against 120 million tons for paper and paperboard in 1970 and 40 million tons in 1940. Forests of the world will have to provide something more than 85 percent of the raw material for this production. Based on these anticipated needs, and on trends in forest utilization over the past 30 years, what pattern of **raw fiber** supply and use can be expected over the next 30 years?

(a) The Fiber Source

- All coniferous wood species available in exploitable amounts, including *Larix sibirica*, will be used for pulping.

- The use of deciduous species will rise from the present proportion of 25 percent to 40 percent or more.

- Industrial forest plantations will provide a greater percent of pulpwood, rising from 1 to 2 percent to 4 to 5 percent.

- Closer utilization of forest resources will take place by a greater use of thinnings, wood presently considered cull, smallwood and, in many areas, of a shorter rotation cycle.

- A major increase in conversion of sawmill residues and wood wastes will take place, particularly in the Soviet Union, to the point where there will be little processing "waste".

- Some reduction to practice of complete-tree utilization will occur. A high percentage of unmerchantable tops will be extracted as part of whole-tree logging; in some regions branches will be utilized for the production of a variety of fiber products; in a few areas, probably on very short rotation cycle, the stump-root systems will be used as a source of fiber.

(b) Fiber Conversion

- The production of sulfite pulp will decrease from its present 25 percent to 10 percent or less of total pulp production.

- The production of kraft, conventional or somewhat modified, will increase to 50 percent or more of the total.

- N.S.S.C. pulps and dissolving-grade pulps will remain at approximately the same level as at present, i.e., each 5 percent of total pulp production.

- Mechanical pulps will constitute approximately 30 percent or more of total pulp production, but they will differ appreciably from the production of present-day conventional mechanical pulps. Processing will include conventional grinding, production of refiner groundwood from chips, sawdust, shavings and otherwise comminuted wood, and combined chemical and mechanical pulping.

- Sawdust and shavings will be used in the refiner groundwood process, or will be pulped. In all integrated forest-products industries, there will be no solid processing waste other than bark, which will continue to be a problem.

- Much pulp produced will have yields in the 85 to 90 percent range, with mild chemical treatment followed by disc refining and brightening. This general type of conversion will be used for the mixed hardwood species of South America, Africa and Asia, and for the *Populus* species of Canada.

Finally, the stage will have been set for complete-tree utilization on a massive scale, and for a beginning on the harvesting of cellulose as a crop (343).

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