CHAPTER III

Pulp, Paper, and Fiber Products

Pulp, Paper, and Fiber Products

Summary and Conclusions

Pulp and paper manufacturing is moving toward the production of higher quality pulps that require less wood input per ton of pulp and paper produced. Increased energy costs, increasing raw material costs (for both roundwood and sawmill residues), a market that now emphasizes printability and other nonstrength factors, and the availability of immense amounts of less expensive hardwood timber have prompted the U.S. pulp and paper industry to consider more energy-efficient and materials-efficient manufacturing technologies.

The adoption of mechanical pulping technologies could reduce the amount of fiber required to produce a ton of paper from about 2.5 tons of wood, for the kraft chemical pulping process, to about 1.05 tons for thermomechanical pulping. With this reduction, it is estimated that each future increase of 2 percent in pulping capacity would necessitate an increase of only 1.7 percent in wood fiber feedstocks.[1] These potential increases in pulping efficiency and fiber yield can effectively extend the Nation's usable wood supply, reducing the likelihood of raw materials shortages and relaxing the pressures on the shrinking U.S. timberland base. Expanded use of hardwood species that are presently underutilized may further extend the domestic timber supply.

Pulping technologies like organosolv hold prospects for the industry to become a net energy producer. The organosolv process may also permit utilizing hardwood species and obtaining high fiber yields with little sacrifice in product strength. Such processes are still in the developmental stages but may be commercially available in 25 years. Meanwhile, the pulp and paper industry could reduce the amount of energy required by increasing the use of mechanical pulping and expanding the use of recycled paper. In addition, the efficiency of chemical pulping may be increased by adopting pyrolytic technologies for the recovery of spent pulping liquor, autocaustisizing to reduce the energy required in the lime-kiln process, and using anthraquinone as a catalyst for chemical kraft pulping to increase fiber yields.

Press-drying technology, while still in developmental stages, shows promise for both reducing the amount of energy required in the papermaking process and enabling the use of hardwood species not currently used in large quantities. In some respects, the quality of the paper produced by this method exceeds that of unbleached kraft paper produced by conventional processes. It may also afford an opportunity for the U.S. pulp and paper industry to capitalize on a growing export market in linerboard and other heavy-duty packaging materials.

Advanced research and development (R&D) on improving the strength and stiffness of paper could lead to development of structural fiber products able to compete with a number of metallic, ceramic, and plastic materials. In addition, paper may be combined with other materials such as plastics, coatings, and synthetic fibers to produce composite materials with superior qualities.

Although plastics have made significant inroads in certain types of packaging, and have significantly displaced paper sacks for light-duty uses, paper still commands a major proportion of this market and will probably continue to do so. Moreover, increases in energy costs could improve paper's competitive position relative to petroleum-based plastics, which require larger energy inputs in production. The paper industry could further strengthen its

[1] G. Styan, "Impact of North American Timber Supply on Innovations in Paper Technology," *Paper Trade Journal,* vol. 164, May 30, 1980.

competitive position if it continued to adopt existing energy-efficient technologies.

Electronic telecommunications technology, on the other hand, could have significant impacts on demand for printing and writing paper in the future. While the magnitude of its effect on paper is yet uncertain, the introduction of advanced electronic devices such as electronic filing (the "paperless" office), video magazines, electronic newspapers, and video catalogs and directories may increasingly affect the use of paper now and during the next two decades. Recently, the use of word processors and office copying equipment has increased the demand for paper products, a trend that may decline as electronic communications gain increased acceptance in offices. In the final analysis, the long-term effects of telecommunications technologies on paper requirements are unknown,

Introduction

Profile of the Pulp and Paper Industry

The United States has the largest per capita paper and paperboard consumption in the world, averaging more than 600 pounds annually. It is also the world's largest producer of paper and paper products, accounting for approximately 35 percent of the world's total output. The U.S. pulp and paper industry is ninth in size of tons produced and 11th in gross assets among the domestic manufacturing industries. In 1981, U.S. production of pulp, paper, and paper products was estimated at $82.1 billion (current dollars).[2]

Raw Materials

In 1978 the pulp and paper industry used approximately 77 million tons of pulpwood (oven dried). Forty-four percent of this came from chips and sawmill residues, which are wood wastes from the manufacture of lumber and other solid wood products. About 26 percent of the pulpwood used in 1978 was hardwood. (Trends in wood use in the past 40 years have been toward increased use of hardwood species and increased reliance on chips and sawmill residues.) In addition, the U.S. pulp and paper industry used approximately 15 million tons of recycled wastepaper for pulp and paper production in 1978.[3]

The pulp and paper industry also uses about one-quarter ton of chemicals for each ton of paper or paperboard produced, ranking sixth among all industries in dollar value of chemical products purchased. It is also the largest user of water for processing among all manufacturing industries. Finally, the industry is one of the leading industrial consumers of energy, using roughly 7,2 percent of the Nation's industrial energy requirements and 2,8 percent of the total energy used in the United States. Approximately half of the energy used by the industry is produced internally from wood residues and other waste products. Because of the large energy requirements and the sensitivity of production costs to energy prices, the pulp and paper industry has become an industrial leader in energy conservation and cogeneration (internal generation of electricity from steam heat),

Product Demand

Demand for paper and paper products is closely tied to economic growth and disposable income levels. Although year-to-year fluctuations occur, correlating with economic trends, the industry is relatively free from the cyclical variations experienced by other primary industries such as mining, metals, and solid wood products.

Capital

The pulp and paper industry has exceptionally high capital requirements for plant and

[2]U. S. Department of Commerce, *1982 Industrial Outlook* (Washington, D. C.: U.S. Government Printing Office, 1982), p. 39.
[3]Joan E. Huber, *The Kline Guide to the Paper Industry* (Fairfield, NJ.: Charles H. Kline & Co., 1980), pp. 66-67.

equipment, Capital investment currently ranges from $350,000 to $1 million per installed ton of daily capacity, depending on a mill's design and whether the investment is an addition to the existing mill or a new facility.[4] The paper industry invested $6.8 billion in capital expenditures in 1980; however, $369 million, or 5 percent, was spent on pollution control equipment that did not increase production capacity.[5]

Industry Size and Production

With over 4,000 firms employing about 626,000 workers, the pulp and paper products industry is an important component of the U. S. economy. It produces over 14,000 different paper products, and its potential for developing new and even better paper and fiber products in the future is high. At the same time, more efficient manufacturing processes could reduce energy use and lead to increased use of presently underutilized, but prevalent, hardwood species.

It is estimated that paper products account for almost three-fourths of the wood-based sales of the top 40 firms in the forest products industry.[6] While the pulp and paper sector consists of a large number of competing firms, the 10 largest firms manufacture over half of the pulp, paper, and paperboard products produced in North America. In addition, a number of the major pulp and paper manufacturers produce a variety of secondary products, including solid wood items, containers, writing papers, and sanitary paper products (table 22). Fifteen companies that produce both paper and solid wood products are prominent among the wood-based industries, but together they accounted for only 24 percent of all wood-based sales in the United States in 1978.[7]

[4] Conversation between Benjamin Stayton, API, and James Curlin, OTA.

[5] George H. Boyd III and Chad E. Brown, *Paper—Forest Products Industries: Capital Expenditure Forecast* (New York: Peabody & Co., 1981), p. 6.

[6] Jay O'Laughlin and Paul V. Ellefson, "U.S. Wood-Based Industry Structure: Part I—Top 40 Companies," *Forest Products Journal*, October 1981, vol. 31, p. 56.

[7] Jay O'Laughlin and Paul V. Ellefson, "U.S. Wood-Based Industry Structure: Part II, New Diversified Entrants," *Forest Products Journal*, November 1981, vol. 3, p. 27.

In 1976, the South produced 67 percent of the Nation's wood pulp. Southern forests are particularly attractive to the industry because of the abundance of both softwoods and hardwoods, The pulp and paper industry has expanded its capacity in the South in recent years; while the South's share of total pulp production was only 48 percent in 1947, it is now over two-thirds, The West produced 17 percent of the Nation's wood pulp in 1976. The remaining 14 percent was produced in the East and in the North Central States.[8]

While pulpmills are located near raw materials, the manufacturing sector of the industry, which makes containers, bags, sanitary products, and stationery, is concentrated near the markets. Thus, the New England Middle Atlantic, and North Central States produce 62 percent of all paper products. Much of the timber resource in these regions is hardwood, which has not been used extensively for paper production in the past. Wood pulp production in these regions currently constitutes only 16 percent of total U.S. wood pulp production.

Uses of Pulp, Paper, and Paperboard

Total U.S. pulp production has been projected to increase from 53.2 million short tons in 1981 to 54.8 million short tons in 1982. However, the actual volume may be lower as a result of the 1981-82 recession.[9] In addition to the domestic products used, approximately 4.3 million short tons of pulp were imported in 1981, primarily from Canada. Pulp exports totaled 3,7 million tons, most of which was shipped to Europe, Mexico, Japan, and Korea. The total 53.8 million short tons of pulp used were converted into over 66 million tons of paper and paperboard. Imports of primary paper and paperboard products were about 8 million tons in 1981, while exports slightly exceeded 4 million tons,

Wood pulp is converted into a variety of paper products (table 23). The major uses of paper, which accounts for 49 percent of the wood

[8] Huber, op. cit., pp. 39-40.

[9] U.S. Department of Commerce, op. cit., p. 42

Table 22.—Estimated North American Capacity by Grade of Top 20 Pulp, Paper, and Paperboard Producers (thousands of tons)

Rank Company	Total market pulp, paper, and paperboard capacity	Pulp: Market pulp	Paper: Newsprint	Paper: Uncoated groundwood papers	Paper: Coated papers	Paper: Uncoated book papers	Paper: Wood pulp writing papers	Paper: Specialities, cover, and thin papers bleached bristols	Paper: Unbleached and bleached packaging papers	Paper: Tissue papers	Paper: Total all papers	Paperboard: Unbleached kraft linerboard	Paperboard: Corrugating medium	Paperboard: Recycled paperboard	Paperboard: Bleached board	Paperboard: Total paperboard	Other: Building and wet machine board
1 International Paper	7,534	1,000	1,440	—	305		830	320	580	59	3,534		2,000	—	1,000	3,000	—
2 Weyerhauser	3,987	1,100	210	—	—	—	550	—	115	—	875	1,235	375	—	275	1,885	127
3 St. Regis Paper	3,470	720	650	58	675	—	—	491	50	—	1,924	850	200	335	50	1,435	—
4 Boise Cascade	3,071	292	690	225	185		860	80	110	—	2,442	370	100	—	—	470	159
5 Crown Zellerbach	3,015	200	485	100	350		140	60	500	350	1,965		525	325	—	850	—
6 Abitibi Price Group	2,999	193	2,001	407	—		218	—	—	—	2,626	—	—	60	—	60	100
7 Georgia-Pacific	2,957	796	—	—	—		421	—	527	443	1,391	272	118	281	119	770	—
8 Champion Internatonal	2,793	280	—	—	330		775	—	225	—	1,330	535	300	118	250	1,203	—
9 Mead	2,612	358	80	—	432		374	54	—	—	940	690	280	206	140	1,316	—
10 Union Camp	2,453	—	—	—	—		525	—	425	—	950	1,300	—	80	125	1,505	—
11 Great Northern Nekoosa	2,407	100	350	375	110		630	12	50	—	1,527	585	215	—	—	780	—
12 MacMillan Bloedel	2,384	507	1,323	—	—		44	—	—	—	1,367	440	70	—	—	510	—
13 Westvaco	1,900	125	—	—	375		150	—	160	—	585	585	100	—	425	1,090	—
14 Container Corp.	1,895	—	—	—	—	—	—	—	—	—	—	745	410	570	170	1,895	—
15 Scott Paper	1,835	—	—	—	350	—		260	—	1,025	1,635	—	—	—	—	—	—
16 Continental Forest nc	1,620	—	—	—	—	—	—	—	375	—	375		785	—	460	1,245	—
17 Time Inc.	1,580	115	—	—	—	—	—	—	100	—	1,200	630	390	—	325	1,345	—
18 Domtar	1,538	147	418	—	—		350	50	78	—	894	313	63	121	—	497	—
19 Kimberly-Clark	1,390	—	730	—	—	—		145	—	515	1,390	—	—	—	—	—	—
20 Owens-Illinois	1,193	—	—	—	—	—	—	—	—	—	—	650	543	—	—	1,193	—

Table 23.—U.S. Production of Paper and Paperboard in 1981 and Projected for 1984 (thousand tons)

	1981	1984[a]
Paperboard	14,558	15,360
Kraft fiberboard	1,067	1,140
Other kraft paperboard	4,717	5,070
Bleached paperboard	3,926	4,100
Recycled paperboard	7,070	7,150
Total paperboard	31,338	33,020
Paper:		
Uncoated free sheet	7,882	8,720
Coated free sheet and groundwood	4,951	5,340
Uncoated groundwood	1,440	1,540
Bristols and other	1,530	1,580
Total printing and writing	15,803	17,180
Newsprint	5,238	5,730
Unbleached kraft	3,891	3,760
Bleached regular and industrial	1,603	1,670
Tissue	4,485	4,730
Total paper	31,020	33,070
Total paperboard and paper	62,358	66,090

[a]Morgan Stanley estimates

SOURCE Thomas P Clephane and Jeanne Carroll Linerboard *Industry Outlook (New* York Morgan Stanley & Co 1982) p 25

pulp produced, are for printing and writing papers [50.9 percent), newsprint (16.9 percent), tissue (14.5 percent), and packaging (17.7 percent). Over 51 percent of U.S. wood pulp production is converted to paperboard (a stiff, heavy paper). Linerboard, which is kraft paperboard used for boxes, shipping containers, and packaging, accounted for 46.4 percent of the paperboard produced in 1981. Overall, packaging materials (both paper and paperboard) made up 59 percent of all paper and paperboard produced in the United States, and was one of the most rapidly expanding pulp uses.

Since the price elasticity of demand (the change in demand resulting from a change in price) for paper products is generally small, the recent decline of relative prices has probably had only a small positive impact on apparent paper consumption.[10] The U.S. Department of Commerce projects shipments of primary paper and paperboard products to rise at the rate of 3 percent annually for the next 5 years. Market projections through 1986 suggest a steady increase in domestic and worldwide demand for paper products in general. Demand for primary paper and board products is expected to be exceptionally strong. Economic factors affecting demands for communications, packaging and shipping papers, and boards, however, will ultimately determine actual demand levels.

The most promising markets during the ensuing 5 years are expected to be for linerboard and high-quality printing papers. An increase of 6 percent in the trend line of 1982 linerboard exports is forecast by some analysts,[11] and the demand for high-grade printing and publishing papers is projected to increase at an annual rate of about 7 percent.[12] Demand for both printing paper and linerboard is expected to expand at rates twice that for products of the paper industry overall. While domestic consumption will probably increase gradually in response to a stronger economy, the demand for exports is expected to increase even more, in response to expansion of the industrial economies of the People's Republic of China, Japan, Malaysia, Indonesia, the Philippines, Taiwan, and Korea.

Advanced Paper Materials

The development of stiff, durable paper, with strength characteristics currently achievable only at the experimental level, offers future prospects for new structural building products, Paperboard has been tested for use as sheathing and wall modules in buildings with mixed results.[13] The effects of moisture on the dimensional stability and stiffness of the paperboard is a major factor limiting the usefulness of paper as a structural material. New high-strength papers with protective coatings, coupled with innovative designs for paper-based structural materials, are a possibility, But considerable R&D remains to be done prior to commercialization.

10Calculations by the Kidder, Peabody Economics Group indicate that the relative price elasticity of demand for paper is approximately 0.5 percent.

11 Thomas P. Clephane and Jeanne Carroll, *Linerboard Industry Outlook (New* York: Morgan Stanley & Co., 1982), p. 12.

12Corporate Strategies, "A Narrowed Boise Cascade Focuses on Paper, " *Business Week*, Apr. 26, 1982, p. 81.

13'' Emergency Housing for $2,500, " *Technology Review*, May/June 1982, p. 86. "Paperboard Houses Now Approved for all Exposures by FHA, " *Paper Trade Journal* (Aug. 23, 1971], p. 53; "Paper Houses Buyers, " *Chemical Engineering,* Sept. 8, 1969, RP 76-71.

Wood pulp may be converted into paper products ranging in character from superabsorbent fluffy tissue to extremely hard, boardlike materials. Wood pulp's versatility results from the ability to vary paper's stiffness over a wide range. Wood fibers are extremely flexible, strong, and durable. When brought into close contact, they form a durable fiber web as a result of hydrogen bonds, strong bonds which provide the strength and stability of paper. Hemicellulose acts as an adhesive between the fibers and adds strength.

Stiffness is the major quality that makes papers so suitable for boxes, shipping containers, and, possibly, structural building materials. Although strength is also important, it is more frequently lack of stiffness that limits the choice of materials for these products. Because cellulose fibers attract water, moisture can affect paper's structural integrity by softening the fibers and reducing their stiffness, Tests in modifying paper to enhance stiffness and moisture resistance, performed at the U.S. Forest Service Forest Products Laboratory (FPL), have demonstrated that super-strength paper may, on a weight basis, be capable of matching the performance of other solid materials like solid wood, aluminum, and steel.[14]

The major factors affecting stiffness that are subject to control by the papermaker are fiber orientation, density and fiber bonding, and shrinkage control during the drying cycle. *s The prospects for improving paper stiffness through the use of synthetic resin additives are not considered as promising as improved bonding and fiber orientation in the papermaking process.

Researchers at FPL hypothesize that an elastic modulus of approximately 1.5 million pounds per square inch (psi), with a specific gravity of 0.4, could be achieved in paper in which the fibers are parallel and shrinkage is carefully controlled during drying. This level of stiffness is approximately equivalent to that of wood parallel to the grain at the same specific gravity. Laboratory tests have produced paper sheets of specific gravity of 0.75, with a tensile strength of 38,000 psi and an elastic modulus of 3.8 million psi.[16] These values substantially exceed the specific strength and stiffness-to-weight ratios of all common structural materials, including solid wood. Only certain graphite and boron fiber composites surpass the strength of this "super paper" at the specific gravity tested. Laboratory researchers conclude that paper can be produced that is stiffer and stronger than the wood from which it is made, If high-strength papers can be developed that are capable of maintaining stiffness and dimensional stability in high humidity, they may be used for a range of structural applications now being served by wood, plastics, or metals—e.g., housing, furniture, and containers,

[14] V. Setterholm, ''Factors That Affect the Stiffness of Paper, *The Fundamental Properties of Paper Related to Its Uses,* vol. *1,* F. Bolam (cd.) (London, England: The British Paper and Paperboard Industry Federation, 1976), pp. 253-266.

[15] Ibid., p. 266.
[16] Ibid., p. 260.

Role of Paper and Cellulosic Materials in the U.S. Material Mix

Competition with traditional paper commodities for U.S. markets comes primarily from two areas: plastics and electronic communications. Competition from plastics is often in the form of substitution of plastic products for paper products and, occasionally, composite products made from paper and plastics, Electronic communications, on the other hand, have the potential for displacing a share of the paper market by reducing the need for writing, copying, printing, and business forms. So far, however, electronic communications has probably resulted in greater consumption of paper, owing to increased use of word processors, high-speed computing systems, and inexpensive office copiers.

The impact of competition from plastics and the electronics media on paper materials will vary among paper products. Newsprint, writing and printing papers, business forms, paper bags, and wrapping papers constituted 47 percent of paper consumption in the United States in 1979 (table 24). Some anticipate that these products, in contrast to linerboard and paperboards used in shipping containers, will be seriously affected by competition from plastic products and the electronic media. The printing and writing paper sector, which constitutes one-third of U.S. paper consumption, will likely experience the greatest impact from the expan-

Table 24.—Uses, Grades, Production, and Consumption of Paper Products in the United States in 1979

Market	Grade	Production (thousand tons)	Percent	Apparent consumption (thousand tons)	Percent
Newspapers	Newsprint	4,062	6	11,215	16
Magazines, directories, catalogs	Uncoated groundwood	1,530	2	2,254	3
Magazines, annual reports, other periodicals	Coated papers	4,526	7	4,640	7
Books	Uncoated book				
Commercial printing, envelopes, business forms, lables, duplicator covers, and text	Writing and related	7,868	12	7,913	11
Cigarettes, carbonizing condensers	Thin paper	376	<1	391	<1
Bond, writing, other business, and technical	Cotton fiber	125	<1	126	<1
Tabulating index, tag and file folder, post card	Bleached bristols	1,114	2	1,116	2
Wrapping, bag, sack, shipping sack	Unbleached kraft packaging and individual converting	3,934	6	3,937	6
Bleached bags, wrapping glassine, greaseproof	Other packaging and industrial converting paper	1,791	3	1.729	2
Industrial converting	Special industrial paper				
Sanitary tissue papers, waxing, and wrapping tissues	Tissues	4,525	7	4,514	6
Total paper		29,851	46	37,835	54
Facing for corrugated or solid fiber boxes	Unbleached kraft linerboard	14,076	22	12,611	18
Tube, can, drum, file folder, shipping containers	Other unbleached kraft fiberboard	1,127	2	1,050	1
Recycled corrugating medium, chip and filler board boxes, partitions and dividers	Semichemical paperboard	4,721	7	4,737	7
Folding cartons, milk cartons, paper plates, cups, posters	Solid bleached paperboard	4,023	6	3,310	5
Folding cartons, setup boxes, gypsum wallboard facing	Recycled paperboard	4,883	12	7,533	11
Total paperboard		31,631	49	29,241	42
Construction products, insulating board, binder, and shoe board	Building and wet machine board	3,466	5	3,763	5
Other		—	—	(462)	—
Total paper		64,947	100	70.340	**100**

SOURCE Adapted from G Boyd III and H Dudley, *Paper Industry Outlook for 1980 Through 1982, Part II* (New York K!dder , Peabody & Co 1980) p 10 sion of electronic communication if telecommunications technology is accepted by the business community and home use expands significantly in the future. Plastic substitutes for paper bags, wrapping papers, and miscellaneous office supplies could displace 10 percent of the paper consumed in the United States annually,

Competition From Plastics

The use of low-density polyethylene film (LDPE) for packaging, wrapping, and sacking, and high-density polyethylene film (HDPE) for printing and wrapping paper, is a comparatively recent trend that began during the past decade and continues to expand at a steady rate. Plastics claimed only a l-percent share of the grocery sack market (small sacks used for individual items) in 1979, but within 2 years expanded to 5 percent of the market. The plastics industry projects that plastics could capture as much as 25 percent of the grocery sack market by 1985,[17] but, according to some analysts, the penetration of plastics into the traditional kraft paper markets will probably be selective, For example, the grocery bag market (larger, multiwalled, heavy-duty bags) may be less vulnerable to inroads by plastics, at least during the intermediate term (10 to 15 years).[18]

Several factors will determine the future competitiveness of plastics in relation to paper products: 1) relative production costs, including raw material (resin for plastics and wood, and chemicals for paper), labor (in general, the paper industry is more labor-intensive), and energy consumption; 2) rate of technical innovation; and 3) consumer acceptance.

Sack/Bag Market

Plastics' share of the merchandise bag market was estimated to be 35 percent in 1981, an increase of 10 percent over the previous year, Investment analysts at Morgan Stanley & Co. estimate that plastic bags will control 60 percent of the merchandise bag market by 1985.[19]

[17]Clephane, p. 18.
[18]Ibid., p. 17.
[19]Ibid., p. 16.

Production of 275,000 tons of finished bags annually account for only 5 percent of the total production of unbleached kraft paper. Morgan Stanley estimates that by 1985, merchandise bags will require no more than 3 percent of the total production of unbleached kraft paper production.

Large grocery bags consumed 12 percent (467,000 tons) of the unbleached kraft paper produced in 1981, Small grocery sacks accounted for 95 percent of the 1.3-million-ton total grocery sack market in 1981 and used approximately 34 percent of the unbleached kraft paper produced during that year. Until recently, plastics were not considered to be serious competitors of kraft paper for the grocery bag/ sack market; however, some analysts now predict that plastics may be able to capture rapidly an increasing and significant share of the market, The paper industry confirms that plastics now compete at prices ranging from $0,029 to $0.031 per sack and sell for 10 to 15 percent less than unbleached kraft sacks. The major plastic sack producers include several oil companies and chemical companies: Mobil, Exxon, and Union Carbide,

One reason for plastics' current success in competing with kraft paper in the bag and sack market is the availability of low-cost resins. Another is technological developments in polyethylene that permit substantial reduction in plastic thickness and volumes without sacrificing strength. For example, development of the Unipol process for making linear, low-density, polyethylene resin in 1979 constituted a major breakthrough for the plastics industry because it required considerably lower capital investment and consumed less energy per unit of resin produced.

Paper currently possesses properties that are superior to plastics as a material for bags and sacks. The rigidity of paper sacks enable them to stand freely for filling in grocery and retail stores. To compensate for lack of sidewall rigidity, plastic sacks must be mounted in racks for ease of filling. Although such technology does not yet exist, it might eventually be possible to develop a rigid-wall plastic sack capable of competing economically with paper sacks. The conversion from LDPE to newer low-density polyethylene film could provide even greater price advantages for plastic sacking.

Multiwall Sacks

One major segment of the paper sack market that has not yet been seriously challenged by plastics is the multiwall, bulk shipping sack. Plastics have not made significant inroads in this sector because the strength properties required put plastics at a cost disadvantage relative to kraft paper. Plastics currently occupy 10 percent of the multiwall sack market, and some industry analysts assume that this market penetration will remain stable over the long term unless unforeseen technological developments occur. Product developments in the pulp and paper industry may reinforce paper's share of the multiwall sack market. For example, St. Regis Paper Co. recently introduced Stress Kraft, a superior-strength paper permitting a 20-percent reduction in the weight of the paper used for multiwall sack construction.[20] Multiwalled sacks consumed approximately 26 percent of the unbleached kraft paper produced in 1981.

Liquid Containers and Packaging

Plastic containers for liquid have made significant gains in competition with glass and coated-paper containers. Plastic l-gallon milk containers now dominate the market, although most smaller l-quart and l-pint containers continue to be coated paper. Technological innovation accounts for the current inroads of plastics in the packaging sector, yet plastics have still captured only a small proportion of the packaging and container market. Because plastics are petroleum derivatives that are not biodegradable, and in some cases may produce toxic fumes if incinerated, plastic packaging products have met opposition from environmentalists.[21]

[20] "St. Regis Introduces New Kraft Paper," *The Journal of Commerce*, Apr. 17, 1982.

[21] "Plastic Food Packaging Makes Deeper Inroad on Paper, Metal, Glass," *The Wall Street Journal*, May 8, 1978, p. 1.

The market for tissue wrapping papers and glassine and parchment papers has not been significantly penetrated by plastics, although plastic bakery bags and cereal box liners are in wide use, The major limitations to the use of plastics in these areas are primarily linked to the difficulty of adapting automatic packaging machines for the new materials. HDPFs have properties similar to the cellulose films and may some day challenge conventional paper materials in this area.

While plastic and aluminum foil trays have significantly challenged paperboard fiber trays for packaging meats, fish, and prepared and frozen vegetables, recent trends in microwave cooking (which cannot use aluminum foil containers and requires heat-resistant receptacles) have resulted in a new generation of oven-resistant packaging. Polyester coatings have been joined with molded paper trays to create a composite product suited for microwave cooking conditions.[22]

A number of composites, which combine paper with plastics and metals, provide a product superior to those made with one material. Among these are collapsible plastic bags inside paperboard cartons equipped with a spout for dispensing liquids, thermoplastic-coated paperboards for water-resistant food containers, paper meat trays coated with plastics, paperboards treated with clay-adhesive mixtures and bonded with metal foils, and paper cartons laminated with plastic foams.

Printing and Writing Papers

Plastic films have not significantly displaced printing and writing papers, except for specialized uses. The properties of paper (printability, flexibility, wearability, and price) are well suited for printing, recordkeeping, business forms, magazines, and books. The durability of plastics (e. g., in Mylar and waterproof papers) makes them useful for transparent reproducible graphics, children's books, and outdoor use, However, the cost of printable plastic films is approximately twice that of the highest

[22] W. Lemaire, "Paperboard Packages for ot'ens,'" *Food Engineering*, January 1978, p. 62,

grades of paper.[23] Paper industry analysts believe the probability is low that plastics will be able to displace paper in general business and commercial use, except for the highly specialized applications named above.

Synthetic **Fibers**

The major petroleum-based synthetic fibers that compete with rayon and acetate are the polyesters, nylons, acrylics, and olefins. In 1968, the worldwide volume of cellulosic manmade fiber produced was about the same as that of noncellulosic manmade fibers (3.9 million tons).[24] Since that time, the noncellulosic fibers have dominated the artificial fiber market. This trend may continue, although the market shares for rayon and acetates appear to have stabilized. Some predict that a slight resurgence in the use of rayon may occur if petroleum prices increase significantly.

Improvements in the viscose rayon process or the development of new processes that could reduce the cost of rayon manufacture may also reinforce the market position of cellulosic products. Some claim that the rayon industry has suffered from a reduction in R&D in the 1950's and 1960's, the period when petroleum-derived synthetics displaced rayon as the predominant manmade fibers.

The rayon and acetate industries, however, consider their major competitor not to be the petroleum synthetics but natural cotton fibers, Cotton and rayon have similar properties with regard to moisture absorption and other wear characteristics, making possible development of improved, cottonlike rayon fibers that are directly substitutable for cotton. The rayon industry sees an opportunity to expand its market without meeting competition from petroleum synthetics, based on the forecast that worldwide demand for cotton will increase at a rate exceeding the capacity of the agricultural industry to meet the requirements.[25]

Competition From Electronic Technologies

Recent developments in large-scale, integrated circuitry are revolutionizing the communications and information fields by reducing the size of computers and microprocessors, expanding their capacities and flexibilities, reducing costs, and increasing availability to a wider range of potential users.[26] Through the use of satellite communications, microwave, and interfacing devices on home television receivers, electronic communications may be linked with large centralized information systems that are capable of providing a wide range of user services. Further developments in optical digital-disk technology (a specially coated plastic disk on which information is encoded by a high-powered laser beam) may enable the permanent storage and relatively cheap retrieval of immense amounts of information.[27] Fundamental research on new concepts of data storage and retrieval may pave the way in the future for even greater expansion of information technology.

Achievements in telecommunications technology during the past two decades offer a number of opportunities for improving the speed and flexibility of communications, Electronic mail is being considered by the U.S. Postal Service and private firms as a way to speed textual communications and eliminate the need for handling and physically transporting mail.[28] Some foresee electronic filing leading to the paperless office.[29] Video magazines, which may be transmitted directly into the

[23] "Where Plastic Papers Stand in Printing, Bags and Tissues, " *Modern Plastics,* March 1973, p. 55.

[24] Committee on Renewable Resources for Industrial Materials (CORRIM), *Fibers as Renewable* Resources *for Industrial Materials* [Washington, D. C.: National Academy of Sciences, 1976], p. 234.

[25] G. Daul, op. cit., p. 84.

[26] U.S. Congress, Office of Technology Assessment, *Computer-Based National Information Systems: Technology and Public Policy Issues,* OTA-CIT-146 (Washington, D. C.: U.S. Government Printing Office, September 1981), pp. 3-12.

[27] C. Goldstein, "Optical Disk Technology and Information, " *Science,* vol. 215, Feb. 12, 1982, p. 862.

[28] J. Free, "Electronic Mail: Good-bye to Paper?" *Popular Science,* September 1980, pp. 78-141.

[29] "Electronic Filing to Threaten Cut Size Paper Markets, " *Fiber Market News, No.* 72, Dec. 14, 1981, p. 1,

home via satellite and conventional television receiver, are in the early stages of development.[30]

Television-adapted versions of the phone directory, retail catalogs, and other merchandising devices, which can be viewed on home televisions, are currently being evaluated for public use.[31] Also, a number of major newspaper publishers are interested in producing electronic newspapers; in the United Kingdom at least three such teletexts are already operating.[32] Futurists consider as long-range prospects the use of vast central information systems—''hypertex capableable of retrieving, displaying, and manipulating information from "grand libraries" through personal consoles.[33]

Such broad-scale application of electronic communications could affect dramatically the use and demand for paper in the future. Although telecommunications has experienced rapid growth during the past decade, its application for office and home use is still in its infancy, Thus, uncertainties regarding the rate of commercialization and public acceptance and forecasts of its impacts on paper must be considered speculative. While there is little disagreement among analysts that electronic communications may ultimately displace the need for some writing and printing papers, the timing and extent of the impacts are subjects of debate.

Euro-Data Analysts, a British-based market consulting group specializing in the paper, board, and packaging industry, forecasts a major shift from the use of paper toward increased reliance on electronic media.[34] Over the long term, Euro-Data considers it likely that the developed countries will achieve a nearly paperless society as the rate of commercialization of electronic communications accelerates. Euro-Data forecasts that during the current decade, paper will lose a share of the market to the electronic media through video telephone directories, office communications, telex, video books, video newspapers, consumer magazines, and electronic funds transfers.

The American Paper Institute (API) sees immediate competition with the electronic media in electronic fund transfers, office reproductions that require less paper, electronic mail, and electronic storage and microforms .35 Beyond 1985, API anticipates competition developing in direct-mail advertising; voice message systems that would reduce the requirements for envelopes and business forms; expanded use of home video catalogs and directories; video publication of periodicals; interactive videotext, which might reduce book publishing; and video systems displaying time-critical news, which could displace some newsprint.

By 1995 and beyond, portable handheld video displays could displace printed magazines, books, and newspapers (table 25). API notes that the electronic media accounted for over 60 percent of the total communications expenditures during the 1970's. If the trend continues, its share could exceed 70 percent by the year 2000, while the paper-based media's share may drop to less than 30 percent.[36]

Other analysts agree that electronics technology will probably reduce the demand for printing and writing papers during the next decade, International Resource Development, Inc. (IRD), a technology consulting firm, sees home video as potentially flattening the growth in demand for paper directories and catalogs within 6 years.[37] IRD projects that by 1991, electronic filing could reduce demand for office paper by 300,000 tons per year (5 percent of current office consumption). Data Resources Inc. (DRI) estimates that home video systems could start affecting newsprint demand by 1985.[38] If elec-

[30]''Tips on Tape:Cassette Magazines Arrive, " *Time*. June 14, 1982, p. 78.

[31]'' Paper Chases the Electronic Age, " *Business Week, Apr.* 5, *1982*, pp. 112-115,

[32]K. Edwards, "The Electronic Newspaper, " *Communications Tomorrow* (Bethesda, Md.: World Future Society, 1981), pp. 54-59.

[33]H. Freedman, "Paper's Role in an Electronic World, " *Communications Tomorrow' (Bethesda,* Md,: World Future Society, 1981), pp. 60-65.

[34]Euro-Data Analysts, *The Impact of Communications Technologies on Demand for Printing and Writing Papers* (Ashtead, Surrey, U. K.: Euro-Data Analysts, 1980),

[35]American Paper Institute, *Information Technology and Paper Demand (New* York: API, 1981], p. 52.

[36]Ibid

[37]''Paper Chases in the Electronic Age, " op. cit., p. 112.

'eIbid.

Table 25.—New Information Technologies and Their Potential Impact on Paper Construction

Paper end-use categories/relevant information techniques

Commercial business and printing papers:

. Printing papers."

—Advertising: direct mail— Home video information (videotex and teletext) may open new avenues for advertising and could thereby adversely impact print-based advertising, including direct mail. Timeframe: beyond 1985.

—Printing: financial and legal— Expanded use of word processors and intelligent printer/copiers will encourage more in-house production of forms. Electronic funds transfers will continue to grow, subtracting from the use of printed forms in financial transactions.

- Office *graphic reproduction —Growth* in the use of intelligent copier/printers will encourage more in-house offset printing. Timeframe: currently taking place; trend is expected to continue.

  Duplexing and reduction capabilities, both of which operate to conserve paper, will become common features of office copiers, including those positioned at the low end of the price scale. Timeframe: currently taking place; trend is expected to continue.

Converting papers:

- Envelopes- Expanded use of electronic mail and voice-message systems may hold down the number of envelopes used by businesses and individuals. (Voice-message systems are not expected to come into widespread use before 1985.)
- *Business forms—An* increased proportion of business forms will be produced in-house using intelligent copier-printers. Electronic storage and microforms will continue to displace paper forms in selected applications.
- *Stationery and tab/et—A* modest, negative impact from electronic mail, electronic pads, and voice-message systems appears possible. Timeframe: beyond 1985.

Paper end-use categories/relevant information techniques

Magazine publishing: Modest, negative impact possible from home video information. The future development of a full-page portable display for reading electronically stored information could also impact paper consumption by magazines. (The advent of portable displays is not anticipated until the 1985-95 timeframe, or beyond.)

Other periodical publishing: Home video information may hold down paper consumption for catalogs and directories. The future use of videodiscs as a storage medium for reference materials may have a negative influence on paper consumption for catalogs and directories. Timeframe: beyond 1985.

Book publishing: Possible use of home and office videodiscs to store large quantities of infrequently examined information could limit future demand for reference books such as encyclopedias. Interactive videotex may likewise have a negative influence on the demand for reference books. Timeframe: beyond 1985.

As noted above, next to magazines, the advent of a portable, full-page display possessing adequate image quality for prolonged periods of reading may lead to reductions in the demand for paper-based, printed materials, including books. Timeframe: 1985-95, or beyond.

Computerized printers reduce the need for special labels in certain applications.

Newspaper publishing: Home video information may draw classified advertising and financial listings away from newspapers. It may also compete with newspapers by becoming an efficient transmitter of time-critical news information. Timeframe: beyond 1985.

Advent of compact display could also have repercussions on newsprint consumption. Timeframe: 1985-95, or beyond.

SOURCE American Paper Institute, Information Technology and Paper Demand (New York, API, 1981), pp 10-11

tronic media affect newspaper advertising as television has, by 1995 they could displace 800,000 metric tons (tonnes) of newsprint annually (15 percent of current U.S. production),

In the short term, demand for writing and printing paper seems to have increased with the proliferation of word processors and office copiers, which enable fast and inexpensive copies of texts and graphics to be made, Although this phenomenon is considered by some industry analysts to be temporary, others forecast that paper will continue to dominate office communications, magazines, and newspapers.[39] However, both International Business Machines (IBM) and American Telephone and Telegraph (AT&T) have stepped up activities in the field of information storage and transmittal, and some analysts consider their entry into the market as the harbinger of rapid progress and expansion in electronic communications.[40]

With 30 percent of U.S. paper production being used for storage and transmission of information, the short-term trend in increased paper usage as a result of electronic office equipment is expected by some industry analysts to give way to sharp decreases in paper use during the next 20 years.[41]

The future impact of electronic media on paper demand may depend on its effects on the attitudes of a generation of children accus-

[39] Freedman, op. cit., p. 60.

[40] C. Brown, "Tomorrow in the Pulp and Paper Industry: An Outsider's View," speech to 1982 Annual Employee Regulations Conference of the American Paper Institute and Fiber Box Association, St. Louis, Me., Jan. 27, 1982 (New York: Kidder Peabody and Co., Inc., 1982), p. 4.

[41] ibid.

tomed to the partial substitution of electronics for paper. While many older people, not so accustomed, find acceptance of nonprinted media difficult, the present school-age generation, who use nonprinted communications throughout their educational careers, will accept electronic communications for business and home use more readily. In addition, although current technology limits the use of electronic communication to desktop consoles and large computer and wordprocessing installations, the development of handheld portable devices with readable screens—and microelectronic processors capable of storing entire books and magazines—could have a significant impact on the substitution of electronic media for print.

Pulp, Paper, and Cellulose Fiber Manufacturing

Paper was supposedly invented in 105 A.D. by Ts'ai Lun, a member of the Chinese imperial court.[42] Ts'ai Lun's method for papermaking involved soaking tree bark, hemp, rags and other cellulosic materials in water to soften them and then beating the softened material until the fibers separated and swelled. He dispersed the fibers in a wet suspension and formed a thin sheet that was transferred to a felt cloth and pressed. The resulting web was dried in the sun.

Paper is still made by essentially the same process: 1) pulping, to separate and clean the fibers; 2) beating and refining the fibers; 3) diluting, to form a thin fiber slurry, suspended in solution; 4) forming a web of fibers on a thin screen; 5) pressing the web to increase the density of the material and remove excess liquid; 6) drying to remove remaining moisture; and 7) finishing, to provide a suitable surface for the end use. The three methods for pulping wood and other cellulose materials include chemical pulping, mechanical pulping, and semichemical or chemimechanical pulping—a combination of the first two methods.

In mechanical pulping, wood chips from debarked logs are ground, or are passed through a mill, and in some versions of the process are treated with high-pressure steam (thermomechanical) to separate the individual fibers, which can then be formed into sheets of paper. Mechanically separated fibers contain lignin, which makes them remain stiff, bond poorly, and yellow with age.

Chemical pulping is done by cooking wood chips in acid, alkaline, or neutral salt solutions under pressure and high temperatures, which breaks down the wood structure and dissolves some or most of the lignin and hemicellulose contents. Delignification by chemicals causes the individual fibers to become flexible and increases contact and binding among the fibers forming the paper mat, thus increasing the strength of the paper. Semichemical and chemimechanical pulping first breaks down the wood chemically, then by grinding.

The range of commercial pulping processes currently used by the pulp and paper industry is shown in table 26. Nearly three-fourths of the wood pulp is produced by the kraft process (fig. 22).

Mechanical Pulping

Commercial Mechanical Pulping Technologies

There are four basic mechanical pulping processes: 1) stone groundwood pulping, 2) refiner mechanical pulping, 3) thermomechanical pulping, and 4) the recycling of paper. Flow diagrams of the three mechanical pulping processes are shown in figure 23. Mechanical pulping is generally used with softwoods because of the added strength imparted by the long fiber length of softwood species. Mechanical pulps are used principally to manufacture newsprint, printing papers, and tissues that do not require high-strength paper. Secondary

[42] F.F. Wangaard, *Wood: Its Structure and properties* (University Park, Pa.: Pennsylvania State University, 1981), p. 335,

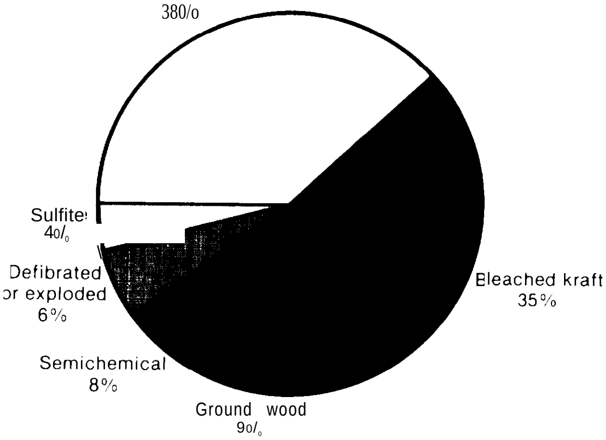
Table 26.—Major Commercial Wood-Pulping Methods, Grades of Pulp, and End-Products

Pulp grades	Wood type	Percent yield per dry weight of wood	End-products, utilizing grade
Chemical pulps:			
Sulfite pulp	Softwoods and hardwoods	53-56[b,c] 45-50[a,d]	Fine and printing papers
Kraft sulfate pulp	Softwoods and hardwoods	40-50[a] 52-53[b]	Bleached—printing and writing papers, paperboard. Unbleached—heavy packaging papers, paperboard
Dissolving pulp	Softwood	33-35	Viscose rayon, cellophane, acetate fibers, and film
Semichemical pulps:			
Cold-caustic process	Hardwoods and softwoods	80-95	Newsprint and groundwood printing papers
Neutral sulfite process	Hardwoods	70-80	Newsprint and groundwood printing papers
Mechanical pulps:			
Stone groundwood[e]	Softwoods	95	Corrugating medium
Refiner mechanical (RMP)[e]	Softwoods	95	Newsprint and groundwood printing papers
Thermomechanical (TMP)[e]	Softwoods	95	Newsprint and groundwood printing papers

[a]Bleached pulps made from softwoods
bun bleached pulps made from softwoods.
[c]Unbleached pulps made from hardwoods
[d]Bleached pulps made from hardwoods
'For paper and board

SOURCE George H Boyd III and Chad E Brown, *Paper Industry. Outlook for Market Pulp (New* York Kidder, Peabody & Co , 1981), p 5

Figure 22.— Proportions of Woodpulp Produced by Commercial Pulping Processes



SOURCE: Joan E. Huber, *The Kline Guide to the Paper Industry* (Fairfield, N.J.: Charles H. Kline & Co., 1980), p. 90.

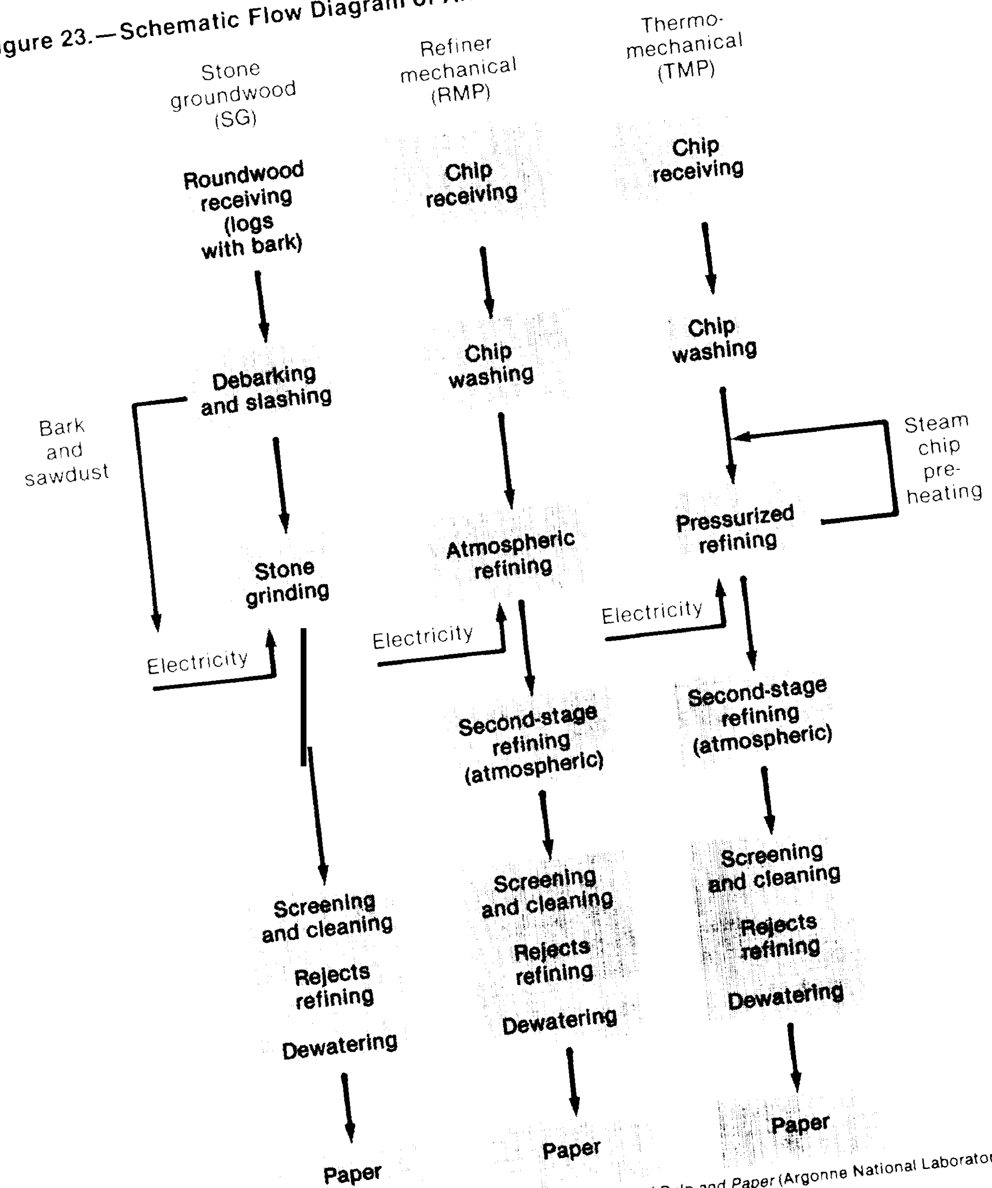
uses include wallpaper and paperboard. Recycled pulp is used mainly for the manufacture of folding boxboard (grayboard), tissue, corrugated board, and newsprint.

In the stone groundwood (SG) process, debarked short logs (roundwood) are fed whole into grinders. The abrasion of the grinding wheel against the wood physically separates the wood fibers. The grinding process usually is automatic and continuous, although sometimes it is semicontinuous, Refiner mechanical pulping (RMP) uses chips in lieu of roundwood and produces paper with higher strength than conventional groundwood because of less damage to the fibers in the pulping process, A wider range of species, including hardwoods, can be processed by the refiner pulping process.

The most advanced commercial mechanical pulping system is the thermomechanical process (TMP), which was developed as a modification of the RMP process. In TMP, wood chips are steamed for several minutes under pressures ranging from 4 to 45 psi and subsequently refined in one or two stages.

Recycled pulp is manufactured from wastepaper, which is processed into paper stock for further use in making paper. A small proportion of the paper stock (5 to 10 percent) is de-inked, usually with caustic, soda-based chemicals. Most recycled paper, however, is pulped without de-inking. Pulping is accomplished through violent agitation and shearing action

Figure 23.—Schematic Flow Diagram of Alternative Mechanical Pulping Processes

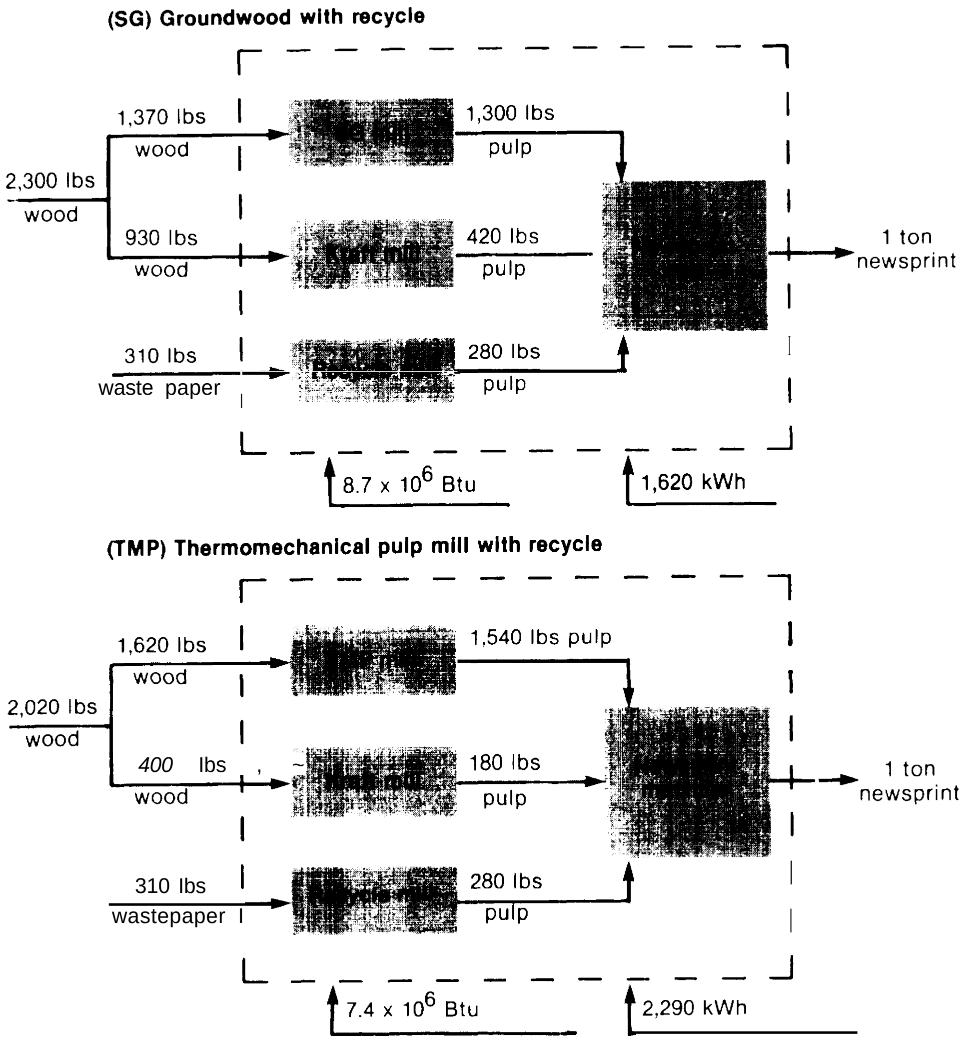


SOURCE: N. H. Hersh, *Energy and Materials Flows in the Production of Pulp and Paper* (Argonne National Laboratory, 1981).

performed at high temperatures. The paper produced from recycled pulp generally is weaker than papers from virgin materials, owing to the breakdown of the used fibers and the loss of bonding.

A comparison of materials and energy consumption for SG and TMP with a recycled pulping operation for the production of newsprint is shown in figure 24. As illustrated, mechanical pulp newsprint uses a small amount

Figure 24.—Wood and Energy Flows in Mechanical Pulping Mills in Conjunction With Recycling



of kraft pulp to improve its wet strength and processing on the paper machine. While paper using TMP consumes 11 to 13 percent less chemical pulp than ordinary newsprint, improved materials efficiency is gained at the expense of higher energy consumption. When the cost of energy is considered as well as the cost of wood, TMP is actually more costly than SG. Pulp yields from all the mechanical pulping processes typically are near 95 percent recovery, which is a higher yield per unit of wood than with the chemical pulping methods. The principal variables that influence the choice of mechanical pulping methods are: 1) furnish (raw material) requirements or wood species, 2) pulp strength, 3) expected gross energy consumption, and 4) expected net energy consumption.

The process variables that affect the quality of mechanically produced pulp are listed in table 27. Increases in paper strength are gained by increases in energy consumption, but brightness and opacity, qualities that affect the use of paper for printing, are largely independent of the pulping process. Recycling can effectively reduce the consumption of both wood raw material and energy when used in conjunction with other mechanical pulping processes. However, it does so at the sacrifice of some paper strength.

Improvements in Mechanical Pulping

Technical improvements in mechanical pulping have largely been directed at reducing energy consumption and improving the quality of mechanical pulps. Pulp yield is approaching the practical upper limit, since all of the lignin and most of the hemicelluloses remain in the fiber, and fiber recovery from mechanical pulping is frequently twice as high as that from competitive chemical pulping. By reducing energy costs, mechanical pulping has remained cost competitive, and improvements in paper quality have enabled mechanical pulps to displace some of the more costly, higher quality pulps produced by chemical processes. As noted in table 27, although improvements in quality result in some increases in the consumption of energy, the higher quality pulp produced more than offsets the higher costs of energy.

Three major developments in mechanical pulping technologies show promise for improving pulp quality and/or reducing energy consumption: 1) pressurized groundwood (PGW) pulping, 2) chemithermomechanical pulping (CTMP), and 3) hardwood chemimechanical pulping (CMP). Each of these new processes has reached some stage of commercialization. A fourth major development is waste-heat recovery.

PRESSURIZED GROUNDWOOD PULPING

In PGW pulping, debarked logs are fed to the grinding wheel through a heated, pressurized chamber. The heat and pressure help separate the fibers, breaking down fewer fibers in the grinding process and improving pulp quality. The longer fibers give the end product a higher tear index than paper made from SG, but it is slightly inferior to that of TMP. The tear resistance for PGW pulp is 5.6, compared with 3.9 for SG and 7.1 for TMP (table 27), The tensile index for PGW pulp (35) also lies between that for SG pulp (32) and TMP (37). In addition to improved strength, PGW promises some reduction in energy consumption. It is estimated that the energy requirement may be reduced by 40 percent from that required for the thermomechanical process, or from 1,833 to 2,417 kWh/ton of pulp to approximately 1,100 to 1,450 kWh/ton.[43]

[43] C. W. Evans, "Pressured Process for Groundwood Production Making Healthy Progress," *Pulp and Paper*, vol 54, 1980, pp. 76-78.

Table 27.—Summary of Process Variables for Mechanical Pulping (based on the production of 1 ton of ovendry pulp)

Variable	Process: Ground wood pulping	Refiner mechanical pulping	Thermomechanical pulping	Recycle
Furnish type . ,	Debarked logs	Residual chips, sawdust	Residual chips, sawdust	Waste paper
Furnish requirements	2,100 lb	2,100 lb	2,100 lb	2,200 lb
Energy requirements (kWh/ton) .	1,340-1,790	1,800-2,400	1,800-2,000	360
Strength:				
Burst	1.4	1.8	2,0	
Tear	**3.9**	**5,7**	*7.1*	
Tensile, ...	32.0	35.0	37.0	
Other:				
Brightness .	60.0	57.0	57.0	
Opacity . ., .	95.0	95.0	94.0	

SOURCE: Envirosphere Company, *Wood: Its Present & Potential Uses*, contract report to OTA, April 1982

By 1980, five mills worldwide had installed PGW systems. Fifteen more plants have been ordered, including four to be located in the United States. Some industry analysts consider PGW technology to have significant potential for reducing mechanical pulping energy requirements and for displacing some high-quality chemical pulps in the manufacture of newsprint and other printing papers.

CHEMITHERMOMECHANICAL PULPING

CTMP involves treating softwood chips with mild sulfite solutions prior to pulping. This "sulfonation" treatment results in paper with higher tear indices than do TMP, RMP, or SG pulping processes.[44] Energy consumption for CTMP may range from 1,360 kWh/ton to 2,000 kWh/ton, depending on the strength of the sulfite solution. Thus, energy consumption of CTMP lies within the range of SG pulping, is less than that required for RMP or TMP, and results in a higher quality paper. Pulp yields decrease slightly to between 85 and 95 percent with CTMP, but these yields are still large compared to chemical pulping and to mechanical chemical pulp blends. Some TMP pulpmills have begun to add sulfite chemicals in their operations to improve pulp quality and reduce energy consumption.

HARDWOOD CHEMIMECHANICAL PULPING

Mechanical methods for producing pulp from underutilized hardwood species involve pretreating hardwood chips with hydrogen peroxide or sodium hydroxide and processing them like RMP. Both poplar [softwood) and red oak (hardwood) have been pulped successfully by these techniques. However, fiber recoveries are lower for hardwood CMP than for softwood CMP. Pulp recoveries of 80 to 85 percent have been reported for poplar, 90 to 95 percent for red oak.

Energy consumption for CMP ranges from 500 to 1,500 kWh/ton using hydrogen peroxide for chemical pretreatment and 700 to 1,100 kWh/ton using sodium hydroxide.[45] Hardwood CMP consumes significantly less energy than do either SG or other chemimechanical hardwood pulping technologies.

Pulp and paper technologists expect hardwood CMP to expand significantly during the next 10 to 25 years because of the large volumes of inexpensive hardwood available, a phenomenon that could have a profound impact on the utilization of presently underutilized species such as poplars, red alder, and American sycamore that are abundant throughout the Eastern United States. Pulp produced by hardwood CMP can be used to produce newsprint and printing papers. Two small U.S. mills, which range in capacity from 200 to 250 tons of pulp per day, have already installed CMP systems to process hardwood species.

WASTE HEAT RECOVERY SYSTEMS

Mechanical pulping systems create a large amount of frictional heat during the grinding and refining processes. Heat recovery systems that enable use of waste heat (for drying paper, space heating, and water treating) are important to the reduction of energy costs in the pulping process. Such systems are particularly important in TMP, which requires large quantities of mechanical energy and produces high-quality heat (i.e., high heat under temperature and adequate pressure) .46 Because of the higher temperature of waste heat from TMP processes, a higher percentage of usable waste heat can be recovered from TMP than from conventional groundwood pulping,

Heat recovery technologies currently recapture 3 million to 5 million Btu/ton of pulp produced." For mills consuming 1,800 to 2,400 kWh/ton, 95 percent efficiency in heat recovery would represent a total of 5.8 million to 7.8 mil-

[44] D. Atack, et al., "Sulphite Chemimechanical Refiner Pulp-Another Option for Newsprint, " *Pulp and Paper,* vol. *54, 1980,* pp. *70-72.*

[45] J.D. Sinkey, "CMP and CTMP—A Review," paper presented at Forest Products Research Society Conference, St. Paul, Minn., 1981.

[46] P. J. Walker and E. J. Batsis, "Heat Recovery From TMP Operations Results in Energy Conservation," *Pulp and Paper,* vol. 52, 1978, pp. 146-148.

[47] *The Fossil Energy Conservation Potential Associated With Producing Wood Products From Managed Stands* (Bellevue, Wash.: Envirosphere Co., 1981).

lion Btu.[48] With current technology, the industry captures 50 to 65 percent of the theoretically recoverable waste heat, Widespread adoption of these efficient systems has not yet occurred because of the problems of retrofitting and high capital costs.

Future Prospects for Mechanical Pulping

The three major new mechanical pulping technologies—PGW pulping, CTMP, and CMP—have improved pulp quality and reduced energy consumption compared with conventional groundwood processes. The resulting higher quality mechanical pulps will displace the kraft pulps that are currently mixed with mechanical pulps to improve paper strength. For example, the shift from SG pulping to TMP displaced 300 pounds of kraft pulp per ton of newsprint. Use of the new technologies will further reduce the amount of kraft pulp required in newsprint and printing papers, reducing the demand for softwood timber because the pulp yield from these processes is nearly twice that of kraft processes.

The configuration of mechanical pulpmills for newsprint manufacturing will likely change significantly during the next 10 to 20 years. By employing CMP and CTMP technologies, using a higher percentage of hardwood as raw material, and installing highly efficient heat recovery systems (85 percent recovery), the mechanical pulpmill of the future could reduce its heat requirements by 1.0 million Btu [300 kWh/ton of heat) and reduce electrical energy consumption by 97o kWh/ton of newsprint from that currently required by TMP mills. Savings of this magnitude of purchased electric power is equivalent to a savings of 11 million Btu of heat input at the powerplant. In addition, 3.5 million Btu of usable heat could be recovered, offsetting over 50 percent of that currently required in the pulp and papermaking process.

Further improvements in energy efficiency and wood utilization could result if a recycle pulpmill were integrated with either SG or TMP pulpmills (fig. 25). The practical upper limit of recycled fiber in the pulp mix is estimated to be about 40 percent. A small proportion of kraft pulp is required in the mix to strengthen the newsprint if larger proportions of recycled pulp are used.[49] The major gains in energy efficiency between a wholly roundwood C M P or CT M P mill and one integrated with a recycle pulpmill are in reduced electrical-energy consumption. Reductions in energy consumption of between 179 and 358 kWh/ton of pulp may be achieved by recycling, so Process heat requirements remain approximately the same when recycling is used, but the amount of recoverable waste heat is decreased from 3.5 million to 2,2 million Btu.

Substantial technical improvements are possible in mechanical pulping processes within the next **20** years, providing that economic incentives exist and capital formation is possible.

Chemical Pulping

Commercial Chemical Pulping Technologies

Chemical pulping processes involve treating wood chips with chemicals to remove the lignin and hemicellulose, thus separating and delignifying the fibers, Delignification gives the fibers greater flexibility, resulting in a substantially stronger sheet of paper—because of greater contact between the fibers in the finished sheet—than can be manufactured from fibers with lignin produced by mechanical pulping.

Two major chemical pulping technologies are currently in use: 1) kraft (sulfate) pulping and 2) sulfite pulping. The kraft process dominates the pulp and paper industry, accounting for over 75 percent of all pulp produced for paper and paperboard in 1979.[51] Other chemical pulping processes, such as acid sulfite pulping, bisulfite pulping, and neutral sulfite semichemical pulping account for approximately 3 percent (the remainder was produced by mechanical pulping), Paper made from pulp

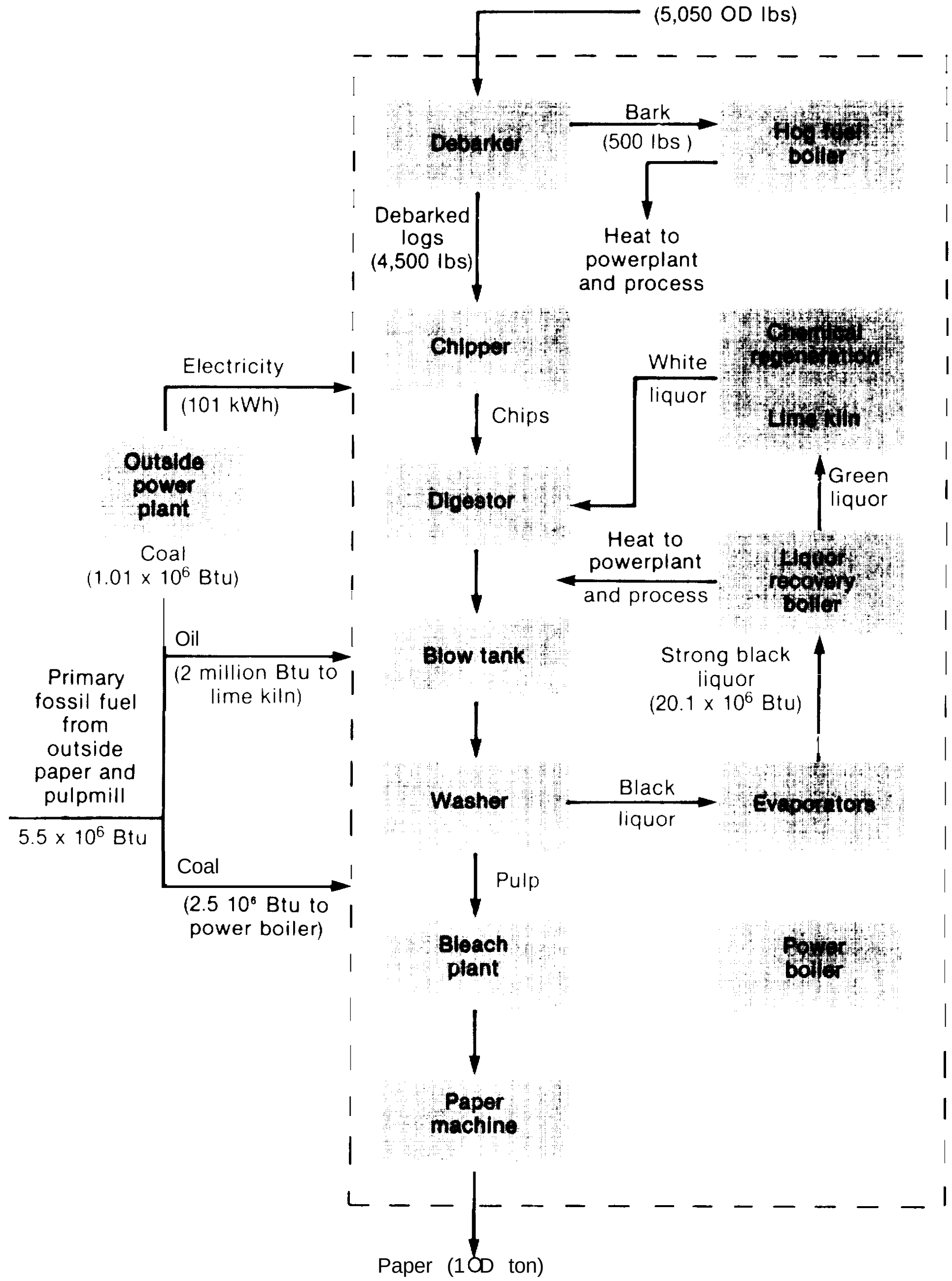
[48] Walker and Batsis, op. cit.

[49] W. E. Franklin, *Paper Recycling: The Impacts of Contaminants 1973-1985, Summary and Overview* (Kansas City, Mo.: Midwest Research Institute, 1975).

[50] P. Sizifert, R. Secor, and P. Cruea, "Waste-Paper Pulping With Minimum Energy," *TAPPI*, vol. 59, 1981, pp. 111-113.

[51] American Paper Institute, *Statistics of Paper and Paperboard: 1980* (New York: API, 1980), p. 54.

Figure 25.—Material and Energy Flow into a Kraft Pulpmill



SOURCE: P. J. Hurley, *Comparison of Mills Energy Balance: Effects of Conventional Hydropyrolysis and Dry Pyrolysis Recovery Systems* (Appleton, Wis.: Institute of Paper Chemistry, 1978).

produced by the kraft process accounts for most of the bleached boxboard and linerboard used by the packaging industry (which consumes 58 percent of the paper in the United States).

In addition, bleached softwood kraft pulps often are mixed with mechanical pulps to add strength to newsprint and printing papers. Bleached hardwood kraft pulps are added to bleached softwood pulp to improve printability for specialty paper products like magazine stock and coated papers.

KRAFT (SULFATE) PULPING

The kraft process involves treating wood chips and sawdust with a sodium sulfide and sodium hydroxide solution. The highly alkaline chemical mixture is cooked in a digester for 1 to 3 hours at temperatures ranging from 320° to 350° F (fig. 25). The complete pulp and paper making process is shown in figure 26.

Fiber recovery from the kraft pulping process is largely a function of the wood species used, the amount of chemicals used, the time and temperature of cooking, the degree of bleaching, and the paper strength required. Generally, kraft pulp recoveries from softwoods are approximately 47 percent for unbleached pulp and 44 percent for bleached.[52] Hardwood recoveries range from 50 to 52 percent for unbleached kraft pulp and 45 to 50 percent for bleached.

Energy is used in a mill in different forms (as chemical heat of reaction, as thermal energy, and as electrical energy), and these typically are expressed in different units (Btu for thermal and for heat of reaction in fuel combustion, and kWh for electricity). While the **units** may be converted simply (i.e., 1 kwh = 3,412 Btu), the actual forms of energy may *not* be converted without loss of energy available for doing useful work. Thus, in a typical powerplant, it takes 10,000 Btu of heat input to produce 1 kWh of electricity (in contrast to the unit conversion above), and two-thirds of the input is lost as exhaust. There are, then, two ways to compare a mill's energy uses: 1) simple unit conversions, representing all uses in a common unit; or 2) representing all uses in terms of the heat values of their original forms, while recognizing energy conversion losses.

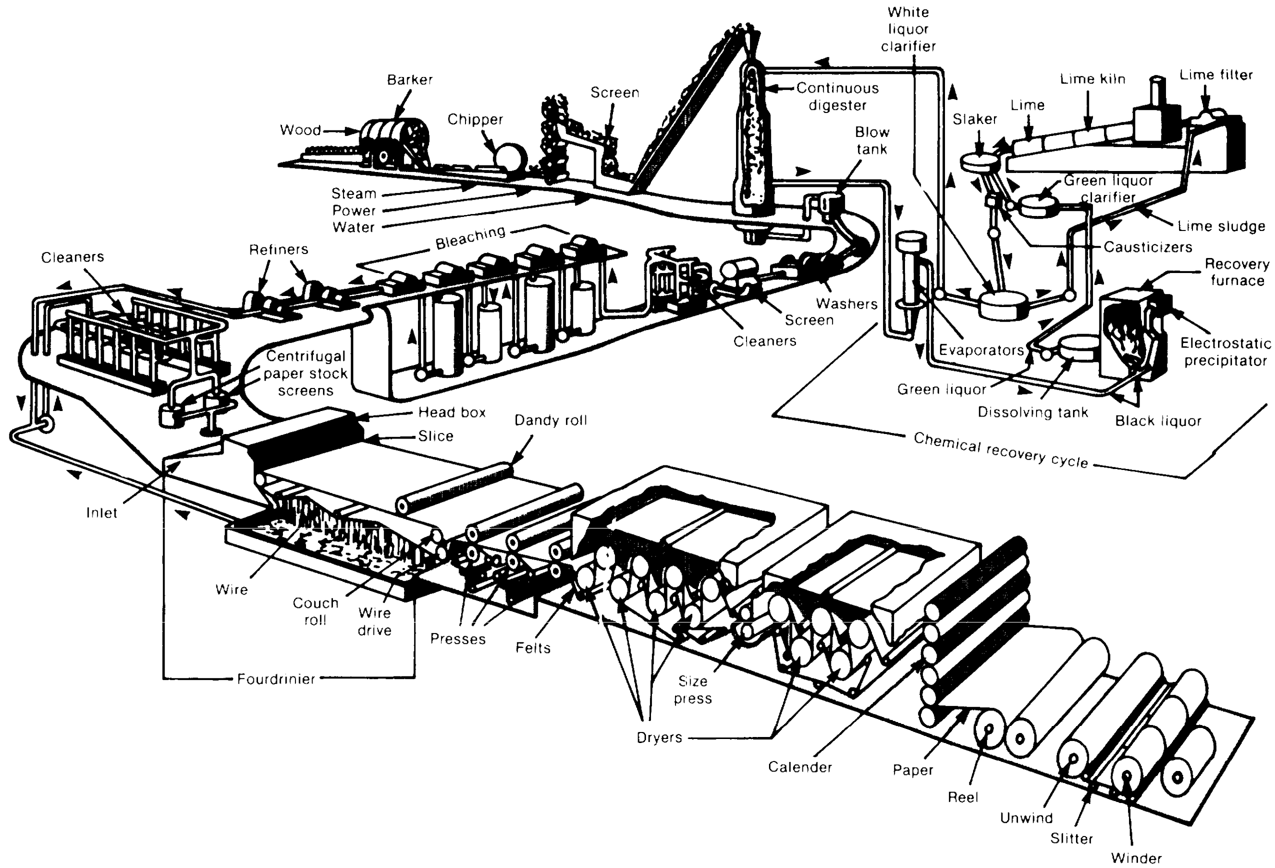
The different conclusions reached by these approaches is illustrated by the following: the first method gives rise to the conclusion that self-generation in today's typical kraft paper mill provides about 50 percent of the mill's energy needs, while the second method (table 28) shows that 82 percent of the primary fuel supplying the total energy needs of a typical kraft mill is self-generated. The first method relates better to concerns for fossil-fuel avoidance, while the second helps relate the fuel value of wood-process residuals to other potential uses. Of the two approaches, the latter is the more useful for assessing process efficiency.

Energy consumption is a major cost in the manufacture of kraft pulp and paper. The combined process requires approximately 30 million Btu of primary fuel per ton of bleached kraft paper (table 29). This energy value includes fossil fuel burned at an outside powerplant to provide purchased electricity as well as the thermal energy derived from the wood resource. Approximately 78 percent of the energy demand is for thermal energy used in the plant, the major portion of which is used for paper making and self-generation of electricity rather than in the pulping process. While the combined kraft pulp and paper making process requires approximately 1,050 kWh/ton of electricity, mostly for drive motors, all but 101 kWh generally is produced internally through cogeneration (table 29). Burning waste liquors and bark provides 82 percent of a mill's primary energy needs.

The kraft process is suitable for pulping both softwoods and hardwoods. Wood chips, sawdust, and wood residues from sawmills and veneer mills can be used as furnish, Over 35 percent of the total wood supplied for kraft paper are wood residues. In the Pacific Northwest, nearly 90 percent of the wood originates from sawmill or veneer mill residues. Whole tree chips, including bark and branches, currently

[52] P. J. Hurley, *Comparison of Mills Energy Balance: Effects of Conventional Hydropyrolysis and Dry Pyrolysis Recovery Systems* (Appleton, Wis.: Institute of Paper Chemistry, 1978).

Figure 26.—Overall View of Papermaking From Chemical Pulp by the Kraft Pulping Process



SOURCE: F. F. Wangaard, *Wood: Its Structure and Properties* (University Park, Pa.: Pennsylvania State University, 1981), pp. 342-343.

are used in limited quantities, although their proportion of the total furnish is increasing. Because of the density, extractive content, and chemical nature of these materials, increases in their use may cause the pulping liquors (chemicals) to react more slowly, resulting in a need for longer digestion periods and increased energy expenditures.

SULFITE PULPING

The four fundamental sulfite pulping processes currently in commercial use are: 1) acid sulfite, 2) bisulfite, 3) neutral sulfite, and 4) alkaline sulfite. The major differences between the sulfite processes are the levels of acidity and alkalinity of the sulfite chemical solutions used to break down the wood and remove the lignins. The cooking liquor consists of a salt base—generally calcium, magnesium, sodium or ammonium—and sulfuric acid. Sulfite processes are suitable only for species with low extractive contents, i.e., those low in tannins, polyphenols, pigments, resins, fats, and the like, because of the interference of these substances with the sulfur pulping process. Although calcium is the cheapest base available, it forms insoluble compounds that cannot be reclaimed economically or disposed of easily. Thus, calcium-based pulping is seldom used. Because magnesium- and sodium-based chemicals are recoverable, and ammonium-based chemicals can be burned without harmful environmental effects, they are the most frequently used.

Sodium-based sulfite pulping can consist of multistage cooking, successive stages of which differ in acidity. Because one stage optimizes chemical liquor penetration and the other the

Table 28.—Energy Demand Per Ton of Kraft Paper

	Energy demands Million Btu	kWh
Thermal:		
Process:		
Digester	3.8	
Bleach plant	2.4	
Paper machine	6.8	
Evaporation	3.0	
Liquid heating	2.9	
Other	2,5	
Subtotal	21,4	
Lime kiln	2,0	
Total	23.4	
Electric:		
Self -generated:		949[a]
Fuel-value material recovered in plant and burned for electricity	5.7[b]	
Purchased from outside:		101[a]
Fuel used by outside powerplant to produce electricity	1.0[c]	
Totals:		
Total electricity		1,050
Total fossil fuel consumed	30.1	

[a]Hurley, P J
[b]Incremental heat rate to generate electricity in plant 6,000 Btu/kWh
[c]Assumes outside electric plant is fossil-fueled at 10,000 Btu/kWh

SOURCES J J Watkins and W S Adams, "The St Regis Hydrolysis Process as an Approach to Energy Conservation in the Pulp & Paper Industry," *Proceedings of TAPPI '78 Engineering Conference Book III*
P J Hurley, *Comparison of Mills Energy Balance Effects of Conventional Hydropyrolysis and Dry Pyrolysis Recovery Systems* (Appleton, Wis Institute of Paper Chemistry, 1978)

removal of lignin, more lignin may be removed with less fiber degradation, so that fiber yields are higher, fibers are stronger, and a wider range of wood species may be used. Neutral sulfite pulping, using sodium and ammonium bases, recovers the largest proportion of fiber (75 to 90 percent) of all the sulfite pulping methods.

Improvements in Chemical Pulping

Two kinds of improvements have been made in chemical pulping technologies: 1) better efficiency of current processes and 2) development of new pulping technologies that depart from the conventional commercial processes. The greatest potential for dramatically improving pulp and paper manufacturing lies in new technologies. Such innovations could enable the use of large quantities of currently underutilized hardwood species and may even have prospects for developing superior new papers for future specialized uses. At the same time, new concepts in energy use and cogeneration could achieve new levels of energy efficiencies. Among the most promising new pulping and papermaking processes are: 1) press-dried paper, **2)** green liquor pulping, 3] autocausticizing, and 4) pyrolytic recovery of chemicals in spent pulping liquor. These developing technologies are not yet commercially available.

PROCESS IMPROVEMENTS

Major efforts in process improvements, or means in which the efficiency of existing commercial processes is improved, have centered on increasing fiber recovery and energy efficiency. Most such efforts have focused on the kraft process, which produces 90 percent of all chemical pulps manufactured. Greatest emphasis has been placed on reducing energy consumption because it is the largest cost factor.

Anthraquinone (AQ) recently has been tested as a catalyst in kraft pulping. When added in small quantities to the cooking liquor, AQ speeds up the pulping process and can improve fiber recovery by as much as 2 to 4 percent. Although the percentage increase in yield may seem small, the increases in absolute yield are considered substantial because of the very large volumes involved. AQ pulping was developed by Canadian Industries, Inc., and is

Table 29.—Energy Consequences of Pyrolytic Recovery (basis: 1 ton pulp)

Energy required	Conventional	Recovery method hydropyrolysis	Dry pyrolysis
Process yield (percent ovendried)	47.5	48.75	47.5
Electricity (kWh):			
Internally generated	949	850	812
Purchased	101	256	258
Inplant fossil fuel (thousand Btu)	10,411	5,458	6,296
Inplant fossil-fuel savings (percent)		48 0/0	40 "/0

SOURCE: P. J. Hurley, *Comparison of Mills Energy Balance: Effects of Conventional Hydropyrolysis and Dry Pyrolysis Recovery Systems* (Appleton, Wis.: Institute of Paper Chemistry 1978) used commercially in both Japan and the United States. Its potential broad-scale application in the United States, however, maybe limited by its cost and the lack of technology to recover the used AQ.[53] The U.S. Food and Drug Administration (FDA) recently has approved AQ for use in paper packing for food, opening new market potentials for AQ pulp.

The industry's goal is for the kraft pulping process to become as energy self-sufficient as possible. Substantial gains in energy efficiency are expected within the next 20 years, but it is not known whether total self-sufficiency is attainable. Kraft mills may approach self-sufficiency if some modifications are made; for example: 1) the temperatures in boilers that burn wood residues and black (lignin) liquor can be reduced (primarily by adding more efficient heat exchangers for heat recovery, and 2) lime kilns maybe fueled with dried sawdust without seriously contaminating the calcined lime used for making the pulping liquor. The latter has been demonstrated successfully in Sweden.[54] These system modifications are expensive and may increase the operating costs of a plant. Their adoption will depend on the future costs of energy and the availability of capital.

GREEN LIQUOR PULPING AND AUTOCAUSTICIZATION

Economy in chemical pulping depends on effective recovery of chemicals from the used cooking liquor. Upon interaction with wood in the cooking process, the "white liquor, " that is, the original sodium sulfide and sodium hydroxide solution, becomes "black liquor," rich in lignin salts and other organics removed from the wood in the pulping process. The black liquor is pumped to evaporators that remove the water and concentrate the remaining salts and organic solids. The resulting viscous solution is burned in a recovery furnace to remove the organic residues (fig. 26).

The remaining salts—mostly sulfides and carbonates of soda—form a molten stream referred to as "smelt" and are recombined with water to form "green liquor. " The sodium carbonates in the green liquor normally are converted into hydroxides for reuse by the addition of calcium hydroxide in a process referred to as "causticizing."

Pulping of hardwoods and softwoods using green liquor, which eliminates the causticizing process, is now an accepted commercial technology for producing semichemical pulps. In this process, disodium borate is used instead of sodium hydroxide in the original white liquor, and the liquor produced by dissolving the smelt can be reused directly in the digester. In this way, the entire regeneration loop, including the lime kiln, is removed. As much as 18 percent of the fossil energy required for pulping can be eliminated by autocausticization. Elimination of the lime kiln not only reduces energy consumption, but reduces capital costs by $35/annual ton of capacity and operating costs by $3/ton.[55] Industry experts give autocausticizing a high probability of commercial acceptance.

PYROLYTIC RECOVERY

Technology for pyrolytic recovery of black liquor has been developed in two processes: 1) a hydropyrolysis method developed by the St. Regis Paper Co., and 2) a dry pyrolysis method developed by Weyerhauser Corp. Pyrolytic recovery consists of applying heat in the absence of oxygen (anaerobic combustion) to decompose the organic compounds in the black liquor. These new spent-liquor recovery techniques, designed to extract energy from the spent liquor while retaining the chemicals for reuse, are more energy efficient than are current processes. They are important because regeneration of the pulping chemicals requires a large share of the energy used in the pulping process.

Hydropyrolysis technology currently is being evaluated on a pilot basis in St, Regis' Pensacola, Fla., mill. The process shows potential

[53] Huber, op. cit., p. 85.

[54] K. Lappe, "Advanced Drying Process is Key to Burning Peat, Wood Byproducts, " *Energy Systems Guidebook (New* York: McGraw-Hill, 1980).

[55] J. Jansen, "Pulping Processes Based on Autocausticizable Borate, " *The Delignification Methods of the Future* (Helsinki, Finland: Europa Symposium, 1980).

for reducing the energy requirements for evaporating weak black liquor, i.e., that recovered in the initial washing stage, and for aiding in the energy recovery process. It is estimated that fossil-fuel energy required for generation of process heat may be reduced by 50 percent with the application of hydropyrolysis technology.[56]

St. Regis' experience with its pilot plant indicates that application of hydropyrolysis technology results in a tradeoff between purchased fossil fuel and purchased electricity. Lowered heat requirements for liquor recovery result in less process steam; thus, the potential for cogenerating electricity along with the steam needed is limited. The results of these tradeoffs are shown in table 29, where the data suggest that an in-mill fossil fuel savings of up to 48 percent can be achieved with hydropyrolysis and approximately 40 percent with dry pyrolysis. However, considering the fossil fuel used to generate the purchased electricity, the net fossil fuel savings are 28 percent and 20 percent, respectively.

OTHER CHEMICAL PULPING TECHNOLOGIES

Attempts to develop alternative pulping technologies that increase yields, energy efficiency, and pulp quality of the kraft process have led to two new chemical pulping concepts that show some promise: 1) organosolv (alcoholysis) pulping and 2) oxygen pulping. Since both still are under development, and neither has reached the demonstration stage, they must be considered long-range (25 + years) prospects for commercial application,

Organosolv Pulping.-Organosolv pulping is a two-stage process involving hydrolysis (decomposition of the wood by dilute acids or enzymes) and the removal of lignin with an organic solvent, usually a mixture of alcohol and water. The still-experimental process is suitable for both hardwoods and softwoods. Pulp recovery from organosolv pulping ranges between 50 and 60 percent for hardwoods, and 40 and 45 percent for softwoods. Typical hardwood-fiber recoveries compare favorably with those from kraft pulping: approximately 50 percent for red alder, sweetgum, and American sycamore, and 60 percent for cottonwood and trembling aspen.

Fibers produced by the organosolv process are weaker than those recovered by the kraft process, Thus, the papers produced from organosolv pulp are suitable for uses where strength is not the most important property, such as for printing papers, fluff pulps, and dissolving pulp,

Reaction temperatures are low—between 320° and 370° F for hardwoods and 360° to 390°F for softwoods if acid catalysts are used. Little waste is produced by the process, and low alcohols are recovered easily by distillation, thus requiring relatively low capital investment.[57]

Oxygen Pulping.—An extension of existing oxygen bleaching technologies, oxygen pulping may reduce or eliminate the need for bleaching plants in the paper mill. Oxygen pulping involves the introduction of gaseous oxygen into the pulping liquor to stimulate oxidative fracture of the cellulose-lignin bonds. This process could save capital and operating costs because equipment costs are lowered, less bleaching chemicals are used, and pollution control expense is cut by eliminating chlorine from the bleaching process.

The cost of oxygen pulping is largely a function of the cost of oxygen. Oxygen production requires approximately 400 lbs of oxygen and 54 kWh/ton of pulp produced (based on 1.2 kWh/hundred cubic feet(H3),or0.135 kWh/lb. Several manufacturers currently are developing plant equipment capable of applying oxygen pulping commercially.

PRESS DRYING PAPER

Press drying technology developed at FPL shows promise for both reducing the amount of energy required in the paper-making process and enabling the use of underutilized hard-

[56]Hurley, op. cit.

[57]N. Sanyer, *Status of New Pulping Processes; Problems and Perspectives* (Madison, Wis.: U.S. Forest Product Laboratory, 1982], p. 10,

wood species. Press drying uses high-yield hardwood or softwood kraft pulp to produce linerboard with strength superior to that of conventional softwood kraft paper in every respect except tear strength (table 30). At the same time, press drying can reduce the amount of energy used in the drying process by applying pressure to the fiber (pulp) mat as it is dried. With conventional drying technology, pressure and heat are applied separately.

The superior strength of press-dried paper comes from the combined effects of heat and pressure, which force the fibers into closer contact and cause stronger bonds to be formed between them. The heat and pressure also cause natural polymer flow and cross-linkages among the fibers as a result of the hemicellulose contained in the pulp. Paper produced from press-drying kraft red oak pulp has been shown to have burst strength and tensile strength approximately 13 percent higher, and compression strength 50 percent better, than that of conventionally dried pine kraft paper. The lower tear strength of press-dried hardwood paper may limit its use for wrapping or sack paper; however, its higher burst strength and tensile strength make it suitable for linerboard.

Estimates of the potential net energy savings from using press-drying technology are about 19 percent for the papermaking process, [58] Although a commercial-scale, press-dried papermaking machine has not been built yet, press drying may actually reduce equipment requirements and capital investment in both the drying section and the pulping process because it can use unrefined pulp.[59] The major limitation to press drying paper, which must be overcome before the technology can be applied commercially, is the low speed of the papermaking machine and the resulting slow production rate of the pilot-scale equipment used at the FPL.

Dissolving Pulp Technologies

Dissolving pulp technologies are not pulping technologies as such, but secondary processes that produce nearly pure cellulose (alpha-cellulose) for conversion to rayon, plastics, and other chemicals. Pulps made by either the kraft or sulfite process are purified further chemically to remove all hemicellulose and leave only pure cellulose, which then can be transformed into products like viscose rayon, cellophane, and acetate fibers and film. The largest single use for dissolving pulp is in the viscose rayon process, which accounts for over 99 percent of the world's rayon production.

A variety of hardwood and softwood species is suitable for the production of dissolving pulp, including pine, hemlock, spruce, oak, birch, and gum. Highly resinous wood, such as Southern yellow pine, normally is not used for dissolving pulp because of the difficulty of removing extractives in the purification process. The highest grades of dissolving pulp are called cord, acetate, and nitrate pulps, which approach 98 percent pure cellulose; normal grades of viscose rayon pulp contain some hemicellulose and maybe only 93 percent pure. Because of the need for nearly pure cellulose,

[58] V. Setterholm and Peter Ince, "The Press Drying Concept for Papermaking," *Southern Lumberman,* Dec. 15, 1980.

59P. J. Ince, "FPL Press Drying Process: Wood Savings in Linerboard Manufacture," *TAPPI,* vol. 64, 1981, p. 109,

Table 30.—Strength Properties of Press-Dried Hardwood Paper and Conventional Softwood Paper

	Anticipated strength with oak	Present strength with oak	Conventional strength with pine
Burst strength (lb/in w)[a]	155	145	97
Tensile strength (lb/in w)	100	68	54
Compression (lb/in w)	45	30	20

aPounds per inch of width

SOURCE U S. Forest Products Laboratory, 1981 pulping yields for the kraft and sulfite processes are reduced to approximately 28 to 38 percent, depending on the pulp purity desired. The low yield of high-quality, alpha-cellulose pulps makes them expensive to produce—energy and pulpwood costs account for **50 to 60** percent of the manufacturing costs.[60]

Total U.S. production of dissolving wood pulp was approximately 1.5 million short tons in **1979 (23** percent of world production). Approximately 61 percent of the dissolving pulp produced was used for textile fibers; the remainder was used for the manufacture (in descending order) of chemicals and plastics, cellophane, cellulose nitrate (for propellants), and specialty papers for use in industrial and automotive filters.

In addition to the viscose rayon process for the production of fibers and cellophane (which is made by the same viscose process but is extruded through a slot to form film rather than through holes to form threads), cellulose may be converted into acetate forms (acetyl esters) that can be manufactured into cellulose acetate, cellulose diacetate, and cellulose triacetate for conversion into fibers. Cellulose nitrate continues to be produced in significant quantities as an explosive and a propellant. Other products manufactured from dissolving pulp include ice cream thickeners, detergents, carbon fibers of high strength and stiffness, and gels used in hand lotions and food products.

Rayon Manufacture

Rayon, first made in 1881, is the oldest manmade synthetic fiber. The success of rayon in the market is due to several factors:

- Cellulose continues to be the cheapest polymer for fabrics.
- Rayon's moisture absorption, capacity for absorbing dyes, and ability to swell makes it suitable for clothing. Rayon also can be blended with other synthetic fibers, like nylon, to improve their moisture-absorbing qualities.
- properties of the dissolving pulp can be varied to produce pulps suited for specific end uses. For example, ITT Rayonier, a leading U.S. producer of dissolving pulps, offers 16 grades of pulp matched to the properties of the rayon to be produced.

Rayon is made by dissolving cellulose xanthate in alkali and spinning the fiber through small pinhole jets into a sulfuric acid bath, which coagulates the fiber into final form. If the same xanthate-viscose solution is forced through a narrow slit, a cellophane film is formed.

Major developments in rayon technology have been aimed at:

- improving the efficiency of rayon production;
- reducing energy requirements;
- controlling or eliminating environmental pollutants generated by the viscose rayon process;
- developing more cottonlike rayons to supplement cotton production; and
- developing a completely new system for converting chemical cellulose to fiber by a nonviscose, environmentally sound, more efficient process using recoverable cellulose solvents.[61]

Major emphasis has been placed on developing a rayon with a high wet-strength to remedy the shortcomings of conventional rayon and to compete with cotton more effectively. A number of new fibers outperform conventional rayon; they include Courtauld's "Corval, " a cross-linked fiber; American Viscose's "Avril"; and Enka's "Fiber 700. "

Process developments within the rayon industry seem to be moving toward automation and computer control. Experts foresee new, versatile rayons made by solvent-extrusion processes similar to those used for making nylon and polyester. These may lead to a future one-step process from pulp to viscose solution; however, many of the current developments in this area are treated as proprietary and are not open to inspection.

[60]C.B. Metz, "Dissolving Pulps-The Future Economic Situation, " *Proceedings of the 5th International Dissolving Pulps Conference* (Vienna, Austria: Oct. 8-10, 1980).

[61]G. Daul, "Rayon Revisited, " *Chemtech*, February 1981, p. 84.

The viscose process is one of the most versatile for manufacturing textile fibers. Modification of the viscose manufacturing process easily can accommodate stretching and orienting the fiber and building certain desired properties into it. For example, it is known that the addition of metallic salts, such as zinc and other modifiers, will delay the reformation to rayon to allow time for spinning and manipulating the fiber. Formaldehyde also has been found to be an effective modifier for the production of super-strong fibers; however, environmental problems associated with it must still be overcome.[62]

Research to improve the strength and performance of rayon materials continues. These efforts include the search for new solvents for use in the spinning (forming) process. One such process that shows promise uses a special solvent (methyl-morpholine-N-oxide, MMNO) to orient the molecules in solution to form rayon with high-strength cellulose fibers. Success of the MMNO process may depend on development of a solvent recovery system needed to make the manufacturing process economically competitive.[63] Some experts see the testing of other new solvents leading to a major new system for manufacturing rayon.[64]

Other Cellulosic Products

A number of other products can be made from dissolving pulp. For example, cellulose acetate is produced by steeping dissolving pulp or cotton liners in acetic acid to prepare fibers for conversion to acetate, This same process may be used to produce cellulose butyrate and cellulose propionate for the production of plastics.

An acetate of slightly different chemical form, cellulose triacetate, also can be made from dissolving pulp. Unlike rayon, it is water-repellent like nylon, orlon, and terylene. Its water repellency is attributable to the degree of acetylation of the fibers. It has good thermal properties and wear characteristics, and frequently is used in fabric blends with nylon, wool, and rayon in women's clothing.

Cellulose esters—acetate ester, acetate butyrate, and acetate propionate—are a family of plastic materials derived from dissolving pulp that can be formed, molded, and extruded by a variety of thermoplastic processes. Higher forms of these materials also maybe prepared; however, their high production costs restrict them to highly specialized applications such as cellulose acetate phthalate, which is used as a coating on pharmaceuticals. Cellulose ester powders are used in fluidized-bed and electrostatic coating processes, as well as in rotational molding processes. Modified cellulosic polymers are used in preparation of films, coatings, fibers, lacquers, and adhesives,

Finally, dissolving pulps also may be used to produce a variety of chemical products, including methyl- and carboxymethyl-cellulose, that are used as thickeners in latex paints and ice cream; ethylcellulose, used as a thermoplastic molding compound; and nitrocellulose, used as a propellant/explosive.

[62] Ibid., p. 84.

[63] R.N. Armstrong, C. C. McCorsky, and J. K. Varoa, ''Spinnable Solutions of Cellulose Dissolved in Amine Oxides, " *Proceedings of the 5th International Dissolving Pulps Conference* [Vienna, Austria: Oct. 8-10, 1980).

[64] H.L. Hergert, R. B. Hammer, and A. F. Turbak, ''New Methods for Preparing Rayon, ' *Proceedings of the 4th International Dissolving Pulps Conference* (Chicago, 111.: Sept. 28-30, 1977),