DRAFT

BACKGROUND PAPER ON ENERGY EFFICIENCY AND THE PULP AND PAPER INDUSTRY

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Contents

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1. INTRODUCTION

Pulp, paper, and paperboard mills account for 95% of energy use in the U.S. paper and allied products industry (SIC 26)[1] and about 12% of total manufacturing energy use in the U.S.

Paper is one of the few basic materials, the per-capita demand for which has not saturated in the U.S. (Williams et al., 1987). The increase in apparent per capita consumption[2] averaged 1.8% per year 1960-1980 and 1.6% per year 1980-1993 (AFPA, 1994). The U.S. has the highest apparent consumption of paper in the world, 313 kg in 1990. For comparison, consumption in 1990 in the United Kingdom, Brazil, and India was 164, 28, and 2.8 kg per capita, respectively (Table 1.1). Consumption in the U.S. has been projected by the USDA Forest Service to reach 413 kg per capita in 2040, corresponding to a 0.6% annual increase from 1990.

Total apparent consumption in the U.S. increased 3.0% per year 1960-1980 and 2.6% per year 1980-1993 (AFPA, 1994). For comparison, the increase in world and Western European consumption averaged 3.2% and 3.1% per year, respectively, 1971-1990. World and Western European demand has been forecast to grow by 2.5% and 2.4% per year, respectively, over the next decade (Gundersby and Rennel, 1992).

1.1 Role in the U.S. economy

The U.S. has the world's largest installed pulp, paper, and paperboard production capacity, some 86 million air-dry metric tonnes (ADMT)[3] per year in 1994, or about 30% of world capacity.[4] In total there are 201 pulp producing mills (AFPA, 1994), many of which are annexed to paper or paperboard producing units. Pulp production capacity is some 63 million ADMT per year. (The next biggest producers are Canada and Scandinavia, with capacities of 29 and 25 million ADMT per year, respectively.) The U.S. has a total of 547 paper and paperboard mills.

The value of exports and imports in 1993 was $9.6 billion and $10.6 billion, respectively. Major imports were newsprint, printing and writing paper, and bleached kraft pulp. Major exports included paperboard, waste paper, and bleached kraft pulp. In addition to traditional competitors in the world market such as Canada and the Scandinavian

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[1] The paper and allied products industry group (SIC 26) consists of five 3-digit level SIC industries: pulp mills (SIC 261); paper mills (SIC 262); paperboard mills (SIC 263); paperboard boxes and containers (SIC 265); and converted paper and paperboard products (SIC 267). In this paper we focus on the first three of these--pulp, paper, and paperboard mills, sometimes called primary mills. We refer at times to these as the pulp and paper industry.

[2] Apparent per-capita consumption is domestic production plus imports less exports, divided by population.

[3] ADMT is a standard measure of the mass of pulp or paper. One ADMT is 10% moisture and 90% dry substance.

[4] For comparison, the approximate capacities of other big producers (in ADMT per year) are Japan (35.6), Canada (20.5) and the former West Germany (14.9) (FAO, 1990).

countries, the U.S. industry is facing increasing competition from low cost producers such as Chile, Indonesia, Brazil, and South Africa.

The value of shipments from the U.S. paper and allied products industry (SIC 26) was $129 billion in 1991, ranking it eighth among all U.S. manufacturing industries, and the value added was $58 billion. The value of shipments from pulp, paper, and paperboard mills was $54 billion, and the value added was $25 billion (AFPA, 1994).

New capital expenditures in the last decade have averaged 10.4% of revenues (AFPA, 1994). This makes paper and allied products the most capital intensive of the manufacturing industries. In addition, pulp, paper, and paperboard mills are more capital intensive than the paper and allied products industry average. Pulp, paper, and paperboard mills employed nearly 200,000 people in 1991 and had a payroll of about $8 billion.

Wood for pulping represents the largest cost among material inputs to the pulp and paper industry, accounting for an average of 21% of total material and energy costs. The corresponding numbers for energy, wood pulp, and chemicals are 17%, 15% and 6%, respectively, Table 1.2. It should be noted, however, that the industry uses about twice as much energy as indicated by these numbers since 56% of total fuel and electricity use is self generated (primarily from spent pulping liquors, wood residues, and bark) and thus does not appear explicitly as a purchased energy cost.

The capital intensity of the industry and associated scale economies have contributed to the closing of many smaller pulp and paper mills. The number of mills in the U.S. fell from 635 in 1980 to 544 in 1990 and most of the shutdowns were of mills that produced 50,000 ADMT per year or less. Mills with a capacity of 500,000 ADMT per year or more grew from 20 to 40 in the same time period (Dils, 1992). However, partly because of the difficulties of siting very large mills and partly because of the geographic distribution of waste paper there is now a trend toward the building of smaller mini-recycled pulp mills near urban areas. The equipment for processing recycled fiber is more modular and thus does not offer the same economies of scale that characterize virgin fiber pulp mills.

Over the past several years, U.S. pulp and paper companies spent about 1% of sales on research and development. For comparison, the automotive and chemicals industries spend more than 4% of sales and the overall average for the industry in 1991 was about 3.6% (Dils, 1992). Companies that supply the pulp and paper industry with equipment, chemicals, etc., have taken a more central role in conducting and sponsoring research than the industry itself.

1.2. Energy use

The energy intensity (expressed in megajoules per $ value of shipments) of the paper and allied products industry was 21 MJ/$ in 1991, ranking it as the second most energy intensive industry group in the manufacturing sector (Figure 1.1). It accounts for 12.4% of total manufacturing energy use, or about 3% of national energy use. At the 4-digit SIC level, the energy intensity of paperboard, pulp, and paper mills puts them in 4th, 6th, and 12th place, respectively (Figure 1.2). Total energy use in the pulp and paper industry in 1991 has been estimated to be 2.5 EJ (MECS, 1994), corresponding to about 95% of total energy use in the paper and allied products industry. For comparison, the American Forestry and Paper Association reports similar numbers based on member surveys: 2.7 EJ in 1991 and 2.8 EJ in 1993 (Table 1.3).

The industry has made important strides in reducing total energy use since 1973 and in increasing the fraction of energy provided from self-generated biomass sources. Total energy use per ADMT decreased by about 1.5% per year between 1972 and 1986 and has remained relatively constant in recent years (Fig. 1.3). Use of fossil fuels and other purchased energy decreased by about 3% per year between 1972 and 1986 (from about 25 GJ per ADMT in 1972 to 17 GJ per ADMT in 1986) and subsequently leveled off.

Figure 1.4 shows estimates of the major energy flows in the industry, based on data from the Manufacturing Energy Consumption Survey (MECS, 1994). The major end uses of process steam are digesters, evaporators, and driers. The major electricity use is for machine drives, which are primarily for pumps, fans, and wood grinding equipment.

The ratio of electricity-to-heat demand has been increasing steadily in the pulp, paper, and paperboard industry. This trend is reflected, for example, in a near doubling of purchased electricity between 1972 and 1993, while total purchased energy decreased by 7%. The trend towards higher electricity to heat ratios is being driven by increasing electrification (in part to meet more stringent environmental regulations), combined with thermal energy efficiency improvements. As a result there is growing interest in the industry in electricity conservation and in cogeneration technologies characterized by higher electricity-to-heat production ratios.

The pulp and paper industry can be distinguished from most other manufacturing industries by its extensive use of biomass fuels and cogeneration. Self-generation of energy amounted to 56% of total industry energy use in 1993 (Table 1.3), up from 40% in 1972 (Fig. 1.3). The most recently available survey data indicates that about 50 TWh of electric power was cogenerated in the industry in 1991 (API, 1992), which is equivalent to about half of total electricity consumed.

1.3. Environment

Environmental concern, manifested in changing market demand and more stringent environmental regulation, is among the most important drivers of technological change in the pulp and paper industry. The industry's annual capital expenditures on environmental protection between 1987 and 1993 was estimated to be between 10% and 19% of total annual capital expenditures (AFPA, 1994). While requiring capital expenditures, environmental concerns have also provided a competitive advantage for the industry against paper substitutes, since the industry produces recyclable products from renewable resources using relatively few non-renewable inputs.

Environmental issues associated with pulp and paper manufacture include solid waste disposal; emissions to water of chlorinated organic compounds or adsorbable organic halogens (AOX), including dioxins and furans, chemical/biological oxygen demand (COD/BOD), phosphorous, and nitrogen; and emissions to air of sulfur and nitrogen oxides from fuel combustion.

The industry has made some important strides in reducing effluents from mills. SO_2 emissions in 1990 from pulp and paper mills were estimated to be 544 thousand tonnes, 75% of which were from fossil fuel fired boilers. This represents 2.6% of the national total SO_2 emissions of 21.1 million tonnes. Emissions of NO_x (277,000 tonnes) represented 1.4% of the national total in 1990. Between 1980 and 1990, a period during which paper production increased by about 30%, the emissions of SO_2 decreased by 30%, primarily as a result of switching to lower sulfur coal and oil, reduced oil consumption, and the installation of desulfurization equipment. NO_x emissions increased by 10% in the same period (NCASI, 1993). The amounts of BOD discharged in final effluent per unit of production in 1988 was one-third to one-quarter of that discharged in 1975 (NCASI, 1991).

The emissions from bleaching operations are considered the most toxic (Paulsson and Fallenius, 1987), and the environmental impacts of AOX have generated considerable debate. AOX is a gross measure of all chlorinated organic compounds and is often used as a measure because testing for it is inexpensive and reliable. AOX emissions are primarily associated with the kraft chemical pulping process, where chlorine or chlorine dioxide is used as a bleaching agent.

Environmental regulation to reduce AOX emissions and market demand for chlorine free products have driven the pulp and paper industry to find alternatives to elemental chlorine (Cl_2) as a bleaching agent. Chlorine dioxide (ClO_2) bleaching gives much less AOX than elemental chlorine bleaching and decreases the relative amount of the highly chlorinated and potentially most toxic compounds in the AOX (SEPA, 1992). Swedish data show that typical AOX emissions from bleach plants using elemental chlorine in the 1970s were 8-10 kg/ADMT (SEPA, 1992). Emissions from U.S. pulp mills have not been measured as consistently but are likely to have been in the same range. Emissions today are typically around or below 1 kg/ADMT from pulp mills in Scandinavia. Many modern North American mills reach the same levels.

There has been no federal or state regulation for AOX emissions although some individual mills have been permitted for AOX at levels similar to those faced by mills in other countries, e.g., 1-2 kg/ADMT for kraft pulp mills at present, and less in the longer term (EPA, 1993). The "cluster rules" which have been proposed by the EPA and that are expected to be promulgated in 1996 cover both air and water emissions and include AOX (Hinsey, 1994).

Elemental chlorine free (ECF) and totally chlorine free (TCF) pulp accounted for an estimated 70% and 30%, respectively, of the bleached chemical pulp production in Finland and Sweden in 1994, up from 25% and 0%, respectively, in 1990. The production of TCF in North America is negligible. ECF pulp was estimated to have a 25% and 50% market share of bleached chemical pulp production in the U.S. and Canada, respectively, in 1994 (NLK, 1994). The switch to TCF in Scandinavia has been driven largely by consumer demand for TCF paper in western Europe. At the current AOX levels from chlorine dioxide bleaching (< 1 kg/ADMT), it has not been possible to predict the environmental impact of an effluent on the basis of its AOX content, in part because non-chlorinated compounds in the mill effluents can contribute a non-negligible effect (Axegård et al., 1993). Since TCF bleaching is relatively new, there are not sufficient data to draw firm conclusions about the environmental impact and toxicity of discharges from TCF pulp mills. Nevertheless, consumer demands are likely to continue to push the industry toward greater use of TCF bleaching.

Environmental concern has also led to increased paper recycling. The solid waste management dilemma in key regions of the U.S. has been especially important in motivating a substantial increase in recycling. It has been estimated that 37.5% (by weight) of all municipal solid waste in 1990 was paper and paperboard (EPA, 1992). It is expected that investments in equipment to utilize recycled paper will account for the largest share of capital expenditures in the industry in the next few years (Metz, 1994). The fraction of new paper supply that is recovered for recycling has increased from 22% in 1970 to 39% in 1993. More than half of the increase occurred between 1988 and 1993. The industry intends to increase the fraction to 50% by 2000 (AFPA, 1994c). The present fraction in leading recycling countries like Japan, Austria, and the Netherlands is slightly higher than 50% (Bryntse, 1992).

Table 1.1. Apparent per capita paper and paperboard consumption in selected countries. Source: FAO, 1993; Bureau of the Census, 1994.

Country	1980 cons. (kg/capita)	1990 cons. (kg/capita)	increase 1980-90 (kg/capita)	annual average increase (%)	total cons. 1990 (million tons)
USA	267	313	47	1.6	78
Sweden	209	250	41	1.8	2.1
United Kingdom	121	164	43	3.1	9.4
France	115	154	39	3.0	8.7
Brazil	28	28	0.4	0.1	4.2
India	1.8	2.8	1.0	4.5	2.4

Table 1.2. Production cost breakdown in million U.S. dollars in the pulp, paper, and paperboard industry in 1987 (Source AFPA, 1994a).

Category	Pulp mills (SIC 2611)	Paper mills (SIC 2621)	Paperboard mills (SIC 2631)	All primary mills
Total mtrls & energy	**2,019**	**14,856**	**6,840**	**23,715**
Pulpwood	752	2,212	2,016	4,980
Chemicals	221	802	352	1,376
Wood pulp	n.a.	3,538	51	3,589
Waste paper	d.w.	541	969	1,511
Other materials	782	5332	2110	8,223
Energy	265	2,431	1,342	4,037
Value added	**2,281**	**14,024**	**6,914**	**23,220**
Employee costs	660	5,641	2,230	8,531
Contrib. to overhead	1,622	8,384	4,684	14,689
Value of shipments[a]	**4,313**	**28,918**	**13,730**	**46,961**

n.a. = not applicable
d.w. = data withheld by Census of Manufacturers to avoid disclosing data for individual companies
(a) Value of shipments is not exactly equal to materials & energy plus value added due to inventory changes.

Table 1.3. U.S. pulp, paper, and paperboard industry estimated energy use in 1993 (Source AFPA, 1994b)

Source	**Estimated Use (thousand Gigajoules)**	**Percent of total**
Purchased electricity[a]	181,878	6.6
Purchased steam	34,424	1.2
Coal	363,104	13.1
Residual fuel oil	186,715	6.7
Distillate fuel oil	6,980	0.2
Liquid propane gas	3,152	0.1
Natural gas	466,280	16.8
Other purchased energy	13,658	0.5
Energy sold	-38,230	
Total purchased fossil fuel & energy	**1,217,959**	**44.0**
Hogged fuel	235,352	8.5
Bark	170,686	6.2
Spent liquor	1,108,689	40.0
hydro electric power[a]	15,282	0.6
Other self-generated	21,477	0.8
Total self-generated and residue fuels	**1,551,486**	**56.0**
Total energy	**2,769,445**	**100**

(a) Electricity has been converted from kWh to GJ using a 3.6 MJ/kWh conversion factor.

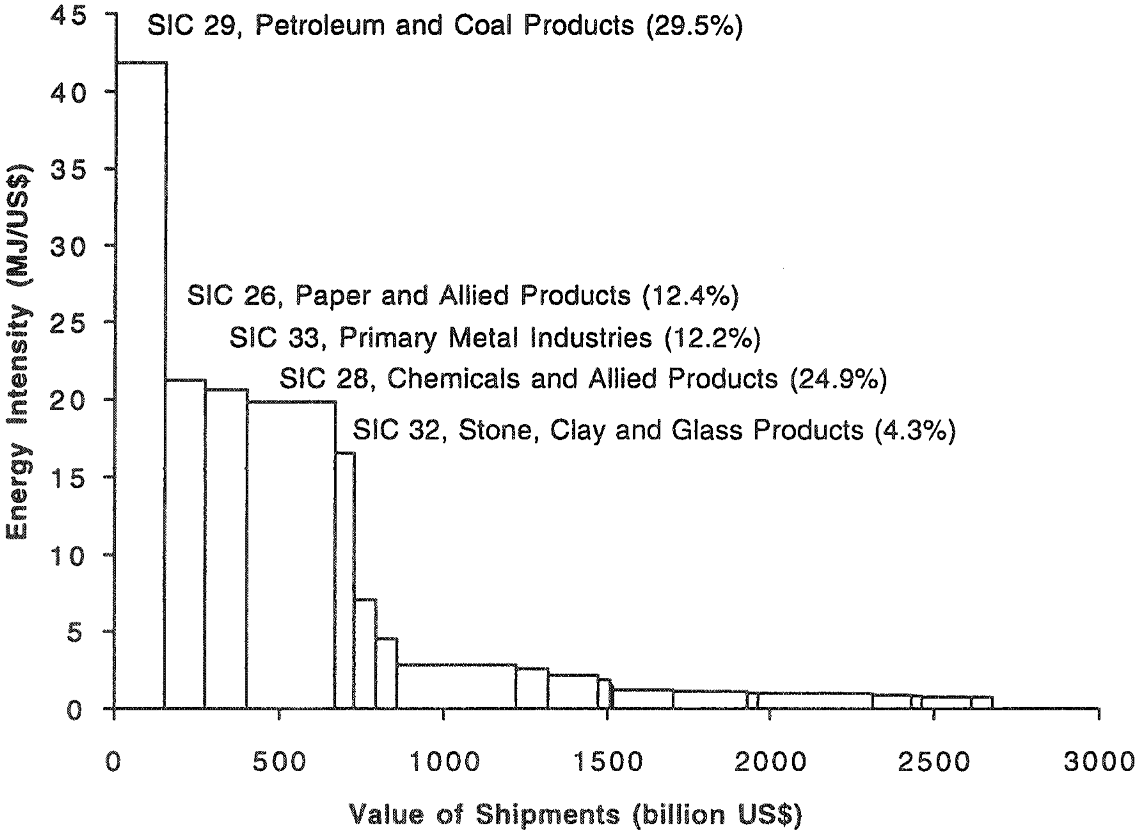

Fig. 1.1. Energy intensity for different industry groups at the 2-digit SIC level plotted against the value of shipments in 1991. Numbers in parentheses are percentages of total manufacturing energy consumption (MECS, 1994; ASM, 1992).

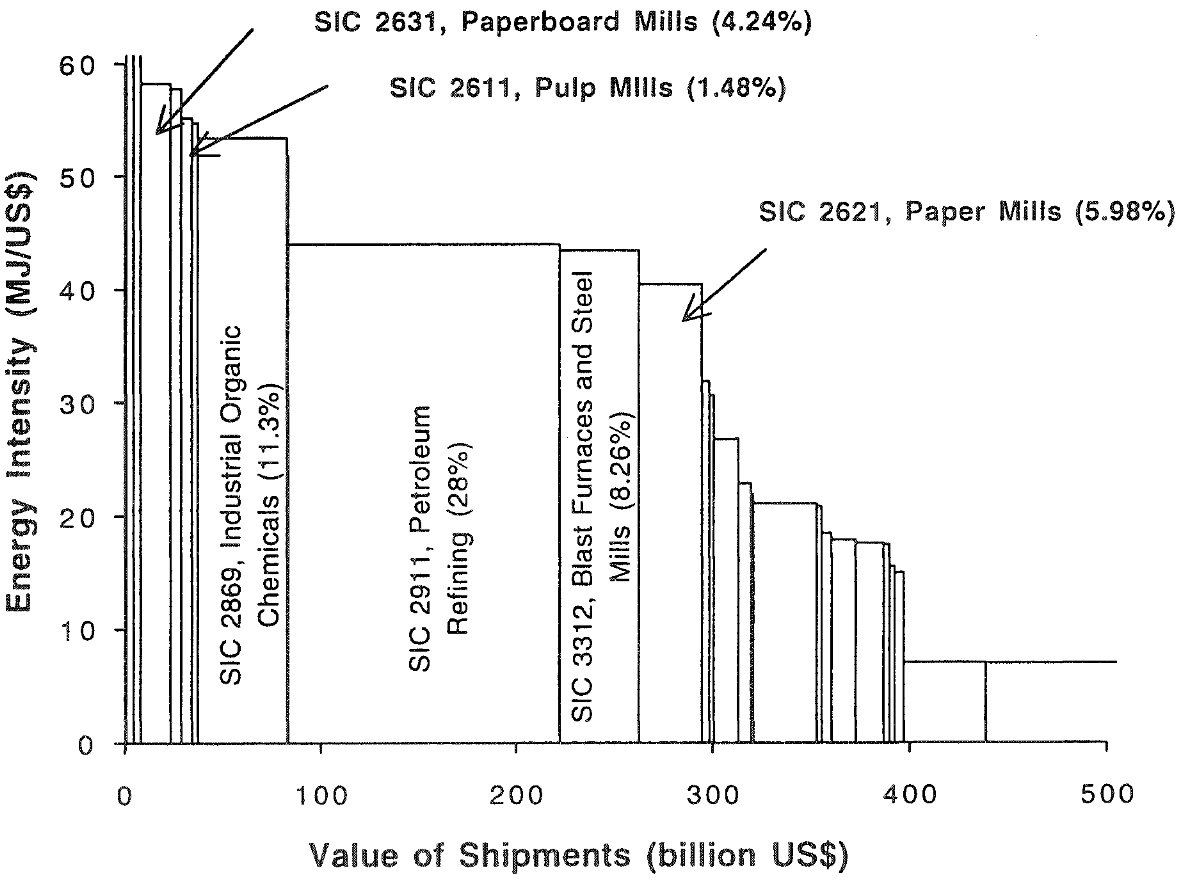

Fig. 1.2. Energy intensity for different industries at the 4-digit SIC level plotted against value of shipments in 1991. Numbers in parentheses are percentages of total manufacturing energy consumption. Paperboard mills are surpassed in energy intensity only by lime (179 MJ/$), nitrogenous fertilizers (174 MJ/$), and cement (89 MJ/$). Industries with energy intensities above 20 MJ/$ account for 74% of total manufacturing energy use but only 13.3% of the total value of shipments (MECS, 1994; ASM, 1992).

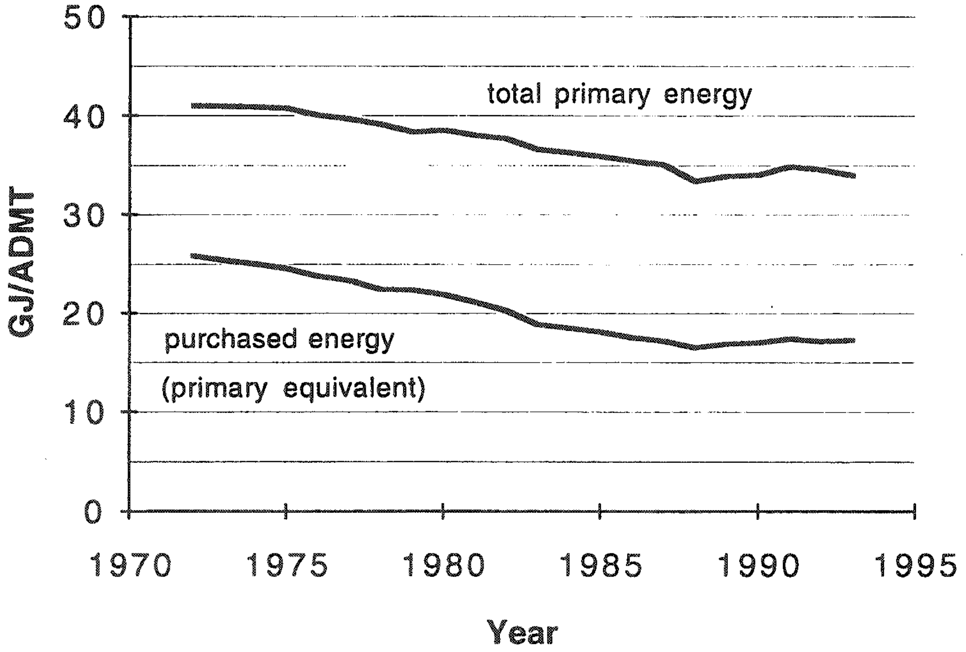

Fig. 1.3. Total primary energy and purchased energy use in the pulp, paper, and paperboard industry. Purchased electricity and steam have been converted to their primary energy equivalents using 10.8 MJ/kWh and an 85% boiler efficiency, respectively. Source: Lisa Wolfe, American Forestry and Paper Association, personal communication, Washington, DC, May 1995.

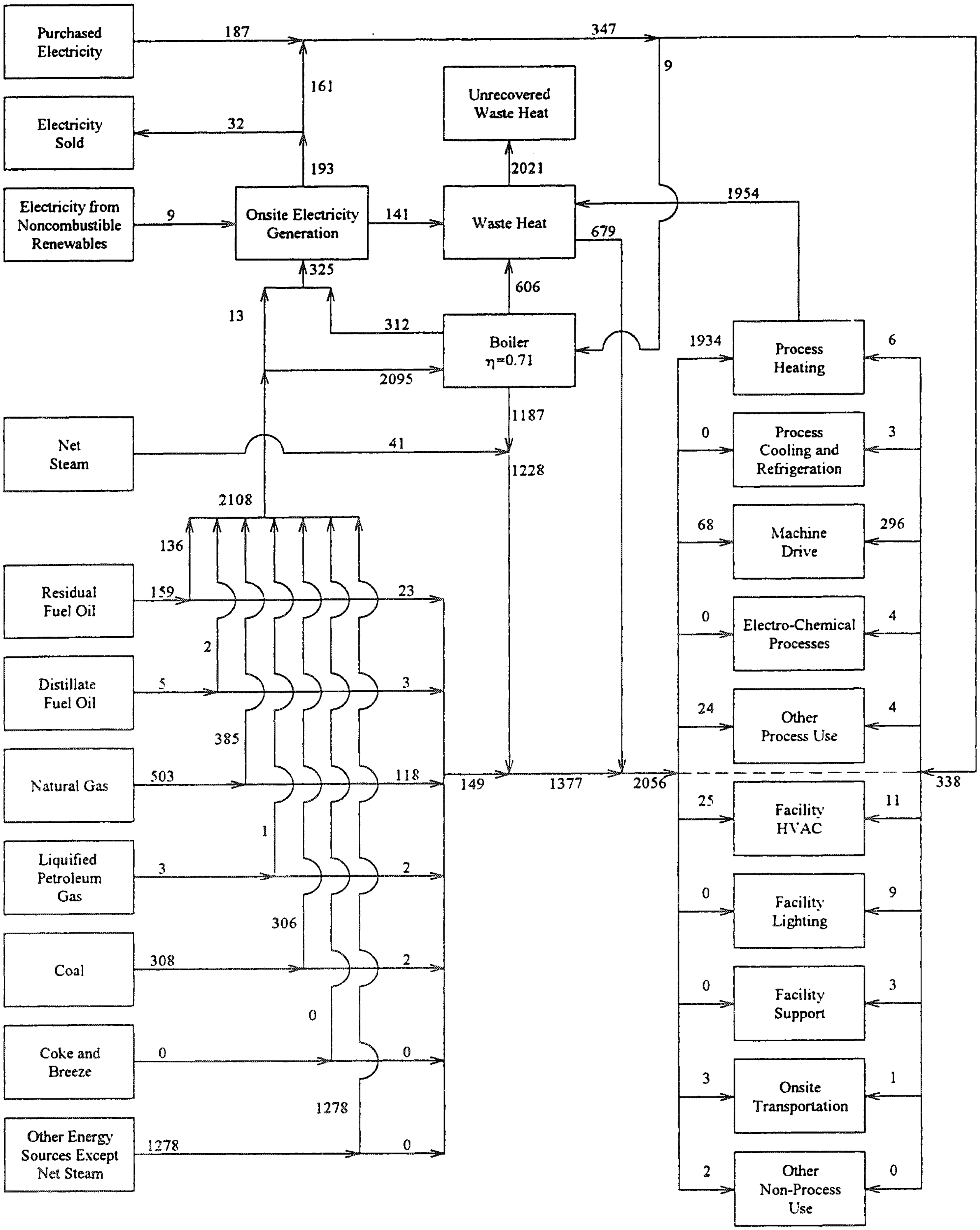

Fig. 1.4. Estimated energy flows (PJ per year) in the pulp, paper, and paperboard industry in 1991. Source: Barry Hyman, Dept. of Mechanical Engineering, University of Washington, personal communication, Seattle, WA, May 1995. See also Giraldo and Hyman (1994).

2. PROCESSES AND TECHNOLOGIES

As background to subsequent discussions on energy use, this chapter gives a brief introduction to the basic principles of pulp and paper making.

2.1. Pulping

Pulping is the process by which the fibers in the wood are separated and treated to produce a pulp. The wet pulp is converted into paper at an integrated pulp and paper mill, or is dried and transported from the pulp mill to a papermill. Different pulping processes are used depending on the raw material and the desired end-product. The processes can be categorized as chemical, mechanical (also called high-yield), semi-chemical, and chemi-mechanical. There are additional processes for extracting fiber from recycled paper.

The predominant process is the chemical process, kraft (also called sulfate) pulping. Kraft pulp accounts for about 80% of all pulp produced in the U.S. (Fig. 2.1). In kraft pulping the lignin[1] is dissolved in a digester where woodchips are cooked. The pulp yield, i.e., the mass of pulp dry substance produced divided by the mass of wood dry substance input, for bleached and unbleached kraft is about 40-50% and 50-65%, respectively. The energy contents of the dissolved lignin and other organic compounds is used to produce heat and electricity for the process.

In high-yield pulping the wood is subjected to shear and compression forces in order to separate the fibers. The mechanical processes have yields above 90% but they produce a pulp which makes a relatively weak paper partly due to the damage done to the fibers in the process. The paper ages relatively rapidly due to the presence of lignin.

Semi-chemical and chemi-mechanical pulping, as the names imply, involve a mix of chemical and mechanical treatment and typical yields are 65-85%, and 85-95%, respectively. Recycled paper is primarily mechanically pulped and may also require deinking. The fiber yield from recycled paper is typically 70-90%.

Most pulp is pumped as a slurry to a paper or paperboard plant where it may be mixed with other pulps, recycle fiber, or fillers such as clay, before going to the paper machine. Only about 10-15% of U.S. pulp production is dried and sold as market pulp. Most (95%) of market pulp is bleached or semi-bleached kraft (AFPA, 1994).

Mechanical pulps are used, for example, to make newsprint and other printing and writing papers, sometimes with the addition of chemical pulps to improve strength and other qualities, Figure 2.2. Another application is fluting material, i.e., the corrugated middle layer in containerboard sandwiched between layers of linerboard. Bleached kraft is used primarily in high quality printing and writing papers. Unbleached kraft pulp is used for producing linerboard and sack paper.[2] Semi-chemical and chemi-mechanical pulps are typically used in boxboard and sanitary products. Recycle fiber can be used in a broad range of products, e.g., boxboard, fluting, newsprint and sanitary tissue. The biggest paper and paperboard products are printing and writing papers, and containerboard (Fig. 2.3).

2.1.1. Kraft (chemical) pulping

As noted earlier, kraft pulping is the dominant pulping process in the U.S. (Fig. 2.1). The name kraft has its origin in the German word for strength, reflecting an important characteristic of this type of pulp. In the kraft process, a mixture of sodium hydroxide ($NaOH$) and sodium sulfide (Na_2S) in an alkaline solution with a pH of 13-14 is used to pulp the wood. An alternative chemical process to kraft pulping is sulfite pulping, which uses hydrogen sulfite (HSO_3^-), or sulfite (SO_3^{2-}), as the active chemical in an aqueous acidic or neutral solution. In either the kraft or sulfite process, woodchips are impregnated with the pulping liquor and then heated under pressure for a few hours in a digester to dissolve the lignin. The fibers are separated from the spent pulping liquor from which process chemicals and energy are recovered in both the kraft and the sulfite processes. Additional discussion here is limited

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[1] The main chemical components of wood are cellulose, hemicellulose, and lignin. The lignin acts as a binder for the wood fibers.

[2] Different wood species have different properties which make them suitable for different products. For example, the mean fiber length of softwood species is usually 1-5 mm whereas it is 0.5-2 mm for hardwood species (Nordman, 1989). The longer fibers make softwood a good raw material for strong papers such as sack and linerboard.

to kraft pulping.

The fiber line in the kraft process (Grace and Malcolm, 1989) is shown schematically in Figure 2.4. Following the debarking and chipping of the pulpwood, the chips are screened for size before being fed to the digester. The digestion may be batch or continuous. The wood chips are first treated with steam (in the presteaming vessel) to drive air from cavities and replace it with steam. When the chips meet the somewhat colder mixture of pulping chemicals--white liquor ($NaOH + Na_2S$)--at about 80-90°C, the steam condenses, creating an underpressure that facilitates impregnation of the chips with white liquor. The chips are heated for 1-1.5 hours up to the desired cooking temperature, where they remain for another one hour or more. The target temperature is usually 165-175°C. Higher temperatures increase chemical reaction rates, but above about 180°C, pulp quality degrades and steam demand increases.

After the digester, the fibers are separated from the spent pulping liquor through several stages of countercurrent washing. Heat is recovered from the digesters as condensate and flash steam. The pulp is then screened, often bleached, and then pumped to the paper mill or dried before shipping it from the mill.

Bleaching increases the brightness of the pulp by decolorizing, degrading and dissolving the colored components. It is done in several steps using oxidants to degrade and decolorize lignin and sodium hydroxide to degrade lignin (by hydrolysis) and aid in its dissolution (Reeve, 1989). The principal oxidants and (in parentheses) their common identifier in the industry, are chlorine (C), chlorine dioxide (D), oxygen (O), hypochlorite (H), hydrogen peroxide (P), and ozone (Z). Sodium hydroxide is identified by the symbol E, for caustic extraction. A common bleaching sequence in the 1980s was C_DE_ODED, where the subscript refers to the chemical used to augment the primary chemical in a particular stage. Modern pulp mills use oxygen delignification to remove more lignin after digestion and before bleaching, thereby reducing the amount of bleaching chemicals required and the bleach plant effluent emissions. Chlorine dioxide (ClO_2) has been substituted for chlorine (Cl_2) in modern bleach plants due to the large emissions of chlorinated organic compounds in the waste water associated with the use of elemental chlorine (see Section 1.3). The demand for totally chlorine free (TCF) paper, primarily in the European market, has led to the increased use of bleaching agents such as hydrogen peroxide and ozone, and development of alternative bleaching technologies. A typical TCF sequence today might be oxygen delignification followed by ZE_OP.

The spent pulping liquor--weak black liquor--is evaporated to increase the solids content (organic compounds and pulping chemicals) from 10-20% to 60-75% and then goes to the "recovery" section of the mill. It is burned there in a Tomlinson recovery boiler (Fig. 2.5). Steam generated in the boiler is used to produce electricity and process steam in a turbine with steam extraction at low and intermediate pressures. (See Section 4 for additional discussion.) The pulping chemicals are recovered from the bottom of the boiler as a smelt of sodium sulfide (Na_2S) and sodium carbonate (Na_2CO_3) which is then dissolved in water to form green liquor. The green liquor reacts with an aqueous solution of calcium hydroxide ($CaOH_2$) (formed by mixing calcium oxide--CaO, or lime--with water) in the causticizer, converting the sodium carbonate to sodium hydroxide and thereby regenerating white liquor for the pulping process. The precipitate from the causticizer, calcium carbonate ($CaCO_3$)--called lime mud--is burned in a lime kiln to regenerate CaO.

2.1.2. High-yield pulping

The main high yield, or mechanical, processes are stone groundwood pulping (SGW) and thermo-mechanical pulping (TMP). Refiner mechanical pulping (RMP) is another important process that was introduced in the 1960s, but which is now increasingly being substituted by TMP. In general, thermomechanical pulp is stronger than refiner mechanical pulp which in turn is stronger than stone groundwood pulp (Malinen, 1989). Stone groundwood pulp was the only mechanical pulping method used for paper production before the introduction of RMP technology in the 1960s. In the SGW process, debarked logs are pressed against a large rotating grindstone which separates the fibers (Fig. 2.6). The fibers are continuously washed off the stone, and the washing maintains the stone temperature below about 100°C. The resulting slurry is screened, and oversized pieces are fed to a reject refiner or grinder. Stone groundwood pulping, which has traditionally been done at atmospheric pressure, is being replaced with pressurized stone groundwood (PGW) pulping where the grinding zone is kept at an elevated pressure. This facilitates the recovery of higher grade heat (in the form of low pressure steam).

Refiners were originally used to produce wood for fiberboard or chipboard from low-quality wood such as crooked lengths of wood, wood thinnings, and some types of chips from sawmills. The technology was developed to produce pulp for paper manufacturing during the 1950s. Refiner pulping is less sensitive to the quality of the feed than stone groundwood (Borg, 1989). Refiners are designed with a single rotating disk against a fixed disk (single-disk refiner) or with two rotating disks (double-disk refiner) (Fig. 2.7). Individual refiner units have from 0.2 MW to 20 MW of installed electric motor power (Gavelin, 1991).

In thermomechanical pulping, the chips are preheated and softened by steam and the refiner is pressurized to facilitate steam recovery. The pulp is screened to remove knots and shives (large fiber bundles) before going to the papermill.

The bleaching technology used for mechanical pulps is different from chemical pulps since the lignin is preserved. Pulp for making newsprint usually does not need any bleaching if fresh and moist chips from spruce are used. Ditionite ($Na_2S_2O_4$) or hydrogen peroxide (H_2O_2) are typically used as bleaching agents if some increase in brightness is desired.

Wastepaper is also pulped, or repulped, mechanically. Wastepaper is mixed with water, agitated to turn it into a slush, and screened to remove metal, plastic, etc. Chemicals and enzymes can be added to remove ink and the pulp may be bleached.

2.1.3. New pulping processes

Chemical pulping processes under development include sulfur free processes, some of which use organic solvents, and alkaline sulfite processes. Environmental concern associated with kraft pulping is an important motivation for developing these processes since they are free from odorous reduced sulfur compounds and may facilitate bleaching (Tulenheimo et al., 1992; Stockburger, 1993).[3] Another advantage of some sulfur free processes is that chemicals recovery can be simpler than for kraft pulping. As a result they can be less capital intensive and sensitive to economies of scale, making smaller size mini-mills feasible (Dils, 1992). Examples include the Alcell process in Canada, which uses ethanol as the pulping chemical, and the Organocell process in Germany, which is based on an alkaline cooking liquor with 25-30% methanol (Lora et al., 1993; Stockburger, 1993). The Alcell process has been operated on a pre-commercial scale at 15 ADMT/day and the Organocell process on a commercial scale at 400 ADMT/day. Other sulfur free processes include a Russian alkali-oxygen process, and the Finnish Milox process which uses peroxyformic acid as a pulping agent (Tulenheimo et al., 1992).

The ASAM (alkaline sulfite anthraquinone methanol) process is another noteworthy process which is based on the commercially proven sulfite process but has improved environmental characteristics and is more flexible with regard to the wood feedstock (Hentges et al., 1993). A 5 ADMT/day pilot plant has been operated at a mill in southern Germany. Potential disadvantages of ASAM when compared with kraft pulping include a more complicated chemical recovery system, higher chemical costs, and higher capital costs (Stockburger, 1993).

One of the reasons that the ASAM and other new processes have been difficult to commercialize is the expectation that the kraft process will be able to meet future stringent demands on environmental performance. Also, because of the capital intensity and yet-to-be-commercially proven nature of such processes, risks in adopting them are relatively high.

In mechanical pulping there has been some interest in developing explosion pulping, a process which has been known since the 1920s but which has been used primarily only for fiberboard manufacture. The principle of explosion pulping is to heat impregnated woodchips at very high pressure and then blow the chips into a vessel of lower pressure where the sudden expansion of steam and gases tears up the chips and produces a coarse fiber. Explosion pulping, as an alternative to chemi-thermomechanical pulping for producing fluff pulp, has been estimated to require one-third the power (Tulenheimo et al., 1992).

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[3] Based on our review of the literature, it appears that these new chemical pulping processes will have energy demands that are similar to the kraft process since they include the major energy using unit processes, i.e., digesters, chemicals recovery, and pulp (or paper) drying.

2.2. Paper manufacturing

The production of paper involves preparing the stock from pulp, forming a sheet, dewatering and drying, and sometimes coating the paper. The stock is often prepared from a mix of different pulps sometimes with the addition of mineral fillers, depending on the desired paper quality, Figure 2.2. For example, newsprint can be made from a mix of mechanical pulp and recycled pulp, with some addition of chemical pulp to increase strength. Chemical pulps are usually refined or beaten to improve fiber bonding and facilitate the forming of a strong paper.

All paper machines have three basic elements, wet end (gravity removal of water), press section (mechanical pressing to squeeze out water), and drying section (evaporation of water) (Fig. 2.8). The stock has a solids content (or consistency) of less than one percent when it is sprayed onto the wire mesh at the wet end for dewatering. Most of the water is removed in the wet end by gravity and vacuum suction boxes. The consistency approaches 20% when the sheet enters the press section where the water is squeezed out by pressing the web between cylinders until the consistency is 40-50%. In the drying section the remaining water in the sheet is removed by evaporation and the paper is dried to 90-95% through contact with steam heated cylinders. The paper may also be coated after drying to make it smoother or brighter.

The papermachine used depends on the type and quality of the paper produced. For example, double-wire machines, where the stock is sprayed between two wire meshes, are often used for newsprint and tissue, whereas sack and liner are made using single-wire machines. The drying section may be a multicylinder machine with 40-100 drying cylinders of 1.5-1.8 m diameter (for example used for newsprint and sack), or a 4-7 m diameter yankee cylinder (for example, used for tissue), or a combination of both (Fig. 2.8).

Economies of scale have resulted in larger and faster paper machines. For example, newsprint machines run at 1,000-1,500 meters per minute and are about 8 m wide. Future machines will be designed for speeds and widths approaching 2,000 meters per minute and 10 meters, respectively (Sobczynski, 1994). The corresponding production rate for a single large newsprint machine would be over 1000 ADMT per day. However, there is a parallel trend toward low cost, simple, and small paper machines for mini-recycled paper mills.

2.3 Integrated pulp and paper mills

Pulp and paper mills are often large and complex facilities that may produce several pulp and paper qualities from both softwood and hardwood feedstocks. The mix of products and qualities complicates comparisons between different pulp and paper mills and their energy use. As an illustration, the Chesapeake Paper Products Company operates a 2,000 ADMT per day containerboard, kraft paper, and bleached hardwood pulp mill in Virginia. Major production facilities at the mill include 8 batch digesters for virgin kraft pine fiber, a continuous digester for virgin kraft hardwood fiber, a 570 ADMT per day hardwood pulp bleach plant, a bleached hardwood market pulp machine, a 900 ADMT per day recycled fiber plant, a corrugating medium machine, a linerboard machine, and a three-ply linerboard machine. Other major facilities include 2 chemical recovery boilers, a wood waste boiler, a coal-fired boiler, two oil-fired boilers, and 7 steam generators. The implication of this diversity is that many of the opportunities for end-use energy efficiency improvements and cogeneration are mill specific.

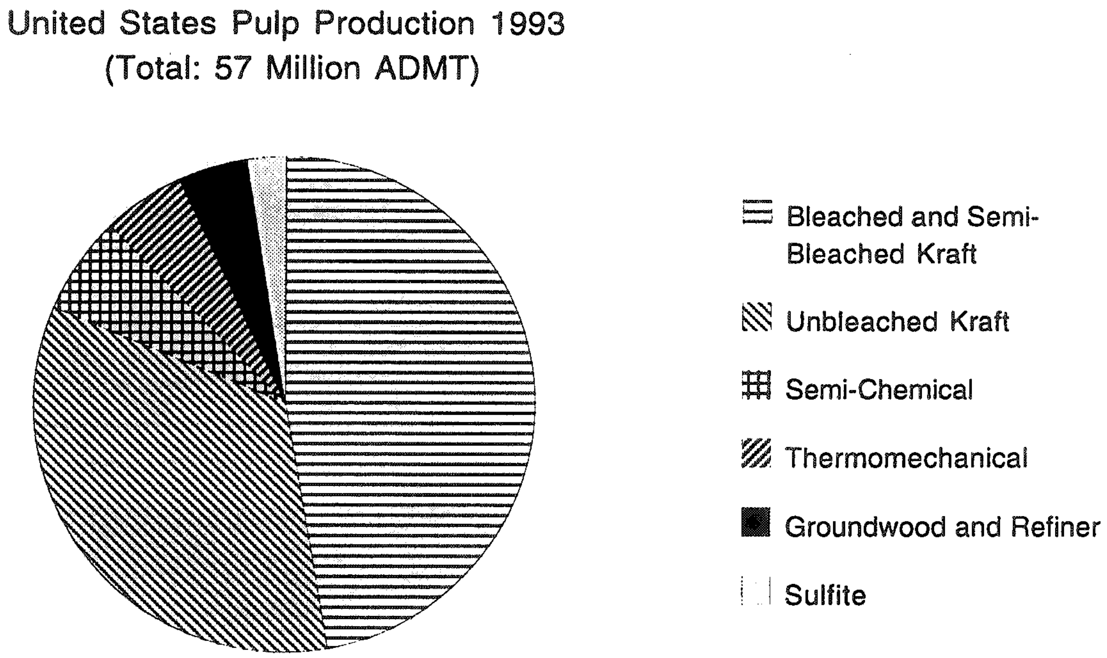

Fig. 2.1. U.S. pulp production by process in 1993 (AFPA, 1994a).

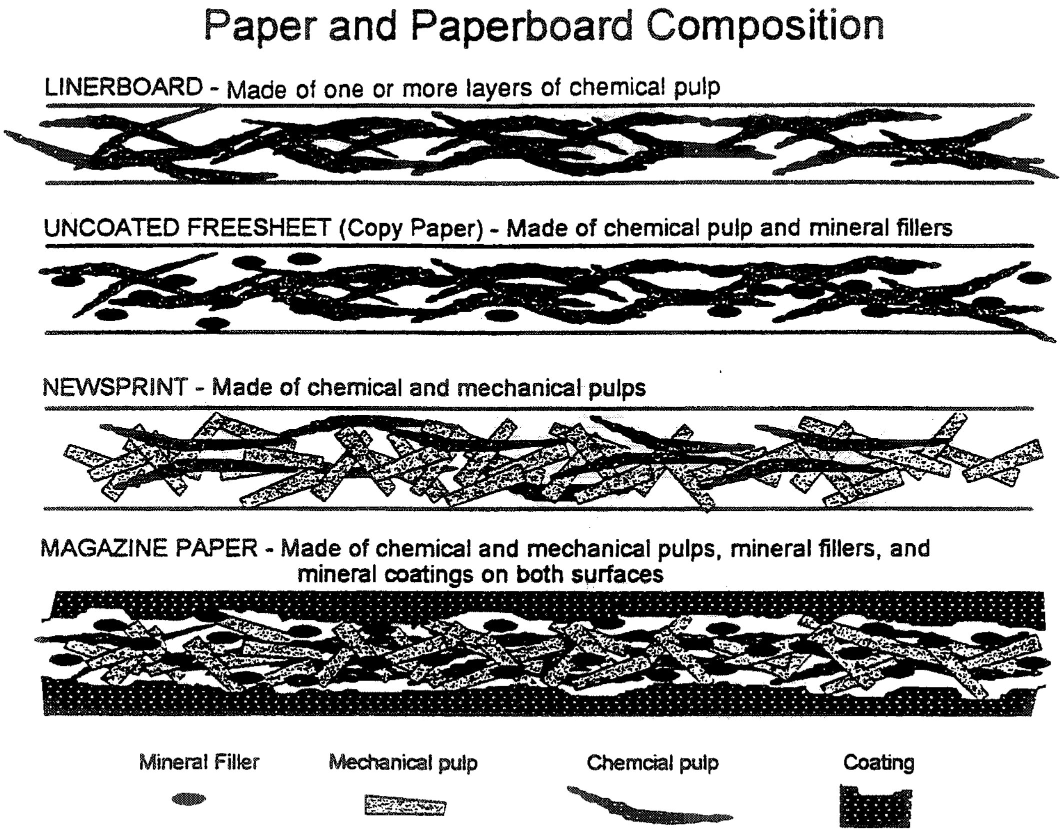

Fig. 2.2. Typical paper and paperboard compositions. Source: R.E. Buttner, H.A. Simons, Vancouver, BC, Canada.

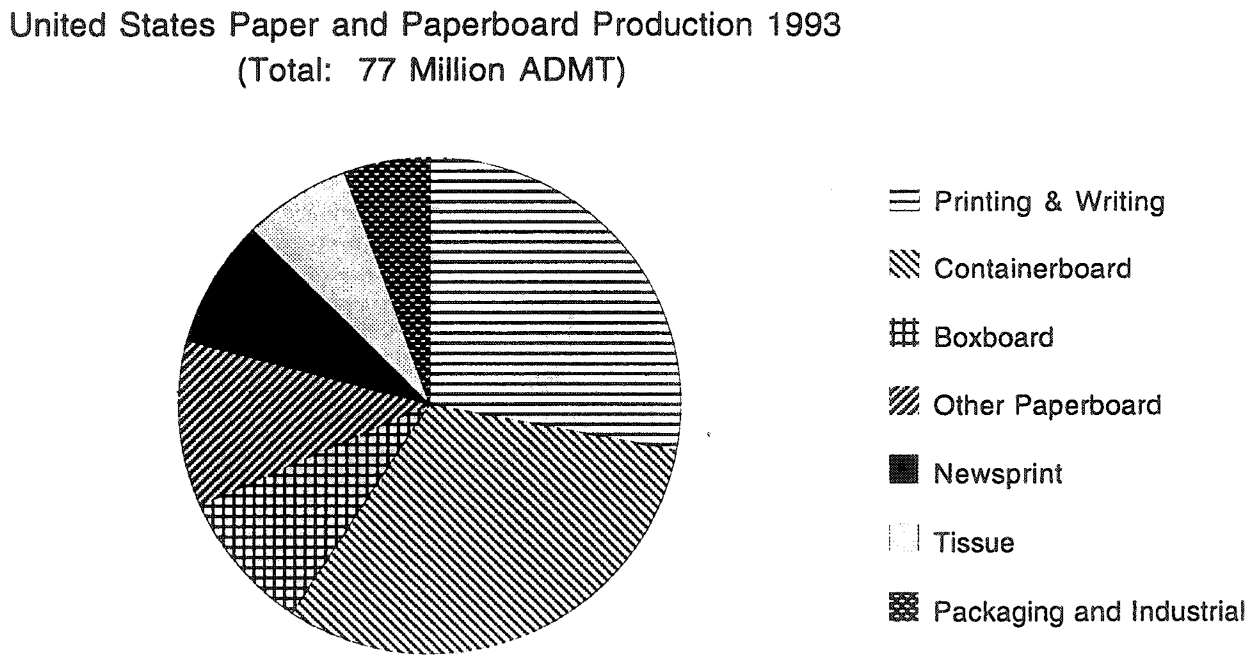

Fig. 2.3. U.S. paper and paperboard production in 1993 (AFPA, 1994a).

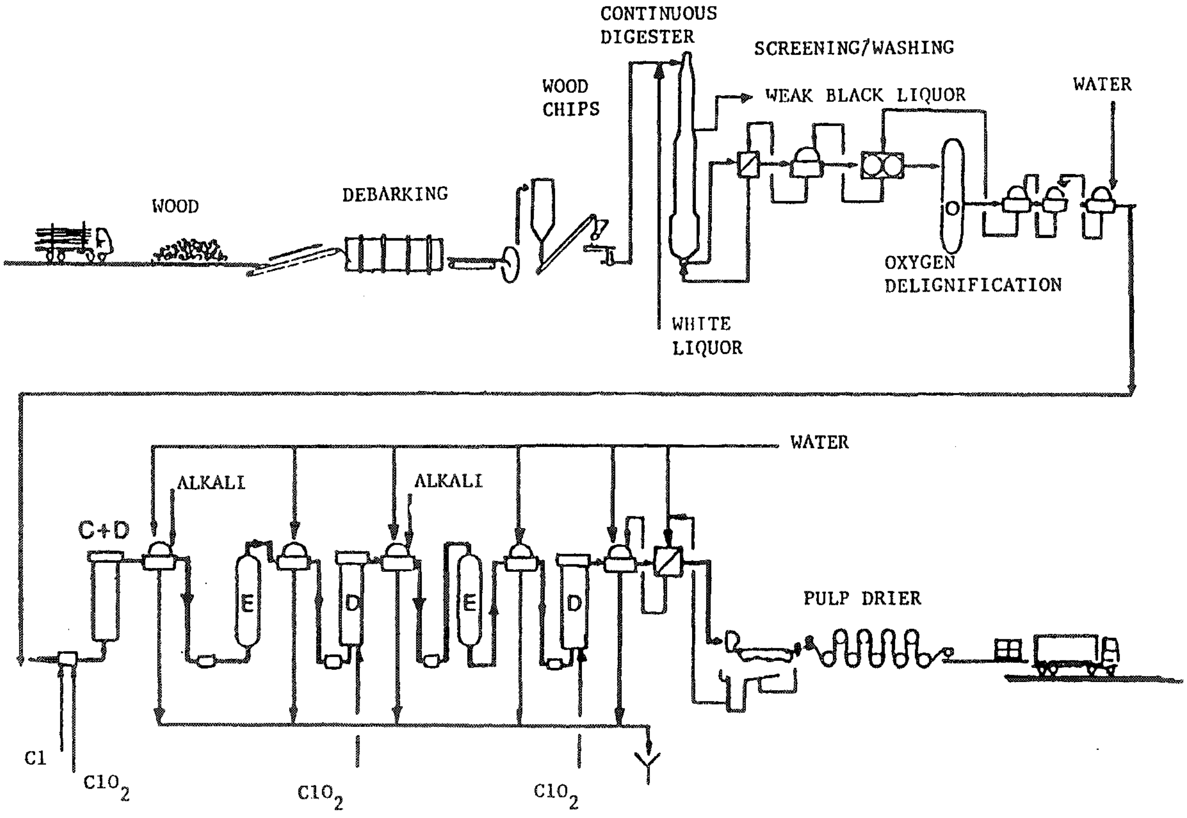

Fig. 2.4. Kraft pulping fiber line (Borg, 1989).

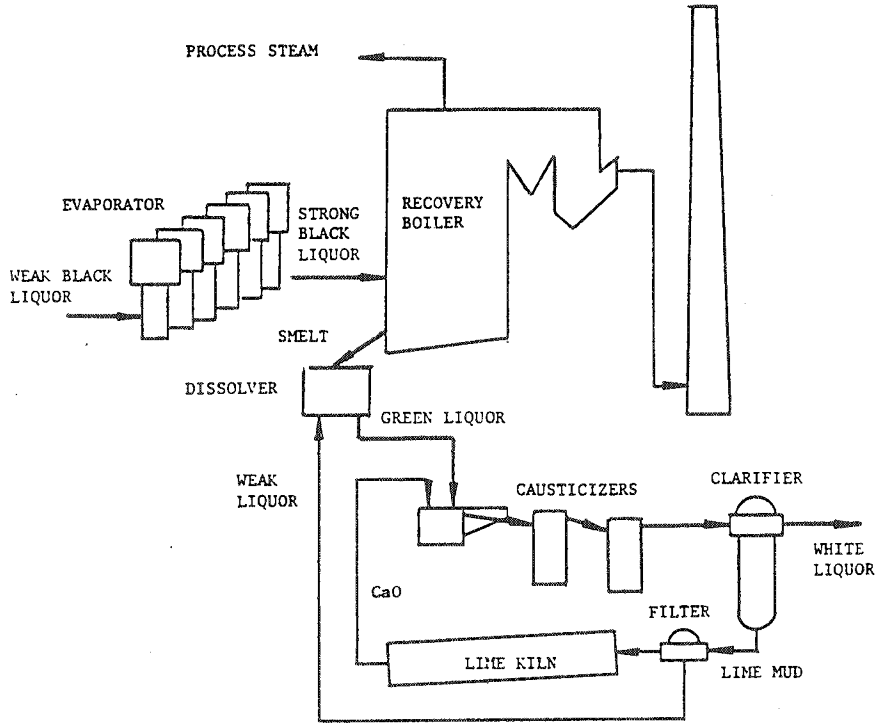

Fig. 2.5. Kraft chemicals recovery cycle (Borg, 1989).

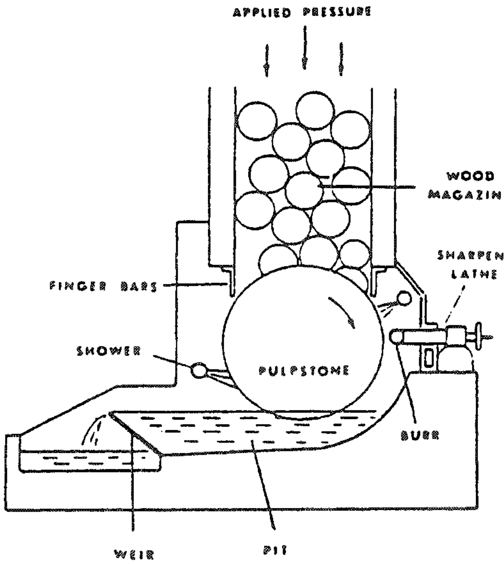

Fig. 2.6. Grinder for stone groundwoood (SGW) pulp production (Eliah and Lowitt, 1988). A recently sharpened pulpstone gives a coarser pulp, so a SGW pulp mill typically has many units from which the pulp is mixed to maintain uniform quality.

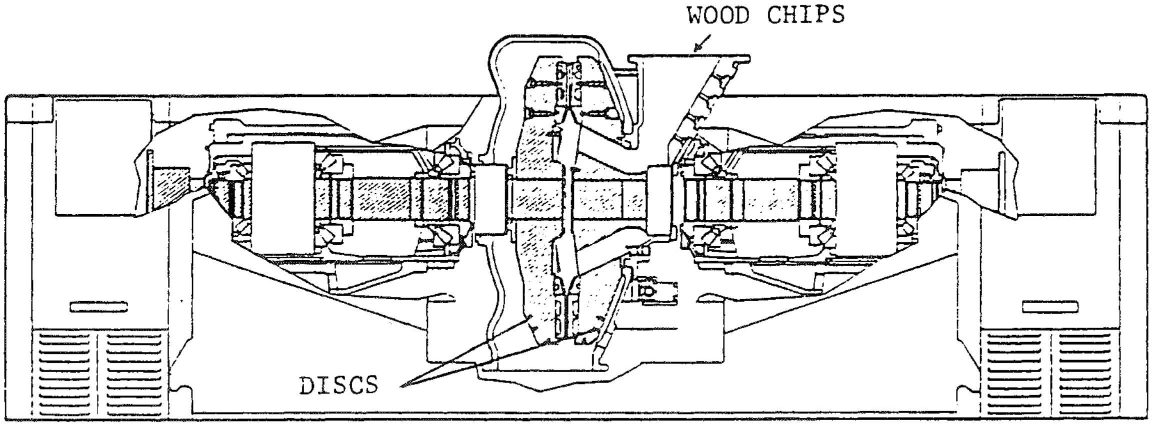

Fig. 2.7. Double disc refiner (Borg, 1989). The gap between the discs at the periphery is only about 0.1 mm. A refiner typically operates at 1500-1800 rpm.

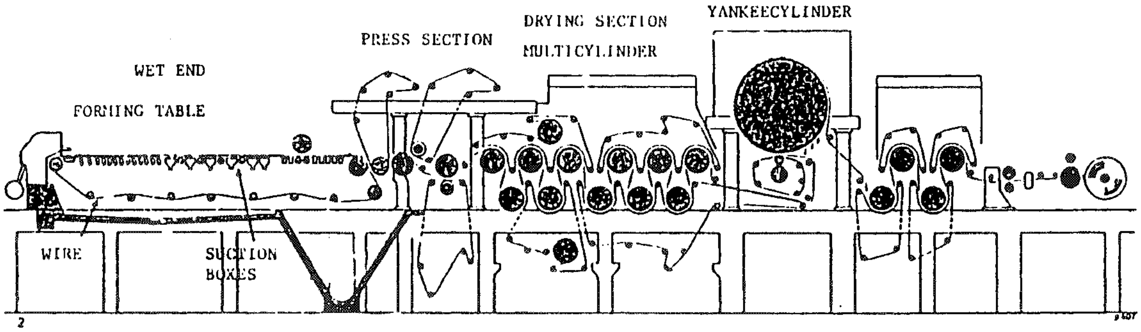

Fig. 2.8. Example of a papermachine with a single-wire wet end, and with both multicylinder and yankee cylinder drying (Borg, 1989).

3. ENERGY USE AND EFFICIENCY

The Manufacturing Energy Consumption Survey (MECS, 1994) gives estimates of energy use in the pulp, paper and paperboard sectors of the paper and allied products industry. However, the wide variety of processes and products within each of these sectors makes it necessary to analyze energy use at a more disaggregated level to understand the underlying trends that affect energy use, as well as the potential for energy efficiency improvements. Energy use in basic materials industries is typically expressed in energy per unit of product. However, such comparisons are complicated by the fact that pulp and paper mills that produce more than one product often do not allocate energy use by product. In addition, different mills may not use the same energy accounting principles or be able to produce the same breakdown of energy use by unit process. Moreover, most mills also consider energy use data proprietary.

It is possible to get some indication of relative energy performance across the industry by focussing on single-product facilities. In this section we focus on two of the most important pulping processes: kraft and thermomechanical. We discuss drying energy use in the context of newsprint, but the discussion is generally applicable to a variety of products. We also discuss some energy end-use technologies that are used throughout the industry, e.g., motors and pumps, and the potential energy impacts of environmentally-driven technology changes. Some of the data presented are from our own energy audits and some are drawn from other sources.

3.1. Bleached kraft market pulp

Bleached and unbleached kraft pulping processes are essentially the same except bleached kraft is cooked to achieve a higher level of delignification in the digester, and the pulp is bleached. The pulp is then dried in a market pulp mill, whereas it is converted into dried paper at an integrated mill. As in most industries, new or modernized plants typically use less energy than old plants. The industry has been more effective in reducing steam demand than electricity demand in new and retrofitted mills, which has contributed to the trend of increasing electricity to heat ratios (Table 3.1).

The major steam users in a kraft pulp mill include the digesters, the evaporators, and the pulp drier (or, alternatively, the paper machine in an integrated mill) (Fig. 2.4 and 2.5). These three unit processes account for about three-quarters of total steam use in most market pulp mills.

Electricity demand is more evenly distributed throughout the mill than steam demand. Most electricity is used in pumps and fans: 40-45% and 15-20% of the total, respectively, according to a detailed electricity audit of two Swedish mills (Axelsson, 1990). Most of the installed fan capacity is in the dryer, lime kiln, and boilers. Major electricity using machine drives are found in the woodyard and the pulp screening plant. Other electricity uses are present at an integrated mill: stock preparation and the paper machine may each account for about 200-300 kWh/ADMT of electricity demand in a linerboard mill (Warnquist, 1989).

Table 3.2 presents a breakdown of energy use for two U.S. mills and two hypothetical model mills in order to illustrate the development in energy use over time and to give an indication of the potential for efficiency improvements. The U.S. mills are described in more detail by Larson (1992) and Subbiah et al. (1995). The two model mills represent what a major Swedish consulting firm considers possible using 1980-vintage and 2000-vintage technology in a greenfield mill.[1] Energy use in unit processes is discussed in more detail below, with reference to Table 3.2.

3.1.1. Woodyard

The main woodyard operations typically include debarking, chipping and conveying, for which electricity demand is about 10, 15, and 20 kWh/ADMT, respectively (Jönsson et al., 1977a). Some pulp mills buy chips from nearby sawmills. There is virtually no heat demand except in cold climates where logs must be thawed before debarking, something which may be done using low level waste heat. Modern plants use dry debarking to avoid generating wastewater with high BOD/COD and increasing the moisture content of the bark which is used as fuel. Chippers equipped with adjustable speed drives to control cutting speed can save electricity might typically be adopted because

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[1] The primary objective for the model mill work has been to develop input to the Swedish government long-term energy planning.

they improve chip and pulp quality (Åberg and Eriksson, 1987). For chip transport under full load conditions, belt conveyors would use only 0.5 Wh per tonne-meter (Wh/t-m) (horizontal) and 5 Wh/t-m (vertical)[2] compared to 15 Wh/t-m and 10 Wh/t-m for pneumatic and screw conveyors, respectively (Nygaard, 1986).[3] Belt conveyors do less damage to the wood chips, in addition to using less energy, and are generally preferred over pneumatic conveyors.

3.1.2. Digester

Kraft pulping can be done in a batch or continuous process. A particular driving force in kraft pulping technology development has been the need to reduce emissions of chlorinated organic compounds from the bleach plant. For this purpose pulping processes have been modified to reduce the need for bleaching by cooking to lower kappa number (i.e., lower lignin content)[4] and by using oxygen delignification before the bleach plant.

Modified cooking or extended delignification can be achieved in both batch and continuous digesters. The basic principle is more selective delignification by controlling primarily the alkali concentration during the cook. For example, in conventional continuous digesters all the alkali--white liquor--is charged at the beginning of the cook. In modified continuous cooking the alkali is charged in three stages and the alkali concentration remains more even throughout the cook.

Oxygen delignification reduces the kappa number by about 50%. Heat and electricity demands are increased by approximately 0.5 GJ/ADMT and 75 kWh/ADMT, respectively, but the additional recovery of organics increases recovery boiler heat output by roughly an equivalent amount. Heat and electricity use in bleaching may decrease as a result of changing the bleach sequence to fewer steps, but the largest economic savings come from lower bleaching chemicals consumption.

New batch processes were developed during the 1980s primarily to reduce digester energy demand since the conventional batch process uses about twice as much heat as the continuous process. It was discovered that displacement heating in combination with pretreating the wood chips with weak black liquor significantly improved pulp quality, in addition to reducing steam demand (Hakamäki and Kovasin, 1992). The basic principle is to utilize the high grade heat in the spent pulping liquor to preheat white liquor and wood chips. (With conventional batch processes, digester pressure is released at the end of the cook, and the resulting flash steam is used to heat water.)

Digester primary steam consumption is typically 3.5-4.0 GJ/ADMT in the conventional batch process and 1.7-2.5 GJ/ADMT in a modern batch or continuous process (Mjöberg, 1992). Energy savings ranging from 30% to 78% have been reported for mills with batch digesters that have converted to displacement processes (Ernerfeldt and Edlund, 1987; Swift and Norman, 1987; Tulenheimo et al., 1992). It should be noted that the evaporator load and the prospects for heat recovery from the digester are different for different digester process designs. For example, evaporator steam demand increases by about 0.5 GJ/ADMT with the displacement batch process since water that goes off as flash steam in the conventional batch process must now be evaporated when concentrating the black liquor.

3.1.3. Medium Consistency Processing

A large amount of electricity is used in pumps in the fiber line following the digester, where the pulp is washed, screened and bleached (Fig. 2.4). Typically the consistency in these operations is 1-3% in washers, 1% in screening, and 3-12% in bleaching. They involve several dilution and thickening loops, resulting in the pumping of large volumes of water and high electricity demand (Simonsen and Davy, 1993). Raising consistency can reduce the volumes of material to be pumped, but it also increases friction losses in piping.

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[2] Theoretical energy demand for lifting 1 tonne 1 m is 9.8 kJ or 2.7 Wh/tonne.

[3] Since roughly 4 tonnes of wood chips with 50% moisture are needed to produce one ADMT of pulp, the corresponding electricity demand per ADMT of pulp is 2, 20, 60, and 40 Wh per meter.

[4] The amount of lignin in the pulp as percent of dry pulp is roughly equivalent to the kappa number multiplied by 0.15. Thus, a kappa number of 30, which is a typical target for bleached kraft pulp, corresponds to 4.5% lignin. With modified cooking processes, it is possible to reach kappa 20.

Environmental and energy conservation concerns are motivating the development of medium consistency (8-15%) processes (Gullichsen 1985, Tulenheimo et al., 1992). One study estimates that mill-wide electricity demand can be reduced by 50-75 kWh/ADMT (or about 10% of typical 1990 levels) by converting the fiber line to medium consistency processing. However, capital costs are too high to make it cost-effective in retrofit applications (Simonsen and Davy, 1993). Also, some unit operations are not yet fully commercial. For example, medium consistency pumping is now an established commercial technology in widespread use, but commercially available equipment for screening at present is limited to 4-6% consistency. Medium consistency processing technology is likely to be installed successively when existing equipment is retired and as it is further developed to meet commercial requirements.

For the model mill 2000 in Tables 3.1 and 3.2 it is assumed that medium consistency is used throughout the fiber line in all pumps, mixers and screens, resulting in significantly lower electricity demand for washing, screening and bleaching. In addition to reduced pumping electricity, further savings in electricity demand for pumping may be possible through the installation of variable speed drives (see Section 3.4).

3.1.4. Bleaching

Bleaching technology is undergoing rapid change, and the many alternative process designs and bleaching sequences make it difficult to compare energy use or assess the energy impact of specific measures. The bleaching of pulp is done in a number of stages with intermediate washing stages. Heating and cooling is needed in some cases to reach desired reaction temperatures (typically 40-90°C), whereas most of the bleach plant electricity use is for pumping and mixing. The relatively low reactor temperatures makes it possible to use mainly low grade waste heat. Electricity demand is typically 20-30 kWh per bleaching step (Jönsson et al., 1977a; Davy and Simonsen, 1993). Thus, fewer steps will result in lower electricity demand, all other things being equal.

A large amount of electricity is consumed in the manufacture of bleaching chemicals. Most of these are purchased and therefore not accounted for in the bleach plant electricity consumption or mill energy balance. Table 3.3 shows typical chemicals consumption for a conventional chlorine/chlorine dioxide bleach sequence with and without oxygen delignification. It also shows electricity demand for the production of the chemicals. The increase in on-site energy demand from using oxygen delignification may be less than the decrease in off-site electricity demand for manufacturing the additional bleaching chemicals that would otherwise be needed.

Environmental concern is now driving the development of elemental chlorine free (ECF) and totally chlorine free (TCF) bleaching technology. The transition is in part facilitated by extended delignification cooking, and oxygen delignification prior to the bleach plant. Ozone is currently a primary alternative bleaching chemical. It is used in sequences with chlorine dioxide in ECF, or with hydrogen peroxide in TCF bleaching. Ozone is generated on-site and therefore shifts electricity demand from the chemicals manufacturers to the mill. Ozone consumption can be 5-7 kg/ADMT or more. The electricity demand for the ozone generation (at 4% O_3 concentration) in oxygen feed systems is 7.5-9 kWh/kg O_3 (38-63 kWh/ADMT).[5] Thus, using ozone can result in a 5-10% increase in on-site electricity demand. About 85-90% of the electricity input to the ozone generator is lost as low grade heat. More is lost for higher ozone concentrations (Byrd and Knoernschild, 1992).

Various studies have shown that ECF and TCF bleaching sequences have higher on-site thermal and electrical energy demands, and the total cost to build and operate a greenfield TCF mill could increase by 10% compared to a conventional mill (Davy and Simonsen 1993; Brunner and Pulliam, 1993; Mannisto et al., 1995). However, rapid onging development of ECF and TCF bleaching technology could reduce differences in total costs and energy demands.

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[5] Electricity demand for oxygen production would be 12.5 kWh/kg of ozone assuming a yield of 0.04 kg ozone per kg oxygen and an electricity demand of 0.5 kWh per kg oxygen. Total electricity demand under these assumptions is, therefore, about 20 kWh/kg of ozone. However, the oxygen carrier gas can be used elsewhere in the mill, or recirculated to the ozone generator.

3.1.5. Pulp drying

Dewatering and drying of pulp in a pulp machine is normally done using similar principles as drying of paper in a wet end, press section and a drying section (see also Sections 2.2 and 3.3). Following dewatering and pressing, the pulp can be dried as a web on cylinders, similar to paper drying, or in an air-float dryer where heated air is blown to support the web and evaporate the water (Fig. 3.1). Air-float driers are claimed to give a better quality product since they avoid subjecting the web surface to high temperatures (Perkins and Cowan, 1989). Typical web surface temperatures are 65-70°C compared to 90-100°C in cylinder drying. The pulp can also be dried in a flash dryer where fluffed pulp is introduced into a stream of hot air and then separated out in a cyclone. Most energy use in a dryer goes to evaporate water. Electricity is used in the wet end vacuum suction boxes, for machine drives, and for fans and pumps. Typical reported steam and electricity demands in a pulp machine are 3.3-3.5 GJ/ADMT and 130-150 kWh/ADMT, respectively (Jönsson et al., 1977a).

Consistency following the press section is typically 45% or less for kraft pulps but it can reach 50% or higher (which results in large steam savings for drying) by using state-of-the-art double wire technology (Perala and Sampi, 1993). This technology also needs lower vacuum in the wet end dewatering thus reducing electricity demand. For example. electricity use decreased from 171 kWh/ADMT to 141 kWh/ADMT in one retrofit where four fourdrinier (single-wire) pulp machines were replaced with a double-wire machine. Total steam consumption in the drying line was reduced from 1.5 tonne of steam per ADMT of pulp (3.39 GJ/ADMT) to 1 tonne of steam per ADMT (2.26 GJ/ADMT) (Ekebro-Graeve and Sampi, 1994).

Drying of fluffed pulp in a steam dryer (similar technology can be used for drying biomass fuels) is a potentially interesting technology depending on the mill energy balance. Primary steam at 10 bar or higher is condensed on the outside of tubes carrying the pulp wherein secondary steam at about 3 bar is generated from the water in the pulp feed, leaving behind dried pulp (Munter, 1990; Gavelin, 1993; Gavelin, 1982). In a simplified heat balance the input is about 3.5 GJ/ADMT of high pressure steam and the output is about 2.5 GJ/ADMT of low pressure steam and 1 GJ/ADMT of clean condensate at high pressure. A drawback with this technology is the loss of relatively high pressure steam that could otherwise be used for power production.

3.1.6. Black liquor evaporation

Black liquor concentration is usually the biggest single steam using operation in a kraft pulp mill (Table 3.2). In an evaporator, primary steam is condensed on one side of a heat-exchanger and steam is generated from the water in the black liquor on the other side. This steam is used on the condensation side in the next evaporator effect, which operates at a lower pressure and temperature than the preceeding effect. To minimize primary steam use, typically 5 to 7 effects are combined in series as a multiple effect evaporator (MEE) (Fig. 3.2). The steam temperature decreases from about 140°C in the first effect to about 60°C in the last effect. Two basic evaporator designs are rising film and falling film. New installations almost exclusively use the falling film design, which operates with a lower temperature difference across the heat exchanger surface and is able to handle higher black liquor solids contents (Rausher, 1995).

Typical primary steam demands in a falling-film MEE are 670 kJ per kg of water evaporated (kJ/kg_w) with four effects, 530 kJ/kg_w with five effects, 440 kJ/kg_w with six effects, and 390 kJ/kg_w with seven effects (Jönsson et al., 1977a; Nygaard, 1986).[6] The optimal number of effects is a trade-off between operating costs and capital costs. Evaporators in the 1960s and 1970s were built with four or five effects, whereas most kraft mills today use five- or six-effect evaporators, with a concentrator to further increase solids content.[7] Firing the recovery boiler at higher solids content improves overall boiler performance and is a general trend in the industry. Increasing viscosity of the

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[6] For comparison, another source reports that 580 kJ/kg_w and 460 kJ/kg_w is typical for five and six effects, respectively (Grace, 1989). One case study of a six effect evaporator installed in 1982 reports that steam use is 440 kJ/kg_w (Anderson and Jansson, 1983).

[7] A concentrator is essentially a final evaporator stage, but is distinguished by a different design and by the use of primary steam.

black liquor makes it difficult, though not impossible, to handle at a solids content above 75%.[8]

The solids content of black liquor reaching the evaporator depends on how much it is diluted in the brownstock washing, i.e., where the fibers are separated from the spent pulping chemicals and dissolved organics, and this affects steam demand. For example, 6.2 kg of water per kg solids must be evaporated to increase solids from 13% to 65% as is done in a MEE system with six effects at the 1980 U.S. mill (Table 3.2). Solids are increased from 18% to 85% in the vintage 2000 mill, requiring evaporation of only 4.4 kg of water per kg solids, or 29% less than the 1980 U.S. mill. Concentrating from 13% to 18% requires evaporation of 2.14 kg water whereas going from 65% to 85% solids requires evaporation of only 0.36 kg water. The vintage 2000 mill uses a seven effect system with a superconcentrator--an evaporator designed to handle very high solids.

Two other evaporator technologies are worth noting. A vapor compression evaporation (VCE) system upgrades the quality of steam by compressing it. In principle, steam demand can be replaced entirely by mechanical energy by taking steam from the evaporation side of a single evaporator stage and feeding it to the condensation side (Fig. 3.3). In practice multiple VCE stages would be needed,[9] and thus the use of VCE is limited to pre-evaporation applications. Even pre-evaporation applications are limited due to the relative costs of electricity and steam at most kraft mills. According to one source there were only six installed VCE systems in kraft mills ten years ago (Ostman and Sebbas, 1985).

Freeze concentration of black liquor also substitutes steam for electricity. The basic principle is to subject the black liquor to freezing temperatures. Only pure water will enter the frozen state and can be mechanically removed. This technology was investigated in the 1970s and 1980s, but has never been tried in any commercial applications. At the time, cost assessments indicated that freeze concentration would not be as economically attractive as MEE, except where electricity prices were very low (Coleman, 1986).

3.1.7. Lime kiln

The lime mud from the causticizing reactions is washed to remove the white liquor and the percent solids in the lime mud is increased to 70% or higher in a filter (Fig. 2.5). The lime kiln where lime mud is calcined to regenerate lime (CaO) is typically fired with oil or natural gas but it can also be fired with gasified biomass. The reaction is endothermic and requires about 3.2 GJ per tonne of CaO (Adams, 1989). The average fuel consumption in 32 Canadian lime kilns surveyed in 1982 was 10.1 GJ per tonne of kiln discharge (Simonsen and Azarniouch, 1987), equivalent to 11.2 GJ per tonne of active CaO assuming that 10% of kiln discharge is inerts. This corresponds to 2.7 GJ/ADMT assuming that a charge of 240 kg active CaO is used per ADMT in the causticizer (Grace, 1989a). The average lime kiln fuel consumption in Swedish kraft pulp mills in 1988 was 1.8 GJ/ADMT (ÅF-IPK, 1989).[10] This suggests that efficiencies are higher in Swedish lime kilns but the numbers may not be strictly comparable due to differences in alkali consumption per ADMT in the digester.[11] The vintage-2000 mill (Table 3.2) assumes use of 1.3 GJ/ADMT, suggesting that more than half of the fuel input would be used for the actual calcining reaction (Warnquist, 1989). This level of fuel consumption is consistent with calculations of the efficiency improvement that could follow from process modifications involving e.g, higher dry solids content in the lime mud, less inerts, and lower exhaust and radiative heat losses (Theliander and Gren, 1986). Additional improvements in overall mill energy

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[8] Heating is used to reduce viscosity at high solids contents (Ryham, 1992).

[9] As the black liquor solids content increases, higher temperatures are required to continue evaporating water. This "boiling point rise" necessitates the use of several VCE stages to reach high solids contents.

[10] Another example is an Austrian pulp mill which converted from oil firing to gasified bark and wood waste in 1986 and reportedly used 2 GJ of gas per ADMT (Schweizer et al., 1987).

[11] According to a North American source (Clayton et al., 1989) the white liquor typically contains 105-155 grams/liter of NaOH with a median of 122, whereas a Swedish source (Mjöberg, 1992) gives 80-100 g/l of NaOH as typical values. We have not established whether the differences are offset by a higher white liquor charge in Scandinavian mills or if they reflect differences in wood species and pulp qualities.

efficiency can be achieved by, for example, pressurizing the white liquor preparation and by increasing the concentration and causticity[12] of the white liquor (Theliander and Gren, 1986; Larsson et al., 1992).

Black liquor gasification (see Section 4.2.1) may offer an opportunity to eliminate the lime cycle entirely, reducing energy use and the cost of the recovery system. Autocausticizing refers to the direct regeneration of sodium hydroxide (used in white liquor) from the bed solids (primarily sodium carbonate) of a gasifier in which metal oxides (e.g., Fe_2O_3, TiO_2, MnO_2) have participated in the gasification reactions. The metal oxide acts as a catalyst in the direct conversion of Na_2CO_3 to NaOH.[13] Autocausticizing is similar to the direct alkaline recovery system (DARS) process using Fe_2O_3 for the recovery of chemicals from black liquor produced by the soda pulping process (Gleadow et al., 1993a; Scott-Young, 1995). The introduction of autocausticizing in kraft mills is expected within a decade, but it could be two decades before it is widely used (Fleischman and Sobczynski, 1993).

3.2. Newsprint from TMP[14]

High yield pulping processes are electricity intensive. The electricity demand varies considerably depending on desired pulp qualities and is lower for groundwood pulps than for TMP pulps (Table 3.4). One measure of pulp quality is freeness, where lower freeness means a more finely ground pulp, which in turn requires more energy. Freeness is lowest for newsprint and catalog qualities and highest for fluff. The type of wood used also affects energy demand, and some wood species are better suited for some processes. There has been relatively little progress in decreasing electricity demand in mechanical pulping so far. Very little heat is used in the mechanical pulping processes. For example, less than 0.5 GJ/ADMT on average is used for TMP operations in Sweden (ÅF-IPK, 1989).

Much of the improvement in energy efficiency has resulted from increased heat recovery where the recovered steam is used to dry the paper. It is possible to recover as much as 65% of the electrical energy used in the TMP refiners as steam that can then be used for paper drying (see Section 3.3). This corresponds to about 4 GJ/ADMT. The amount of heat recovered as steam in the TMP mills that used heat recovery in Sweden in 1988 was on average 32% of total average electricity demand, or 2.7 GJ/ADMT. The level of heat recovery ranged from 18-50% in individual mills. The average steam demand in newsprint production, primarily for paper drying, was 4.9 GJ/ADMT of which 2.0 GJ/ADMT was recovered steam, 1.5 GJ/ADMT came from purchased fuels, and 1.4 GJ/ADMT came from bark and other self generated fuels (ÅF-IPK, 1989).

The minimum electricity demand, in principle, to produce mechanical pulp from logs has been estimated to be 300-400 kWh/ADMT (Mohlin, 1987), which is far below actual electricity use and thus suggests that major improvements should be possible. It is difficult to estimate the technical potential for energy savings in mechanical pulping since most research results are proprietary and process changes generally also result in pulp quality changes. One energy saving measure is to switch from single-disc refiners, which use about 2200 kWh/ADMT in the refiner stage, to double-disc refiners, which use about 1800 kWh/ADMT. These numbers do not including refining of the screening reject which requires an additional 200-300 kWh/ADMT (Wikberg, 1994). Other energy saving measures include improving process control, higher refiner speed, changing the design of the grinder segments on the discs, refining at lower concentrations, and various combinations of thermal, mechanical, chemical, or enzyme pretreatment. Some sources suggest that electricity use in TMP could be reduced by about 50% (Pöyry, 1989; Christiansson, 1995). One equipment manufacturer is reportedly undertaking full scale tests where electricity use is reduced by 30%, largely by changing the operating strategy (Christiansson, 1995).

For a conceptual greenfield newsprint mill design using technology that is projected to be available in the year 2000, the calculated electricity demand is 1495 kWh/ADMT of paper made from TMP (60%) and recycled pulp (40%), Table 3.5. The TMP fraction would use 1475 kWh/ADMT of virgin pulp. Pulping of the recycled fiber, including

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[12] The amount of NaOH divided by total titratable alkali (TTA = NaOH + Na_2S + Na_2CO_3).

[13] The two basic reaction steps are: $Na_2CO_3 + M_xO_y \rightarrow Na_2M_xO_{y+1} + CO_2$ and $Na_2M_xO_{y+1} + H_2O \rightarrow 2NaOH + M_xO_y$, where M_xO_y represents the metal oxide catalyst.

[14] This section draws heavily from Christiansson (1995).

mixing the two pulps, would use 475 kWh/ADMT of recycled pulp. This advanced design newsprint mill would purchase all electricity and have about 0.25 GJ/ADMT surplus steam, 0.47 GJ/ADMT bark, and 0.22 GJ/ADMT methane from anaerobic waste water treatment that could be exported from the mill.

3.3. Pressing and drying paper

Water removal from pulp slurry is among the largest steam users at any mill (see Table 3.2 for a kraft pulp mill). Typically, over 100 tonnes of water must be removed per ADMT of product. Two-thirds of the energy needed to do this is used in the drying section of a paper (or pulp) machine to remove the final 1% of this water (Table 3.6).

Paper drying starts by heating the sheet from the temperature leaving the press section. The most common type of drying technology is the multiple cylinder machine, where the sheet is brought in contact with a series of steam heated cast iron cylinders (see Fig. 2.8). Increasing the consistency of the sheet leaving the press section can reduce energy costs, but capital and O&M costs are likely to increase (Gavelin, 1982). The choice of technology in the press section also depends on what paper quality is produced. In the dryer, most of the energy is used to evaporate water, but a significant amount goes to other uses, especially where dryer energy efficiency is poor (Table 3.7).

A Canadian survey of newsprint dryer sections reported 36% to 45% consistency in the web after the press section, with an average of roughly 40% (Sayegh, et al., 1988). A Swedish survey reported a range between 39% and 47%, with an average of 43% for papers weighing between 40 and 60 g/m^2, some of which are newsprint (Christerson, 1993). The consistency that can be reached in modern press sections is reported to be above 50% (Hansson, 1988). Assuming that an energy demand of 2.83 MJ/kg of evaporated water (MJ/kg_w) can be reached, Table 3.7, the energy needed for drying from 50% to 90% is 2.264 GJ/ADMT of paper produced.

The reported steam consumption in the Canadian survey of newsprint dryer sections is 1.2-2.3 kg of steam per kg of water evaporated (kg_s/kg_w). The average reported steam consumption was 1.54 kg_s/kg_w and 2.0 kg_s per kg of paper, equivalent to about 4.5 GJ/ADMT of paper (Sayegh, et al., 1988).[15] The reported steam consumption in the survey of Swedish paper machines ranged from 2.4 to 5.5 GJ/ADMT with an average of 3.39 GJ/ADMT (Christerson, 1993).

Important ways of improving the efficiency of paper drying, in addition to higher solids from the press section, include reducing overall heat losses, using less air, and reducing the amount of steam going to the condenser, Table 3.7. Several technologies to increase solids from the press section and alternatives to the conventional cylinder drying that would impact energy use are being developed or already in use.

A common feature with new press technologies is that they operate at higher temperatures (to decrease the viscosity of the water) and higher pressures, in longer press nips, i.e., where pressure is applied to squeeze out water from the sheet. The extended nip press (Fig. 3.4) is a technology which was originally introduced by Beloit in 1980 and since then other major equipment manufacturers have developed their own designs using similar principles. More revolutionary drying concepts include the Condebelt process and impulse drying.

In the condebelt process (Fig. 3.5), the web is carried between a metal and a plastic mesh, which in turn are sandwiched between two steel bands, one heated and one cooled (Lehtinen, 1992). Steam is generated from water in the web by heat from one of the bands, and the steam condenses on the cooled band. This creates a significant pressure gradient that mechanically forces water out of the web. It is expected that most paper grades can be dried to final or near final dryness in two to three passes (Lehtinen, 1992). The process is in the pilot plant stage. The energy use is expected to be some 2.2 to 3.0 MJ/kg_w (Hansson, 1988). The lower end of this range is some 30% below levels achieved in conventional commercial driers (see footnote 15).

With impulse drying, the wet paper web passes through a press nip in which one of the rolls is maintained at a high temperature. In principle, the layout would be similar to the extended nip press (Fig. 3.4), but the press roll

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[15] 1.54 kg_s/kg_w is equivalent to 3480 kJ/kg_w assuming 2.26 MJ/kg_s. Another source reports that the post-retrofit steam consumption in a newsprint paper machine is 1.25-1.34 kg_s/kg_w equivalent to 2.8-3.0 MJ/kg_w (Persson, 1988).

temperature would be 200-400°C instead of below 100°C in a conventional press. A steam layer adjacent to the heated surface grows and displaces water from the sheet without evaporating it. The energy demand can be half or less compared to conventional evaporative drying (Lavery, 1988). Size and capital costs are likely to be lower since impulse drying has water removal rates[16] that are 100-1000 times those found in conventional drying sections. A potential application of impulse drying is to increase solids up to 60-70% or higher, followed by evaporative drying, which would then require many fewer cylinders and significantly reduced energy inputs compared to conventional drying. Total drying energy use has been estimated to be 0.6-1.4 MJ/kg_w (Hansson, 1988), or 50-80% less than conventional drying. Research in recent years on implusc drying has focused on reducing delamination of the sheet, which has been a particular problem with thick paper grades (Orloff, 1991).

3.4. Technologies used throughout the industry

Electricity end-uses common to all pulp and paper mills include pumping, air-handling, and lighting. In addition, steam needs and the large number of process streams makes the industry a good candidate for improved heat integration. Information technology, e.g., sensors, computers and controls systems, is developing rapidly and offers the potential for higher product quality and lower energy use. Other generic energy uses that will not be discussed here include compressed air systems, mixers, paper machine drives, vacuum pumps, and energy use in offices.

In addition to taking measures to reduce fluid flows, energy use in pumping and air-handling can be reduced by improving pump, fan, and other component efficiencies, reducing flow resistances, and by applying variable speed control instead of throttle control. Pumps and fans typically account for 40-45% and 15-20% of total electricity use in kraft pulp mills (Larson and Nilsson, 1991).

An energy analysis of one kraft pulp mill in the U.S. shows power demand to be nearly constant over a range of production rates (Fig. 3.6). This indicates that pumps and fans are operated with throttle control (power demand in pumps and fans at reduced flow is essentially the same as power demand at full flow when throttle control is used). Power demand would decrease with reduced flow if variable speed control were to be used.[17]

Average potential cost-effective savings through replacing worn pumps, downsizing oversized equipment, installing variable speed drives, etc., for pumps greater than 50 kW have been estimated based on a number of audits in Scandinavian pulp and paper mills to be about 30% (IndMeas, 1989). Similar results are reported for some U.S. mills (Herzog et al., 1992). The results of a pumping system audit for a specific pulp mill are shown in Table 3.8. Most of the savings would be achieved by replacing worn or oversized pumps and motors, or by trimming pump impellers. Although throttling losses associated with oversized equipment operating at more-or-less constant loads can be reduced by applying variable speed control, it will often be less expensive to downsize the equipment than to invest in a frequency converter for speed control. Another interesting example is the application of speed control to medium consistency pumps. This technology was first tried in a bleach plant retrofit in 1990 at a paperboard mill in Sweden. Pumping electricity use decreased by 26-27%, or 20 kWh/ADMT, and the payback period was two years (Caddet, 1993). Throttling valves are still needed at very low flows because medium-consistency pumps must maintain a specified minimum speed to insure that the fiber suspension remains fluidized.

Air-handling systems with variable flow are also good candidates for variable speed control. For example, one case study estimated that replacing variable inlet vane control of boiler fans with variable speed drives would result in cost-effective savings of 50% (Nyberg, 1989b). Natural ventilation driven by temperature differences can replace conventional mixing ventilation to supply fresh air in some cases. One paper mill recently eliminated 160 kW of installed fan power that was used to blow fresh air from the ceiling to the work zone in a factory building (Burängen, 1990). Enough heat is generated by the equipment to drive the circulation of air in a natural draft ventilation system with the air-intakes placed at the work zone level (Fig. 3.7). Waste heat is used to preheat the incoming air to comfortable levels.

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[16] Kg water removed per m^2 and hour.

[17] The savings are possible because the input power to many pumps and fans varies with the cube of flow, while flow varies directly with speed.

High quality illumination is important for safety and to enhance productivity and working conditions. Lighting typically accounts for only a few percent of mill electricity demand, but this corresponds to several hundred kilowatts of electric load. Modern lighting systems based on high pressure sodium lamps can reduce electricity costs by 50-80% relative to systems with mercury vapor lamps. There would be similar savings in maintenance costs, and the pay-back in typical retrofit applications ranges from 5 to 22 months (Maillet A.J., 1985).

Heat and power integration, i.e., the integration of heat-exchangers, heat pumps, heat-recovery systems, combined heat and power generation, etc., is critical for energy efficient operation of a mill. Pinch analysis is a systematic methodology that can be used to optimize this integration. Reported energy savings range from 10-35% with simple payback times of 1-3 years for pulp and paper mill retrofits made based on pinch analyses (Karp, 1990). In another case, pinch analysis identified cost effective savings corresponding to 9% of the heat demand in an already energy efficient kraft pulp mill that used 15-16 GJ/ADMT (Persson et al., 1990).

It appears that the pulp and paper industry has been slow to adopt new technologies for process control, analysis, and automation (Stephens, 1992; Bialkowski, 1991). Energy efficiency in the pulp and paper industry is affected in several ways by information technology. Computer programs aid the designer of plants and processes. On-line sensors and process control systems can provide precise control of anything from an individual pump to a paper machine. Computers help operators to monitor and optimize the operation of unit processes and whole plants. Specific to the pulp and paper industry, the development of on-line sensors for a number of difficult to measure paper, pulp, and wood properties is important. It is difficult to assess how computer control compared to manual control could impact energy use specifically since new control systems are often implemented in combination with other process changes and involve considerable operator training. We have not found any reported results from the pulp and paper industry but a detailed evaluation of a control system for steel reheating furnaces in the steel industry may serve as an illustration. Here it was concluded that computer control may well result in 15-20% savings, largely due to the information handling capability, speed and precision of computers (Mårtensson, 1994).

3.5 Energy Impacts of Environmentally Driven Technology

Efforts to reduce emissions from pulp and paper mills include external control measures, e.g. waste water treatment plants and electrostatic precipitators, as well as internal process changes, e.g., oxygen delignification with return of more organics to the recovery boiler. External control measures, for example, an aerated lagoon waste water treatment plant, often increase energy demand. However, the total energy impact depends on technology choice. For example, the anaerobic treatment of papermill sludges in model mill 2000 in Table 3.5. requires 85 kWh/ADMT. This is partly off-set by the heating value of the generated methane, 0.22 GJ/ADMT (Warnquist, 1989). Electricity use in an electrostatic precipitator corresponds to about 6 kWh/ADMT, but it allows the recovery and reuse of sodium and sulfur from the precipitator catch (Jönsson et al., 1977a). Oxygen delignification can result in increased on-site energy demand, which is partly offset by burning more organics in the recovery boiler, but if the lower use of bleaching chemicals is accounted for (see Section 3.1.4), it may lead to an overall decrease in energy use.

Complete elimination of solid waste and of all emissions to air and water from pulp and paper mills is not possible. The industry is pursuing the concept of "closed cycle" operation, particularly as it relates to the bleaching cycle to minimize liquid and gaseous emissions. One important characteristic of mill closure will be the return to the recovery boiler of essentially all organic material and reaction products dissolved in post-delignification and post-bleaching wash stages. Complete closed-cycle operation is not possible, because minerals, metals, and other "non-process elements" that enter the mill with the wood or process chemicals must be removed to prevent their continuous buildup. Some key non-process elements are chloride, potassium, phosphorous, calcium, silicon, and a number of metals. Some non-process elements will have natural points in the process from where they can be purged. Others may be more problematic. In any case, closed cycle operation will mean that emissions of solid waste will take on greater importance. Closed cycle operation may also require more de-coupling of process areas through buffer storage capacity. Advanced process control and monitoring systems will also likely be necessary to effectively deal with disturbances, because the margin for deviations from design operating conditions are likely to decrease.

Some modeling studies suggest that a closed cycle bleached kraft pulp mill may have 10-20% higher steam and electricity demands than a conventional mill due the need to concentrate bleach plant effluents, waste water treatment, and the addition of new processes and equipment (Gleadow et al., 1993b; Patrick et al., 1994). However, some 4-8% more steam can be generated in the recovery boiler due to the return of more organics (Mannisto et al., 1995; Patrick et al., 1994; Gleadow et al., 1993b).

Table 3.1. Comparison of specific energy use in kraft pulp mills

	Including powerhouse[a]		Excluding powerhouse[a]		
Mill	Steam demand (GJ/ADMT)	Electricity demand (kWh/ADMT)	Steam demand (GJ/ADMT)	Electricity demand (kWh/ADMT)	Electricity-to-heat (kWh/GJ)
1960 U.S. mill[b]	24.5	920	22.3	756	34
1980 U.S. mill[c]	20.2	780	16.3	656	40
Average 1988 Swedish[d]	15.2	840	-	-	55[d]
Best 1988 Swedish[d]	12.4	720	-	-	58[d]
Model mill 1980[f]	12.2	740	11.7	680	58
Model mill 2000[f]	7.8	640	7.8	580	84

(a) Powerhouse energy demand is the cogeneration plant's parasitic energy consumption.

(b) Source: (Subbiah et al 1995)

(c) Source: (Larson, 1992).

(d) Steam data for average and best 1988 Swedish mills (ÅF-IPK, 1989). Swedish data were collected by ÅF-IPK on behalf of the energy committee of the Swedish Forestry Industries Association.

(e) Electricity to heat ratio is based on steam and electricity demand including powerhouse because separate estimates of powerhouse steam and electricity consumption were not available.

(f) Data for the model mill 2000 is from (Warnquist, 1989). The model mills shows what is considered to be technically and economically feasible in a greenfield mill with 1980 and 2000-vintage technology, respectively. The model mill 2000 is still based on the kraft process but uses extended modified cooking, oxygen delignification and elemental chlorine free bleaching.

Table 3.2. Comparison of unit-level steam and electricity demands for bleached kraft pulp production in a U.S. mill built in the 1960s, US60 (Subbiah et al., 1995), a U.S. mill built in the 1980s, US80, adopted from (Larson, 1992), a hypothetical mill that would use the best available technology in 1980, M80, and in 2000, M00, both adopted from (Warnquist, 1989). Note that different accounting principles complicates comparisons at the unit level.[a]

	STEAM (GJ/ADMT)				ELECTRICITY (kWh/ADMT)			
Mill identifier →	US60	US80	M80	M00	US60	US80	M80	M00
Woodyard	n.a.	n.a.	0.3	0.1	-	25	75	75
Digester	4.57	2.89	2.5	1.5	212	43	50	40
Washing	n.a.	n.a.	0	0		103	40	10
Screening	n.a.	n.a.	0	0			45	20
Oxygen delig.	0.43	n.a.	0.35	0.7	185	47	60	85
Bleaching[b]	1.15	0.51	1.35	0.15		42	120	60
Screening and storage	n.a.	1.08	0	0.2	n.a.	74	50	40
Drying and baling	5.92	3.94	3.25	2.15	174	153	130	110
Black liquor concentration	5.26	4.33	3.75	2.95	n.a.	66	25	30
Powerhouse	2.50[c]	3.91	0.50	0	n.a.	125	60	60
Caust. & lime kiln (excl. fuel)	0.31	n.a.	0.15	0	141	42	35	45
Waste water treatment	n.a.	n.a.	0	0		n.a.	35	30
Other	4.41[d]	3.51[e]	0	-	208[f]	61[g]	15	35
TOTAL	24.55	20.16	12.15	7.75	920	780	740	640

(a) For example, the high electricity use in causticizing and lime kiln in the US60 mill suggests that it includes electricity use in black liquor evaporation.

(b) The US80 mill has a 3-step bleaching sequence and the other mills have 5-steps bleaching.

(c) Consists of 1.44 GJ/ADMT and 1.06 GJ/ADMT to utilities and soot blowing, respectively.

(d) Consists of 2.34 GJ/ADMT, 1.01 GJ/ADMT, and 1.06 GJ/ADMT to deaerator, water heater, and chiller.

(e) Consists of 1.75 GJ/ADMT, 0.70 GJ/ADMT, and 1.06 GJ/ADMT to deaerator, chiller, and other, respectively.

(f) Consists of 164 kWh/ADMT and 44 kWh/ADMT to utilities and water plant, respectively.

(g) Consists of 16 kWh/ADMT, 25 kWh/ADMT, 5 kWh/ADMT, 2 kWh/ADMT, and 14 kWh/ADMT to water supply, air supply, chiller/HVAC, odor control, and miscellaneous, respectively.

Table 3.3. Bleaching chemicals consumption for bleached kraft pulp and electricity use in their manufacture (Nygaard, 1986).

Bleach sequence →		CEDED		O-C_DEDED	
Chemical	kWh/kg	kg/ADMT	kWh/ADMT	kg/ADMT	kWh/ADMT
Oxygen (O_2)[a]	0.5	-	-	20	10
Chlorine (Cl_2)	1.7	70	119	35	60
Sodium hydroxide (NaOH)	1.7	46	78	20	34[c]
Chlorine dioxide (ClO_2)	5.0	22	110	25	125
Hypochlorite (NaOCl)	3.4	12	41	-	-
Total			348		229

(a) Oxygen can be purchased or made on-site. The oxygen delignification stage involves heating, pumping and washing which increases heat and electricity demand at the mill by approximately 0.5 GJ/ADMT and 75 kWh/ADMT, respectively.

(b) Chlorine dioxide is generally made on-site by mixing purchased sodium chlorate, some reducing agent, and acid. Because it decomposes explosively in the gas phase, the ClO_2 and is dissolved in water soon after it is formed. The electricity demand shown here is for the manufacturing of the purchased chemicals. Very little energy is required on-site.

c) The use of NaOH is lower with this bleaching sequence, despite the added use of an oxygen stage, because it has been assumed that some oxidized white liquor would be used in the oxygen stage instead of NaOH, and also less NaOH is required in the caustic extraction stages.

Table 3.4. Electricity use in mechanical pulping processes.

Source	Application/Quality	Electricity use, kWh/ADMT
Stone Groundwood and Pressurized Stone Groundwood Pulping		
ÅF-IPK, 1989[a]	Swedish average	1920
	newsprint	1790-2300
	catalog/journal	2100-2350
	board/carton	800-1290
Eliah and Lowitt, 1988[b]	SGW typical	1260-1450
Thermomechanical pulping		
ÅF-IPK, 1989	Sweden average	2300
	newsprint	2200-2450
	catalog/journal	2080
	board/carton	1670-2170
Eliah and Lowitt, 1988[b]	average TMP	1800
Wikberg, 1994	newsprint	1850-2500
Chemi-thermomechanical pulping		
Wikberg, 1994	fluff pulp	900
	tissue	1400-1600
	printing and writing	2200-2400
Recycled paper		
ÅF-IPK, 1989	liner	260
	newsprint	370
	other	440

(a) The Swedish SGW data may not be representative since they are based on a production of only 497,000 tons in 1988 in much of which is probably old equipment since SGW is being replaced by TMP in Sweden. The data from ÅF-IPK are the reported results of an extensive survey of energy use in the Swedish pulp and paper industry in 1988, reported electricity use is for pulp making and includes only refining, screening, and reject refining.

(b) Includes only the TMP refiner SGW itself and apparently not reject refining.

Table 3.5. Process heat and electricity demand per ADMT of paper produced in two hypothetical newsprint mills. Source: Warnquist, 1989.

	Newsprint mill model 1980-85[a]		Newsprint mill model 2000[b]	
	GJ/ADMT	kWh/ADMT	GJ/ADMT	kWh/ADMT
wood preparation	-	23	-	45
TMP pulp	-	1624	-	885
recycled fiber	-	80	-	160
stock preparation	-	75	-	30
paper machine	3.36	265	2.33	290
waste water	-	34	-	85
Total	3.36	2,101	2.33	1,495

(a) Newsprint made from 80% TMP pulp and 20% recycled fiber. The refiner uses 1,750 kWh/ADMT pulp, screening and reject refining uses 280 kWh/ADMT pulp.

(b) Newsprint made from 60% TMP pulp and 40% recycled fiber. The refiner including reject refining uses 1,400 kWh/ADMT pulp and screening uses 75 kWh/ADMT pulp.

Table 3.6. Newsprint machine water removal and energy use, adopted from (Jönsson et al., 1977b)

	wet end	press section	drying section
percent solids, in-out	0.8-20%	20-42%	42-90%
ton water removed per ADMT	109	2.36	1.14
energy use, MJ/ADMT[a]	810	972	3,824
energy use, MJ per ton water	7.44	412	3,350

(a) Electricity has been converted to primary energy using a heat rate of 10.8 MJ per kWh. Wet end and press section use no steam. Electricity use in the drying section is 43 kWh/ADMT and steam use is 3.36 GJ/ADMT

Table 3.7. Calculated energy demand in kJ per kg of water for drying paper. Source: Gavelin, 1982.

Evaporated water, kJ/kg	Best practice	Poor practice
Heating and evap. of water[a]	2460	2460
Heating of fiber[b]	70	100
Desorption heat[c]	20	60
Air preheating[d]	140	1600
Condenser losses[e]	70	300
Heat losses[f]	70	300
Total	2830	4820

(a) Assuming water is heated from 50°C and the heat of evaporation is 2.26 MJ/kg of water.

(b) Heat needed for heating the fiber from 50°C.

(c) Water binds chemically to the fibers and above 70% consistency, requiring desorption heat.

(d) Preheating 7.25 ton of dry air per ton of water assuming heat recovery.

(e) Steam condensed in the condenser.

(f) Radiative heat losses from the dryer hood.

Table 3.8. Electricity savings potential estimated for 12 pumps based on measurements at a pulp and paper mill in Wargoen, Sweden, based on (Nyberg, 1989a) as presented in (Larson and Nilsson, 1991).

Pump application and capacity (kW)	Recommended investments[a]				Investment cost (k$)[b]	Annual savings (MWh/yr)	CSE[c] (c/kWh) for disc. rate =	
	M	P	TI	VSD			6%	20%
Raw-water intake (119)	X	X			44.3	475 (50%)	1.3	2.2
Wash water (380)		X		X	86.2	550 (18%)	2.1	3.6
Tank drainage (69)				X	29.2	216 (42%)	1.8	3.2
Bleached pulp (36)		X			8.9	43 (31%)	2.8	4.9
Return water (101)	X	X		X	85.8	610 (68%)	1.9	3.4
Warm water filter (54)	X	X			19.1	192 (40%)	1.4	2.4
Mixing (184)	X		X		32.3	331 (23%)	1.3	2.3
Fresh water supply (59)	X	X			14.9	414 (82%)	0.5	0.9
Effluent (28)	X	X			13.1	130 (57%)	1.4	2.4
Paper mach. water (28)				X	13.4	162 (79%)	1.1	2.0
Mixing tank (26)				X	13.4	153 (78%)	1.2	2.1
Waste water (52)			X		5.2	200 (48%)	0.4	0.6
TOTALS	6	7	2	5	365.8	3476 (38%)[d]	1.4	2.5

(a) M = replace motor, P = replace pump, TI = trim pump impeller, VSD = install variable-speed drive.

(b) Costs are given in thousand 1990$. Original costs in Swedish kronor (SEK) were converted using 6.5 SEK per U.S. dollar. The present exchange rate is approximately 7.5 SEK per U.S. dollar.

(c) Cost of saved electricity (CSE) calculated assuming 10-year lifetime. CSE is calculated as the annualized capital costs divided by the annual electricity savings.

(d) The savings represent 26% of the electricity used by a total of 32 pumps that were originally selected for this study. Detailed savings estimates were made only for those listed in this table.

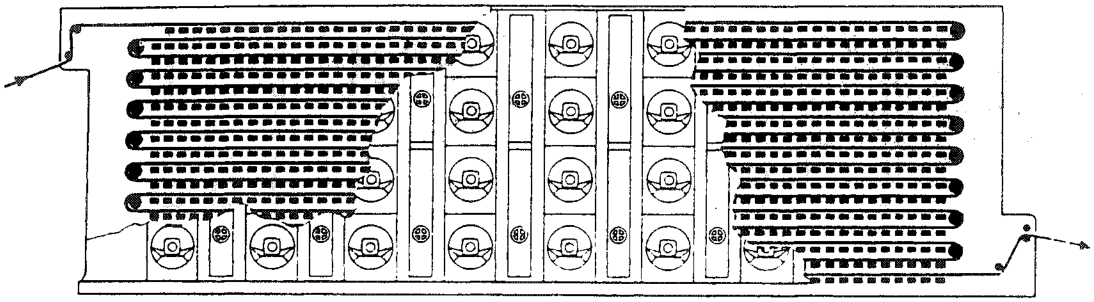

Fig. 3.1. An air float dryer (Perkins and Cowan, 1989). The pulp web moves over the dryer decks where hot air is blown to support the web and evaporate water. Turning rolls at the end sections move the web.

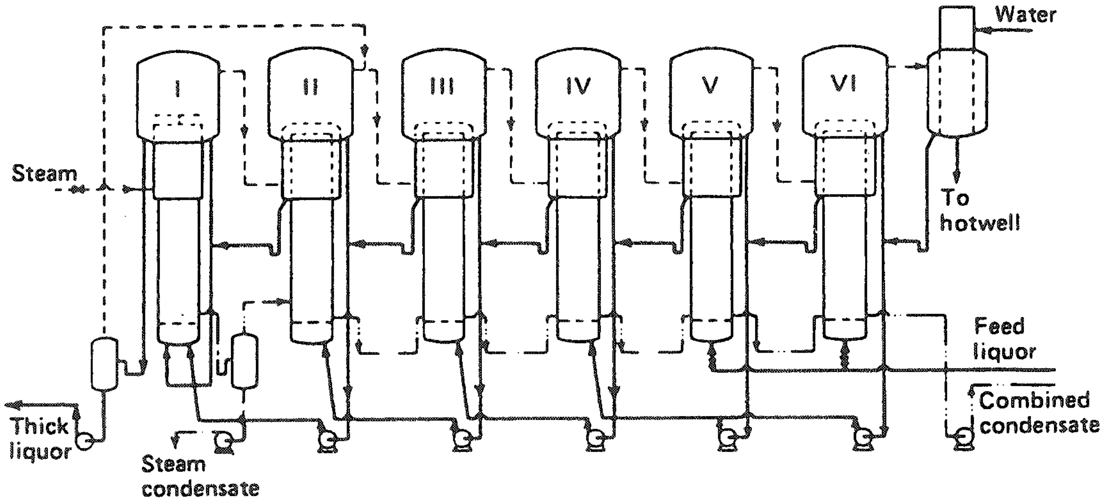

Fig. 3.2. Sample multiple effect evaporator sequence (Grace, 1989b).

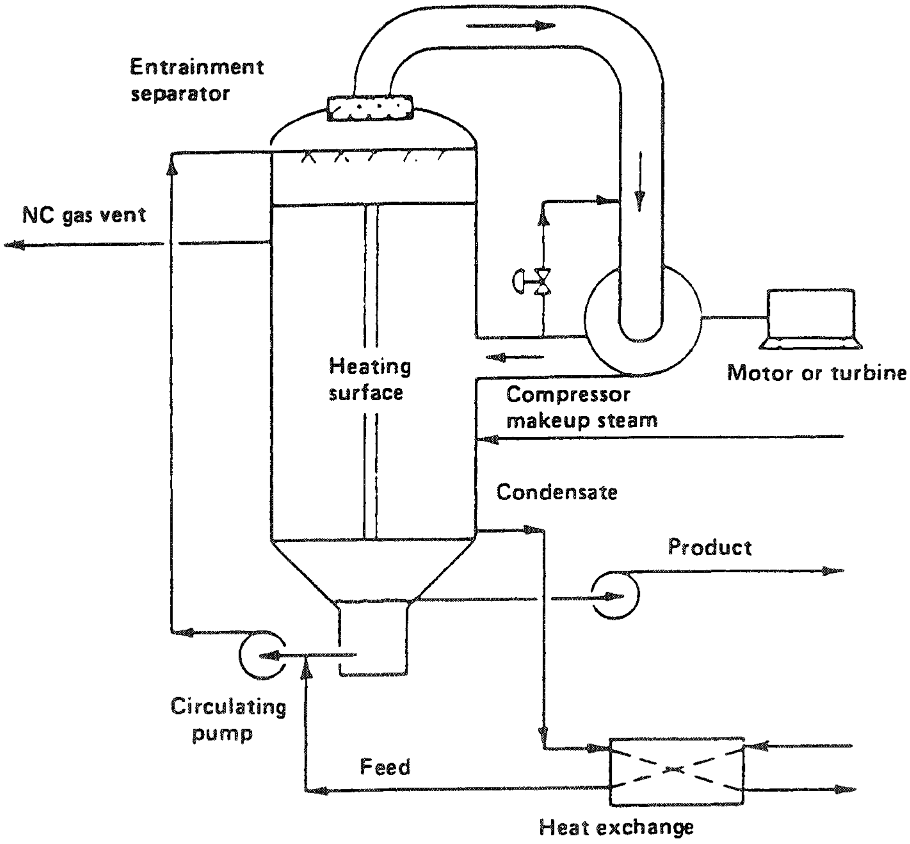

Fig. 3.3. Illustration of vapor compression evaporation principle (Grace, 1989b).

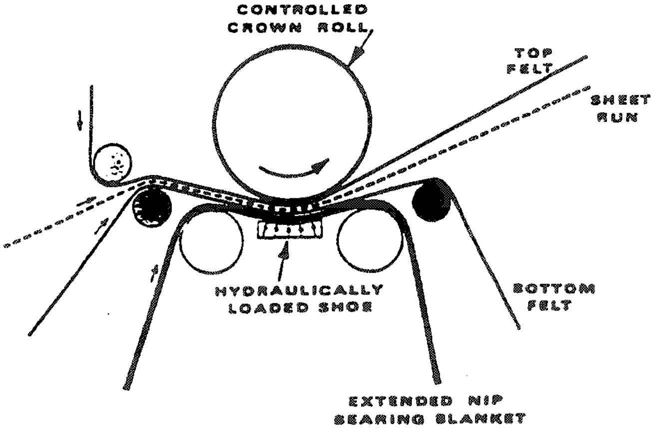

Fig. 3.4. Principle of the extended nip press (deBeer et al., 1993).

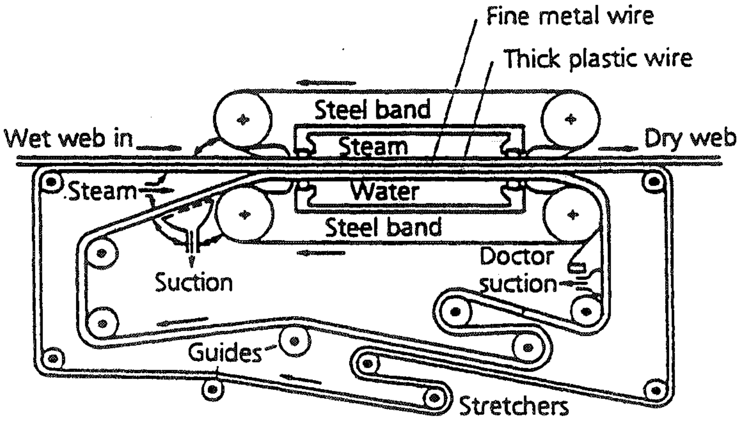

Fig. 3.5. Principle of the Condebelt drier (deBeer et al., 1993).

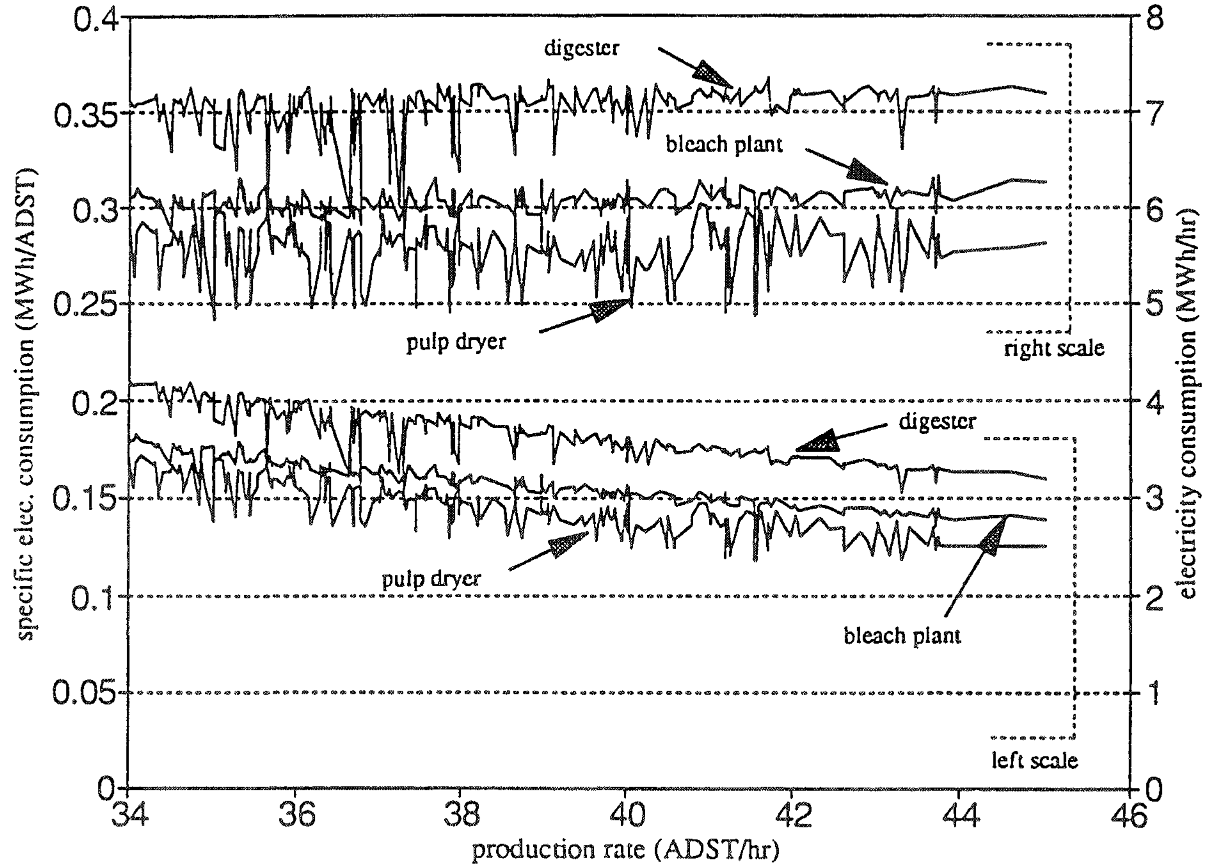

Fig. 3.6. Power demand in digesters, bleach plant, and pulp machine for a U.S. kraft pulp mill (Subbiah et al., 1995). Power demand in digesters is dominated by pumps, in the bleach plant by pumps and mixers, and in the pulp machine by fans and vacuum pumps.

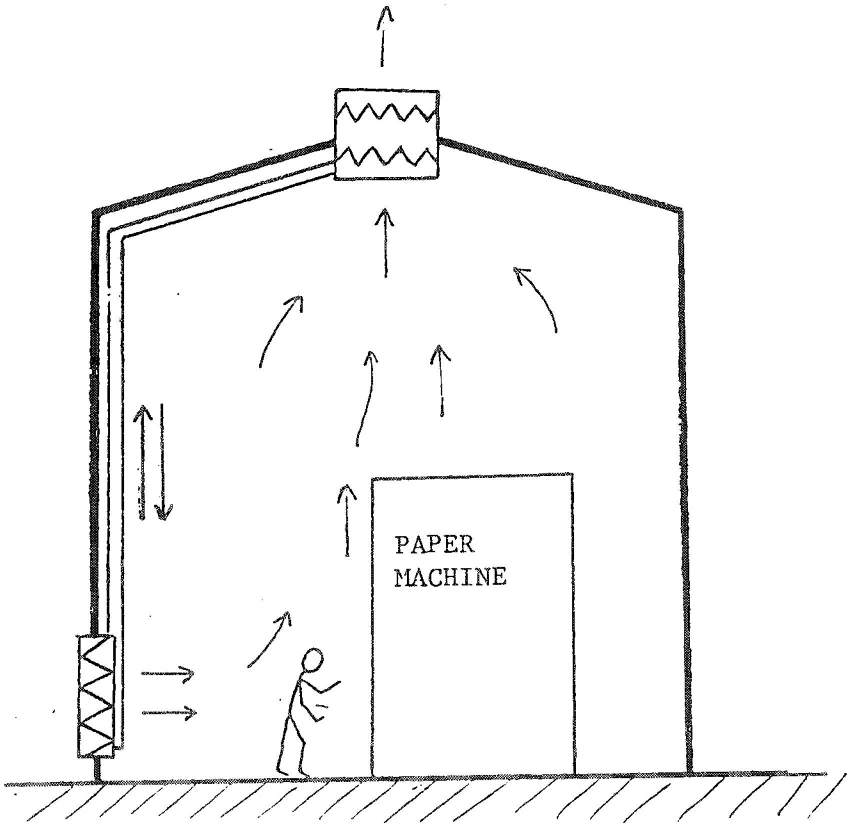

Fig. 3.7. Natural draft ventilation principle used in the paper machine area of a mill.

4. BIOMASS BASED COMBINED HEAT AND POWER GENERATION

In addition to being the feedstock for pulp and paper production, biomass is also a major energy resource for the industry. Black liquor and solid-biomass residues (bark and hog fuel) generated at the mill and used for energy amounted to some 1.5 EJ in 1993 (Table 1.3). The industry also has access to residues of pulpwood harvesting, some of which can be removed from the forest without serious environmental consequences.[1] One estimate of the amount of environmentally recoverable forest residues (applicable in the Southeastern U.S.) is some 0.15 tonnes per tonne of pulpwood (Larson, 1992). If applied to the total U.S. pulpwood consumption,[2] this corresponds to about 17 million dry tonnes of biomass, or an additional 0.34 EJ per year of biomass.

All black liquor and most mill residues are used at mill sites to fuel cogeneration systems providing steam and electricity for on-site use. In 1991, the industry generated a total of 54 TWh of electricity, which met 56% of its electricity needs (MECS, 1994). Essentially all of this power was produced in steam-rankine cycles, with black liquor accounting for about 43% and bark and wood chips for about 18% of the fuel input to the boilers (Giraldo and Hyman, 1993; MECS, 1994). The remaining 39% came from fossil fuels, predominantly natural gas, coal, and residual fuel oil.

Energy implications of alternative biomass-fueled cogeneration technologies fuels for the industry are discussed here.

4.1. Existing cogeneration technology

The average heating value of spent pulping liquors in the U.S. is equivalent to 23 GJ/ADMT of chemical pulp and it accounts for 73% of the biomass derived fuels used in the pulp and paper industry today.[3] The concentrated black liquor in the kraft pulping process today is burned in Tomlinson recovery boilers, to *(i)* recover process chemicals in the form of Na_2S and Na_2CO_3 and *(ii)* generate steam from combustion of the contained organic matter. The recovery boiler is thus an integral part of the process and of the mill's steam and power system. The cost of a recovery boiler for a 1,200 ADMT per day bleached softwood kraft pulp mill firing 2,000 tonnes of black liquor per day is about $65 million (McKeough et al., 1995). An entire chemical recovery system costs about $100 million, about one-sixth of the total cost for a 1,200 ADMT per day bleached kraft market pulp mill (Weyerhaeuser, 1992). The recovery boiler is a primary reason for the capital intensity and economies of scale associated with kraft pulp mills.

In a recovery boiler, droplets in a black liquor spray dry, pyrolyze and burn. The inorganic chemicals are extracted as a smelt at the bottom of the boiler. Steam is usually produced at about 60 bar and 450°C and fed to one or more back-pressure steam turbines from which some process steam is extracted at 10-12 bar and the rest exhausts at 4-5 bars. Bark, hogged fuel, and other fuels are fired in separate boilers to raise steam which typically augments the steam from the recovery boiler.

The electricity-to-heat production ratio for a conventional back-pressure steam turbine is about 0.23 (60 kWh/GJ) with no intermediate extraction and about 0.15 (40 kWh/GJ) with an intermediate extraction (Warnquist, 1992). These electricity-to-heat ratios are relatively well matched to the steam and electricity needs at older kraft mills (Table 3.1). However, increasing electricity-to-heat demand ratios (see Section 1.2) are motivating interest in

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[1] The impact on soil nutrients and organic content are key concerns associated with removal of logging residues. Recycling of ash from the mill back to the forest may be necessary or desirable to minimize long-term nutrient depletion (Ericsson and Börjesson 1991; Åbyhammar et al., 1994). Removing residues for energy without recycle might actually be beneficial in areas with high nitrogen deposition from air-pollution (Lundborg, 1993).

[2] Pulpwood consumption in 1993 was 67 million cords (1 cord = 128 ft^3) of softwood and 39 million cords of hardwood (AFPA, 1994a), or about 110 million dry tonnes assuming a dry matter content of 2000 lb/cord (908 kg/cord) for softwood and 2800 lb/cord (1,270 kg/cord) for hardwood (Clayton et al., 1989).

[3] Based on a production of 46.55 million ADMT of kraft pulp and 1.29 million ADMT of sulfite pulp (AFPA, 1994a) and a total of 1.11 EJ in spent pulping liquors (Table 1.3).

alternative cogeneration technologies.

Electricity-to-heat ratios can be increased to some extent by increasing boiler pressures and temperatures. For example, 60 to 80 kWh/GJ can be achieved with steam conditions of 105 bar and 520°C (Warnquist, 1992). The overall ratio of electricity to heat output may also be increased by using a condensing extraction steam turbine where some of the steam is expanded to sub-atmospheric pressure to produce additional power and then condensed. Condensing power can also be produced by adding a separate condensing steam turbine after the back-pressure turbine. The technology of choice depends on the specific energy balance and relative fuel and electricity prices for each mill.

There are several reasons for industry interest in alternatives to the Tomlinson recovery boiler/steam turbine systems, in addition to limitations on the electricity to heat ratios that can be achieved. The black liquor handling capacity of the recovery boiler is typically the bottleneck to expanding overall production capacity at a mill, and adding incremental recovery boiler capacity (as many mills would like to do) is prohibitively capital intensive. (Recovery boilers are built large to take advantage of economies of scale.) Other drawbacks of Tomlinson recovery boilers include dangerous explosions that can occur when water or wet black liquor inadvertently contacts the smelt, as well as emissions of odorous and acid gases. Furthermore, a large fraction of the existing recovery boilers were installed from 1965-1975 (Fig. 4.1). It is expected that 70% of all boilers will need some type of major rebuild or replacement in the next decade (Patrick et al., 1994).

4.2. Future cogeneration technology

The focus of most interest in new biomass cogeneration technologies are those that would utilize gas turbines rather than steam turbines. Gas turbines are generally characterized by higher electricity-to-heat ratios than steam turbines, as well as lower unit capital costs. The key requirement for using biomass in a gas turbine is a clean gaseous fuel. Thus, there is significant development ongoing of technologies for converting black liquor or biomass residues into combustible fuel gas,[4] and the cleanup systems that would be needed to enable use of the gas in gas turbine cycles.

4.2.1. Black liquor gasification

Black liquor gasification (Ihren, 1994; Grace and Timmer, 1995) is attracting considerable interest from industry today primarily because gasifiers are expected to be able to cost-effectively add incremental chemicals recovery capacity to mills. In the longer term, full scale black liquor gasification/gas turbine cogeneration systems as replacements for recovery boiler/steam turbine systems should offer higher overall energy efficiency, higher electricity-to-heat ratios, and lower emissions than recovery boilers.

Gasification processes are categorized as low-temperature/solid-phase (below approximately 750°C) or high-temperature/smelt-phase (above approximately 900°C). They produce fuel gas with higher heating values (HHV) of 3-4 MJ/Nm^3 (with air as the gasifying agent) or 8-9 MJ/Nm^3 (with oxygen or with indirect heating) (Grace and Timmer, 1995). With either gasifier, cleanup of the fuel gas is required to recover inorganic chemicals that may leave the gasifier with the gas, to prevent damage to the turbine, and to meet emissions regulations.

The main feature of the low temperature gasification processes are that they employ fluidized bed gasification. Solid sodium carbonate (Na_2CO_3) is precipitated out during gasification and forms the bed material. Some 70% or more of the sulfur in the black liquor leaves as H_2S gas, which then is scrubbed from the gas (Fig. 4.2). Manufacturing and Technology Conversion International (MTCI) and Asea Brown Boveri (ABB) are two leading developers of low-temperature gasifiers. The MTCI design is an indirectly-heated fluidized bed (with in-bed heater tubes). The ABB design (Fig. 4.2) is an air-blown circulating fluidized bed. MTCI is testing a 50 tonne black liquor solids per day gasifier at Weyerhaeuser's New Bern kraft pulp mill in North Carolina. ABB has a tested a 2-4 tonne per day pilot gasifier in Sweden since 1991 and is planning a 50-100 tonne per day demonstration unit in the U.S.

One of the main difficulties associated with low temperature processes is that they must operate within a narrow

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[4] Hydrogen and carbon monoxide are the most important combustible components in most fuel gases from gasifier. The full composition of the gas depends on the design and operating conditions of the specific gasifiers.

temperature window--high enough to achieve satisfactory gasification rates and tar destruction, but low enough to avoid softening of the bed material leading to agglomeration. Closed cycle operation of mills (see Section 3.5) could lead to accumulation of potassium and chloride in the bed material. If not removed, these elements will lower the melting point of the bed and further narrow the temperature window.

High temperature gasification uses an entrained flow reactor (Fig. 4.3). Inorganic chemicals (Na_2CO_3 and Na_2S) are recovered as a smelt similar to that from a recovery boiler. About half the sulfur leaves as H_2S in the fuel gas. The high reactor temperatures give higher rates of carbon conversion than with the low temperature design. Kvaerner Pulping is currently the leading developer of the high temperature technology. An atmospheric-pressure unit having a capacity of 75 tonnes per day is operating commercially at a Swedish mill in parallel with a recovery boiler to boost chemicals recovery capacity. Kvaerner has also operated a pressurized (6-7 tonne per day capacity) gasifier with a gas clean-up system at a Scandinavian mill since February 1994 (Stigsson, 1994). Large atmospheric-pressure units--250 tonne per day--are now being offered on commercial terms for incremental capacity increases. Tampella, a Finnish equipment supplier to the pulp and paper industry, undertook limited pilot scale tests beginning in 1991 with a 2-3 tonne per day gasifier. However, the unit is no longer being operated, and Tampella's activities are at present limited to fundamental studies (Janka, 1995).

The higher rate of carbon conversion is an important advantage of the high temperature gasifiers. There is some concern regarding the materials and corrosion problems associated with operating at high temperatures. Higher concentrations of potassium and chloride as a result of mill closure are likely to be an advantage in high temperature gasifiers since they increase the reactivity of the black liquor. (Salmenoja et al., 1993: Stigsson, 1994.).

4.2.2. Bark and wood waste gasification

Black liquor is the most abundant biomass energy source at a kraft pulp mill, providing some 20-25 GJ of energy per ADMT.[5] However, bark and wood wastes also make important contributions at most mills. Typically, 5-10% of the pulpwood that enters a mill is bark and other residues, corresponding to roughly 200 kg of dry substance (DS) or 4 GJ per ADMT of pulp. The recovery of logging residues (see introduction to Section 4) might add another 8 GJ/ADMT so that bark and wood waste might make up 12 GJ/ADMT, or 50% of the energy value of the black liquor.

A handful of large (>30 MW biomass input) atmospheric pressure, air-blown wood-chip gasifiers are operating commercially today, most of which are supplying fuel gas to lime kilns at kraft pulp mills. Pressurized and other advanced gasifier designs are the focus of demonstration efforts of biomass integrated gasifier/gas turbine (BIG/GT) technology in several countries (Williams and Larson, 1995). The first BIG/GT system to be built is a 6 MW_e and 9 MW_{th} (20 MW biomass input) combined cycle district heating cogeneration facility in Värnamo, Sweden. Testing of that system began in 1994 and is ongoing. Other planned demonstration efforts include a commercial scale combined cycle in Northeast Brazil that will be partially financed by the Global Environmental Facility (Elliott and Booth, 1993). Several demonstration projects in the 8-20 MW_e range have recently been announced in the European Union and two projects receiving partial backing from the Department of Energy are ongoing in the U.S.

4.2.3. Electricity exports from kraft pulp mills

Mills with kraft pulp production might become significant electricity exporters if they adopt full-scale black liquor and biomass gasification gas turbine technologies (Larson, 1992; Ihren, 1994; Berglin, 1995; McKeough et al., 1995). Commercial biomass gasifier/gas turbine systems might be commercially available as soon as the end of the decade. Commercialization of systems using black liquor gasification will probably require somewhat longer, because gasifier/gas clean up technology is at a less mature stage for black liquor than for woody biomass.

The potential impact of alternatives to existing cogeneration systems using back pressure steam turbines can be appreciated from an examination of three configurations of black liquor/biomass cogeneration systems at a kraft pulp mill, assuming biomass fuel availability of 21 GJ/ADMT of black liquor and 4 GJ/ADMT of bark: *(1)* biomass and

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[5] With closed cycle operation, the energy available from black liquor would be somewhat higher than this.

recovery boilers are used, but a condensing-extraction steam turbine (CEST) replaces the back-pressure system; *(2)* black liquor and biomass gasifiers fuel a gas turbine/steam turbine combined cycle; and *(3)* the same as the previous system, but assuming the supplemental availability of 8 GJ/ADMT of logging residues as fuel.

Figure 4.4 from Subbiah, et al (1995) summarizes the estimates of electricity and steam production for each case. Varying electricity-to-heat ratios can be generated with the CEST and gas turbine technologies to match the particular energy demands of a mill. Mill demands correspond to those shown in Table 3.1 for alternative mills.

The CEST option in the full cogeneration mode (maximum process steam production) generates about 600 kWh/ADMT of electricity and 14.4 GJ/ADMT of steam. With this technology an efficient kraft mill can be essentially energy self-sufficient. With option 2--the integrated gasification/gas turbine combined cycle using mill residues--1,800 kWh/ADMT and 11 GJ/ADMT would be generated in the full cogeneration mode. Further reductions in steam demand would be needed compared to option 1. Assuming these can be achieved, there would be about 1100 kWh/ADMT, or 35 to 45 MW of baseload power (at a 1200 ADMT/day mill), available for export from the mill after meeting on-site demands. The value of the excess electricity (assuming 5 c/kWh revenue) would be $55/ADMT, which is significant relative to the value of the primary product, pulp. (Pulp prices range from $400 to $800 per ADMT.) The same system but including use of logging residues (Option 3) would generate 2440 kWh/ADMT and 14.5 GJ/ADMT in the full cogeneration mode, and would thus provide still greater electricity revenues. The economic viability of the gas turbine options would need to be examined carefully, but some preliminary assessments (McKeough et al, 1995; Larson, 1992) show potentially attractive returns.

Assuming an average electricity production of 2000 kWh/ADMT of bleached, semi-bleached, and unbleached kraft pulp, and a production of 50 million ADMT of kraft pulp per year, the total annual electricity production in U.S. kraft pulp mills could be 100 TWh. This is roughly double the amount of electricity self-generated by the pulp and paper industry today. It is the equivalent of total electricity consumed by all pulp, paper, and paperboard mills in the U.S.

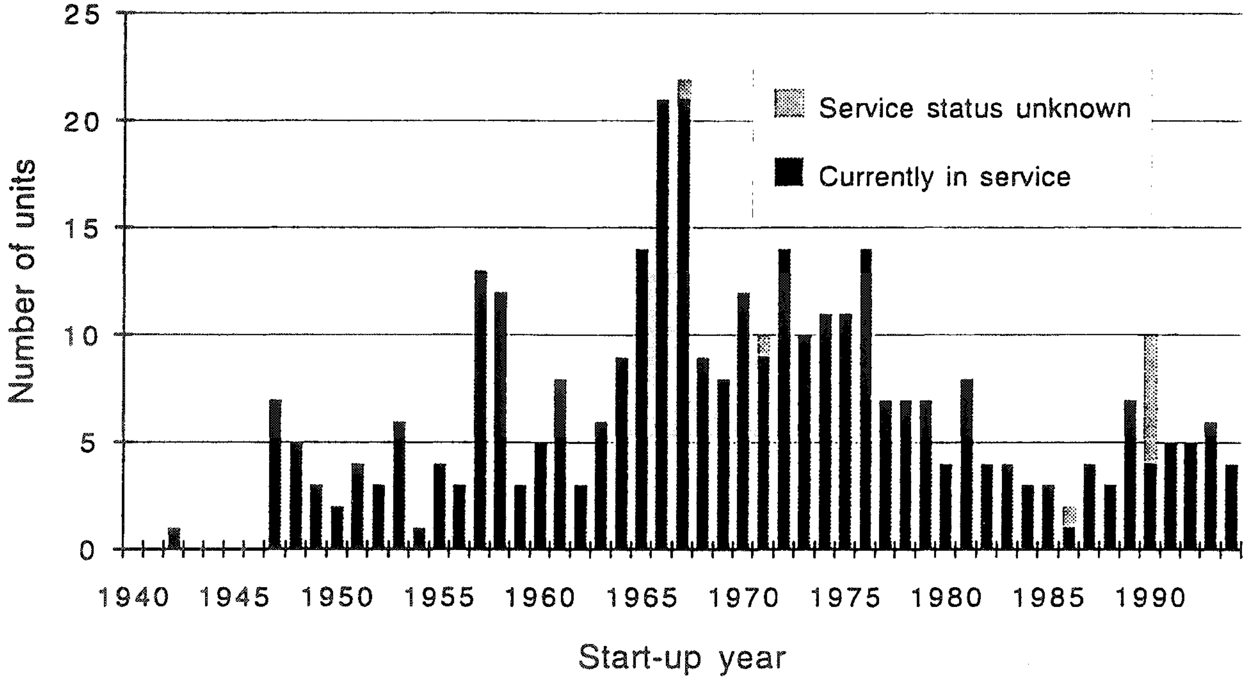

Fig. 4.1. Number of recovery boilers by start-up year or latest rebuild year. Adapted from Patrick, et al. (1994).

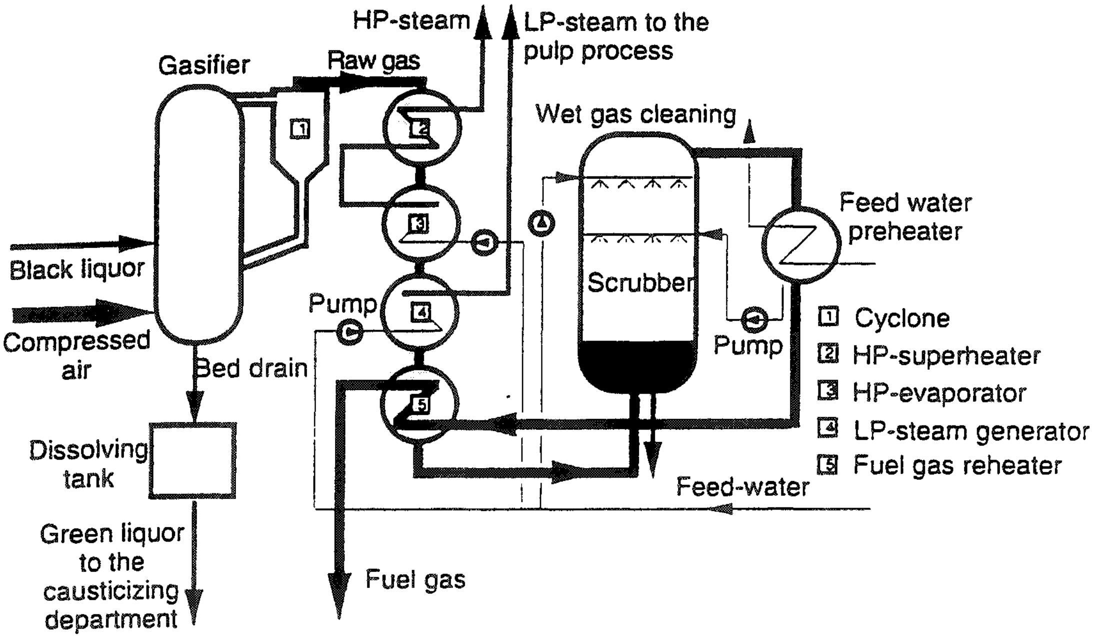

Fig. 4.2. Low-temperature/solid-phase, circulating fluidized bed black liquor gasifier (ABB type) with wet gas clean up (Ihren, 1994).

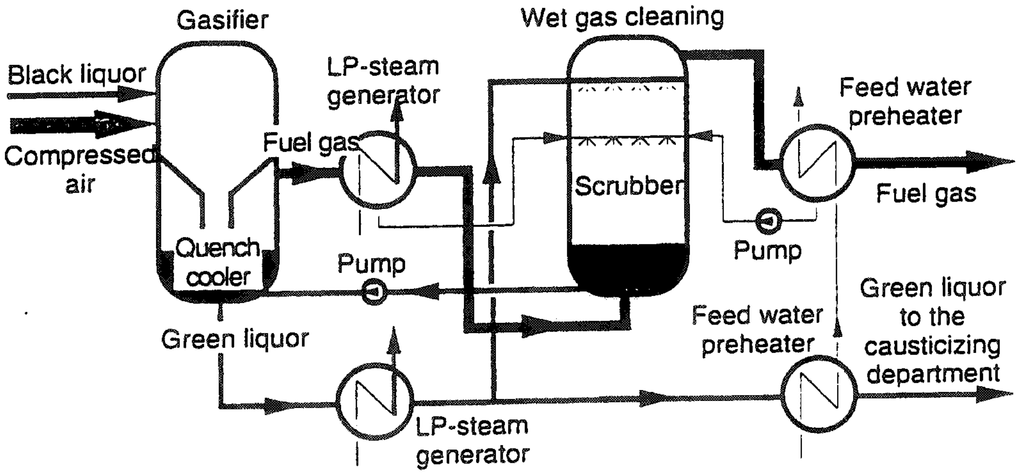

Fig. 4.3. High-temperature/smelt-phase, entrained-bed black liquor gasifier with quench (Kvaerner type) and wet gas clean up (Ihren, 1994). Pressurization of the gasifier facilitates recovery of heat at higher temperature and pressure.

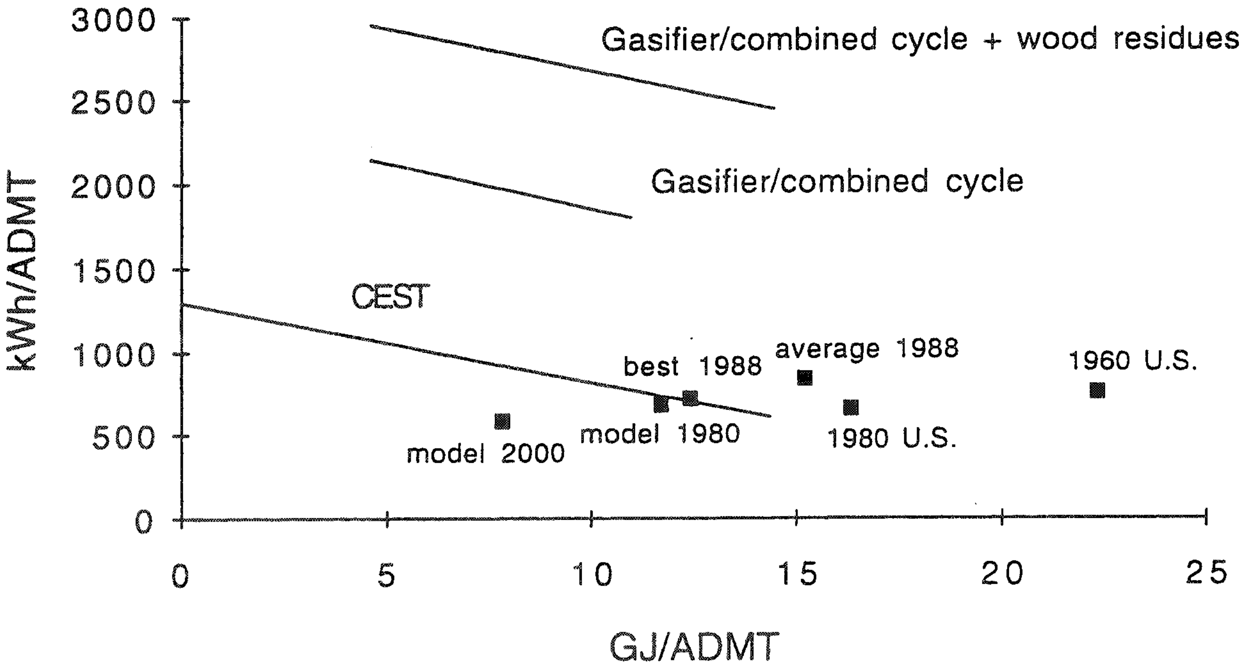

Fig. 4.4. Steam and electricity production potential (net of cogeration plant) at a kraft pulp mill from bark (4 MJ/ADMT) and black liquor (21 MJ/ADMT) fuels using alternative cogeneration technologies. Steam and electricity demands (excluding powerhouse, Table 3.1) for alternative mill technologies are also shown. The cogeneration technologies are the condensing extraction steam turbine (CEST) and black liquor/bark integrated gasification/gas turbine combined cycle (black liquor and bark are gasified separately). For the latter technology, two lines are shown. The upper line assumes the use of 8 MJ/ADMT of forest or other biomass residues in addition to the 25 MJ/ADMT of fuels assumed for the lower line and for the CEST case. See Subbiah, et al (1995) for details of the calculations.

5. INDUSTRY ENERGY POLICY AND DECISION MAKING[1]

To identify effective approaches to improving energy efficiency that would also enhance the competitiveness of the industry, an understanding of processes and technologies is necessary (Section 2-4). Equally important is some understanding of decision-making processes and strategies. The understanding of technology and decision-making provide a foundation for exploring energy efficiency strategies, including how and in which areas there might be beneficial cooperation between the industry, utilities, government, regulatory agencies, and other institutions.

5.1. Energy decision making in the industry

Purchased energy (Table 1.2) and capital investments to utilize these and self-generated biomass fuels represent major production costs. The variety of corporate philosophies and structures across the industry preclude generalizations about how decisions are made relating to these energy-related costs. Some companies use very decentralized structures, with even relatively major energy or non-energy related investment decisions made at the mill level. In other cases, capital budgets and decision making are centralized and investments require approval from division and/or corporate headquarters. Many mill managers can decide on capital expenditures up to some limit and within a set budget, but both the limit and budget may vary with the economic climate (Aho and Boner, 1985). Several companies have corporate energy management teams responsible for negotiating contracts with suppliers of fuels and electricity. Many corporations have more or less explicitly formulated environmental goals, in some cases including energy strategies. Other corporations are in the process of developing such goals and strategies.

While generalizations are difficult, several observations relating to personnel and capital investment decision-making are worth noting. An important lesson from the chemicals industry is that for the purpose of improving energy efficiency it is necessary to create an empowered efficiency culture in the company (Nelson, 1993). Also, when upper management declares a company's serious commitment to the environment and to energy efficiency, the words must be backed by commitment of resources.

Traditionally, pulp and paper companies have maintained skilled staff with responsibilities ranging from energy purchases to operation of on-site heat and power generation and energy demand management. However, a general trend in this and other industries is toward reduced staff dedicated to energy, with greater reliance on outside specialist consultants. One positive effect is that good ideas are spread more rapidly throughout the industry. At the same time, there are fewer people on-site with the plant-specific experience that may be crucial to identifying the best site-specific opportunities to improve efficiency.

Energy related investments compete with other investments for capital. The relatively low fuel and electricity prices prevailing since the mid-1980s have reduced the profitability of investments in energy efficiency improvements. Projects are generally ranked according to *(1)* profitability and *(2)* if they make the mill more competitive. In practice, this means that shorter paybacks are required for pure cost cutting measures, such as installing energy efficient motors or lighting, than for measures to increase production, improve product quality, increase market share, etc. However, many of the best opportunities for improving efficiency will also lead to improved productivity, quality, environmental performance, or other factors. For example, introduction of a variable speed drive might save electricity while affording better process control.

Investments that impact energy efficiency will tend to follow general investment patterns in the industry. The latter are highly cyclical (Nykanen, 1995). Annual capital expenditures in the U.S. pulp and paper industry reached $17 billion in the 1989/1990 period, fell to about $10 billion in 1993, and are now on the upswing again. To some extent, this investment pattern aggravates the cyclic pricing of industry products, since capacity expansions can lead to over-capacity and hence falling product prices: high kraft market pulp prices in the late 1980s dropped to about $400 per tonne in the early 1990s and increased to more than $800 per tonne in the 1994/1995 period.

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[1] This chapter is partly based on discussions with representatives from International Paper, Georgia-Pacific Corp., Weyerhaeuser Co., Union Camp Corp., Potlatch Corp., Stone Container Corp., CRS Sirrine Inc., Southern Electric International Corp., BC Hydro, Minnesota Power, Bonneville Power Administration, and Barakat & Chamberlin.

5.2. Industry-utility cooperation in DSM programs

Electric utility demand side management (DSM) programs aimed at load management and electricity conservation have historically targetted the residential and commercial sectors. Industrial programs were introduced later. Utility DSM program designs and experience vary from case to case (Jordan and Nadel, 1993).

A general concern with DSM are the consequences of rate increases that are needed for the utility to compensate for lost revenue and program cost. While participating customers reduce consumption and as a result get lower electricity bills, non-participating ones may only see rate increases, if the DSM programs are not appropriately designed. A number of approaches have been tried to deal with this concern. For example, industrial customers of Niagara Mohawk can opt to be ineligible for financial DSM incentives and thereby avoid being allocated some of the program cost. For large industrial customers of Minnesota Power, 1.5% of the revenues from each customer are set aside by the utility for that customer to draw on when investing in energy efficiency.

In the preparation of this document, we undertook an informal sampling of pulp and paper companies to better understand the extent of interest in utility DSM programs. All of the contacted companies have had some experience with utility sponsored programs, and several felt a useful role for utilities was in assisting mills to improve efficiency in relatively generic end-use areas e.g., lighting, compressed air supply, pumping, and air-handling systems. At the same time, most said they would rather have lower per-kWh electricity rates than utility-DSM programs. This may be due to the perception that DSM programs contribute to higher overall electricity bills, because utility costs to administer DSM programs are included in total program costs. (Companies feel they are able to more effectively spend funds for DSM measures on their own than through utility-related DSM programs.)

An ACEEE survey of industrial DSM programs (Jordan and Nadel, 1993) identified some common characteristics of successful programs. These included understanding of the customer perspective, personal contact between customer and utility, program flexibility, and financial incentives. Understanding the customer's perspective is clearly important in the pulp and paper industry where each corporation and individual mill may be different in terms of products, technology, markets, organization, etc. It is also important for the mill to have an appreciation of the utility's perspective. Such mutual understanding and trust is best developed through personal relationships between mill and utility representatives.

A good dialogue between utility and industry can also foster the development of more innovative and flexible programs that better suit the needs of each party. For example, one important lesson from an internal energy conservation competition at DOW Chemical is that nearly all winning projects involved modifications to process equipment, changes to the process itself, or to process operating strategies (Nelson, 1993). Almost none of the projects involved areas typically covered in utility DSM programs, e.g. lighting and energy efficient motors. Minnesota Power's industrial DSM program provides some flexibility that addresses this shortcoming in traditional DSM programs. For example one Minnesota Power customer used its set-aside funds to install a process control system that yielded energy beneftis (among others).

Utilities are now increasingly downsizing industrial DSM programs, in particular by removing financial incentives, largely due to regulatory uncertainty with regards to increasing competition in the electricity sector. If a retail wheeling/direct access model being advocated by large users is adopted, then pulp and paper mills would get full access to buying electricity at wholesale prices. This is likely to result in a withdrawal by utilities from DSM activities and an increased emphasis on lower rates rather than lower bills. The final outcome, however, remains uncertain, especially given the fact that critical decisions may well be made one state at a time.

5.3. Cogeneration plant and other on-site utility systems

The pulp and paper industry is distinguished from many other industries by the extensive use of black liquor and biomass fueled cogeneration to provide much of on-site heat and power demands. There are also a number of other utility systems on which the industry relies, including water supply, waste water treatment, oxygen generators, and compressed air systems. Changes to these utility systems are generally not given as high priority as product related process improvements, although financial risks associated with the former may be lower because such utility systems tend to have longer useful lives than process changes. In fact, it is not uncommon for companies to farm-out the operation of mill utilities (typically to private independent companies), and in some cases such assets have been sold to free up capital and to allow industries to concentrate on their core business--making paper.

Will the pulp and paper industry opt to make fuels and electricity production a part of their business or will other parties own and operate the energy assets? Raymond (1993) reports that energy experts at some companies think that within two decades many pulp mills will derive as much value from energy ventures as from the pulp itself. At another extreme, some companies are selling off their entire energy complexes to free up capital that can be reinvested in the core business.[2] In another case, plans are being developed between Virginia Power and the Chesapeake Corporation for Virginia Power to build, own and operate a natural gas fired cogeneration plant at Chesapeake's West Point mill to replace an old fossil fuel fired boiler.

Since power is their core business, independent power producers or utilities could conceivably be more effective than paper companies at operating cogeneration plants as profit centers, and they might be better positioned to adopt new technology. Oxygen is another case where it can make sense, if oxygen demand is high, for a pulp mill to buy over the fence rather than own and operate its own equipment. This is done, for example, at Chesapeake's West Point mill, where an oxygen supplier combines the production of oxygen next to the mill with the production of other marketable gases. Depending on contract arrangements, however, there could be disincentives to improving energy or overall resource efficiency if the ownership/operation and the end-use of such mill utilities are separated. For example, if a utility (compressed air, oxygen, etc.) were to be provided at a flat rate, or under a take-or-pay contract, the user would have little incentive to reduce consumption.

It remains to be seen to what extent there will be a market for electric utilities, independent power producers, and others to own and operate cogeneration and other utilities plants adjacent to pulp and paper mills, as well as what the impact of different ownership structures will be on energy efficiency in the industry.

5.4. Industry-government cooperation

The pulp and paper industry has not participated in federally funded industrial research to the same extent as many other industries. However, guided by existing industry-government partnerships in the semiconductor, textiles, and automotive industries, the U.S. Department of Energy and the American Forest and Paper Association announced a major new joint research initiative in November 1994 aimed at promoting industrial growth, energy efficiency, and international competitiveness, while preserving the environment (AFPA, 1994c). The next step is to develop an operating structure, a framework for the partnership, and a blueprint for the implementation program and evaluation of results. An important objective of establishing this voluntary collaborative effort is to leverage industry R&D spending through identifying appropriate areas for joint government-industry R&D and thereby insure that limited funds are spent strategically. Product related R&D is not included in the agreement since it is the basis for competition between companies and is best left to individual efforts of proprietary R&D programs.

The six key areas identified in Agenda 2020 are sustainable forest management, environmental performance, energy performance, improved capital effectiveness, recycling, and sensors and controls. Specific priorities within the energy and environment areas include reduction of gaseous, liquid and solid waste emissions, non-process element removal, drying technologies, and gasification and cogeneration technologies.

5.5. Standards and eco-labels

The pressures on industry to improve environmental performance is also manifested in the development of eco-labelling, international standards, and changing markets. For example, L.L. Bean and IKEA catalogues, Der Spiegel in Germany, and several other publications are now printed on chlorine free or recycled paper. The EPA has issued guidelines that specify the amount of recycled fiber from post consumer waste that should go into different paper and paperboard products procured by government and federal agencies (EPA, 199_). Such policies may be effective

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[2] Scott Paper recently sold off the energy complexes at Mobile, Alabama and Chester, Pennsylvania mills to independent power producers Southern Electric International and CRSS Inc., respectively (Scott Paper, 1994; Scott Paper, 1995; CRSS, 1995). The energy complex in Mobile includes two new recovery boilers. As part of the agreement, the mills will purchase steam and electricity from these companies.

in addressing some environmental problems, e.g., by reducing the amount of municipal solid waste going to landfills, but may create others, e.g., increased fossil fuel use and related emissions due to recycling. Careful life-cycle analyses (LCA) can help address such problems (Gilbreath, 1995), and the acceptance for such policies can be substantially improved by ensuring industry participation in the development of guidelines.

The role of international environmental standards, such as ISO 14000 which is now being developed, is to certify that a company has an environmental policy. For a company to get certified it must be able to show that it has an environmental management system and that it is being implemented. The earlier standard ISO 9000, requires quality management systems. Buyers of various products, for example, auto manufacturers, may require that companies are ISO certified in order for them to qualify as suppliers. A standard such as the ISO 14000 is relatively weak in that the subject company specifies the environmental policies and goals. The strength is that the company is checked regularly and loses certification (and thus risks losing customers) if it does not implement the policies and meet stated goals. Certifying agencies are, for example, Norske Veritas and Lloyds.

Eco-labels usually have quantitative requirements as to product content and production method. Environmental and governmental organizations in Europe appear to have been more active in developing eco-labels than American organizations. An important feature of many of these labels are that they have been developed cooperatively by environmental organizations, industry and government agencies. Such labels include the Nordic Swan, the Blue Angel in Germany, and Green Seal in the U.S. (Richards, 1994). Eco-labels complement environmental management system standards since they are used primarily for consumer products, such as detergents, paper, and foods. They are likely to play an increasingly important role as consumer awareness of environmental issues increases.

6. FUTURE DIRECTIONS

To conclude, we discuss some possible future directions in energy efficiency in the U.S. pulp and paper industry. Energy efficiency in the context of this industry (unlike most industries) must include, in addition to process energy use, consideration of how the biomass-derived fuels that are available at many mill sites are used.

As discussed in earlier sections of this document, there are potentially major opportunities for improving the efficiency of process energy use. For example, comparisons of specific energy use in the U.S. industry against that in Scandinavia, where historically greater emphasis has been placed on minimizing process energy use, demonstrate that large reductions in energy use are technically possible. While there are important opportunities for improving efficiencies of equipment found throughout all industry (e.g. pumps, fans, etc.), the best opportunities will typically involve process-related changes. A number of new energy-saving process technologies, e.g. digesters and paper or pulp dryers, are under development or recently commercialized, and process heat integration (pinch) analysis has been applied in a handful of mills. Undertaking to capture the energy savings associated with process-related changes is made more difficult by the generally capital-intensive nature of the required investments. Utility or government-backed energy efficiency programs or policies are more likely to be successful if they address this issue specifically. On the other hand, most process-specific changes that bring energy efficiency improvements also bring productivity or other improvements, so that such investments need not be justified on the basis of energy savings alone.

Measuring (or score-keeping) energy savings and the related return on investments has been demonstrated in other industries and sectors to be crucial to succeeding in capturing energy savings. At present there is no systematic reporting of energy use in the pulp and paper industry, except total industry energy use, as reported by the American Forest and Paper Association based on survey data. These data are useful for tracking national trends, but not for assessing product-specific energy efficiency performance. Sweden's Forest Industries Association regularly reports the highest, average and lowest energy use per tonne of product for some key products (without disclosing proprietary information), which provides benchmarks against which individual mills can calibrate their energy performance. The U.S. industry might consider such an approach. With greater emphasis on tracking energy use at the mill level, companies would be able to better evaluate energy performance over time and between different mills within the company.

Reducing process energy needs per tonne of product might have some important cascade effects. It should lead directly to reduced environmental impacts. It might also facilitate quantum improvements in cogeneration technologies for on-site heat and power generation. The pulp and paper industry is in a unique and enviable position of being able to rely on its own internally-generated fuels from renewable biomass sources for more than half of its process energy requirements. In the relatively near future, the industry has the potential to provide essentially all of the energy requirements needed at many of its facilities, and perhaps even export biomass-generated power to other users.

Advanced biomass-gasifier and black-liquor gasifier/gas turbine power systems, which would provide quantum improvements in cogeneration efficiency over existing boiler-steam turbine technology, are undergoing rapid development. Such systems are likely to be commercially ready by around the turn of the century. The pulp and paper industry is a prime initial market for such systems because it has biomass fuels available on-site and because it will be retiring much of its existing biomass-cogeneration equipment during the next decade or so. Together with advanced biomass-cogeneration technologies, competition in wholesale electricity markets may create opportunities for the industry to market renewable-electricity directly. The industry might alternatively opt to divest its energy assets and primarily be a supplier of biomass fuels without adding much value to them. The industry would likely benefit in either case, so their taking a leadership role in developing and commercializing such technologies would seem entirely appropriate.

Finally, environmental issues will continue to play a key role in driving technology development and related energy use in the pulp and paper industry. These issues might be most effectively addressed to the benefit of the industry through partnerships with government, utilities, and non-governmental organizations. The Agenda 2020 initiative (AFPA, 1994c), which targets the development of environmentally-responsive, energy-related technologies and processes (among a select number of other areas) is a useful initial step in this direction.

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