PAPER TASK FORCE

*Duke University ** Environmental Defense Fund*
*Johnson & Johnson ** McDonald's*
*The Prudential Insurance Company of America ** Time Inc.*

WHITE PAPER NO. 12

COMPARISON OF KRAFT, SULFITE, AND BCTMP MANUFACTURING TECHNOLOGIES FOR PAPER

DECEMBER 19, 1995

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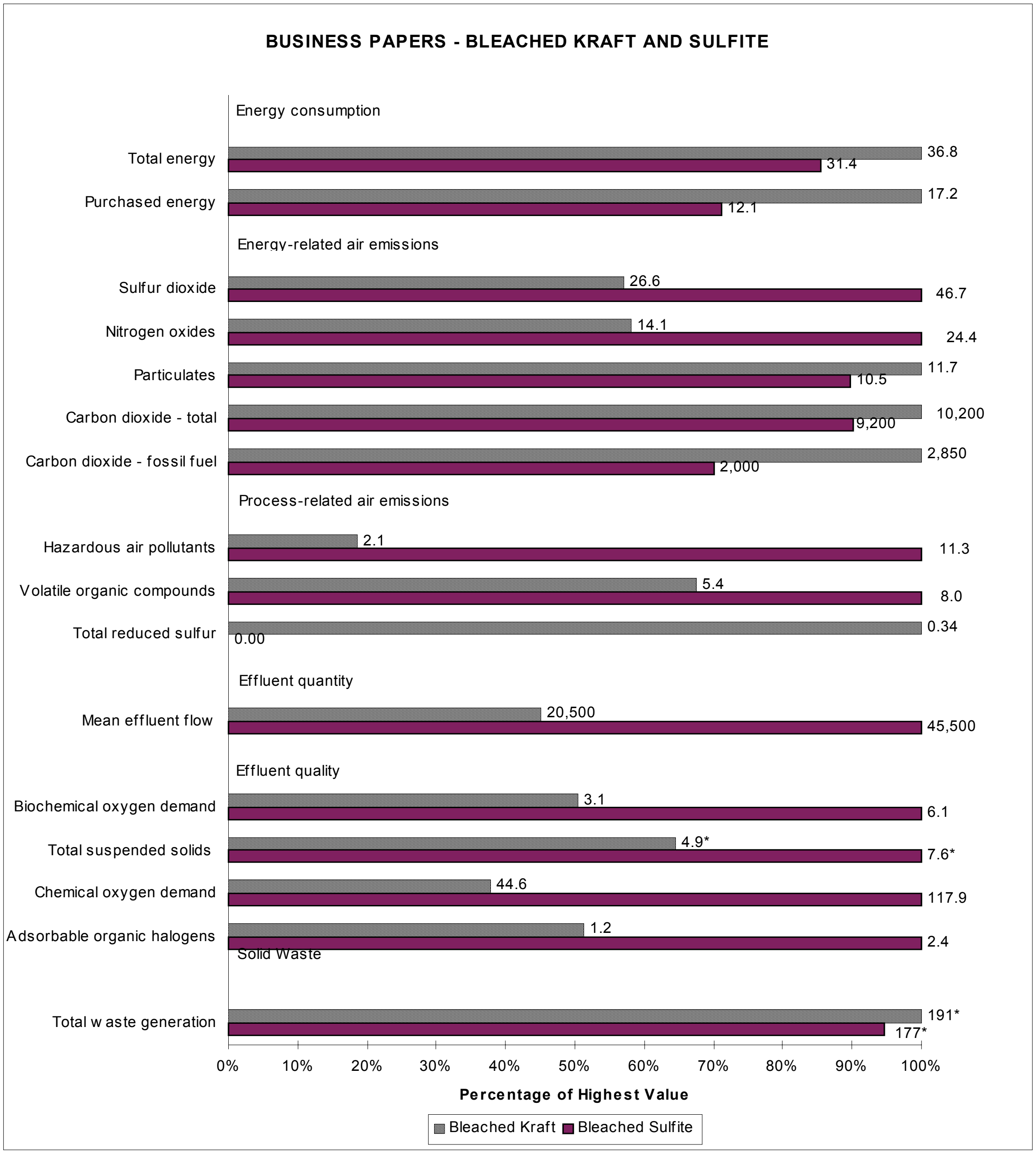
Table 1. Ranges of environmental parameters for bleached kraft,bleached sulfite and bleached chemithermomechanical (BCTMP) pulp manufacturing processes

Environmental parameters	Bleached Kraft Pulp				Bleached Sulfite pulp [3]	BCTMP
	50% D	100% D	O + 100% D	Average		
ENERGY CONSUMPTION (millions of BTUs per air dried ton of product)						
Total	29.9 - 31.8	32.5 - 34.4	27.2 - 29.0	29.7 - 31.6	22.8	24.4
Purchased	1.5 - 10.4	4.1 - 13.0	(3.2) - 5.7	0.9 - 9.8	(1.9)	22.1
ENERGY-RELATED AIR EMISSIONS (pounds per air dried ton of product)						
Sulfur dioxide (SO_2)	9.3 - 19.0	12.6 - 22.2	4.0 - 13.6	8.7 - 18.3	4.5	21.6
Nitrogen oxides (NO_x)	7.3 - 10.6	9.0 - 12.2	4.8 - 8.1	7.0 - 10.3	4.5	13.9
Particulates	10.4	11.5	9.4	10.4	8.4	8.6
Carbon dioxide (CO_2) - total	9,600 - 10,600	9,900 - 11,000	9,500 - 10,500	9,600 - 10,600	8,700	4,200
Carbon dioxide (CO_2) - fossil fuel	0 - 1,700	400 - 2,100	(800) - 900	(100) - 1,600	(600)	3,200
PROCESS-RELATED AIR EMISSIONS (pounds per air dried ton of product)						
Hazardous air pollutants (HAP)	2.5	2.1	2.4 - 3.2	2.5	16.6	0.3
Volatile organic compounds (VOC)	5.7	5.9	5.3 - 5.9	5.7	11.3	2.7
Total reduced sulfur (TRS)	0.4	0.4	0.4	0.4	0.0	0.0
EFFLUENT QUANTITY (gallons per air dried ton of air-dried pulp)						
Mean effluent flow	18,700	18,700	9,300	16,800	39,500	2,800
EFFLUENT QUALITY (kilograms per air dried metric ton of final product)						
Biochemical oxygen demand (BOD)	0.3 - 6.7	0.3 - 6.7	0.3 - 6.7	0.3 - 6.7	2.7 - 13.7	0.0 - 3.6
Total suspended solids (TSS) [1]	0.2 - 9.8	0.2 - 9.8	0.2 - 9.8	0.2 - 9.8	3.0 - 22.7	1.3
Chemical oxygen demand (COD)	15.8 - 79.5	15.8 - 79.5	15.8 - 79.5	15.8 - 79.5	63.7 - 200.0	0.0 - 20.0
Adsorbable organic halogens (AOX)	1.54 - 1.76	0.6	0.1 - 0.2	1.1 - 1.3	0 - 5.2	0.0
SOLID WASTE (kilograms per air dried metric ton of final product)						
Total waste generation [2]	190	190	190	190	180	180

[1] Not statistically different for bleached kraft and bleached sulfite pulps.
[2] Not statistically different for any of the pulps.
[3] The ranges for the BOD and TSS loadings in the final effluent are correct in this table.

Figure 1. Environmental parameters for bleached kraft and sulfite business papers



Note: * Not statistically different

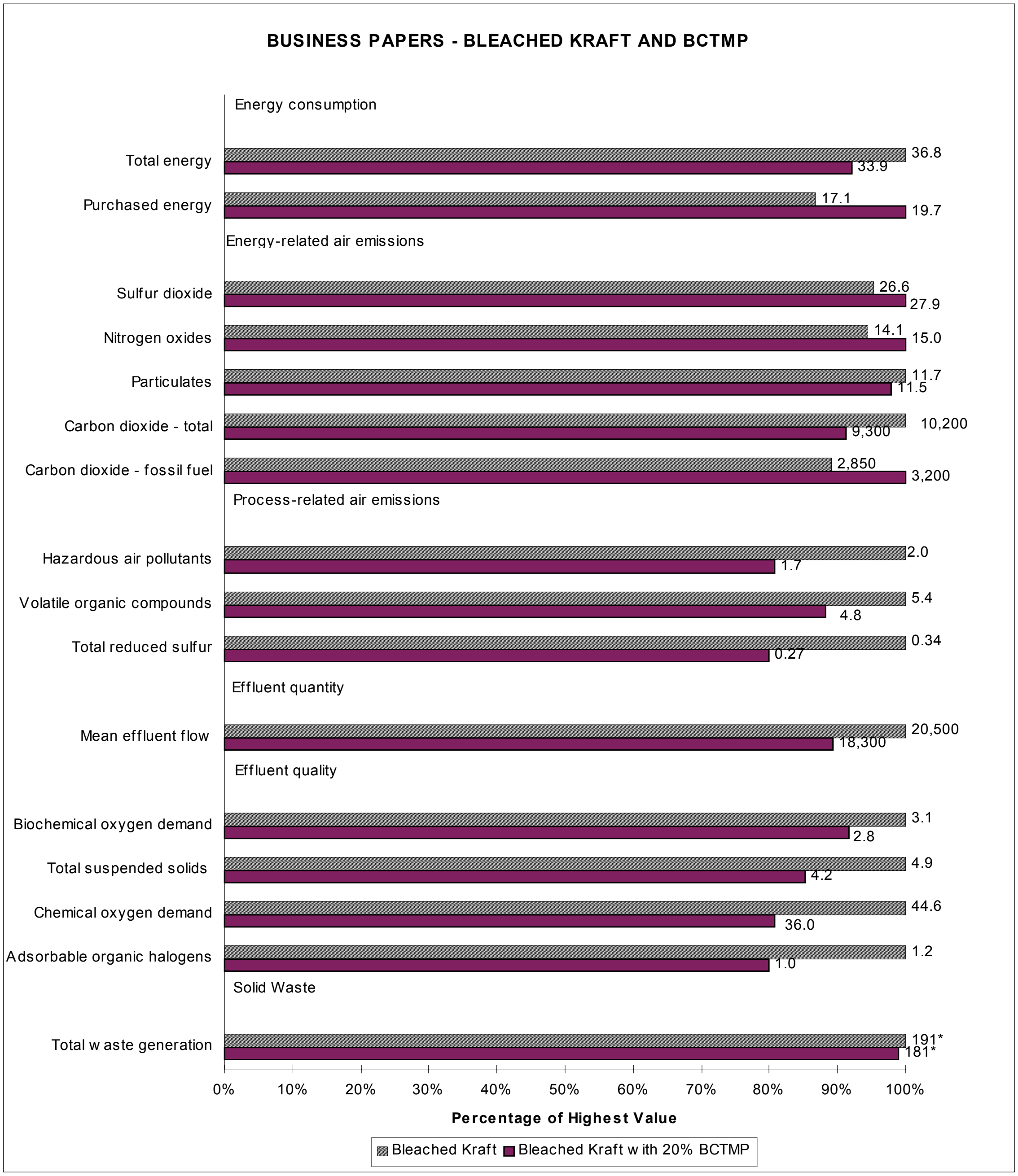
Energy consumption: millions of BTU per air dried ton of product

Air emissions: pounds per air dried ton of final product

Effluent flow: gallons per air dried ton of final product

Effluent quality and solid waste: kilograms per air dried metric ton of final product

Figure 2. Environmental parameters for bleached kraft business papers with 0 and 20% BCTMP



Note: * Not statistically different
Energy consumption: millions of BTU per air dried ton of product
Air emissions: pounds per air dried ton of final product
Effluent flow: gallons per air dried ton of final product

Table 2. Environmental parameters for business papers

Environmental parameters	Bleached Kraft				Bleached Sulfite [1]	Bleached Kraft with 20% BCTMP
	50% D	100% D	O + 100% D	Average		
ENERGY CONSUMPTION (millions of BTU per air dried ton of product)						
Total	36.2 - 37.7	38.2 - 39.7	34.1 - 35.5	36.0 - 37.5	31.4	31.4 - 36.4
Purchased	14.1 - 21.0	16.1 - 23.1	10.4 - 17.3	13.6 - 20.6	12.1	16.9 - 22.5
ENERGY-RELATED AIR EMISSIONS (pounds per air dried ton of product)						
Sulfur dioxide (SO2)	23.4 - 30.9	25.9 - 33.4	19.2 - 26.7	22.9 - 30.4	20.9 - 72.6	24.9 - 31.0
Nitrogen oxides (NOx)	13.1 - 15.6	14.4 - 16.9	11.1 - 13.7	12.9 - 15.4	11.4 - 37.4	13.9 - 16.0
Particulates	11.7	12.6	11.0	11.7	10.5	11.4 - 11.5
Carbon dioxide (CO2) - total	9,700 - 10,500	10,100 - 10,900	9,700 - 10,500	9,800 - 10,600	9,200	9,000 - 9,600
Carbon dioxide (CO2) - fossil fuel	2,300 - 3,700	2,600 - 3,900	1,600 - 2,900	2,200 - 3,500	2,000	2,700 - 3,700
PROCESS-RELATED AIR EMISSIONS (pounds per air dried ton of product)						
Hazardous air pollutants (HAP)	2.2	1.8	2.0 - 2.7	2.1	11.3	1.8
Volatile organic compounds (VOC)	5.4	5.4	5.5	5.4	8.0	4.9
Total reduced sulfur (TRS)	0.34	0.34	0.33	0.34	0.00	0.27
EFFLUENT QUANTITY (gallons per air dried ton of final product)						
Mean effluent flow	22,000	22,000	14,700	20,500	45,500	18,300
EFFLUENT QUALITY (kilograms per air dried metric ton of final product)						
Biochemical oxygen demand (BOD)	0.3 - 6.7	0.3 - 6.7	0.3 - 6.7	0.3 - 6.7	2.7 - 13.7	2.8
Total suspended solids (TSS)	0.2 - 9.8	0.2 - 9.8	0.2 - 9.8	0.2 - 9.8	3.0 - 22.7	4.2
Chemical oxygen demand (COD)	15.8 - 79.5	15.8 - 79.5	15.8 - 79.5	15.8 - 79.5	63.7 - 200.0	36.0
Adsorbable organic halogens (AOX)	1.5 - 1.8	0.6	0.1 - 0.2	1.1 1.3	0.0 - 5.2	0.9 - 1.0
SOLID WASTE (kilograms per air dried metric ton of final product)						
Total waste generation [1]	190	190	190	190	180	190

Note: [1] Not statistically different
[2] The ranges for the BOD and TSS loadings in the final effluent are correct in this table. Please correct Table C-3 on page 218 of the main report.

WHITE PAPER NO. 12

COMPARISON OF KRAFT, SULFITE, AND BCTMP MANUFACTURING TECHNOLOGIES FOR PAPER

DECEMBER 19, 1995

I. INTRODUCTION

This paper summarizes the research and findings of the Paper Task Force on a comparison of kraft, sulfite, and BCTMP manufacturing processes that are used to make uncoated free sheet (UCFS). The information presented in this paper has come from a range of sources including articles in peer reviewed journals, the trade press, conference proceedings, reports of studies commissioned by the pulp and paper industry, relevant documents from the U.S. Environmental Protection Agency (EPA), information gathered during Paper Task Force technical visits and other presentations from experts.

The Paper Task Force members endorse the broad principles set forth by the Task Force's final report. The findings and research in this White Paper reflects the contribution of Paper Task Force Working Groups and changes made in response to comments received from expert reviewers through the White Paper review process. The contents of this paper do not reflect the policy of individual Task Force member organizations.

The research presented in this paper is one element of the *environmental* analysis being performed by the task force. Other White Papers address the economic and functional issues relevant to the manufacture of paper.

A. Manufacturing Processes

The task force examined several manufacturing processes that are used to make uncoated free sheet (UCFS). Uncoated freesheet paper produced with an alkaline papermaking process is about 78% pulp, 16% filler and 6% moisture.[1] While many virgin and recovered fiber pulps can be used to produce UCFS, bleached kraft pulp is the dominant furnish for this grade.

1. Kraft Process

The kraft process is the dominant chemical process in the paper industry. It accounts for 80% of the world's chemical pulp production and almost 98% of U.S. chemical pulp production. The kraft process typically produces paper with twice the strength of mechanical pulps. This is achieved by chemical pulping and bleaching which removes all of the lignin from the pulp.

The kraft process cooks wood chips in a solution of white liquor, which consists of a mixture of sodium hydroxide and sodium sulfide. The spent pulping liquor is sent to a chemical recovery system where the concentrated black liquor is incinerated to produce energy and chemicals are recovered. This is followed by a causticizing step to regenerate the white liquor which then is used to cook the next batch of wood chips.

In this paper, we consider three bleaching processes for bleached kraft pulp. These bleaching processes are:

- Bleached kraft pulping with 50% chlorine dioxide substitution for elemental chlorine in the first bleaching stage, the "base case" manufacturing process used in the Task Force's studies of bleached kraft pulp manufacturing technologies (White Papers No. 5 and 7); we refer to the bleaching sequence as "50% D".

- Bleached kraft pulping with 100% chlorine dioxide substitution for elemental chlorine in the first bleaching stage; we refer to this bleaching sequence as *traditional ECF* or "100% D".

- Bleached kraft pulping with oxygen delignification and 100% chlorine dioxide substitution for elemental chlorine in the first bleaching stage; we refer to this bleaching sequence as *enhanced ECF* or "O + 100 % D".

2. Sulfite Process

Unlike the kraft process, which operates at alkaline pH, sulfite pulping is practiced with numerous variations. The pulping process can be varied to manufacture a wide range of pulp grades which include newsprint-reinforcement, packaging, wood-free printing, tissue/fluff, and dissolving. Cooking can be done with calcium, magnesium, ammonium, and sodium bisulfites and at different pH levels, ranging from acid to alkaline pH. In general, utilization of the higher pH ranges will produce a stronger pulp.

The extent of energy and chemical recovery depends on the type of base used. For calcium-based liquors, only heat recovery is possible because the calcium compounds cannot be recovered economically.[2] For ammonium-based liquors, heat and SO_2 recovery is possible; however, no base recovery is possible because ammonia is converted to elemental nitrogen upon combustion. For magnesium-based liquors, the spent liquor is burned to form magnesium oxide ash and SO_2 gas. Both the gas and the oxide are used to regenerate the cooking liquor. For sodium-based liquors, chemical and energy recovery is based on the combustion of the concentrated black liquor in a kraft-type recovery furnace.

The number of mills using the sulfite process has greatly diminished in the recent years because of the lack of a simple economical chemical recycling system, and the resulting problem of disposal of the sodium sulfate ash from waste liquor combustion. The sensitivity of the classic acidic sulfite process to wood species with high resin content, the weaker pulp strength, and greater difficulty in chemical recovery are the major reasons for its decline relative to the kraft process. No new sulfite mills have been built since the 1970s.[3] Paper companies have closed or converted most sulfite mills to other pulping processes rather than upgrade them to comply with environmental regulations. In the United States, there are fifteen sulfite mills as of 1994.[4] Of these mills, only six make either book or writing papers.[5]

3. BCTMP Process

Bleached Chemi-Thermo-Mechanical Pulping (BCTMP) is a chemi-mechanical pulping process. These high-yield pulps differ from chemical pulps, such as sulfite and kraft, in that the lignin is retained. Chemical pulps have most of their lignin dissolved away by using chemical processes, but this results in a yield around half of that achieved for BCTMP. High-yield pulps may replace some of hardwood kraft pulp in “free sheet” papers.

BCTMP is a bleached version of CTMP; however, it is stronger and brighter than CTMP. The CTMP process combines thermal and chemical pretreatment methods before physically separating the fibers in a two-stage refining process. Pre-treatment can be used to adjust the pulp properties, such as bonding, debris level, and opacity.

A variety of hardwoods and softwoods can be used to make BCTMP. Woods typically used are maple, aspen, birch, spruce, and pine. Softwood BCTMP has an ISO brightness range of 80 - 83 and a typical pulp yield of 90%. Hardwood BCTMP, on the other hand, has an ISO brightness range of 85 - 87 and a typical pulp yield of 88%. In particular, aspen has a typical pulp yield of 87%.[6] The use of aspen is of particular importance because its economic rotation length is 25 years, as opposed to the longer rotation lengths of other hardwoods. Ease of regenerating hardwoods is another advantage to using hardwood pulps.

BCTMP has become well established and accepted as a viable pulp by many buyers in the world pulp market. In 1993, BCTMP represented 5% of total world market pulp shipments. Data obtained for this study came from three operating BCTMP mills located in Canada. Of the three mills, two are effluent-free and the other mill has secondary treatment for its effluent.

B. Major Topics

We present the research in three sections: environmental comparisons, economic comparisons, and functional properties for bleached kraft, bleached grade sulfite, and BCTMP pulps. We also present an environmental, economic, and functional comparison of uncoated freesheet papers that contain bleached kraft pulp, bleached kraft and 20% BCTMP, and bleached sulfite pulp in the furnish. We have assumed that all of the papers are produced with an alkaline papermaking process.

The environmental comparison includes energy consumption and releases to the environment associated with the production of uncoated freesheet paper. The examination of energy consumption will focus on the total and purchased energy required to produce these grades of paper. Total energy includes the electricity and steam required to produce the bleaching chemicals and to run the equipment at the mill. Purchased energy refers to the electricity and fossil fuels that mills purchase. Releases to the environment include air emissions, effluent, and solid waste generation.

The economic comparison briefly discusses the capital and operating costs of the BCTMP and sulfite processes. This discussion supplements White Paper No. 7 which describes the economics of bleached kraft pulp manufacturing processes.

The section on functional properties compares kraft and sulfite pulps as well as the functional properties of UCFS produced with BCTMP.

C. Methodology for the environmental comparisons

1. Estimating the Magnitude of the Environmental Parameters Associated with The production of the Paper Grades

Most of the data on environmental releases and energy consumption are gathered at mills that produce products from one type of pulp - i.e. bleached kraft pulp mills, mechanical pulp mills and DIP mills. Data from these mills provide estimates of environmental releases and energy consumption generated at the mill7 during the production of virgin UCFS. To obtain estimates of environmental releases and energy consumption associated with the production of UCFS with bleached kraft pulp and 20% BCTMP, we calculate these parameters by using a weighted average of the pulps that comprise the furnish. Uncoated freesheet papers made with an alkaline process generally contain 78% bleached pulp, 16% calcium carbonate filler and 6% water.

Environmental releases and energy consumption are measured either per ton of pulp or per ton of product. For parameters, such as air emissions and energy consumption and mean effluent flow, that are measured per ton of pulp, we based the contribution of each pulp on its percent of the total weight of the paper. Because most of the effluent parameters and total solid waste quantity are measured per ton of product, we estimated the contribution of each pulp based on its percentage of the fiber weight. We use a weighted average of the environmental parameters of the three bleached kraft pulping processes to calculate the magnitude of the parameters associated with the production of lightweight coated paper and uncoated freesheet with 20% recycled-content.[8]

The summary tables, **Tables 1-2**, reflect this difference. **Table 1** summarizes the data on the environmental parameters associated with producing bleached kraft, mechanical and deinked recovered fiber pulps, while **Table 2** summarizes the data for the different paper grades. The data for energy consumption, air emissions and mean effluent flow are different in **Table 1** than for **Table 2**. This difference reflects the fact that these parameters are calculated per ton of pulp. In contrast, the effluent quality and total solid waste generation parameters are generally calculated per ton of final product; thus the magnitude of these parameters in both tables is the same for both the pulps and the paper grades.

The magnitude of the effluent parameters for bleached kraft pulping processes in **Table 1** also differs from those in Chapter 5 of the Final Report and White Paper No. 5. Chapter 5 and the White Paper focus on the bleach plant only, while the parameters for the bleached kraft pulping processes in **Table 1** include the pulping and chemical recovery stages as well. We present **Tables 1-2** after the lists of tables and figures at the beginning of the paper.

2. Using averages

We consider both the mean and the ranges of these environmental parameters in this analysis. In the comparison of the paper grades, the mean values have been normalized as a percentage of the highest value to facilitate a comparison of the data. The environmental characteristics of individual pulp and paper mills will almost always vary from the average for a particular class of facilities. In most cases, however, average data are most appropriate for our purposes, because we are most interested in comparing typical activities and facilities, not best-case or worst-case ones.

In cases where a paper user is purchasing through a distributor or retailer and does not have specific information about where the paper was made, the use of averages in an environmental comparison is not only appropriate, but is, in fact, the only approach to identifying environmental preferences. Purchasers in this situation who make decisions based on averages will, in the aggregate, select environmentally preferable paper products. For purchasers who buy paper directly from mills, facility-specific data can be compared with the average or typical values as a starting point for a discussion with a supplier.

3. The Magnitude of Releases to The Environment vs. Environmental Impacts

The environmental comparisons focus on the relative magnitude of energy consumption and releases to the environment. The Task Force has not attempted to assess the magnitude of environmental impacts – for example, effects on the health of humans or wildlife – that arise from the energy use and environmental releases associated with the manufacture of the paper products. Actual environmental impacts caused by the release of specific chemical compounds, for example, depend on site-specific and highly variable factors such as rate and location of releases, local climatic conditions, population densities, etc. These factors determine the level of exposure to substances released to the environment. To conduct such an assessment would require a detailed analysis of all sites where releases occur, a task well beyond the scope of this project and virtually any analysis of this sort.

In a larger sense, reducing the magnitude of energy use or environmental releases will represent a genuine environmental improvement in the vast majority of cases. Indeed, the widely embraced concept of pollution prevention is based on the sound tenet that the avoidance of activities linked to environmental impacts is far preferable to seeking to moderate the extent of impacts after the fact.

II. FINDINGS

The findings have been divided into three sections: 1) an environmental comparison that includes energy consumption, air emissions, effluent, solid waste generation; 2) an economic comparison; and 3) a description of the functional properties of uncoated free sheet that contains BCTMP or sulfite pulp in its furnish.

We have adopted standard units for reporting the various environmental releases discussed in this paper. We present air emissions and energy data in English units: pounds per oven-dried short ton of pulp (lb/ODTP) or per air-dried ton of final product produced (lb/ADTFP), and millions of Btu's/ton, respectively. We present effluent and solid waste data in metric units: kilograms per oven-dried ton of pulp (kg/ODMTP) or in kilograms per air-dried metric ton of final product (kg/ADMTFP). Where we do not know whether the pulp has been air- or oven-dried, we present data in units of "tons of pulp;" these data have an associated uncertainty factor of ± 10%.[9]

The data on which these findings are based show significant variability because of the range of ages and geographical locations of the mills, as well as differences in the processes that mills use to produce a given type of pulp. In some cases, few data exist because mills do not have extensive operating experience with these technologies. We document ranges and perform statistical analyses of the data where sufficient data exist.

A. General Findings

In general, it appears that kraft pulping will remain the dominant wood pulping process in the paper industry for some time. Kraft is the strongest pulp in the industry and because of economies of scale, kraft pulp mills can install cost-effective chemical recovery systems. In North America, 35.3 million metric tons of bleached kraft pulp were produced in 1994.[10] In contrast, North American mills produced 1.5 million metric tons of bleached sulfite pulp[11] and 1.2 million metric tons of BCTMP market pulp[12] in that same year. As paper production capacity grows, BCTMP offers a lower cost source of additional fiber.

BCTMP should be considered as a partial substitute for hardwood kraft in coated and uncoated free-sheet papers or as a recycled fiber supplement. It will never completely replace bleached kraft pulp. However, BCTMP, like recycled fibers, can help extend the global fiber supply. In comparison to kraft, BCTMP has three advantages: 1) it has twice the yield; 2) it has lower process-related air emissions and lower releases to water; and 3) lower capital costs. It has, however, three disadvantages: 1) lower tear strength; 2) higher optical reversion; and 3) higher energy consumption, which may result in higher-energy emissions of sulfur dioxide, nitrogen oxides and carbon dioxide emissions from fossil fuel.

On average, sulfite pulp mills in the United States have higher air and water emissions than bleached kraft pulp mills per ton of production. The size of releases, however, show more variability than do releases from bleached kraft mills, because sulfite mills use different pulping chemicals and technologies that depend on the mix of final products.

Older sulfite mills have few advantages over bleached kraft mills for printing and writing papers. Papergrade sulfite pulp yields are about the same as bleached kraft, and sulfite pulps are generally weaker than kraft pulps.[13] **The sulfite process also results in appreciable water pollution unless chemical recovery is installed**.[14] It is costly to recover sulfite liquor; and there are increased disposal costs and SO_2 emissions compared to kraft. In the United States, no new sulfite mills have been built since the 1960s and companies have closed a number of old mills rather than spend $20M to $50M to solve their pollution problems.[15] Pilot plant scale research continues on two new sulfite processes, Alkaline Sulfite process using Anthraquinone and Methanol (ASAM)[16] and Neutral Sulfite-Anthraquinone (NSAQ),[17] which indicate increased environmental performance. However, because of a reluctance to invest in new sulfite mills, these technologies have not developed much of a track record.

B. Environmental Comparison

This section presents comparisons of the magnitude of energy consumption and releases to air, water and land associated with the production of uncoated freesheet paper (UCFS) made with three pulp furnishes: bleached kraft pulp, papergrade sulfite pulp, and bleached kraft pulp with 20% BCTMP by fiber weight. Where sufficient data exist, we distinguish the UCFS with bleached kraft pulp by bleaching process.

For uncoated free-sheet with bleached kraft with 20% BCTMP, we have used the average of the three bleaching processes for our calculations of the contributions of the bleached kraft pulp.[18] We present a summary of the environmental comparison for the three pulp furnishes in **Table 1**.

1. Energy consumption of the Pulping Processes

We present comparisons of the range total and purchased energy consumption consumed to produce bleached kraft pulp, bleached sulfite pulp and BCTMP in **Table 1**. **[Section III.A.3 - Section III.A.5]**

- **The total energy required to produce a ton of bleached kraft pulp is about 20% higher than the total energy required to produce a ton of BCTMP.** This difference results from the high energy consumption of the bleaching chemicals used to make bleached kraft pulp. Unbleached CTMP is brighter than unbleached kraft pulp; as a result, the contribution of bleaching chemical manufacture to the total energy consumption is lower for BCTMP.

- **The purchased energy consumed to produce a ton of BCTMP is significantly higher than the purchased energy consumed to produce a ton of bleached kraft pulp.** The purchased energy consumption is lower for bleached kraft pulp because chemical pulping processes generate almost all of their energy requirements from burning black liquor solids and wood residues produced on-site**.**

- **The total and purchased energy consumed to produce a ton of bleached sulfite pulp is generally lower than the energy consumed to produce a ton of bleached kraft pulp.** The process energy and the amount of energy generated on-site from wood-based fuel is similar for the two processes. However, unbleached sulfite pulps are brighter than unbleached kraft pulps, and thus consume smaller quantities of bleaching chemicals to produce 90 GE brightness pulp.

2. Energy-Related Air Emissions

We compared emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulates, and carbon dioxide (CO_2) in this section. To develop estimates of the emissions of air pollutants released to generate energy, we used the 1992 industry average fuel mix and the national grid fuel mix for electricity. The emissions of the energy-related air pollutants such as SO_2, NO_x, and CO_2 will vary depending on the fuel mix available to a particular mill. **In Table 1**, we present ranges of emissions of SO_2, NOx, particulate and CO_2 emissions generated during the production of bleached kraft pulp, bleached sulfite pulp and BCTMP based on our knowledge of the range of energy use of different processes. **[Section III.B.5 and Section III.B.6]**

- **Based on the U.S. national grid for electricity:**

  - **Emissions of SO_2, NO_x, and fossil-fuel based CO_2 are higher for BCTMP than for bleached kraft and sulfite pulping processes.**

  - **The particulate and total carbon dioxide emissions associated with BCTMP manufacture reflect the lower total energy and the fuel mix used.** Not only is the total energy lower, but these processes rely primarily of electricity and natural gas, two fuels with relatively low CO_2 emissions.

  - **The CO_2 emissions from fossil fuels are higher, on average, for the BCTMP process than for the bleached kraft pulp manufacturing process.** Bleached kraft mills generate most of their energy from renewable wood-based fuels. In some cases, the processes received a credit for these emissions to reflect the small surplus of energy that they generate on-site.

- **The magnitude of energy-related air emissions, however, depends on the fuel mix used to produce the electricity used at BCTMP mills.** The magnitude of the reported energy-related air emissions associated with BCTMP production is actually lower than the magnitude of the estimated emissions for bleached kraft and sulfite pulp production because the three Canadian mills use hydropower to generate their electricity.

- **On average, the magnitude of the energy-related air emissions generated during the production of bleached sulfite pulp is lower than the magnitude of these emissions generated during the production of bleached kraft pulp.** While the process energy and the amount of energy generated on-site from wood-based fuel is similar for the two processes, unbleached sulfite pulps are brighter than unbleached kraft pulps, and thus consume smaller quantities of bleaching chemicals to produce 90 GE brightness pulp.

3. Process Related Air Emissions: HAPs, VOCs, and TRS

Table 1 also contains estimates of the magnitude of three process-related air emissions generated during the production of bleached kraft pulp, papergrade sulfite pulp and BCTMP: hazardous air pollutants (HAPs), volatile organic compounds (VOCs) and total reduced sulfur compounds (TRS). Both process and combustion sources contribute to VOCs, but we include them in this section because process sources account for over 60% of VOCs generated by chemical pulping processes. We do not present a range for these emissions because the contribution from combustion sources has little effect on the magnitude of these parameters.

- **Methanol accounts for most of the HAP emissions associated with the bleached kraft and mechanical processes.**

- **On average, the bleached sulfite pulping process generates the highest HAP and VOC emissions of the three pulping processes.**

- **BCTMP, as a high-yield pulp, has lower process-related air emissions because most of the organic material in the wood stays in the pulp.**

- **Only the kraft process produces TRS emissions.**

4. Effluent

In this section, we consider effluent quantity (mean effluent flow per ton of final product produced) and four measures of effluent quality: biochemical oxygen demand (BOD), total suspended solids (TSS), chemical oxygen demand (COD), and adsorbable organic halogens (AOX). **[Sections III. D.3, Section III.D.4]**

- **Bleached kraft pulping processes require more fresh water than does the BCTMP process.**

- **The final effluent generated by BCTMP production has lower BOD, COD and AOX loadings than does the final effluent from bleached kraft pulp mills.** Two Canadian BCTMP mills currently operate without any effluent discharge.

- **The bleached sulfite pulp manufacturing process has a higher effluent flow, along with higher BOD and COD loading in the final effluent than does the bleached kraft pulp manufacturing process.**

- **The TSS and AOX in the final effluent that results from bleached kraft and bleached sulfite pulp production are about the same.** A statistical comparison found no difference in the TSS loadings in the final effluent generated by these pulping processes.

5. Solid Waste Generation

We have developed estimates of the quantity of solid waste and quality of wastewater sludge from bleached kraft, papergrade sulfite and BCTMP mills. **Table 1** contains estimates of total solid waste generation for the pulping processes. The variability of the sludge quality data precluded its quantification. **[Section III.E..3, Section III.E.4]**

- **There is no statistical difference in the magnitude of the total solid waste generated during the production a ton of bleached kraft pulp, bleached sulfite pulp or BCTMP.**

- **The metals content of wastewater sludge from BCTMP mills is close to the low end of the range of the loadings of metals in bleached kraft mill sludge**.

6. Comparisons of Uncoated Freesheet Made with Bleached Kraft, Bleached Sulfite and BCTMP furnishes

In this section we summarize the environmental comparisons of the uncoated freesheet that contains bleached kraft pulp, bleached sulfite pulp and bleached kraft pulp with 20% BCTMP. **[Section III.F]**

Comparison I: Uncoated Freesheet Made with Bleached Kraft and Bleached Sulfite Pulps

Figure 1 and **Table 2** present a comparison of the energy consumption and releases to the environment generated by manufacturing business papers that contain bleached kraft pulp and bleached sulfite pulps.

- **With the exception of mean effluent flow, the relative magnitude of the environmental parameters associated with the production of bleached kraft and bleached sulfite pulps determines the relative magnitude of the environmental parameters for the UCFS papers made from these pulps.** On average, the effluent flow from paper machines that produce UCFS with sulfite pulp is higher than the effluent flow for paper machines that produce bleached kraft pulp.

- **Although the loading of total suspended solids in the final effluent is not statistically different for the two processes, releases to water are higher, on average, for paper that contains sulfite pulp.**

- **The ranges of the environmental parameters for the UCFS with sulfite pulp, however, are generally larger than are those for the paper that contains bleached kraft pulp.** Sulfite mills choose from a wider range of pulping chemicals and process conditions than do bleached kraft pulp mills. Thus, the releases to the environment from sulfite mills will vary widely depending on the manufacturing process and on the products made at the mill.

Comparison II: Uncoated Freesheet paper made with bleached kraft pulp and bleached kraft pulp with 20% BCTMP

In this case, we compare a business paper that contain bleached kraft pulp with one in which BCTMP replaces 20% of the hardwood bleached kraft pulp. **Figure 2** and **Table 2** present a comparison of the energy consumption and releases to the environment generated by business papers that contain bleached kraft pulp and bleached kraft pulp with 20% BCTMP.

- **Purchased energy, sulfur dioxide, nitrogen oxides and carbon dioxide from fossil fuels increase when BCTMP replaces hardwood kraft; process-related air emissions, effluent flow and releases to water decline.**

- **The energy-related air emissions will decrease as BCTMP made from electricity that is generated by hydropower replaces bleached kraft pulp.** Using hydropower, however, results in other environmental impacts.

C. Economic Comparison

We present a brief summary of the economic comparison of bleached kraft mills with BCTMP and papergrade sulfite mills. [**Section IV]**

1. Sulfite Processes

Insufficient data exists to compare the capital and operating costs of papergrade sulfite mills with bleached kraft pulp mills.

2. BCTMP Processes

- **The capital cost to install a state-of-the-art BCTMP mill at about $330,000 per metric ton of daily capacity is about half that of a greenfield bleached kraft mill at about $500,000 to $750,000 per metric ton of daily capacity. The operating costs are similar to those of a hardwood bleached kraft pulp mill.**

- **The total *cost* to produce a ton of BCTMP is about 12.5% lower than the total costs to produce a ton of southern bleached hardwood kraft pulp. The average *price* for a ton of BCTMP delivered to the United States was about 5% lower than that for bleached kraft pulp in 1995.**

- **BCTMP mills can take advantage of forest lands that are unsuitable for bleached kraft pulping operations.** State-of-the-art, economically efficient BCTMP mills need 25% of the forest land of a state-of -the-art bleached kraft pulp mill. The ability to operate without any effluent also allows BCTMP mills to be sited in areas where receiving waters are small.

D. Functionality

We summarize the discussion of the functional performance of uncoated freesheet paper with bleached kraft pulp, papergrade sulfite pulp and BCTMP furnishes. [**Section V**]

Mechanical pulps are also known as *high-yield* pulps because they convert almost all of the wood used in the process to paper. Therefore, as compared to chemical pulping processes, fewer trees are required to produce a ton of pulp. Because mechanical processes use most of the tree, the pulps contain lignin, which may cause the paper to yellow when exposed to sunlight. This is what happens when a newspaper is left outdoors for a few days. The naturally low lignin content of certain hardwood species allows the production of high-brightness mechanical pulps, such as hardwood BCTMP, and reduces this change in brightness and color.[19]

The short, stiff fibers produced in mechanical pulping processes provide a smooth printing surface and greater opacity, as compared to chemical pulps. They are also comparatively inexpensive to produce, but have about half the strength of kraft pulps. Mechanical pulps are therefore generally unsuitable for applications where strength is important, which typically means packaging. Mechanical pulps are used in newsprint, magazines and other applications that require opacity at low basis weight and are sometimes blended with softwood kraft pulp in these uses.

1. Sulfite Pulps

A telephone survey of foreign sulfite mills by Radian Corporation has shown no runability problems associated with 100% TCF sulfite pulp.[20] There have been problems with an increased dirt count in making TCF pulp. This problem has been addressed by installing additional pulp cleaners.

2. BCTMP Pulps

In mill trials at Slave Lake Corporation (Alberta, CANADA), the addition of 25% aspen BCTMP to 55% recycled fiber and 20% softwood kraft had the same functional results as virgin sheet with bleached kraft pulp furnish. Uses of papers with this furnish were uncoated papers, bond papers, and offset papers. Similar performance results were observed with the addition of 30% aspen BCTMP to a furnish containing 20% DIP and 50% kraft in three types of uncoated papers: copy paper, bond paper, and offset paper. Mills can produce printing and writing papers that incorporate up to 50% BCTMP with mechanical and optical permanence similar to paper with bleached kraft pulp.

Like other mechanical pulps, BCTMP generally survives more recycling cycles with less pulp degradation than do chemical pulps. The lignin content of the pulp improves its ability to survive the mechanical repulping and refining processes associated with the production of recycled-content paper. Paper made with mechanical pulps traditionally have been considered a contaminant in recovered office paper, because the chemicals used to brighten the deinked pulp darkened the mechanical pulps and reduced pulp yield. Unlike other mechanical pulps, BCTMP is restored to a brightness similar to bleached kraft when brightened with hydrogen peroxide and other oxygen-based chemicals used in most deinked pulp mills.

III. ENVIRONMENTAL COMPARISONS ASSOCIATED WITH PULP AND PAPER MANUFACTURING PROCESSES

A. Energy Consumption

1. Scope

We examine the total and purchased energy consumed at the mill to produce a ton of bleached kraft pulp, BCTMP pulp, and sulfite pulp. We also examine the total and purchased energy consumed at the paper mill to produce a ton of uncoated free sheet that contains these pulps in its furnish. The *total* energy requirement consists of the electricity and steam required to produce the bleaching chemicals and to operate the equipment at the mill. The *purchased* energy consists of the electricity[21] and fossil fuels that the mill purchases to meet its energy needs. Mills that produce pulp from wood generate energy on-site by burning black liquor and wood-wastes in furnaces or boilers designed to handle these fuels.

This analysis includes processes that take place at the mill site. It does not, as a result, include the energy consumed to transport wood or recovered paper to the mill. For a more detailed discussion of the calculations of total and purchased energy for bleached kraft and bleached sulfite pulping processes, please see **Appendix B**.

2. Sources

We have used three major sources to estimate the total and purchased energy consumed in the production of a ton of pulp.

- A 1988 study by Energetics for the U.S. Department of Energy contains a comprehensive analysis of energy use for a range of pulp and papermaking processes (the Energetics Study, hereafter).[22]

- A 1993 study prepared by Simons Strategic Division for the Electric Power Research Institute (the EPRI study, hereafter).[23] This study contains recent data on the energy requirements to make several different types of paper with virgin and recovered fiber.

- The American Council for an Energy-Efficient Economy (ACEEE) 1995 Summer Study on Energy Efficiency in Industry also contains recent energy consumption figures for bleached kraft and mechanical mills.[24]

3. Bleached Kraft Pulp Production

Table 3 presents the total and purchased energy consumption of the three bleached kraft pulp manufacturing processes. Mills built in the 1980s and the 1990s represent the high and low ends, respectively, of the range of energy used to produce a ton of bleached kraft pulp today.[25] **Tables B-1 - B-3** in Appendix B contain the calculations of the energy consumed to produce an oven-dried ton of bleached kraft pulp.

Table 3. Total and purchased energy requirements to produce a ton of oven-dried bleached kraft pulp

(Millions of Btu's per oven-dried ton of pulp)								
Bleaching process	**50% D**		**100% D**		**O+ 100% D**		**Average [3]**	
	Low [1]	High [2]	Low [1]	High [2]	Low [1]	High [2]	Low [1]	High [2]
Total Energy								
Process energy	22.3	24.2	22.3	24.2	22.1	24.0	22.3	24.1
Bleaching chemical energy	7.6	7.6	10.2	10.2	5.0	5.0	7.4	7.4
Total	**29.9**	**31.8**	**32.5**	**34.4**	**27.2**	**29.0**	**29.7**	**31.6**
Self -generated energy								
Black liquor	23.8	19.0	23.8	19.0	25.8	21.0	24.2	19.4
Wood waste	4.6	2.3	4.6	2.3	4.6	2.3	4.6	2.3
Total	**28.4**	**21.3**	**28.4**	**21.3**	**30.4**	**23.3**	**28.8**	**21.7**
Purchased energy	**1.5**	**10.4**	**4.1**	**13.0**	**(3.2)**	**5.7**	**0.9**	**9.8**

[1] High energy consumption mills were built in the early 1980s.
[2] Low energy consumption mills were built in the 1990s.
[3] A weighted average based on the quantity of each type of pulp produced in 1994.

While bleached kraft pulp mills have high total energy requirements, they generate a significant amount of their electricity and steam by burning black liquor in the recovery boiler, and bark and other wood waste in hog-fuel boilers. For example, AF&PA estimated that bark, hog fuel and black liquor provided 56% of the entire industry's energy requirements in 1992.[26] This estimate includes some mills that purchase all of their energy. Bleached kraft pulp mills have further reduced their energy consumption by employing cogeneration to produce both electricity and process steam from their boilers.

The difference in purchased energy consumption between the 1980 and 1990 mills is about 9 million Btu's per oven-dried ton of pulp. Process technology improvements and increased steam generation from recovery furnaces and hog-fuel boilers accounts for this difference. The energy consumption estimates in **Table 3** indicate that the 1980s mill purchases about 10% percent of its energy, not including the energy consumed off-site to manufacture the bleaching chemicals, while the modern mill generates a surplus. These estimates of purchased energy consumption correspond to those suggested by International Paper.[27] The purchased energy estimate corresponds to McCubbin's estimate that a modern mill can generate 500 kWh per metric ton of pulp (5.25 million Btu's per ODTP).[28]

4. Bleached Sulfite Pulp and BCTMP Production

Table 4 presents the total and purchased energy consumed during the production of an oven-dried ton of bleached sulfite pulp and BCTMP.

Table 4. Total and purchased energy requirements for bleached sulfite pulp and BCTMP

(Millions of Btu's per oven-dried ton of pulp)	**Bleached sulfite pulp**	**BCTMP**
Total Energy		
Process energy	21.0	22.3
Bleaching chemical energy	1.9	2.1
Total	**22.8**	**24.4**
Self Generated Energy		
Black liquor	21.4	0.0
Wood waste	3.3	2.3
Total	**24.7**	**2.3**
Purchased energy	**(1.9)**	**22.1**

Results from sodium base and magnesium base bisulfite pulp mills indicate that if a sulfite mill sold only market pulp, it would be almost self-sufficient in electrical power.[29] For example, the Altholville magnesium bisulfite mill in Canada was 85% self-sufficient in thermal and electrical energy.[30] **Table B-8** presents the detailed calculation of energy consumed to produce a ton of bleached sulfite pulp.

Of the three pulping processes, the BCTMP process, a chemi-mechanical process, consumes the most purchased energy. Over 95% of this energy is electricity. For BCTMP, natural gas consumption ranges from 100 to 137 m^3/ton[31] and electrical consumption ranges from 1745 to 2250 kwh/ton.[32] Converting to millions of Btu's per ton, the range is 19.88 to 25.89 million Btu's/ton.

5. Papermaking – Uncoated Freesheet Paper

Paper machines used to produce uncoated freesheet paper consume about 12.9 million Btu's of energy per ton of final product produced.[33] Paper machines use more electricity and less steam compared to the machines 10 years ago. Elaahi and Lowitt reported that about 75% of the energy consumed by paper machines in 1985 was steam.[34] The typical paper machine operating today has realized the steam savings that these researchers identified.

6. Summary

- **The total energy required to produce a ton of bleached kraft pulp is about 20% higher than the total energy required to produce a ton of BCTMP.** This difference results from the high energy consumption of the bleaching chemicals used to make bleached kraft pulp. Unbleached papergrade sulfite pulp and CTMP are brighter than unbleached kraft pulp; as a result, the contribution of bleaching chemical manufacture to the total energy consumption is lower for these processes.

- **The purchased energy consumed to produce a ton of BCTMP is significantly higher the purchased energy consumed to produce a ton of bleach kraft pulp.** The purchased energy consumption is lower because chemical pulping processes generate almost all of their energy requirements from black liquor solids and wood residues produced on-site**.**

- **The total and purchased energy consumed to produce a ton of bleached sulfite pulp is generally lower than the energy consumed to produce a ton of bleached kraft pulp.** The process energy and the amount of energy generated on-site from wood-based fuel is similar for the two processes. However, unbleached sulfite pulps are brighter than unbleached kraft pulps, and thus consume smaller quantities of bleaching chemicals to produce 90 GE brightness pulp.

B. Energy-Related Air Emissions

1. Scope

In this section, we estimate the emissions of four energy-related air pollutants. As they generate energy, combustion sources at the mill and off-site release sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulates and carbon dioxide (CO_2). Combustion sources also release volatile organic compounds (VOCs). We discuss VOCs with process-related air emissions, because both energy-related and process sources emit them.

We can estimate the emissions of these pollutants from the mix of fuels used to produce the steam and electricity used at the mill. We consider a range of emissions levels of these pollutants from both 1980s and 1990s bleached kraft mills.

To estimate the energy related air emissions, we need emission factors, the quantity of the substances that are released when different fuels are consumed, and the quantities of different fuels that mills use to satisfy their energy demand. We assume that mills use a combination of six types of fuel. Kraft pulp mills generate significant amounts of waste that they can burn to generate energy. Bark and wood-waste account for 23% of this fuel and black liquor accounts for the rest. Mills also rely on combinations of purchased fuels - generally electricity, coal, oil and natural gas.

2. Sources

We use a range of sources to develop the emission factors and estimate the fuel mix for different mills.

a) Emission Factors

We present emission factors by fuel type for SO_2, NO_x, VOCs, particulates and CO_2 in **Table C-1** in Appendix C. Franklin Associates developed emission factors for electrical power from utilities based on the national mix of fuels.[35] These emission factors also include the impact of extracting and transporting the fuels to the utility. The National Council of the Paper Industry for Air and Stream Improvement (NCASI), a research organization that focuses on the environmental impacts of pulp and paper production, reported emission factors for SO_2, NO_x and VOCs for power boilers and other kraft pulp mill sources in February 1993.[36] We have used estimates of particulate emissions from EPA's AP-42 summary of emission factors[37] and NCASI estimates for coal and oil boilers.[38] Zerbe published CO_2 emission factors for all of the fuels of interest except black liquor.[39] We estimated CO_2 emissions for black liquor using a method described by Takeyama and Otsuka.[40]

b) Fuels

The analysis of energy consumption provided estimates of the energy produced from self-generated fuels for bleached kraft, BCTMP and sulfite pulp manufacturing processes. We used the 1992 industry average fuel composition to develop estimates of the percentages of purchased fuels to produce a ton of pulp.[41] In many cases, we were able to estimate the quantities of purchased electricity and steam. For mills that generated little energy from wood-based fuels, we assumed that they purchased fossil fuels to produce the required steam. With the exception of electricity, these fuel values represent the amount of energy delivered to the equipment by boilers that burn these fuels; so, we adjusted the energy values by the efficiency of the boiler to determine the gross energy, the actual quantity of energy provided by the fuel itself. We present the industry average fuel composition in **Table C-3**, the percentages of electricity and steam used to manufacture pulps and bleaching chemicals in **Table C-4** and the fuel mix for different pulping and papermaking processes in **Table C-5** of Appendix C.

3. Descriptions of the Energy-Related Air Pollutants

Brief definitions and description of potential environmental impacts of the four energy-related air pollutants follows.

a) Sulfur Dioxide (SO_2)

Sulfur dioxide (SO_2) is generated when fuels that contain sulfur are burned. While some of the sulfur in the black liquor that enters the recovery boiler is emitted as SO_2, most of this sulfur is regenerated into sodium sulfide, a key pulping chemical. A small portion leaves the recovery boiler as fine particles of sodium sulfate. These particulate emissions are captured in electrostatic precipitators and returned to the chemical recovery system.[42] Recovery boilers accounted for 14% of the SO_2 generated by pulp and paper mills in the U.S. in 1990.[43] Coal and oil used in boilers at the mills accounted for 75% of these emissions; wood has a low sulfur content so it does not contribute significantly to the industry's SO_2 emissions.

Of the fuels used at paper mills, burning coal and oil releases the largest quantities of SO_2 in the generation of 1 million Btu's of energy. Burning coal releases 1.96 pounds of SO_2 per million Btu's of energy, while burning oil releases 1.81 pounds of SO_2 per million Btu's of energy.[44] It is important to note that SO_2 emissions also depend on the fuel mix used by utilities to generate the electricity. We have assumed that the utilities use the fuel mix for the national grid of which coal and fuel oil, relatively high sulfur fuel sources, comprise 55.6% and 4.2% respectively.[45]

Exposure to high concentrations of SO_2 emissions may cause respiratory illness in humans. SO_2 emissions have more impact, however, on a regional scale because, SO_2 contributes to acid rain. Mills control SO_2 releases with chemical scrubbers and by burning fossil fuels with low sulfur content.

b) Nitrogen Oxides (NO_x)

Emissions of nitrogen oxides (NO_x) occur when fuels that contain high levels of nitrogen are burned. The major contribution to NO_x forms at high temperatures from the combustion of nitrogen in the air. Boilers generated 75% of the paper industry's NO_x emissions in 1990. Burning coal in boilers accounted for 40% of the total emissions; burning wood in boilers accounted for 11%; recovery furnaces at kraft mills accounted for 17%.[46]

As with SO_2 emissions, the NO_x emissions for pulping processes that use mechanical energy depend on the mix of fuels that the utilities use to generate electricity. The difference in the magnitude of NO_x emissions for oil, coal and wood is smaller for NO_x than it is for SO_2. Most mills control NO_x releases by optimizing the combustion temperature of their boilers.

NO_x emissions affect the environment on a regional and a local scale. NO_x contributes to acid rain, a regional environmental issue. NO_x can also react with volatile organic compounds in the atmosphere to produce the ozone in photochemical smog, a local environmental issue. Most mills control NO_x releases by optimizing the combustion temperature of their boilers.

c) Particulates

Particulates are small particles that are dispersed into the atmosphere during combustion. The ash content of a fuel determines the particulate generation upon combustion. Kraft recovery boilers generate particulate emissions of sodium sulfate and sodium carbonate. Solid fuels like coal and wood have the highest ash contents and are burned in furnaces with a control device to minimize the discharge of particulates.[47]

Particulate emissions create a local environmental impact. Most of the larger particles released to the air settle out within 2 miles of the plant site, and can cause soiling or staining of cars and buildings. Smaller sodium sulfate and sodium carbonate particles remain in the atmosphere longer and travel farther from the mill. These smaller particulates can penetrate the lung and be transported into the blood stream.[48] Recent research on particulates has indicated that health effects are more strongly associated with the levels of inhalable particles (with a diameter of less than 10 microns), fine particles (with a diameter less than 2 microns) and acid sulfate particles than with other particulates.[49]

d) Carbon Dioxide (CO_2)

Carbon dioxide (CO_2) results from the complete combustion of the carbon in organic materials; the magnitude of CO_2 emissions associated with paper production depends both on the total energy consumed to produce the paper and on the fuel mix. **Table C-1** contains estimates of CO_2 emissions per million Btu's of energy. Power boilers that burn natural gas generate about half the carbon dioxide emissions per million Btu's of energy produced as do boilers that burn wood, coal, and oil. The CO_2 emissions associated with the production of electricity at a utility are about half those generated by wood-burning power boilers. The typical fuel mix for the national energy grid is 55.6% coal, 4.2% fuel oil, 9.4% natural gas, 20.6% nuclear, and 10.2% other.[50]

We have included the CO_2 emissions from fossil fuel as a parameter to indicate one aspect of the use of fossil fuels on the environment. Additional environmental impacts result from the extraction, refining and transportation of these fuels. The CO_2 emissions from wood-based fuels are almost fully balanced by the CO_2 uptake of young, fast-growing trees that are planted to replace the trees that were harvested; thus, the net release of CO_2 associated with renewable biomass fuels is smaller than that for nonr-renewable fossil fuels. Planting and harvesting trees for paper products and fuel also may result in a range of environmental impacts. White Paper No. 4 discusses the environmental impacts of forest management practices.

CO_2 is a greenhouse gas that is associated with global climate change.[51] It creates no local or regional environmental impacts.

4. Pulp Manufacturing Processes

We present energy-related air emissions generated during the production of bleached kraft pulp, bleached sulfite pulp and BCTMP in **Table 5.**

Table 5. Energy-related air emissions associated with the production of bleached kraft, pulp, bleached sulfite pulp and BCTMP

(pounds/oven-dried ton of pulp)	**Sulfur dioxide (SO_2)**		**Nitrogen oxides (NO_x)**		**Particulates**		**Carbon dioxide (CO_2)–total**		**Carbon dioxide (CO_2)–fossil fuel**	
	Low [1]	High[2]	Low	High	Low	High	Low	High	Low	High
Pulp										
Bleached kraft - 50%D	9.32	18.96	7.28	10.55		10.39	9,600	10,600	0	1,700
Bleached kraft - 100%D	12.58	22.23	8.96	12.24		11.54	9,900	11,000	400	2,100
Bleached kraft - OD + 100%D	3.99	13.64	4.79	8.06		9.45	9,500	10,500	(800)	900
Bleached kraft - average	8.68	18.32	7.01	10.29		10.38	9,600	10,600	(100)	1,600
Sulfite		4.46		4.49		8.42		8,700		(600)
BCTMP [3]	0.18	21.59	2.64	13.95	5.35	8.57	1,300	4,200	1,300	3,200

[1] Low energy-use bleached kraft mills are being built in the 1990s

[2] High energy-use bleached kraft mills were built in the 1980s
[3] The "High" emissions for BCTMP mills were calculated using the model which assumes that electric utilities use the U. S. national energy grid for electricity. The "Low" emissions for BCTMP mills are the actual emissions reported by the Canadian BCTMP mills. The magnitude of these emissions is lower than those calculated by the model because all three mills use hydropower to generate electricity.

Based on the U.S. national grid for electricity, emissions of SO_2, NO_x, and fossil-fuel based CO_2 are higher for BCTMP than for bleached kraft and sulfite pulping processes. The magnitude of these releases, however, depends on the fuel mix used to produce the electricity used at BCTMP mills. The magnitude of the reported energy-related air emissions associated with BCTMP production is actually lower than the magnitude of the estimated emissions for bleached kraft and sulfite pulp production because the three Canadian mills use hydropower to generate their electricity.

On average, the magnitude of the energy-related air emissions generated during the production of bleached sulfite pulp is lower than the magnitude of these emissions generated during the production of bleached kraft pulp. While the process energy and the amount of energy generated on-site from wood-based fuel is similar for the two processes, unbleached sulfite pulps are brighter than unbleached kraft pulps, and thus consume smaller quantities of bleaching chemicals to produce 90 GE brightness pulp. The difference in the emissions of energy-related airpollutants reflects the difference in energy consumption associated with the off-site production of the bleaching chemicals.

Various process sources within the sulfite mill can emit SO_2. The main sources are the digester blow pits, multiple-effect evaporators, and liquor burning or chemical recovery systems.[52] Minor process sources include pulp washers and the acid preparation plant.[53] In recovery furnaces that burn alkaline sulfite liquors, chemical reduction of the sulfite may result in hydrogen sulfide, a TRS compound.

Nitrogen oxides are emitted from various combustion sources at sulfite mills, particularly from the recovery furnace of ammonium-based mills. In ammonium-based sulfite pulp mills, combustion of the spent sulfite liquor will result in emission of nitrogen oxides from the recovery furnace.

The recovery furnace is the significant process source of particulate matter in a sulfite pulp mill. Potential particulate matter emissions depend greatly on the type of recovery of sulfite waste liquor, as well as the degree of control technology used.

5. Emissions Associated with Papermaking

Table 6 illustrates the range of emissions associated with the papermaking process for uncoated freesheet paper. Paper machines generate no energy on-site; thus, we assumed that they consume purchased electricity and fossil fuels. Thus, the magnitude of the emissions corresponds to the total energy consumed to produce each type of paper. There also is no difference between the total and fossil fuel-based carbon dioxide emissions.

Table 6. Emissions of energy-related air pollutants associated with the papermaking process

(pounds/ADTFP)	Sulfur dioxide (SO_2)	Nitrogen oxides (NO_x)	Particulates	Carbon dioxide (CO_2)– Total
Uncoated freesheet	16.10	7.39	3.62	2,300

pounds/ADTFP = pounds per air-dried ton of final product

6. Summary

- **Based on the U.S. national grid for electricity:**

  - **Emissions of SO_2, NO_x, and fossil-fuel based CO_2 are higher for BCTMP than for bleached kraft and sulfite pulping processes.**

  - **The particulate and total carbon dioxide emissions associated with BCTMP manufacture reflect the lower total energy and the fuel mix used.** Not only is the total energy lower, but these processes rely primarily of electricity and natural gas, two fuels with relatively low CO_2 emissions.

  - **The CO_2 emissions from fossil fuels are higher, on average, for the BCTMP process than for the bleached kraft pulp manufacturing process.** Bleached kraft mills generate most of their energy from renewable wood-based fuels. In some cases, the processes received a credit for these emissions to reflect the small surplus of energy that they generate on-site.

- **These magnitude of energy-related air emissions, however, depends on the fuel mix used to produce the electricity used at BCTMP mills.** The magnitude of the reported energy-related air emissions associated with BCTMP production is actually lower than the magnitude of the estimated emissions for bleached kraft and sulfite pulp production because the three Canadian mills use hydropower to generate their electricity.

- **On average, the magnitude of the energy-related air emissions generated during the production of bleached sulfite pulp is lower than the magnitude of these emissions generated during the production of bleached kraft pulp.** While the process energy and the amount of energy generated on-site from wood-based fuel is similar for the two processes, unbleached sulfite pulps are brighter than unbleached kraft pulps, and thus consume smaller quantities of bleaching chemicals to produce 90 GE brightness pulp.

C. Air Emissions from Process Sources (HAPs, VOCs, and TRS)

1. Scope

Hazardous air pollutants (HAPs), volatile organic compounds (VOCs) and total reduced sulfur compounds (TRS) comprise the three classes of process-related air emissions generated during the pulping and papermaking processes. These sources include the pulp and bleach plants, the chemical recovery system and the paper machine. Energy generation contributes to HAP and VOC releases; thus, we include both energy- and process-related sources for these pollutants. **Table 1** contains estimates of the magnitude of these parameters associated with the production of an oven-dried ton of bleached kraft pulp, papergrade sulfite pulp and BCTMP.

2. Sources

The National Council of the Paper Industry for Air and Stream Improvement (NCASI), a research organization that focuses on the environmental impacts of pulp and paper production, reported emission factors for HAPs, VOCs and TRS from kraft pulp mill sources in June 1993.[54]

In late 1994, NCASI published a detailed study of the release of 28 organic HAPs, VOCs and TRS developed from field tests at 16 mills - nine bleached kraft mills, four unbleached kraft mills, two sulfite mills and one unbleached semichemical pulp mill. NCASI also measured the emissions from other pulping processes at three mills that also produce other types of pulp. One bleached kraft mill produces dissolving kraft pulp, while another produces TMP. One unbleached kraft pulp mill also produces semichemical pulp. [55]. In Appendix C, we present a summary of the emissions of ten HAPs from mill sources included in the study in **Table C-14**, and VOCs and TRS emissions in **Table C-15**.

3. Hazardous Air Pollutants (HAPs)

The 1990 Clean Air Act Amendments defined 189 substances as hazardous air pollutants because of their toxicity. We examined the compounds that comprised a minimum of one percent of the total HAPs from any source from the mill. Studies have shown that acetaldehyde, formaldehyde and chloroform, three HAPs emitted by bleached kraft pulp mills, can cause cancer in animal livers and degeneration of animal olfactory epithelium. Other compounds can exhibit toxic effects above a threshold level.[56] HAP emissions affect the local environment around the mill. These emissions are regulated to maintain releases at the mill fence line below levels that cause these toxic effects in the laboratory. Mills control these releases with chemical scrubbers and by routing the releases from vents to the lime kiln or another power boiler where these compounds are burned as fuel.

Most of the HAP emissions at bleached kraft mills are from process sources. The energy-related HAPs are about two orders of magnitude lower than those from process sources.[57] As a result, the age of the mill has little effect on the magnitude of the HAP emissions. We consider HAPs released from both energy-related and non-combustion process sources at the mill.. We have grouped HAP emissions from kraft pulp mill recovery boilers with the chemical recovery emission sources. We present the HAP emissions from all sources at the mill in **Table C-12** of Appendix C.

a) Bleached Kraft Pulping Processes

Major bleached kraft pulp mill sources include the pulp and bleach plants, storage tanks and the chemical recovery system. The bleached kraft mills included in this study use a continuous digester, and diffusion and vacuum drum brownstock washing. Methanol, chloroform, acetaldehyde, methyl ethyl ketone and formaldehyde account for most of the HAPs emitted by a bleached kraft mill. On average, pulping and bleaching processes and the chemical recovery system account for 98% to 99% of the organic HAP emissions from pulp mill sources We present the major HAP emissions from the process and combustion sources at bleached kraft pulp mills in **Table 7.**

Table 7. HAP emissions from bleached kraft pulp mill sources

Bleached kraft pulp with 50% D		
HAP	**Pulp mill sources** (lb/ODTP)	**Bleach Plant sources** (lb/ODTP)
Total	**2.54**	**0.68**
Methanol	2.18	0.52
Acetaldehyde	0.08	0.00
Formaldehyde	0.02	0.00
Chloroform	0.13	0.12
Bleached kraft pulp with 100% D		
HAP	**Pulp mill sources** (lb/ODTP)	**Bleach Plant sources** (lb/ODTP)
Total	**2.132**	**0.270**
Methanol	1.912	0.250
Acetaldehyde	0.085	0.003
Formaldehyde	0.019	0.000
Chloroform	0.021	0.011
Bleached kraft pulp with O+100% D		
HAP	**Pulp mill sources** (lb/ODTP)	**Bleach Plant sources [1, 2]** (lb/ODTP)
Total	**3.193 (2.402)**	**1.329 (0.54)**
Methanol	2.932 (2.182)	1.270 (0.52)
Acetaldehyde	0.128 (0.094)	0.047 (0.012)
Formaldehyde	0.021 (0.020)	0.002 (0.000)
Chloroform	0.013 (0.014)	0.002 (0.002)

[1] Bleach plant sources include the oxygen delignification system and the bleach plant.
[2] Numbers in parentheses include emissions from an oxygen delignification system that used fresh shower water (Mill N).

The chloroform emissions of the three mills in **Table 7**, indicate that these emissions decrease by about 90% in mills that substitute chlorine dioxide for all of the elemental chlorine in the first bleaching stage. Bleach plant air emissions of chloroform decreased from 0.12 lb/ODTP for the bleach plant with 50% chlorine dioxide substitution to 0.002 lb/ODTP for the bleach plant at a mill with an O+100% D process.[58] This measured reduction in chloroform emissions supports the hypothesis that once a mill has eliminated hypochlorite from the bleaching process, the formation of chloroform depends on the amount of elemental chlorine present in the first bleaching stage. According to an earlier NCASI study, mills with 100% chlorine dioxide substitution may emit less than 0.02 pounds of chloroform to air and water per ton of pulp.[59]

The control of HAP emissions from the oxygen delignification stage may be a particular need for mills with O+100%D bleaching sequences. Of the bleached kraft pulping processes, the bleached kraft pulp mill with oxygen delignification had the highest total HAP emissions, because some methanol, methyl ethyl ketone, acetaldehyde and formaldehyde are emitted from the oxygen delignification system. NCASI has shown that the source of the water used on the post-oxygen showers determines the quantity of HAPs released from this source. Studies to determine whether oxygen delignification systems generate methanol were inconclusive.[60] Mills tend to reuse process water in the oxygen stage as part of their water conservation programs.

For mills that use chlorine dioxide in the first bleaching stage, the clean condensates from the black liquor evaporators are often used because the chloride levels of the bleach plant filtrate are too high to recirculate to the recovery boiler. During oxygen delignification, some of the HAPs and VOCs in the condensates are released into the environment. Treating the condensates in the secondary treatment system may also result in HAP and VOC emissions because volatile compounds can be stripped from the effluent during treatment. The NCASI study did not measure fugitive emissions from mill or secondary treatment system sources.

b) BCTMP and Sulfite Pulping Processes

We do not have estimates of the magnitude of the HAP emissions for the individual BCTMP mills. Given the similarity of the pulping processes, we have assumed that the HAP emissions from a TMP mill are similar to those from the BCTMP mill. Air emissions of HAPs from a TMP mill are an order of magnitude lower than those from a bleached kraft pulp mill. The major components of the organic HAP emissions for the BCTMP and sulfite pulp mills are presented in **Table 8.**

Table 8. HAP emissions from sulfite pulp and BCTMP mill sources

Sulfite pulp mill (Magnesium base)			BCTMP mill		
HAP	**Quantity** (lb/ODTP)	**Percent of total**	**HAP**	**Quantity** (lb/ODTP)	**Percent of total**
Total	**16.64**		**Total**	**0.2876**	
Methanol	14.44	86.8%	Methanol	0.1500	52.2%
Acetaldehyde	1.24	7.5%	Acetaldehyde	0.0006	0.2%
Formaldehyde	0.28	1.7%	Formaldehyde	0.1301	45.2%
			Chloroform	0.0003	0.1%
		96.0%			**97.7%**

4. Paper Machines

We present the organic HAP emissions released by paper machines that produce uncoated and coated paper at a bleached kraft pulp mill in **Table 9**. These emissions are low compared with those from the pulp and bleach plants at bleached kraft pulp mills.

Table 9. HAP emissions from paper machine sources

Paper machine		
HAP	**Quantity** lb/ODTP	**Percent of total**
Total	**0.1513**	
Methanol	0.0410	27.1%
Acetaldehyde	0.0482	31.9%
Formaldehyde	0.0102	6.8%
Chloroform	0.0180	11.9%
		77.6%

5. Volatile Organic Compounds (VOCs)

Volatile organic compounds are a broad class of organic gases such as vapors from solvents and gasoline. Trees and other plants also produce VOCs, with especially high emissions in hot weather. Mills control VOC releases by routing air emissions from pulp mill vents to the lime kiln and other boilers where these compounds serve as fuel. The control of VOC emissions is important because these compounds react with nitrogen oxides (NO_x) to form ozone in the atmosphere, the major component of photochemical smog.[61] We consider VOCs separately from HAPs because not all VOCs are classified as HAPs. Before EPA found that acetone did not react with sunlight, it was classified as a VOC; acetone is not a HAP. We present the HAP emissions from all sources at the mill in **Table C-13** of Appendix C.

Note of Caution: We cannot directly compare the total HAP and total VOC emissions from a given source. NCASI used a different method to measure the total HAP and VOC emissions. VOC emissions are measured as pounds of carbon per oven-dried ton of pulp (lb C/ODTP).[62]

a) Bleached Kraft Pulp Mills

We present total VOC emissions for bleached kraft pulp mills using three different bleaching sequences in **Table 10**. As with HAPs the age of the mill has little impact on the magnitude of the VOC releases.

Table 10. VOC emissions from bleached kraft pulp mill sources

Bleached kraft pulp with 50% D		**Bleached kraft pulp with 100% D**	
Source	**Quantity** lb C/ODTP	**Source**	**Quantity** lb C/ODTP
Pulping	1.11	Pulping	1.11
Bleaching	0.31	Bleaching	0.03
Chemical Recovery	0.97	Chemical Recovery	0.97
Energy	3.30	Energy	3.82
Total	**5.69**	**Total**	**5.93**
Bleached kraft pulp with O+100%D			
Source	**Quantity** lb C/ODTP		
Pulping	1.11		
Bleaching [1, 2]	0.68 (0.15)		
Chemical Recovery	0.97		
Energy	3.10		
Total	**5.86 (5.32)**		

[1] Bleaching sources include the oxygen delignification system and the bleach plant.
[2] Numbers in parentheses include emissions from an oxygen delignification system that used fresh shower water (Mill N).

Pulping and chemical recovery sources account for about 40% of the VOC emissions from bleached kraft pulp mills. The oxygen delignification system releases VOCs and accounts for the difference between the emissions for the mill with 100% D and the mill with O + 100% D. As with HAPs, VOC releases may increase as bleached kraft mills reuse more process water.

b) BCTMP and Bleached Sulfite Pulping Processes

We present total VOC emissions for a BCTMP mill and a sulfite pulp mill in **Table 11**. We have assumed that the VOC emissions from the non-combustion process sources at the BCTMP mills are similar to the emissions from the TMP mills.

Table 11. VOC emissions from BCTMP and sulfite pulp mill sources

BCTMP		Sulfite (Magnesium)	
Source	**Quantity** lb C/ODTP	**Source**	**Quantity** lb C/ODTP
Pulping/Bleaching	0.31	Pulping/Bleaching	0.40
Chemical Recovery		Chemical Recovery	8.42
Energy	2.43	Energy	2.43
Total	**2.74**		**11.33**

The chemical recovery system accounts for about 75% of the VOC emissions from a sulfite mill with a magnesium base. Energy-related emissions account for over 85% of the VOC emissions from BCTMP mills.

c) Paper Machines

We present the VOC emissions from paper machines used to produce uncoated and coated paper in **Table 12**. Energy-related VOC emissions account for over 90% of the VOC emissions from paper machines.

Table 12. VOC emissions from paper machine sources

Paper machine producing uncoated paper		Paper machine producing coated paper	
Source	**Quantity** lb C/ODTP	**Source**	**Quantity** lb C/ODTP
Machine	0.04	Machine	0.06
Energy	0.92	Energy	0.92
Total	**0.96**	**Total**	**0.98**

6. Total Reduced Sulfur Compounds (TRS)

Total reduced sulfur compounds include hydrogen sulfide, methyl mercaptan, dimethyl sulfide and dimethyldisulfide. The NCASI study did not measure hydrogen sulfide emissions at any of the mills. Mills that use sodium sulfide in the cooking process produce these malodorous compounds. Of the three pulping processes only bleached kraft processes release TRS.. While these compounds are not considered to show acute toxicity, systematic surveys of odor pollution caused by pulp mills have supported the link between odor and respiratory responses.[63]

a) Bleached Kraft Pulp Mills

The pulping process and the chemical recovery system are the sources of TRS at a bleached kraft pulp mill. Bleached kraft pulp mills have reduced the quantity of totally reduced sulfur compounds released by installing low-odor recovery boilers and systems that capture and incinerate these gases.

b) BCTMP and Sulfite Pulping Processes

BCTMP pulping processes do not generate these compounds. BCTMP mills with alkaline peroxide processes do not use any sulfur compounds in the production process. The BCTMP mills that use alkaline sulfite processes and sulfite mills do not generate reduced organic sulfur compounds in the pulping process.

7. Summary

- **Methanol accounts for most of the HAP emissions associated with the bleached kraft and mechanical processes.**
- **On average, the bleached sulfite pulping process generates the highest HAP and VOC emissions of the three pulping processes.**
- **BCTMP, as a high-yield pulp, has lower process-related air emissions because most of the organic material in the wood stays in the pulp.**
- **Only the kraft process produces TRS emissions.**

D. Effluent

1. Scope

We examine the quantity and quality of the effluent associated with the production of uncoated free-sheet paper with bleached kraft, bleached kraft with 20% BCTMP, and papergrade sulfite pulps. We compare effluent flow along with five parameters that describe effluent quality: biochemical oxygen demand (BOD), total suspended solids (TSS), chemical oxygen demand (COD), and adsorbable organic halogens (AOX). We examine the variability of the data for each parameter in the comparisons as well.

While we have been able to estimate the contributions of the pulping and papermaking processes to effluent flow, insufficient data precluded allocating the loading of BOD, TSS, COD or AOX in a mill's final effluent to specific components of the production process. Where paper grades contain more than one type of pulp, we have estimated the contribution of each pulp manufacturing process in proportion to its percentage of the fiber weight. In UCFS with bleached kraft pulp and 20% BCTMP, for example, we have estimated the effluent quality parameters based on an 80% contribution from the groundwood and 20% contribution from the BCTMP.

2. Sources

Two sources provide most of the data on the environmental releases to water examined in this White Paper.

- EPA's *Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper and Paperboard Point Source Category* provides the most complete data on releases to water for bleached kraft pulp mills.[64] This document also includes information from the 1990 industry questionnaire on mean effluent flow, along with final BOD and TSS loadings for 33 bleach kraft pulp mills, and 8 papergrade sulfite mills. EPA also provides COD loadings in final effluent for 13 bleached kraft pulp mills and 3 sulfite mills, as well as an estimate of the mean AOX loadings for mills with different degrees of chlorine dioxide substitution.

- A 1989 NCASI survey of 41 bleached kraft pulp mills, and 11 sulfite mills provides estimates of mean flow, BOD and TSS loadings in the final effluent of these mills. NCASI does not include any data from individual mills in this report.[65]

3. Effluent Quantity

The sources of fresh water to a mill can include groundwater, water diverted from a river or lake and water that enters the mill with the wood and chemicals. For example, wood is 50% water as received and starch solutions are 90%. Water leaves the mill by several routes: with the evaporation of water from the black liquor before firing in the recovery boiler; the paper machine removes water through the drying process; and lime kilns evaporate water during the calcining of lime. The amount of water entering the mill from raw materials and losses from evaporation are about equal;[66] thus, the quantity of fresh water consumed to produce a ton of final product and the effluent flow from the mill are essentially the same. The industry has responded to constraints on fresh water availability, limitations on treatment capabilities, and limits in discharge permits by developing technologies that both use less water and facilitate the reuse of process water. The industry has reduced water use by 34% from 1975 to 1988.[67]

We present estimates of effluent flow for bleached kraft mills, BCTMP mills, sulfite mills in **Table 13.**

Table 13. Estimates of effluent flow

Gallons per air-dried ton of final product					
		Range			
Process	**Mean**	**low**	**high**	**# of mills**	**Reference**
Bleached kraft	24,800			40	NCASI 1989[66]
Bleached kraft	22,000				EPA 1993[68]
Bleached kraft	17,000	15,500	35,500		Garner[67]
Bleached kraft		12,000			Raymond[66]
Sulfite	45,600			8	EPA 1993[69]
BCTMP	5283			1	

EPA has estimated the contribution to the effluent flow from the components of the manufacturing processes for bleached kraft, and papergrade sulfite mills.[68] Using these data, we can estimate the effluent flow associated with producing bleached kraft and mechanical pulps. The effluent flow associated with the production of bleached kraft pulp is about half that associated with the 50%D and 100%D pulping processes.[69] We present these estimates of effluent flow for the pulping and papermaking processes in **Table 14**.

Table 14. Contribution of mill processes to the total effluent flow

Process	**Mean**	**Reference**
Paper machine (gallons per ton of *final product*)		EPA 1993[68]
Bleached kraft	7,400	
Papergrade Sulfite	14,600	
Pulping processes [1] (gallons per ton of *pulp*)		
Bleached kraft		EPA 1993[68]
50%D	18,700	
100%D	18,700	
O+100%D	9,300	Erickson[69]
Average [2]	16,800	
Sulfite	39,500	
BCTMP	2,000	

[1] We have divided the effluent from the mill into papermaking and pulping for this analysis.
[2] The average effluent flow for the bleached kraft pulping processes is a weighted average based on estimates of 1994 production of pulps using these processes.

The estimate of 16,800 gallons per ton for the wastewater generated during the pulp manufacturing process represents the average for the industry in 1990. International Paper, for example, reports that one of its bleached kraft pulp mills uses 7,000 gallons per ton of pulp.[70] Modern mills that use 12,000-15,000 gallons per ton of final product, would generate approximately 4,500-7,500 gallons per ton of pulp. This estimate is consistent with the reported effluent flow of 6,000-8,000 gallons per ton of pulp for modern bleached kraft mills.[71] Although bleached kraft pulp mills have reduced their water consumption by reusing the white water from the paper machine, these mills still need additional fresh water for the pulping process.

Effluent flow,per ton of pulp, associated with the production of sulfite papers is almost twice that of bleached kraft. For a BCTMP mill which is not effluent-free, the effluent flow is about 5300 gallons/ADMT of pulp.[72] For an effluent-free BCTMP mill, the water consumption is 530 gallons/ADMT.[73]

4. Effluent Quality

a) Biochemical Oxygen Demand (BOD)

BOD is a measure of the tendency of an effluent to consume dissolved oxygen from receiving waters over a pre-set time period. Microorganisms in the receiving water consume oxygen as they metabolize the organic material in the effluent. High levels of BOD in the effluent stream can deprive fish, shellfish, fungi and aerobic bacteria of the oxygen they need to survive.[74] Mills employ secondary biological treatment systems to remove over 95% of the BOD from the raw effluent. For BOD, environmental impacts are relatively well-controlled by local permitting and monitoring. "In most cases, NPDES permits have strict limits based on the assimilative capacity of local receiving waters."[75] These limits keep BOD discharges below the assimilative capacity to protect aquatic communities.

In **Table 15**, we present a summary of the available data on BOD loadings in the final effluent of bleached kraft pulp mills, BCTMP mills and sulfite mills. The BOD loadings of the BCTMP are within the range of the mechanical pulp mills surveyed by the EPA; therefore, we have used the EPA data for the statistical analysis of the BOD loadings of the BCTMP mills. We present the BOD loading for individual mills in **Table E-1** of **Appendix E**. The BOD loading in the effluent of a sulfite mill is about twice that of bleached kraft mills. The BOD loadings for the three pulping processes are statistically different. We present this analysis in **Table E-13**.

Table 15. BOD data for bleached kraft, BCTMP, and sulfite mills

kg/ADMTFP		**Range**			
Process	**Mean**	**low**	**high**	**# of mills**	**Reference**
Bleached kraft	5.5			41	NCASI 1989[69]
Bleached kraft	3.05	0.26	6.68	33	EPA 1993[76]
BCTMP	1.57	0	4.0	3	private communication[77]
Sulfite [1]	6.06	2.69	10.70	8	EPA 1993[76]

[1] This range for BOD loading in the final effluent of sulfite mills is correct.

b) Total Suspended Solids (TSS)

Suspended solids such as bark, wood fiber, dirt, grit and other debris can cause long-term damage to benthic habitats in freshwater, estuarine or marine ecosystems. TSS can cause a range of effects from increasing the water turbidity to physically covering and smothering stationary or immobile benthic flora and fauna. Before mills removed solids that could settle out of the effluent, these solids formed fiber mats on the bottom of rivers or lakes that could decompose to reduce the dissolved oxygen levels in the water column.[78] Mills use primary treatment to remove all solids that might settle from the effluent; thus, treated mill effluent contains minimal amounts of settleable solids.[79]

We present a summary of the data on mean TSS loading in the final effluent of bleached kraft, sulfite, and BCTMP mills in **Table 16**. The TSS loadings of the BCTMP mills are within the range of the mechanical pulp mills surveyed by the EPA; therefore, we have used the EPA data for the statistical analysis of the TSS loadings of the BCTMP mills. We present the TSS loadings for individual mills in **Table E-1** of **Appendix E**. Again, we see a similar trend in the magnitude of the TSS loading in the final mill effluent. The BCTMP mills have the lowest mean loading, while the mean loading of the sulfite mills is almost twice that of the bleached kraft mills. We present a statistical analysis of the TSS loading in the final effluent for bleached kraft, bleached sulfite, and mechanical pulp mills in **Table E-13**. The TSS loadings of bleached sulfite and bleached kraft are not statistically different, while the TSS loadings of the mechanical pulp mills are statistically lower than that of the bleached kraft or sulfite mills.

Table 16. TSS loading in the final effluent of bleached kraft, sulfite, and BCTMP mills

kg/ADFMTP		**Range**			
Process	**Mean**	**low**	**high**	**# of mills**	**Reference**
Bleached kraft	7.5			41	NCASI 1989[69]
Bleached kraft	4.92	0.24	9.79	33	EPA 1993[76]
BCTMP	1.3			1	Private communication[80]
Sulfite [1]	7.62	2.99	22.71	8	EPA 1993[76]

[1] This range for TSS loading in the final effluent of sulfite mills is correct.

c) Chemical Oxygen Demand (COD)

Chemical oxygen demand is the amount of oxidizable compounds present in water. The COD of a biologically treated effluent represents the fraction of the organic substances in an effluent that the natural ecosystems cannot readily degrade, but provides no indication whether these substances are harmful.[81] COD does provide useful information about the sublethal toxicity of bleached kraft mill effluents, but the source of COD within the pulp mill provides the most pertinent information.[82] The European Environmental Research Group has performed model ecosystem studies on pulp mill effluents since 1982 that include up to 54 different parameters. They developed a "response index" that summarizes the results of a model ecosystem test on a scale of 1 to 5, where higher numbers correspond to increased effects. Folke examined the relationship between the response index and COD loading for 14 bleached kraft mill effluents. He has found that the response index increases with the COD loading in the effluent.[83]

Data for bleached kraft pulp mills from EPA's 1990 industry questionnaire[84] and from the short-term mill effluent study[85] comes from the Development Document for Effluent Limitations Guidelines. Three Canadian BCTMP mills provided data on their COD discharges. We present the estimates of COD loading in effluent that has undergone secondary treatment for the three types of mills in **Table 17**. Of the three pulping processes, the sulfite process has the highest COD loading while the BCTMP process has the lowest. The BCTMP COD loadings are roughly 10% that of sulfite.

Table 17. Estimates of COD loading in the final effluent of bleached kraft, BCTMP pulp, and sulfite mills

kg/ODTMP Process	Mean [1]	Range low	Range high	# of mills	Reference
Bleached kraft [2]	44.5	15.8	79.5	13	EPA 1993[84]
Bleached kraft		12.1	84.7	12	EPA 1993[85]
BCTMP	10	0	20	3	Private communication[86]
Sulfite	82.5	70	95	2	Soteland[87]
Sulfite	118	63.7	200	2	EPA 1993[84]

[1] We used the mid-point of the range for BCTMP and sulfite mills.
[2] We use this range in **Table 1** because it includes data from 13 mills.

To support our conclusion that sulfite COD discharges are higher than those of the other two pulping processes, **Figure 3** presents COD data obtained from a 1995 European survey of kraft and sulfite mills.[88] These data indicate that the distribution for the sulfite mills, as opposed to kraft mills, is skewed to the higher COD loading numbers.

d) Adsorbable Organic Halogens (AOX)

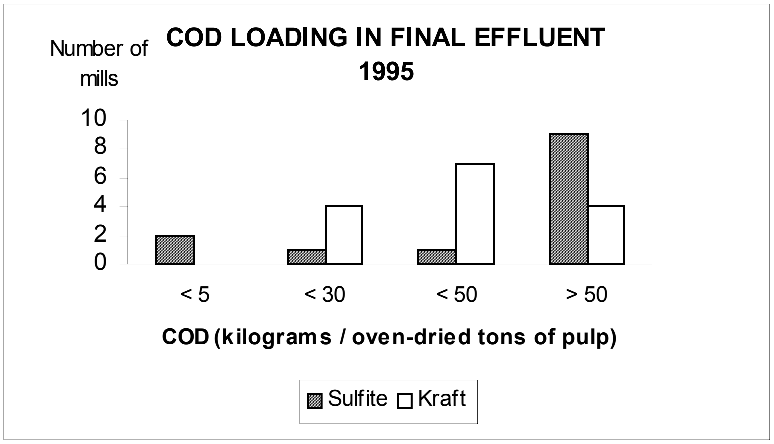
AOX is a summary parameter that measures the approximate amount of organically-bound chlorine that adsorbs to activated charcoal; thus, AOX provides an estimate of the chlorinated organic material in the effluent.

Note of caution: In the regulatory impact assessment of the proposed effluent guidelines, EPA states some of the issues associated with controlling AOX. "Although AOX concentrations can be used to determine the removal of chlorinated organics to assess loading reductions, they do not provide information on the potential toxicity of the effluent, and therefore, are not appropriate to evaluate the potential impacts on the environment. Although no statistical relationship has been established between the level of AOX and specific chlorinated organic compounds, AOX analysis can be an inexpensive method for obtaining the "bulk" measure of the total mass of chlorinated organic compounds."[89]

(1) Bleached kraft pulp mills

We present data on AOX loading in the final effluent of bleached softwood kraft pulp mills that use 50% D, 100% D and O + 100% D in **Table 18**. AOX loadings in the final effluent decrease with chlorine dioxide substitution for elemental chlorine in the first bleaching stage, and when mills reduce the amount of lignin in the unbleached pulp.

Figure 3. Distribution of COD loading in final effluent of European bleached kraft and sulfite mills



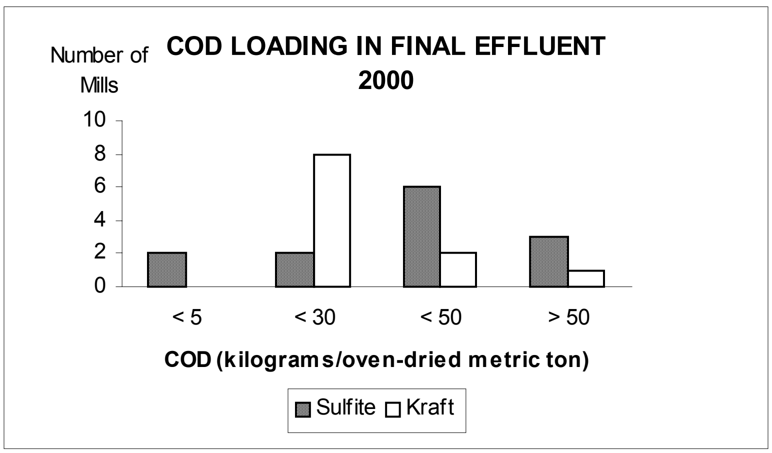


Table 18. AOX loading in the final effluent of bleached softwood kraft pulp mills

kg/ODMTP		**Range**			
Process	**Mean [1]**	**low**	**high**	**# of mills**	**Reference**
50% D	1.8			1	Morgan[90]
50 % D	1.5			1	Stinchfield[91]
50% D	1.6			1	Phillips[92]
100% D	0.59			4	NCASI[93]
O + 100% D	0.18	0.15	0.24	5	NCASI[93]
O + 100% D	0.15				EPA 1993[95]

(2) Sulfite mills

In **Table 19**, we present data on AOX loading in the final effluent of bleached sulfite pulp mills that use different bleaching sequences.

Table 19 AOX loading in the final effluent of bleached sulfite pulp mills

kg/ODMTP **Process**	**Mean**
CEH[94]	3.6
CEH[95]	5.2
D(EOP)D(EP)D[94]	0.7
PP[96]	0.02
P[96]	0.07

If we compare similar bleaching processes among the bleached kraft and sulfite processes, the AOX loading is about the same for both. For example, the mean AOX loading from bleached kraft and bleached sulfite processes with 100%D bleaching sequences is 0.6 and 0.7 kg/ODMTP, respectively.

(3) BCTMP mills

Releases of AOX are not expected to be associated with BCTMP mills. Chlorine compounds are not used to brighten mechanical pulps because these chemicals would remove the lignin and thus lower the yield of the pulp. One BCTMP mill (Slave Lake Pulp) measured its AOX discharge at less than 0.01 kg/ton. More sulfite mills produce totally-chlorine free pulp because of the ability to bleach the pulp to 90 GE brightness with combinations of oxygen and hydrogen peroxide.

e) Summary

- **Bleached kraft pulping processes require more fresh water than does the BCTMP process.**

- **The final effluent generated by BCTMP production has the lower BOD, COD and AOX loadings than does the final effluent from bleached kraft pulp mills.** Two Canadian BCTMP mills currently operate without any effluent discharge.

- **The bleached sulfite pulp manufacturing process has the higher effluent flow, along with higher BOD and COD loading in the final effluent than does the bleached kraft pulp manufacturing process.**

- **The TSS and AOX in the final effluent that results from bleached kraft and bleached sulfite pulp production are about the same.** A statistical comparison found no difference in the TSS loadings in the final effluent generated by these pulping processes.

E. *Solid waste Generation*

1. Scope

In this section we examine the quantity of the solid waste generated at bleached kraft pulp, BCTMP, and sulfite mills. The discussion of the quality of solid waste focuses on sludge quality because of the interest in using sludge as a land amendment.

2. Sources

The 1989 NCASI mill survey provides estimates of the mean quantity of sludge generated per ton of final product for bleached kraft pulp and sulfite pulp, [97] while a more recent NCASI study provides additional information on total quantity of solid waste generated by different types of mills.[98]

3. Solid waste quantity

Pulp and paper mills generate five types of solid waste: unburned wood yard waste, wastewater sludge; ash from the recovery and power boilers; solid residuals from the chemical recovery system; and general mill refuse.[99] Currently, primary and secondary sludge from wastewater treatment systems account for the largest portion of the solid waste stream.[100] While some of these residues provide energy to operate the mills, the rest must be disposed of in an ecologically sound and economical manner. Mills currently dispose of most of the solid waste in landfills. Mills incinerate about 20% of the wastewater sludge,[101] and a growing number of mills are exploring beneficial uses for sludge including land-spreading, and landfill cap material.

Bleached kraft, BCTMP, and sulfite pulp mills generate wastewater sludge. Pulp and paper mills generate two types of sludge: primary and secondary (or biological) sludge. Clarifiers used *before* biological treatment generate primary sludge as gravity or flotation thicken the organic and inorganic materials suspended in the untreated mill wastewater. Primary sludge contains wood fibers as the principal organic component, and inorganic materials such as clay, calcium carbonate, titanium dioxide, inert solids rejected during the chemical recovery process, and ash.

Clarifiers used *after* biological treatment to remove biological solids in the treated effluent generate secondary sludge. The solids in secondary sludge are mostly organic and contain bacterial and other microbial biomass.[102] Mills usually generate larger quantities of primary sludge.[103]

a) Bleached Kraft Pulp Mills

We present data on solid waste generation for bleached kraft pulp mills in **Table 20.** More detail on the calculation of total sludge quantity can be found in **Table E-6** of Appendix E.

Table 20. Solid waste from bleached kraft pulp mills (kg/ADMTFP)

Solid Waste	Mean	Std. Dev.	No. of Mills
Sludge			
Primary	57.0	42.2	44
Secondary	26.5	27.0	17
Dredged	19.5	25.9	19
Total [1]	**79.2**		
Misc. Solid Waste [2]	**85.5**	**93.2**	**51**
Total Solid Waste	**191**	**135.6**	**51**

[1] NCASI does not estimate total sludge quantities for the mills in Technical Bulletin No. 641. We have estimated the sludge quantity by assuming that mills with activated sludge treatment produce secondary sludge and mills with aerated lagoons produce dredged sludge. We then calculated a weighted average.

[2] Misc. Solid Waste accounts for all non-sludge waste generated at the mill except ash. The difference between the total and the miscellaneous solid waste and the sludge is ash from the recovery furnace and other boilers.

b) Sulfite Pulp Mills

We present data on solid waste generation for sulfite pulp mills in **Table 21.**

Table 21. Solid waste from sulfite pulp mills (kg/ADMTFP)

Solid Waste	Mean	Std. Dev.	No. of Mills
Sludge			
Primary	53.5	22	9
Secondary	28.0	12.0	9
Dredged	12.5	5.4	4
Misc. Solid Waste [1]	**88.5**	**155.8**	**11**
Total Solid Waste	**177.0**	**152.2**	**11**

[1] Misc. Solid Waste accounts for all non-sludge waste generated at the mill except ash.

c) BCTMP Mills

(1) Solid waste from BCTMP mills

We have limited data on solid waste generated at BCTMP mills. Based on information from Slave Lake Pulp, sludge generation is similar to that generated by mechanical pulp mills in the United States. Thus, we have used data on mechanical pulp mills for this comparison.

We present data on total solid waste generated by mechanical pulp mills in **Table 22**. More detail on the calculation of the total sludge quantity can be found in **Table E-14, Appendix E**.

Table 22. Solid waste from mechanical pulp mills (kg/ADMTFP)

Solid Waste	Mean	Std. Dev.	No. of Mills
Sludge			
Primary	70.5	52.9	13
Secondary	18.0	11.7	9
Dredged	4.5	0.1	1
Total [1]	**84.3**		
BCTMP Sludge	**72**[104]		
Misc. Solid Waste [2,3]	**43.5**	**44.37**	**13**
Total Solid Waste	**181**	**92.31**	**13**

[1] NCASI does not estimate total sludge quantities for the mills in Technical Bulletin No. 641. We have estimated the sludge quantity by assuming that mills with activated sludge treatment produce secondary sludge and mills with aerated lagoons produce dredged sludge.

[2] Misc. Solid Waste accounts for all non-sludge waste generated at the mill except ash. The difference between the total and the miscellaneous solid waste and the sludge is ash from power boilers at the mill.

A statistical analysis of the quantities of primary sludge generated by 43 bleached kraft pulp mills, the 13 mechanical pulp mills, and the 9 sulfite mills in the NCASI survey shows no significant difference in the quantity of primary sludge generated by the three types of mills. A statistical analysis of total solid waste yielded a similar result for 51 bleached kraft pulp mills and 11 sulfite mills in the NCASI survey. We present the results of this analysis in **Table E-14** of Appendix E.

d) Comparison of Municipal and BCTMP Sludge

Sludge can be disposed of in several ways. Slave Lake Pulp dries its sludge to 60% solids content and then burns it or it uses it on agricultural farmland. This fertilizer has been distributed to the local farmlands for the last two summers and has had positive results, in terms of increased yields and enhancement of soil properties. The sludge generated is composed of pulping fibers rejects (60%) and biological solids (40%, produced by effluent treatment process). As seen in **Table 23**, the metals content of BCTMP sludge is generally at the low end of the range of metals loading in bleached kraft sludge. Wastewater sludges generated by both processes generally have lower metals content than does municipal sewage sludge.

Table 23. Comparison between BCTMP and municipal sludge.[105]

Table 23. Metal loadings in BCTMP and bleached kraft mill wastewater sludge

Metal (1)	**BCTMP 1995 [1]**	**Bleached kraft 1992-93 (1) [2]**	
	(ppm dry weight) (2)	Min	Max
Boron	ND	ND(5.00)	0.0
Cadmium	0.8	ND(3.00)	0.0
Chromium	22.0	0.1	14.0
Copper	6.0	0.1	36.0
Iron	1.5	2.6	7,640.0
Lead	2.8	ND(0.01)	ND(25)
Manganese	30.0	1.1	1,020.0
Mercury	ND	ND(0.0)	ND(0.5)
Nickel	5.0	ND(11)	0.1
Zinc	40.0	0.2	184.0

Notes: (1) Primary, biological and combined sludges from 14 bleached kraft pulp mills
(2) Non-detectable loadings of a given metal are presented as ND.

Sources: [1] Data obtained from Christer Henricksson, Technical Supervisor, Slave Lake Pulp.
[2] U.S. EPA, *Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper and Paperboard Point Source Category.* Washington: U.S. EPA Office of Water, EPA-821-R-93-019, Appendix C, pp. 112-120.

4. Summary

- **There is no statistical difference in the magnitude of the total solid waste generated during the production a ton of bleached kraft pulp, bleached sulfite pulp or BCTMP.**

- **The metals content of wastewater sludge from BCTMP mills is close to the low end of the range of the loadings of metals in bleached kraft mill sludge. Both sludges have lower metals content than does municipal sewage sludge.**

F. Comparisons of Uncoated Freesheet with Bleached Kraft, Bleached Sulfite and BCTMP furnishes

Uncoated business papers made with an alkaline process generally contain 78% bleached pulp, 16% calcium carbonate filler and 6% water. We compare the environmental profiles of uncoated freesheet paper that contains bleached kraft pulp and bleached sulfite pulp in the furnish. We also examine the effect on the environmental parameters associated with the production of uncoated freesheet of replacing 20% of the bleached kraft pulp with BCTMP.

1. Comparison I: Uncoated Freesheet Paper with Bleached Kraft and Bleached Sulfite Pulps

Figure 1 and **Table 2** present a comparison of the energy consumption and releases to the environment generated by business papers that contain bleached kraft pulp and bleached sulfite pulps.

- **With the exception of mean effluent flow, the relative magnitudes of the environmental parameters associated with these UCFS papers is the same as those for the pulping processes described earlier.** On average, the effluent flow from paper machines that produce UCFS with sulfite pulp is higher than the effluent flow for paper machines that produce bleached kraft pulp

- **Although the loading of total suspended solids in the final effluent is not statistically different for the two processes, releases to water are higher, on average, for UCFS that contains sulfite pulp.**

- **The ranges of the environmental parameters for the UCFS with sulfite pulp, however, are generally larger than are those for the paper that contains bleached kraft pulp.** Sulfite mills choose from a wider range of pulping chemicals and process conditions than do bleached kraft pulp mills. Thus, the releases to the environment from sulfite mills will vary depending on the manufacturing process and on the products made at the mill.

2. Comparison II: Uncoated Freesheet paper with bleached kraft pulp and bleached kraft pulp with 20% BCTMP

In this case, we compare an uncoated freesheet paper that contains bleached kraft pulp with one in which BCTMP replaces 20% of the hardwood bleached kraft pulp. **Figure 2** and **Table 2** present a comparison of the energy consumption and releases to the environment generated by business papers that contain bleached kraft pulp and bleached kraft pulp with 20% BCTMP.

Purchased energy, sulfur dioxide, nitrogen oxides and carbon dioxide from fossil fuels increase when BCTMP replaces hardwood kraft. Process -related air emissions, effluent flow and releases to water decline.

The releases associated with the BCTMP process also depend on the age of the mill and the fuels used to produce electricity for the pulping process. Two new Canadian BCTMP market pulp mills operate in an effluent-free mode. These mills also use hydropower to generate electricity. Thus, energy-related air emissions for paper that contained BCTMP from these mills would be lower than those shown in **Figure 2**. Using hydropower, however, results in other impacts on the environment. The releases of sulfur dioxide, nitrogen oxides, particulates and carbon dioxide in all four comparisons assume that the mill purchases electricity from a utility that uses the national fuel mix of the United States. This fuel mix contains mostly oil and coal.

IV. ECONOMIC COMPARISON

There are four important components to the cost of paper: capital costs, fiber costs, purchased energy costs, and chemical costs. When a mill's operating costs are higher than the revenues they receive from paper sales, the mill faces pressure to close. The Altholville magnesium bisulfite mill provides an example of this economic reality. In 1981-1983, the company invested $200 million into an expansion and modernization project at the mill.[106] In 1990, the company spent $9 million to give the mill chlorine-free capabilities.[107] This mill closed because its pulp production costs were 20% higher than the price the pulp realized in the market.[108] The demand for TCF pulp was insufficient to save the mill.[109]

A. Capital Costs

- Capital cost is the amount of money of required to build a mill with a certain capacity.

- In 1992, an *American Papermaker* report stated that it costs $630,000 to $650,000 per daily ton of capacity to build a mill producing bleached kraft pulp.[110]

- Estimates made by the investment firm Morgan Stanley put replacement costs at $1.152 billion for the pulp mills that Weyerhauser purchased from Procter & Gamble in November 1992; these figures translate into a capital cost of $600,000 per daily ton for bleached kraft pulp capacity.[111]

- In the same report, Morgan Stanley has also estimated the cost of additional capacity for virgin bleached market pulp to be $550,000 per daily ton, based on major paper acquisitions that have taken place since September, 1988; its estimate for the period prior to September, 1988 was $500,000 per daily ton.

The Capital costs to build additional bleached kraft pulp capacity are roughly twice those to build a state-of-the-art BCTMP mill. Several estimates for capital costs needed to produce bleached kraft pulp are available and fairly consistent:

- The cost per ton of daily capacity of Millar Western's BCTMP mill in Meadowlake, Saskatchewan was about $365,000 per daily metric ton of capacity.[112] Louisiana-Pacific reported its costs of C$165 million to install a 450 metric ton mill, or US$275,000 per daily ton of capacity.[113]

BCTMP mills can take advantage of forest lands that are unsuitable for bleached kraft pulping operations. State-of-the-art, economically efficient BCTMP mills need 25% of the forest land of a state-of -the-art bleached kraft pulp mill. The ability to operate without virtually any effluent also allows BCTMP mills to be sited in areas where receiving waters are small.

In most cases, papermakers will consider adding BCTMP to meet the incremental demand for bleached pulp. With an economic scale of 500 ADMT per day, few integrated mills are likely to add a BCTMP process to meet this capacity. Companies may, however, use the pulp from this mill at more than one paper mill or produce market pulp. The first U.S. BCTMP market pulp mill has been financed and will be built in northern Michigan where energy costs are low.[114]

B. Fiber Costs

Fiber costs are the largest variable cost component in pulp production. For example, wood accounts for 30-35% of the operating costs of making a ton of virgin bleached kraft pulp[115] and about 20% of the cost to produce a ton of BCTMP. Energy costs, however, account for about 16% of the total costs to produce a ton of BCTMP while they are less than 10% of the cost to produce a ton of bleached kraft pulp.[116]

C. Operating Costs

Operating costs include the costs of wood, chemicals, and energy as well as labor and maintenance. The operating costs of BCTMP mills are similar to those of hardwood bleached kraft pulp mills.[117] The energy costs offset the savings in wood and chemical costs.

D. Summary

Table 24 presents the per-ton capital and operating costs and average prices for delivery to the U.S. of producing comparable grades of hardwood bleached kraft pulp and BCTMP in 1995. The difference in total costs has resulted in 12.5% lower total costs and about 5% lower prices for BCTMP in 1995.

Table 24. 1995 Average manufacturing costs and prices for market hardwood bleached kraft pulp and BCTMP

(Delivered US)	Southern Hardwood Kraft	Hardwood BCTMP
Variable Cost	$340[118]	$334[119]
Total Cost	$481[118]	$421[119]
Prices	$ 831[120]	$ 791[120]

V. FUNCTIONALITY

The Paper Task Force has defined functionality as the ability of a sheet of paper to meet the purchasers' expectations for running in an office machine or offset printing press and creating the desired end product. With respect to both runability and print quality,[121] the Task Force has identified the following properties as critical for the functional performance of reprographic grades. These properties are strength, stiffness, dimensional stability of paper, opacity, smoothness, weight/caliper, electrical properties, and permanence and reversion.

A. Mechanical and Optical Permanence

1. BCTMP

Tests on papers containing various amounts of BCTMP show that papers with up to 7.5% lignin (40% aspen BCTMP) exhibited retention of mechanical properties similar to wood-free papers with less than 1% lignin.[122] Depending on the chemical treatment and wood species, tear can vary from 9 to 14 and tensile from 30 to 65.[123] Abadie-Maumer and Soteland conducted studies on the optical and mechanical permanence of handsheets and commercial papers prepared from unbleached and bleached CTMP, groundwood, bisulfite, and bleached kraft pulp.[124] Their results showed that at a similar pH, the rate of loss of tear strength with accelerated aging was lower for CTMP and groundwood pulps. In addition, Johnson and Bird showed that when bleached CTMP is added in increasing amounts (up to 50%) to a bleached hardwood kraft pulp in the presence of calcium carbonate, papers with mechanical and optical permanence are obtained.[125]

Mill trial results on uncoated free sheet have shown similar performance even up to a substitution of 40% hardwood BCTMP. Similar performance results were also observed with the substitution of 30% aspen BCTMP to a furnish containing 20% deinked recovered fiber pulp (**Table 25**) in three types of uncoated papers, copy paper, bond paper, and offset printing paper. Data on uncoated papers indicate that as hardwood BCTMP replaces hardwood bleached kraft pulp, brightness reversion increases.[126] Although the mechanical pulp-containing papers turned yellow upon aging, they were still legible and were copied with ease.

2. Sulfite Pulp

Sulfite pulp is a chemical pulp. As a result, one would expect its permanence, in writing papers, to be similar to kraft. In addition, because it has very little lignin, reversion is not expected to be a problem.

B. Recyclability of BCTMP

Adding BCTMP to business papers will affect the recyclability of the paper, but the recycling collection infrastructure can adapt to its presence in paper products. In some cases, a bale of recovered paper with a large percentage of paper containing BCTMP (scrap from a printer, for example) would have a lower market value than a bale containing only kraft fibers.

Table 25. Functional Results of Copy, Bond, and Offset BCTMP papers.[127]

		Copy Paper		Bond Paper		Offset Paper	
		Std.	30% BCTMP	Std.	30% BCTMP	Std.	30% BCTMP
Basis Weight (g/m^2)		76.6	76.6	56.9	56.3	88.7	87.8
Caliper (mils)		4.1	4.1	3.1	3.1	4.5	4.5
Smoothness	T	158	161	190	200	145	155
	W	164	172	200	216	126	130
Stiffness (Gurley)	MD	227	224				
	CD	100	104				
Mullen				24	23	29	28
Tear (g)	MD			49	48	57	53
	CD			53	52	63	59
HST (secs)		178	174			274	162
Wax Pick						16	14
Densometer (secs)		14	13	11	16	274	162
Opacity		92.9	92.0	84.6	83.8	94.8	95.2
Brightness		84.3	84.3	84.4	83.7	84.4	83.8

Mills that make tissue and newsprint from recovered paper already use recovered mechanical fiber, so the presence of BCTMP in the coated papers used in magazines and catalogs would not require change in the recycling infrastructure.

For manufacturers of deinked white pulp used in printing and writing paper, BCTMP will enter the recycling system gradually in the future, as non-integrated manufacturers of high-value printing and writing papers add this lower-cost pulp to their paper. Deinking mills already allow a small percentage of groundwood in the recovered paper they purchase. These factors should allow the markets for recovered paper to adjust to the use of BCTMP in printing and writing papers in the United States.

Incorporating BCTMP fibers into business papers may improve its ability to withstand several recycling cycles. BCTMP manufacturers prepare pulps with specific freeness levels because the refiners at paper mills do not have enough power to change the freeness of these pulps. As a result, BCTMP fibers will survive more recycling cycles than bleached kraft pulp.

Mechanical pulps generally survive recycling cycles with less pulp degradation because the lignin content improves their stiffness. The lignin content of BCTMP pulps serves this purpose well. BCTMP can add bulk and stiffness to paper with high levels of deinked pulp in its furnish

In the past, the groundwood content has been a concern because deinked recovered fiber pulp mills brightened the pulp with elemental chlorine and/or hypochlorite. These chemicals reacted with the lignin in the pulp to decrease pulp yield and to darken the mechanical pulp. Many mills currently use oxygen-based chemicals, such as oxygen and hydrogen peroxide, to brighten deinked recovered fiber pulps. These chemicals will also restore the brightness of the BCTMP.[128]

ENDNOTES

1 R. T. Campbell, Manager, Technology Support, International Paper, personal communication, February 24, 1995.

2 Allan Springer, Industrial Environmental Control: Pulp and Paper Industry, 2nd. Ed. (Atlanta: TAPPI Press, 1993), 270.

3 Ibid.

4 "Comments on the Proposed Cluster Rule submitted by the Northwest Pulp and Paper Association," DCN 20,016 A2, 4.

5 1994 Lockwood Post's Directory of the Pulp, Paper, and Allied Trades (New York: Miller Freeman Publications, 1994).

6 P. Sharman & G. Harris, "High Yield Pulping," Mill Product News, September-October 1994, 31. Two ways have been suggested to decrease the gap in tear strength between kraft softwood and sulfite softwood. A. Wong, C. Chiu, & R. Krzywanski, "Can Sulfite Pulp Challenge the Predominance of Kraft Pulp Successfully?", 1993 Pulping Conference (TAPPI: 1993), 137. One approach is to use different sulfite cooking conditions. The other approach is to boost the lower tear strength with the inclusion of specific agriculture-based fiber. Ibid.

7 An exception are the energy-related air emissions generated by utilities that produce electricity. The emission factors include emissions from extracting and transporting the fuels. As a result, these values are higher than those for the other fuels.

8 We present estimates of the amounts of bleached kraft pulp produced with a range of manufacturing technologies in Figure 1 of White Paper No. 5. Our analysis indicates that about 11.8, 2.3 and 3.5 million metric tons of bleached kraft pulp using some elemental chlorine, 100%D and extended cooking and/or oxygen delignification and 100%D, respectively. Thus we assigned weights of 67%, 13% and 20% to the three pulping processes, respectively.

9 The uncertainty factor of +/- 10% arises from the difference between the pulp being air- or oven-dried.

10 Data were obtained from: 1) S. Lancey, "USA: Recovering Industry Has Both Production and Consumption On the Rise," *Pulp & Paper International*, **37(7)**: 57 (1995); and 2) K. McElhatton, "Canada: Mills Reach Capacity, Prices Rise and Companies Finally Show Profits," *Pulp & Paper International*, **37(7)**: 58 (1995).

11 Ibid.

12 Bleached Chemi-Thermomechanical Pulp (BCTMP), information package prepared for the Paper Task Force by DuPont Canada, Fibreco Pulp, Louisiana-Pacific Corp., Millar Western Pulp, Slave Lake Pulp, Tembec, and Quesnel River Pulp Company, (New York, October 1994), 5.

13 Gary A. Smook, *Handbook for Pulp and Paper Technologists, 2nd ed*. (Vancouver: Angus Wilde Publications, 1992) 39.

14 Because chemical recovery is not routinely practiced in a calcium-based sulfite mill, calcium based sulfite systems are ruled out for any environmentally sound pulping system. Allan Springer, *Industrial Environmental Control: Pulp and Paper Industry,* 2nd. Ed. (Atlanta: TAPPI Press, 1993), 270.

15 James Cook, "Everybody wanted the Second Plant," *Forbes*, (August 8, 1988) at 92; A. Wong, *Preface*, *in*, Sulfite Science & Technology, v (O.V. Ingruber, et al. eds. 1985) (noting that in 1970s, many dilapidated sulfite mills in North America and Scandinavia closed because of the unsolvable problem of pollution control).

16 The ASAM process (Alkaline sulfite process using Anthraquinone and Methanol) has a number of advantages such as high pulp yield, high strength, insensitivity to wood species, high unbleached brightness, and easy bleaching which would make it competitive with kraft. N.P Black, *ASAM Alkaline Sulfite Pulping Process Shows Potential for Large-Scale Operation*, TAPPI Journal (April 1991).

17 Another competitive sulfite process is the neutral sulfite- anthraquinone (NSAQ) pulping process. It has a yield of over 70% for linerboard, which is higher than the kraft yield of 55%. Functionally, NSAQ softwood pulp is comparable to kraft, except in the area of tear strength, where it is typically 10% lower. NSAQ pulp has been shown to be satisfactory in the manufacture of SC paper, newsprint, and wood-free printing and writing papers. . A. Wong, C. Chiu, & R. Krzywanski, "Can Sulfite Pulp Challenge the Predominance of Kraft Pulp Successfully?", *1993 Pulping Conference* (TAPPI: 1993), 138. Advantages of NSAQ over kraft: 1) higher pulping yield, 2) easier to bleach chemical pulp, 3) less energy-intensive chemical recovery system, and 4) less air pollution propensity. Ibid.

18 We present estimates of the amounts of bleached kraft pulp produced with a range of manufacturing technologies in Figure 1 of White Paper No. 5. Our analysis indicates that about 11.8, 2.3 and 3.5 million metric tons of bleached kraft pulp using some elemental chlorine, 100%D and extended cooking and/or oxygen delignification and 100%D, respectively. Thus we assigned weights of 67%, 13% and 20% to the three pulping processes, respectively.

19 R. W. Johnson, "CTMP in Fine Papers: On-Machine Surface Treatments for Improved Brightness Stability," *Tappi Journal*, **74(5):** 210 (1991).

20 Telephone survey conducted by Radian Corporation to identify candidate foreign TCF sulfite mills for sampling. A total of 22 mills were interviewed.

21 *We include the transmission losses for all electricity used at the mill; thus, 1 kilowatt-hour of electricity equals 10,500 Btu of energy.* Many kraft mills have installed turbines that produce electricity for the mill. Although the turbines at a mill generates electricity more efficiently than does a utility, it is difficult to assess how much electricity a mill actually purchases. Many mills both sell and purchase electricity from the utility. These mills sell electricity during peak hours when power costs are high and purchase electricity during off-peak hours when demand is lower.

22 A. Elaahi and H.E. Lowitt, *The U.S. Pulp & Paper Industry and Energy Perspective*, report for the Department of Energy, DE88-008615 by Energetics Inc., April 1988. (*1988 Energetics Report*, hereafter.)

23 Paper Recycling: Impact on Electricity Use, Electro-technology Opportunities, draft report. EPRI document number TR102-379, prepared for the Electric Power Research Institute Pulp & Paper Office, Atlanta, GA, April 1993).

24 There are two relevant papers from this conference. Kenneth R. Gilbreath, et. al., "Background Paper on Energy Efficiency and the Pulp and Paper Industry," and Alex Orr, "Energy Generation and Use in the Kraft Pulp Industry," in ACEEE 1995 Summer Study on Energy Efficiency in Industry, Vol. 1, (Berkeley, CA: American Council for an Energy-Efficient Economy, August 1995).

25 Both mills use Union Camp's estimate of energy consumption for bleaching. Wells Nutt, president, Union Camp Technology, Inc., Letter to Harry Capell, Johnson & Johnson, 12 July 1995. Other process energy data for the 1980s mill was taken from K. R. Gilbreath, et. al., "Background Paper on Energy Efficiency in the Pulp and Paper Industry," p. 36. Process data for the 1990s mill can be found in Alex Orr, "Energy Use in the Kraft Pulp Industry," pp. 192 - 193. For the 1980s mills we assumed that mills recovered 19 million Btu's/ODTP

from black liquor and used the 5% of the dry wood that is bark and residues in hog-fuel boilers. The 1990s mills recovered 23.7 million Btu's/ODTP and used 10% of the dry wood in hog-fuel boilers. K.R. Gilbreath, et. al., "Background Paper on Energy Efficiency in the Pulp and Paper Industry," p. 52. **Table B-3** contains the calculations of the total and purchased energy for the three bleached kraft pulp manufacturing processes.

26 American Forest and Paper Association, *1994 Statistics: Paper, Paperboard & Wood Pulp* (Washington: American Forest & Paper Association, September 1994), p. 51.

27 Jean Renard, Manager, Pulp Technology, International Paper, letter to Lauren Blum, November 22, 1994.

28 N. McCubbin Consultants Inc. and MFG-European Environmental Research Group Ltd., *Environmental Choice Program Guidelines for Pulp and Paper Products -- Briefing Notes for Pulp and Finished Paper*. Final report submitted to the Environmental Choice Program, Environment Canada, Ottawa, Ontario, September 1993, p. 114.

29 O.V. Ingruber and A.M Ayroud, "Descriptions of Modernized Sulfite Pulping Operations," in Pulp and Paper Manufacture Volume IV: Sulfite Science & Technology, O.V Ingruber, et. al. eds. (Montreal: Technical Section, Canadian Pulp and Paper Association, 1993), 301, 307, 311.

30 Ibid., 311.

31 Millar Western Pulp (Meadow Lake): 1745 KWH/ADT. LA Pacific: 2250 KWH/ton. Slave Lake Pulp: 1800 KWH/ton.

32 Millar Western Pulp (Meadow Lake): 100 m^3/ADT. LA Pacific: 137 m^3/ton. Slave Lake Pulp: 125 m^3/ton.

33 Paper Recycling: Impact on Electricity Use, Electro-technology Opportunities, draft report. EPRI document number TR102-379, prepared for the Electric Power Research Institute Pulp & Paper Office, Atlanta, GA, April 1993), p. 1-58.

34 A. Elaahi and H.E. Lowitt, *1988 Energetics Report*, 2.

35 Franklin Associates, Ltd., *The Role of Recycling in Integrated Solid Waste Management to the Year 2000*, prepared for Keep America Beautiful, Inc., Stamford, CT, September 1994, p. I-10. (*Keep America Beautiful Report*, hereafter.)

36 NCASI, "Emission Factors for NO_x, SO_2, and Volatile Organic Compounds for Boilers, Kraft Pulp Mills, and Bleach Plants," *Technical Bulletin No. 646*, February 1993, p. 34.

37 U.S. EPA, EPA's Compilation of Air Pollutant Emission Factors (AP-42), Fifth Edition (Raleigh, NC: Office of Air and Radiation, July 1995.)

38 Richard Storat, vice president, economics and materials, American Forest & Paper Association, letter to David Refikin, Time Inc, 26 May 1995, 13.

39 John Zerbe, "Reduction of Atmospheric Carbon Emission Through Displacement of Fossil Fuels," *World Resource Review*, **5(4)**, December 1993.

40 Saburo Takeyama and Hiroaki Otsuka, "Waste Paper Utilization in Japan and Its Effect on the Environment," *TAPPI Proceedings of the 1994 International Environmental Conference*, (Atlanta, GA: TAPPI Press, 1994), 331.

41 American Forest & Paper Association, *1994 Statistics: Paper, Paperboard & Wood Pulp* (Washington: American Forest & Paper Association, September 1994), p. 51.

[42] Gary Smook, *Handbook for Pulp and Paper Technologists, 2nd Ed*., (Vancouver, BC: Angus Wilde Publications, 1992), 402.

[43] John E. Pinkerton, "Emissions of SO_2 and NO_x from Pulp and Paper Mills," *AIR & WASTE*, **43**, October 1993, p. 1405.

[44] NCASI, *Technical Bulletin No. 646*, p. 34.

[45] Franklin Associates, Ltd., *Keep America Beautiful Report.*

[46] John E. Pinkerton, "Emissions of SO_2 and NO_x from Pulp and Paper Mills," at 1406.

[47] Allan Springer, *Industrial Environmental Control: Pulp and Paper Industry, 2nd. Ed*. (Atlanta: TAPPI Press, 1993), 577 - 578.

[48] Ibid., 530 - 531.

[49] Douglas W. Dockery, et. al., "An Association Between Air Pollution and Mortality in Six U.S. Cities," *New England Journal of Medicine*, **329**, December 9, 1993, p. 1755.

[50] Franklin Associates Ltd., *Keep America Beautiful Report*, I-10.

[51] J.T Houghton et. al. (eds.), Climate Change 1994: Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios, Cambridge, England: published for the Intergovernmental Panel on Climate Change by Cambridge University Press, 1995, chapter 1.

[52] U.S. EPA, Environment Pollution Control: Pulp and Paper Industry, Part I, Air, (Washington: EPA-625/7-76-001, October 1976), 1-9.

[53] Ibid.

[54] NCASI, “Compilation of ‘Air Toxic’ Emission Data for Boilers, Pulp Mills, and Bleach Plants, *Technical Bulletin No. 650,* June 1993, 23, 24, 26-33; 34-37.

[55] NCASI, "Volatile Emissions from Pulp and Paper Mill sources, Volumes I - IX", *Technical Bulletin Nos. 675 - 683*, August - November 1994.

[56] U.S. EPA, *Regulatory Impact Assessment of Proposed Effluent Guidelines and NESHAP for the Pulp, Paper and Paperboard Industry*, (Washington: Office of Water, EPA-821-R93-020, November 1993), 7-7 - 7-8. (*Regulatory Impact Assessment,* hereafter.)

[57] Using bark and wood residue as fuel generates the highest emissions of energy-related HAPs.

[58] In his review of a draft of White Paper No. 5, Harry Hintz of Westvaco noted that the chloroform concentrations in the filtrates of traditional ECF bleach plants were lower than those from enhanced ECF bleach plants. The NCASI 16 mill study does not measure the chloroform concentration in the filtrates of the mill with an enhanced ECF process. As a result, we cannot make a direct comparison of the total chloroform concentration generated by these processes. A NCASI study of the effluents of six ECF bleached kraft pulp mills in Canada does measure the chloroform concentration in the bleach plant filtrates of mills. This study shows mean chloroform concentrations of 0.52 and 1.86 grams chloroform per metric ton of softwood bleached kraft pulp, respectively, in the bleach plant filtrates of mills with traditional ECF processes and enhanced ECF processes. [Source: NCASI, “Characterization of Effluent Quality at Seven Canadian Kraft Mills Operating Complete Substitution Bleach Plants,” *Special Report No. 95-09*, July 1995, 10.] The total chloroform

concentration of 2.86 grams per air-dried metric ton of softwood bleached kraft pulp generated by the mill with the enhanced ECF process is lower than that of the mill with a traditional ECF process at 6.02 grams of chloroform per air-dried metric ton of softwood bleached kraft pulp.

59 Robert J. Crawford *et al.,* "Chloroform generation at bleach plants with high chlorine dioxide substitution or oxygen delignification," *Tappi Journal*, **74(4)**: 163 (1991).

60 NCASI, "Volatile Organic Emissions from Pulp and Paper Mill Sources: Part I - Oxygen Delignification Systems," *Technical Bulletin No. 675,* August 1994, 88 -91.

61 U.S. EPA, *Regulatory Impact Assessment*, p.7-8.

62 NCASI emissions for total HAPs is the sum of the emissions of the individual HAPs measured in the study. NCASI collected the raw emission data for each HAP as a concentration, and then converted the concentration to pounds per oven-dried ton of pulp using the molecular weight of each compound. NCASI measured total VOC emissions using an EPA test for these emissions. The concentrations of the raw total VOC data are converted to mass emissions using the molecular weight of carbon rather than the molecular weight of the individual compounds. The EPA method is used to measure VOC emissions for regulatory purposes. Richard Storat notes that this test is known to have a poor response to certain compounds such as methanol and formaldehyde. Richard Storat, American Forest & Paper Association, letter to David Refkin, 26 May 1995, 10. Thus, it is possible that this test underestimates the actual VOC emissions.

63 U.S. EPA, *Regulatory Impact Assessment*, 7-11.

64 U.S. EPA, *Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper and Paperboard Point Source Category* (Washington: Office of Water, EPA-821-R-93-019, October 1993). (*Development Document for Proposed Effluent Limitations Guidelines* hereafter)

65 NCASI, "Progress in Reducing Water Use and Wastewater Loads in the U.S. Paper Industry," *Technical Bulletin No. 603*, February 1991, A5 -A8.

66 Dale Raymond, Director of Quality and Technology, Union Camp Corporation, letter to Lauren Blum, November 21, 1994.

67 Jerry W. Garner, "Water, water everywhere and not a drop to waste," *Papermaker*, **56 (10)**: 18 (1993); NCASI, "Progress in Reducing Water Use and Wastewater Loads in the U.S. Paper Industry", *Technical Bulletin No. 603*, February 1991, 3.

68 U.S. EPA, *Development Document For Effluent Limitations Guidelines*, 6-48 - 6-49.

69 Dick Erickson, "Closing Up the Bleach Plant: Striving for a Minimum-Impact Mill," Paper presented at the 1995 Chemical Week Conference, New Orleans, LA, 11 April 1995.

70 Terry Campbell, manager, Technology Support, International Paper, presentation to the Paper Task Force, September 1, 1994.

71 Richard Storat, American Forest & Paper Association, letter to David Refkin, 26 May 1995, 12.

72 We assume that the water consumption of 20 m^3/ADMT, is equivalent to the effluent flow. Communication with Lars Dannberg (Mill Manager) and Christer Hendrikson (Technical Supervisor) at Ranger Pulp, Slave Lake Corporation.

73 We assume that the make-up water or the water lost to evaporation is equivalent to the effluent flow. The make-up water is approximately 2 m3/ADMT. Personal communication with David Haskett, Louisiana-Pacific Corporation.

74 Jocelyn Woodman, *Pollution Prevention Technologies for the Bleached Kraft segment of the U.S. Pulp and Paper Industry* (Washington: U.S. EPA Office of Pollution Prevention and Toxics, EPA/600/R-93/110, 1883), 2-4.

75 Robert Shimp, section head, paper products division, environmental safety and external relations, Procter & Gamble, letter to Linda Fransen, June 9, 1995.

76 U.S. EPA, *Development Document For Effluent Limitations Guidelines*, 6-54, 9-81 - 9-84.

77 Millar Western Pulp has a closed loop effluent system; therefore, they have no BOD discharge. LA Pacific: 4 kg/ton. Slave Lake Pulp: 0.7 kg/ADMT. Using a conversion factor of 1 ton of paper = 0.78 ton of pulp, these numbers convert to 5.1 kg/ADMTFP and 0.9 kg/ ADMTFP.

78 U.S. EPA, *Regulatory Impact Assessment*, 7-27 - 7-28.

79 Dale Raymond, Director of Quality and Technology, Union Camp Corporation, letter to Lauren Blum, November 21, 1994.

80 Slave Lake Pulp: 1.3 kg/ADMT.

81 Jens Folke, Lars Landner, Karl-Johan Lehtinen, Neil McCubbin, "Simplified Bioassays and Chemical Analyses to be used for Regulatory Purposes in the Pulp Industry," *TAPPI Proceedings 1993 Environmental Conference* (Atlanta, GA: TAPPI Press, 1993), 413.

82 Jens Folke, "Does COD Provide a Useful Indication of the Sub-lethal Toxicity of ECF and TCF Effluents?" *1995 International Non-Chlorine Bleaching Conference* (San Francisco: Miller Freeman, Inc., March 1995), 1.

83 Ibid., 12-13.

84 U.S. EPA, *Development Document for Proposed Limitations Guidelines*, 10-42.

85 Ibid., 3-2, 6-35.

86 Millar Western Pulp has closed loop effluent system; therefore, it has no COD discharge. LA Pacific: >20 kg/ton of pulp. Slave Lake Pulp: 17 kg/ton of pulp.

87 N. Soteland, E. Lystad, G.E. Carlberg, G. Tveten, and T. Kaalqvist, "Reducing Discharges from Sulfite Pulp Bleach Plants," *Tappi Journal*, **74(5)**: 122-23 (1991)

88 M. Sinner, "Integrated Application of Available Optimized Technologies for NCB Low Emission Pulp Mills: An European View," *Proceedings of the 1995 International Non-Chlorine Bleaching Conference*, (San Francisco: Miller Freeman, Inc., 1995), 4-5.

89 U.S. EPA, *Regulatory Impact Assessment*, 7-25 - 7-26.

90 John Morgan, "Mill Experience with 100% ClO_2 Substitution Bleaching," *Proceedings of the 1993 Non-Chlorine Bleaching Conference* (San Francisco: Miller Freeman Inc., March 1993).

[91] Alan E. Stinchfield and Michael G. Woods, " Mill Experience with Reduction of Chlorinated Organic Compounds from Bleached Kraft Mills Using Complete Substitution of Chlorine Dioxide for Chlorine in the First Bleaching Stage," *NCASI Technical Workshop on Effects of Alternative Pulping and Bleaching Processes on Production and Biotreatability of Chlorinated Organics*, (Washington: February 1994), 6.

[92] L. Lancaster, J. Renard, C. Yin and R. B. Phillips, "The Effects of Alternative Pulping and Bleaching Processes on Product Performance - Economic and Environmental Concerns," *Proceedings of the International Symposium on Pollution Prevention in the Manufacture of Pulp and Paper - Opportunities and Barriers* (Washington: U.S. EPA Report No. EPA-744R-93-002, February 1993), 200.

[93] NCASI, "Characterization of Adsorbable Organic Halide (AOX) Discharge Rates at Kraft Mills Employing Complete Chlorine Dioxide Substitution," *Technical Bulletin 667*, June 1994.

[94] Gary Hickman and Llewellyn Matthews, "Bleached Sulfite Mill Effluent and AOX Treatment," *TAPPI proceedings: 1995 International Environmental Conference* (Atlanta: TAPPI Press, 1995), 475

[95] Dale Phenicie, manager, environmental regulatory affairs, Georgia-Pacific Corp., letter to Lauren Blum, Environmental Defense Fund, 14 October 1995.

[96] N. Soteland, E. Lystad, G.E. Carlberg, G. Tveten, and T. Kaalqvist, "Reducing Discharges from Sulfite Pulp Bleach Plants," 122.

[97] NCASI, *Technical Bulletin No. 603*, A8.

[98] NCASI, "Solid Waste Management and Disposal Practices in the U.S. Paper Industry," *Technical Bulletin No. 641*, September 1992.

[99] NCASI, "Solid Waste Management and Disposal Practices in the U.S. Paper Industry," *Technical Bulletin No. 641*, September 1992, 2.

[100] Gary Scott and Amy Smith, "Sludge Characteristics and Disposal Alternatives for the Pulp and Paper Industry," *TAPPI Proceedings of the 1995 International Environmental Conference* (Atlanta: Tappi Press, 1995), p. 269.

[101] A. Springer, *op. cit*., p. 484.

[102] NCASI, "Alternative Management of Pulp and Paper Industry Solid Wastes," *Technical Bulletin No. 655*, November 1993, 3.

[103] U.S. EPA, *Development Document for Proposed Effluent Limitations Guidelines*, 8-46.

[104] The data for this calculation was obtained from Christer Henricksson, Technical Supervisor, Slave Lake Pulp. The number generated is derived from this calculation: 84.2 kg sludge/ADMT (1 ADMT/).9 ODMT)(1 ODTP/0.78 ADMTFP) = 120 kg/ADTFP. The sludge is dried to 60% solids which is equivalent to 72 kg/ADTFP.

[105] Data obtained from Christer Henricksson, Technical Supervisor, Slave Lake Pulp.

[106] "Fraser Closes Altholville Pulp Mill," *Pulp & Paper*, **65(13):** 33(1991).

[107] Ibid.

[108] "Market Pulp: Strike in British Columbia Helps Keep Recovery in Pulp Market Moving," *Pulp & Paper*, **66(8):** 11(1992).

[109] Ibid.

[110] *American Papermaker* (March, 1992).

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[116] Resource Information Systems, Inc. *Pulp & Paper Review*, (Bedford, MA: RISI, July 1995), 319, 324.

[117] Alan Bird, Marketing Manager for DuPont Canada, telephone interview, August 15, 1995.

[118] Resource Information Systems, Inc. *Pulp & Paper Review*, (Bedford, MA: RISI, July 1995), 319.

[119] Ibid., 324.

[120] Ibid., 288.

[121] Runability refers to the paper properties that affect the ability of the paper to run in office equipment and printing presses. M. Bruno, *Pocket Pal*, 15th ed., (International Paper, 1992). Print quality refers to the paper's properties that determine the quality of appearance of the sheet after printing, as judged by contrast, resolution of the printed image, type, and reproduction of halftones. Ibid.

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[123] K.J. MacIntosh and SY Marr, "Temcell's BCTMP: Custom-made pulps," Pulp and Paper Canada, 91(1): 134 (1990).

[124] F.A. Abadie-Maumert and NA Soteland, "Résistance des CTMP au Vieillissement," Review ATIP, 44(6): 223-232 (1990).

[125] RW Johnson and A Bird, "CTMP in Fine Papers: Impact of CTMP on Permanence of Alkaline Papers," *Proceedings of Papermakers Conference*, Seattle, WA, April 1991, at 267-273.

[126] "The Use of Hardwood High Yield Pulps in Higher Quality Printing Paper" at vi.

[127] Data obtained from Alan Bird, DuPont Canada.

[128] *Future Fibers*, report prepared by H.A. Simons Ltd. & AF-IPK, March 1992, II-5.