PAPER TASK FORCE

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WHITE PAPER NO. 10A

ENVIRONMENTAL COMPARISON - MANUFACTURING TECHNOLOGIES FOR VIRGIN AND RECYCLED-CONTENT PRINTING AND WRITING PAPER

DECEMBER 19, 1995

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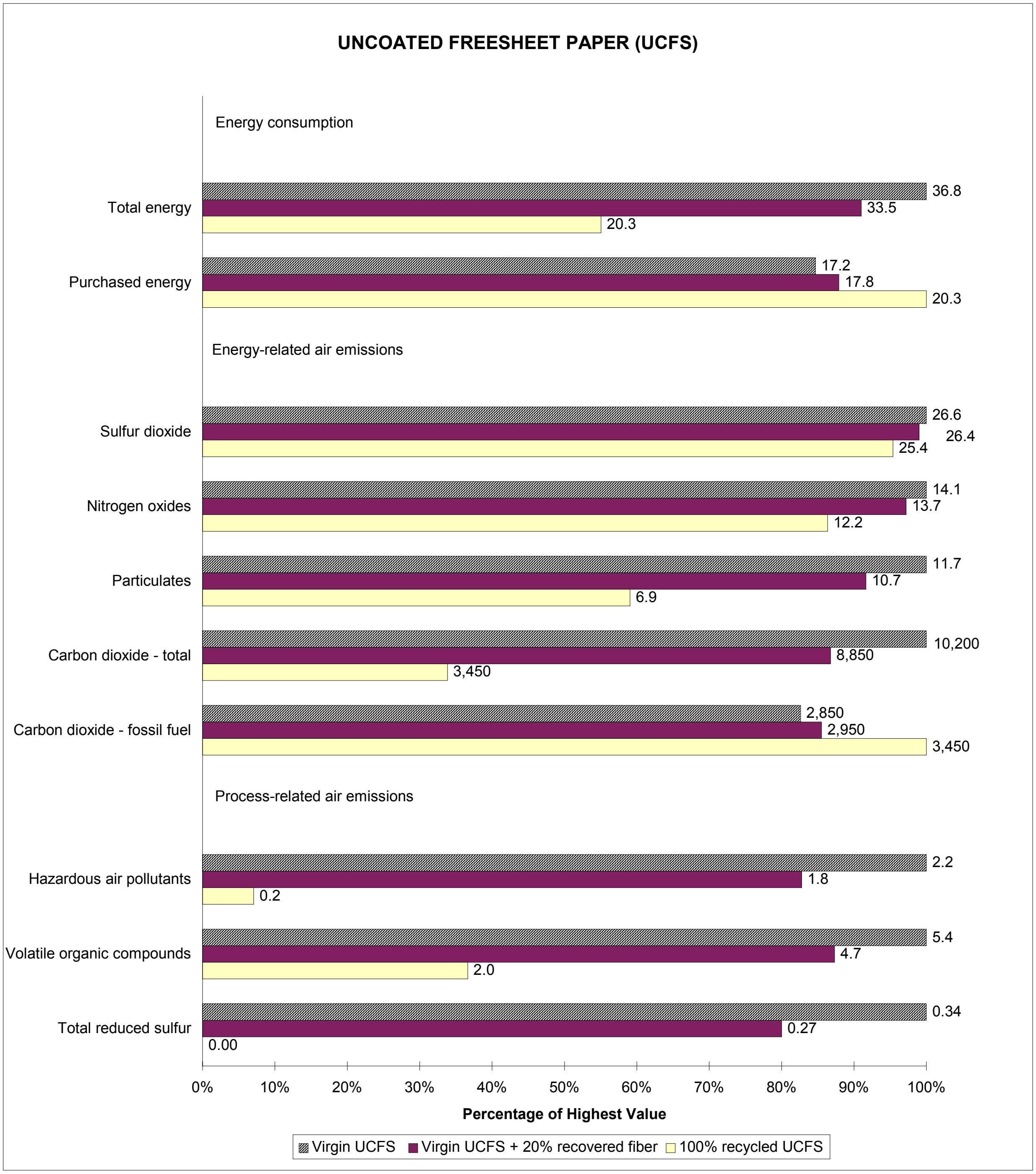
Table 2. Ranges of environmental parameters for bleached kraft, mechanical and deinked recovered fiber pulp manufacturing processes

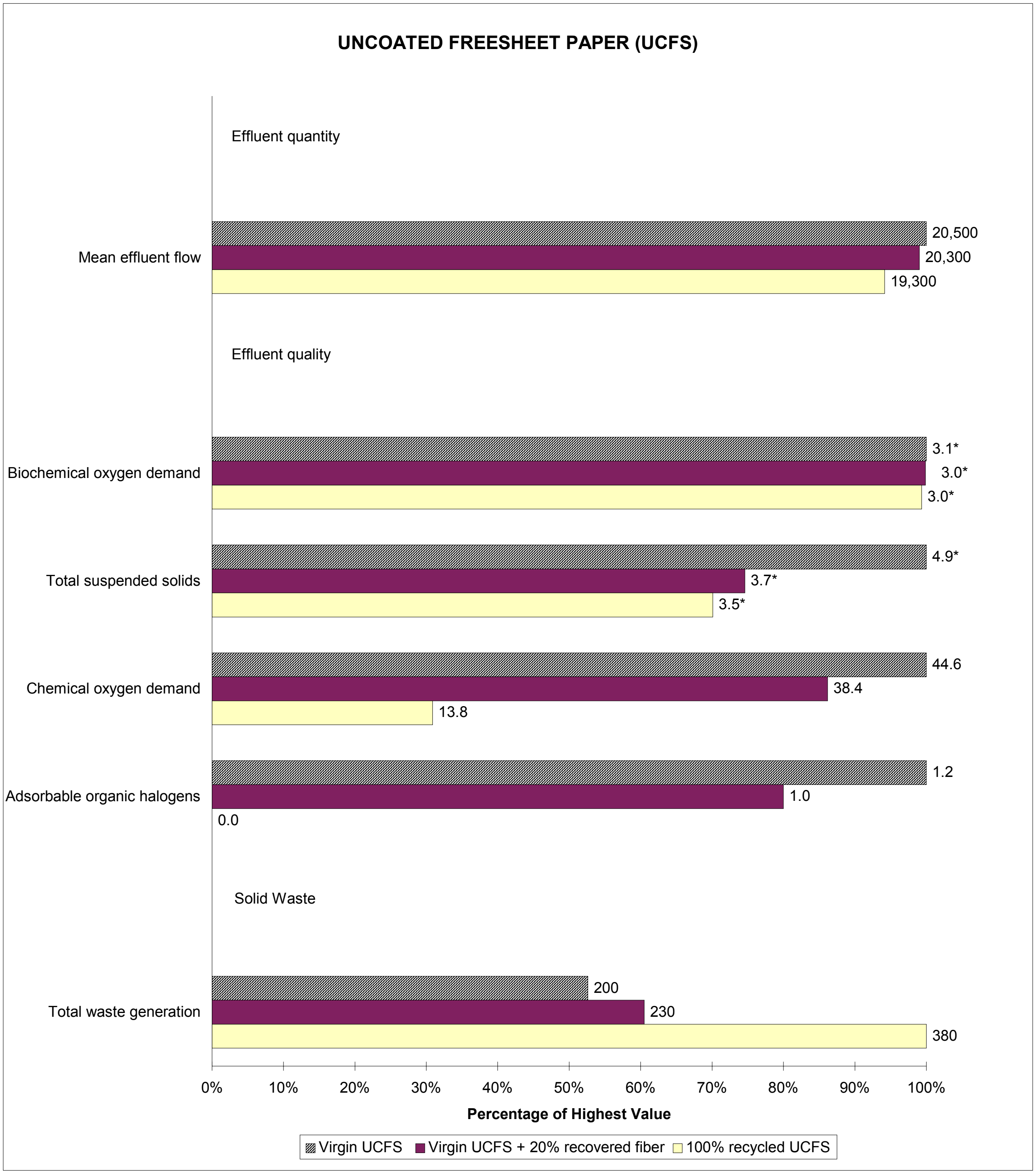
Environmental parameters	Bleached Kraft Pulp				Stone Groundwood pulp	TMP	Deinked Recovered fiber
	50% D	100% D	O + 100% D	Average			
ENERGY CONSUMPTION (millions of BTUs per air dried ton of product)							
Total	29.9 - 31.8	32.5 - 34.4	27.2 - 29.0	29.7 - 31.6	23.5	27.6	7.8 - 10.7
Purchased	1.5 - 10.4	4.1 - 13.0	(3.2) - 5.7	0.9 - 9.8	20.0	24.1	7.8 - 10.7
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	25.2	31.0	9.2 - 13.4
Nitrogen oxides (NO_x)	7.3 - 10.6	9.0 - 12.2	4.8 - 8.1	7.0 - 10.3	13.7	16.3	4.8 - 7.0
Particulates	10.4	11.5	9.4	10.4	9.6	11.1	3.3 - 4.8
Carbon dioxide (CO_2) - total	9,600 - 10,600	9,800 - 11,000	9,400 - 10,500	9,400 - 10,600	3,600	4,300	1,100 - 1,600
Carbon dioxide (CO_2) - fossil fuel	0 - 1,700	400 - 2,100	(800) - 900	(100) - 1,600	3,000	3,700	1,100 1,600
PROCESS-RELATED AIR EMISSIONS (pounds per air dried ton of product)							
Hazardous air pollutants (HAP)	2.5	2.1	2.4 - 3.2	2.6	0.3	0.3	0.0
Volatile organic compounds (VOC)	5.4	5.9	5.3 - 6.0	5.8	3.0	3.4	0.9 - 1.3
Total reduced sulfur (TRS)	0.43	0.44	0.43	0.43	0.0	0.0	0.0
EFFLUENT QUANTITY (gallons per air dried ton of final product)							
Mean effluent flow	18,700	18,700	9,300	16,800	4,900	4,900	7,500
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	0.2 - 3.6	0.2 - 3.6	0.9 - 7.6
Total suspended solids (TSS)	0.2 - 9.8	0.2 - 9.8	0.2 - 9.8	0.2 - 9.8	0.5 - 6.7	0.5 - 6.7	0.4 - 10.7
Chemical oxygen demand (COD)	15.8 - 79.5	15.8 - 79.5	15.8 - 79.5	15.8 - 79.5	3.3 - 33.0	3.3 - 33.0	11.0 - 16.5
Adsorbable organic halogens (AOX)	1.54 - 1.76	0.6	0.1 - 0.2	0.1 - 0.2	0.0	0.0	0.0
SOLID WASTE (kilograms per air dried metric ton of final product)							
Total waste generation	200	200	200	200	180	180	380

Figure 1a. Environmental parameters for uncoated freesheet paper with 0%, 20% and 100% recycled content



Note: Energy consumption: millions of BTU per air dried ton of product
Air emissions: pounds per air dried ton of final product

Figure 1b. Environmental parameters for uncoated freesheet paper with 0%, 20% and 100% recycled content

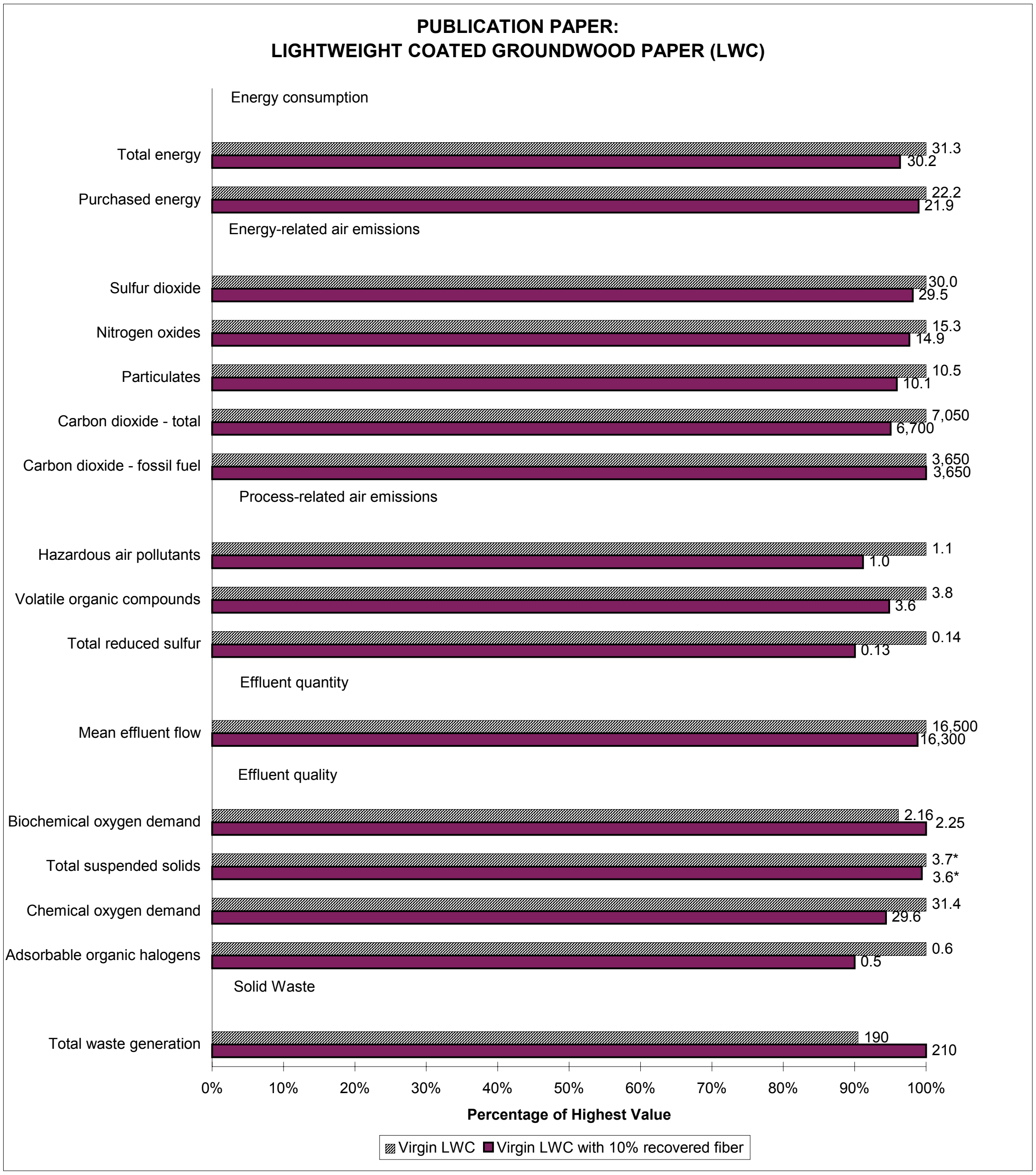


Note: * Not statistically different
Effluent flow: gallons per air dried ton of final product
Effluent quality and solid waste: kilograms per air dried metric ton of final product

Table 3. Environmental parameters for uncoated freesheet paper with 0%, 20% and 100% recycled content

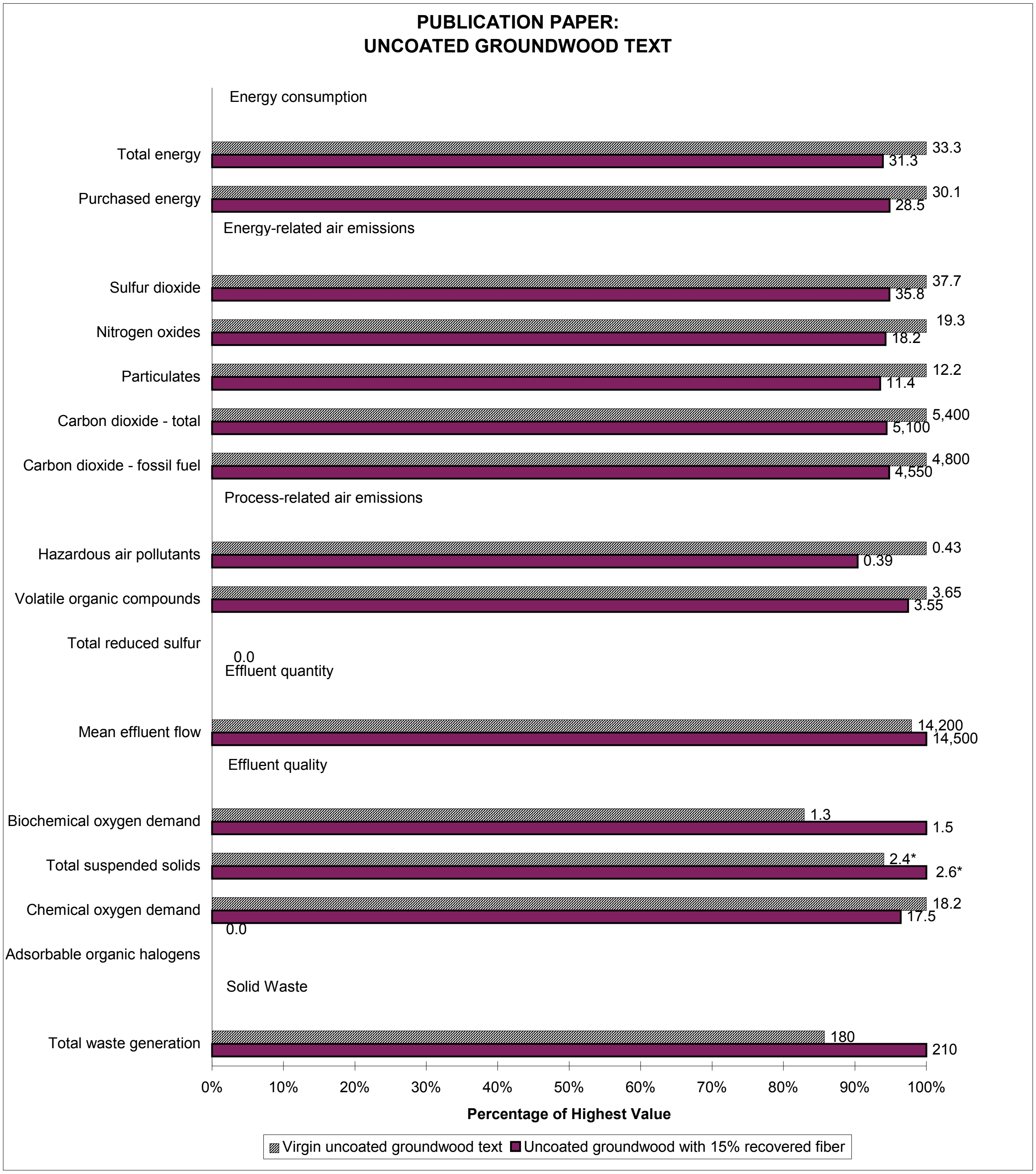
Environmental parameters	Virgin Uncoated Freesheet (UCFS) 50-70% D	100% D	O + 100% D	Average	UCFS with 20% recycled content	UCFS with 100% recycled content
ENERGY CONSUMPTION (millions of BTU per air dried ton of product)						
Total	36.2 - 37.7	38.2 - 39.7	34.1 - 35.5	36.2 - 37.5	32.6 - 34.4	19.0 - 21.6
Purchased	14.1 - 21.0	16.1 - 23.1	10.4 - 17.3	13.8 - 20.6	14.7 - 20.9	19.0 - 21.6
ENERGY-RELATED AIR EMISSIONS (pounds per air dried ton of product)						
Sulfur dioxide (SO_2)	23.4 - 30.9	25.9 - 33.4	19.2 - 26.7	22.9 - 30.4	23.0 - 29.7	23.7 - 27.0
Nitrogen oxides (NO_x)	13.1 - 15.6	14.4 - 16.9	11.1 - 13.7	12.9 - 15.4	12.6 - 14.9	11.4 - 13.1
Particulates	11.7	12.6	11.0	11.7	10.6 - 10.9	6.3 - 7.5
Carbon dioxide (CO_2) - total	9,700 - 10,500	10,100 - 10,900	9,700 - 10,500	9,800 - 10,600	8,600 - 9,100	3,200 - 3,700
Carbon dioxide (CO_2) - fossil fuel	2,300 - 3,600	2,600 - 3,900	1,700 - 3,000	2,200 - 3,500	2,400 - 3,500	3,200 - 3,700
PROCESS-RELATED AIR EMISSIONS (pounds per air dried ton of product)						
Hazardous air pollutants (HAP)	2.0 - 2.3	1.7 - 1.9	2.5 - 2.8	1.8 - 2.7	1.8	0.2
Volatile organic compounds (VOC)	5.1 - 5.7	5.1 - 5.7	5.3 - 5.8	5.4 - 5.5	4.7	2.0
Total reduced sulfur (TRS)	0.32 - 0.35	0.32 - 0.36	0.32 - 0.35	0.33 - 0.34	0.27	0.00
EFFLUENT QUANTITY (gallons per air dried ton of final product)						
Mean effluent flow	22,000	22,000	14,700	20,500	20,300	19,300
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	0.4 - 6.9	0.9 - 7.6
Total suspended solids (TSS)*	0.2 - 9.8	0.2 - 9.8	0.2 - 9.8	0.2 - 9.8	0.8 - 7.4	0.4 - 10.7
Chemical oxygen demand (COD)	15.8 - 79.5	15.8 - 79.5	15.8 - 79.5	15.8 - 79.5	24.4 - 64.2	11.0 - 16.5
Adsorbable organic halogens (AOX)	1.54 - 1.76	0.56 - 0.62	0.17 - 0.19	1.14 - 1.30	0.91 - 1.04	0.00
SOLID WASTE (kilograms per air dried metric ton of final product)						
Total waste generation	200	200	200	200	230	380

Figure 2. Environmental parameters for lightweight coated groundwood publication paper with 0% and 10% recycled content



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 3. Environmental parameters for uncoated groundwood papers with 0% and 15% recycled content



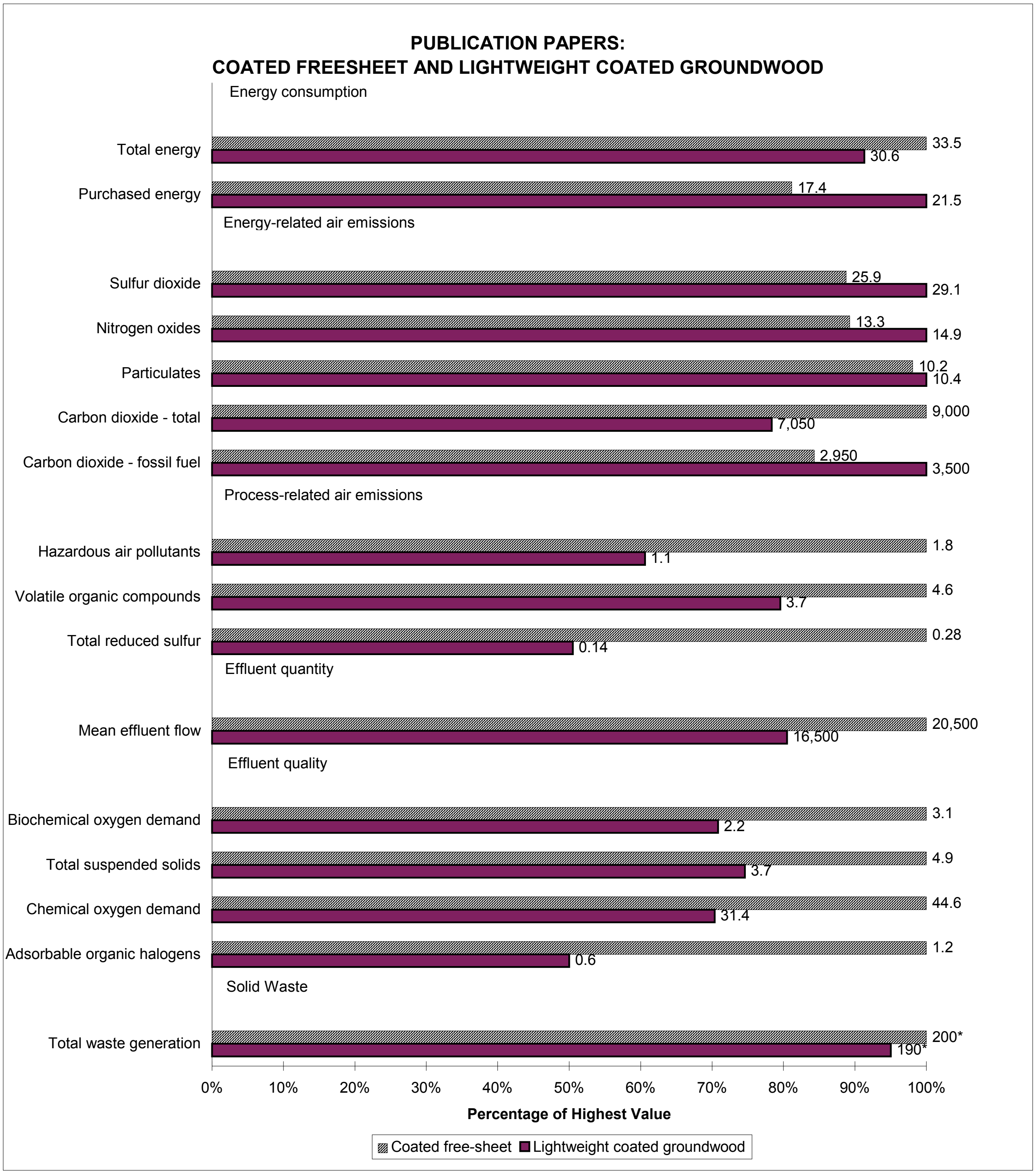
Note: * Not statistically different
Energy consumption: millions of BTU per air dried ton of product
Air emissions: pounds per air dried ton of final product
Effluent flow: gallons per air dried ton of final product
Effluent quality and solid waste: kilograms per air dried metric ton of final product

Table 4. Environmental parameters for lightweight coated groundwood publication paper with 0% and 10% recycled con and uncoated groundwood paper with 0% and 15% recycled content

Environmental parameters	Lightweight coated groundwood paper		Uncoated groundwood paper	
	virgin	with 10% recycled content	virgin	with 15% recycled content
ENERGY CONSUMPTION (millions of BTU per air dried ton of product)				
Total	31.0 - 31.6	29.8 - 30.6	33.3	31.0 - 31.5
Purchased	20.7 - 23.6	20.5 - 23.3	30.1	28.3 - 28.7
ENERGY-RELATED AIR EMISSIONS (pounds per air dried ton of product)				
Sulfur dioxide (SO2)	28.5 - 31.6	28.0 - 31.0	37.7	35.5 - 36.0
Nitrogen oxides (NOx)	14.8 - 15.8	14.4 - 15.5	19.3	18.1 - 18.4
Particulates	10.5	10.0 - 10.1	12.2	11.3 - 11.5
Carbon dioxide (CO2) - total	6,900 - 7,200	6,600 - 6,800	5,400	5,100
Carbon dioxide (CO2) - fossil fuel	3,400 - 3,900	3,400 - 3,900	4,800	4,500 - 4,600
PROCESS-RELATED AIR EMISSIONS (pounds per air dried ton of product)				
Hazardous air pollutants (HAP)	1.11	1.02	0.43	0.39
Volatile organic compounds (VOC)	3.8	3.6	3.6	3.6
Total reduced sulfur (TRS)	0.14	0.13	0.00	0.00
EFFLUENT QUANTITY (gallons per air dried ton of final product)				
Mean effluent flow	16,500	16,300	14,200	14,500
EFFLUENT QUALITY (kilograms per air dried metric ton of final product)				
Biochemical oxygen demand (BOD)	0.2 - 5.1	0.3 - 5.4	0.2 - 3.6	0.3 - 4.2
Total suspended solids (TSS)*	0.7 - 7.4	0.7 - 9.8	0.5 - 6.7	0.5 - 7.3
Chemical oxygen demand (COD)	24.4 - 41.4	40.6 - 52.0	3.3 - 33.0	4.4 - 30.5
Adsorbable organic halogens (AOX)	0.6 - 0.7	0.5 - 0.6	0.0	0.0
SOLID WASTE (kilograms per air dried metric ton of final product)				
Total waste generation	190	210	180	210

Note: * Not statistically different

Figure 4. Environmental parameters for publication papers



Note: 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

Table 5. Environmental parameters for virgin publication papers

Environmental parameters	Coated Free Sheet 50% D	Coated Free Sheet 100% D	Coated Free Sheet O + 100% D	Coated Free Sheet Average	Lightweight Coated Paper
ENERGY CONSUMPTION (millions of BTU per air dried ton of product)					
Total	32.8 - 34.3	34.6 - 36.1	31.0 - 32.5	32.8 - 34.3	30.2 - 31.0
Purchased	14.6 - 20.6	16.4 - 22.5	11.4 - 17.4	14.4 - 20.4	19.9 - 23.0
ENERGY-RELATED AIR EMISSIONS (pounds per air dried ton of product)					
Sulfur dioxide (SO_2)	23.0 - 29.6	25.3 - 31.9	19.4 - 26.0	22.6 - 29.1	27.5 - 30.8
Nitrogen oxides (NO_x)	12.3 - 14.6	13.5 - 15.8	10.7 - 12.9	12.2 - 14.4	14.3 - 15.5
Particulates	10.3	11.1	9.6	10.3	10.4
Carbon dioxide (CO_2) - total	8,700 - 9,300	9,000 - 9,600	8,700 - 9,300	8,700 - 9,300	6,900 - 7,200
Carbon dioxide (CO_2) - fossil fuel	2,500 - 3,600	2,800 - 3,900	1,900 - 3,100	2,400 - 3,500	3,200 - 3,800
PROCESS-RELATED AIR EMISSIONS (pounds per air dried ton of product)					
Hazardous air pollutants (HAP)	1.8	1.5	1.7 - 2.2	1.8	1.1
Volatile organic compounds (VOC)	4.6	4.6	4.3 - 4.7	4.6	3.7
Total reduced sulfur (TRS)	0.28	0.28	0.27	0.28	0.14
EFFLUENT QUANTITY (gallons per air dried ton of final product)					
Mean effluent flow	22,000	22,000	14,700	20,500	16,500
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	0.2 - 5.1
Total suspended solids (TSS)	0.2 - 9.8	0.2 - 9.8	0.2 - 9.8	0.2 - 9.8	0.4 - 8.2
Chemical oxygen demand (COD)	15.8 - 79.5	15.8 - 79.5	15.8 - 79.5	15.8 - 79.5	9.6 - 56.3
Adsorbable organic halogens (AOX)	1.5 - 1.8	0.6	0.1 - 0.2	1.1 - 1.3	0.6 - 0.7
SOLID WASTE (kilograms per air dried metric ton of final product)					
Total waste generation	200	200	200	200	190

PAPER TASK FORCE WHITE PAPER NO. 10A

ENVIRONMENTAL COMPARISON - MANUFACTURING TECHNOLOGIES FOR VIRGIN AND RECYCLED-CONTENT PRINTING AND WRITING PAPER

DECEMBER 19, 1995

I. INTRODUCTION

This paper summarizes the research and findings of the Paper Task Force on an environmental comparison of virgin and recovered fiber pulp manufacturing processes. This paper is one element of an extensive research process in support of the task force's work to develop recommendations for purchasing "environmentally preferable paper", paper that reduces environmental impacts while meeting business needs.

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.

As one step in the research process, on November 3, 1994 the Task Force assembled a panel of experts to discuss the environmental comparison of virgin and recovered fiber pulp manufacturing processes. In preparation for this panel, the task force prepared an "issue paper" that examined relevant issues and a range of perspectives on the environmental comparison of virgin and recovered fiber manufacturing processes. The panelists addressed topics discussed in this paper during the panel. The issue paper and a draft of this paper were reviewed by several expert reviewers from companies and institutions not represented on the panel. Appendix A contains a list of the panelists and reviewers of the issue paper and draft white paper.

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 performed by the task force. Other White Papers address the economic and functional issues relevant to the manufacture of paper.

A. Paper Grades

The task force examined several types of printing and writing papers. These grades include uncoated free sheet (UCFS), with 0% and 20% deinked recovered fiber for business printing and writing paper, and 100% deinked recovered fiber for books; lightweight coated groundwood paper with 0% and 10% deinked recovered fiber; and uncoated groundwood text paper used in mass-market paperback books with 0% and 15% deinked recovered fiber. (All recovered fiber content is on fiber weight basis.)

Based on the results of its research into the different furnishes that are used in these paper grades, the task force examined: bleached kraft pulping; mechanical pulping processes including stone groundwood, pressurized groundwood and thermomechanical[1]; and deinked recovered fiber pulp.

1. Uncoated Freesheet Paper (UCFS)

Uncoated freesheet paper produced with an alkaline papermaking process is about 78% pulp, 16% filler and 6% moisture.[2] While many virgin and recovered fiber pulps can be used to produce UCFS, bleached kraft pulp is the dominant furnish for this grade. We consider three bleached kraft pulping processes:

- 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. Coated publication papers: Coated Freesheet and Lightweight Coated Groundwood (LWC)

The clay coating of coated publication papers accounts for about 30% of the weight of the paper; the pulp furnish accounts for about 64% and moisture for the remaining 6%. Coated freesheet paper contains a mix of softwood and hardwood bleached kraft pulp, while the furnish of lightweight coated groundwood papers (LWC) contains an equal mix of bleached softwood kraft and mechanical pulps, which varies with basis weight. The softwood kraft pulp provides strength; the mechanical pulps impart opacity at low basis weights. The mechanical component of the furnish may contain stone groundwood pulp (SGW), pressurized groundwood pulp (PGW), thermomechanical pulp (TMP), or a combination.

The groundwood and TMP processes use mechanical energy to separate the wood into fibers. Pressurized groundwood produces a stronger groundwood pulp by grinding the wood in a pressurized chamber. These mechanical pulping processes typically have pulp yields above 88%;[3] thus, most of the lignin remains with the fibers. The yield loss includes small bundles of fibers and water soluble extractives such as resin and fatty acids.

3. Uncoated groundwood book paper

Uncoated groundwood book paper (referred to herein as “text”) does not contain any fillers; thus, it contains 94% pulp and 6% moisture. The furnish is groundwood or pressurized groundwood pulp.

4. Deinked recovered fiber pulp (DIP)

Mills use deinked recovered fiber pulp made from office paper in all of these grades of paper. We will refer to deinked recovered fiber pulp as “DIP” throughout the paper. UCFS comprises the bulk of the paper recovered from offices; as a result, deinked recovered fiber pulps produced from recovered office paper contain a high percentage of bleached hardwood kraft pulp. DIP manufacturing processes use a combination of heat and mechanical and chemical processes to produce pulp from recovered paper. Mechanical energy is applied to separate the fibers from coatings, fillers, additives and external contaminants in the paper. The ink is then separated from the fiber; most of the ink is removed using either flotation or washing. The remaining ink particles are then dispersed mechanically to make them invisible to the human eye.

A few older deinked recovered fiber mills use sodium hypochlorite to brighten deinked pulp made from waste office paper[4], but new mills and many existing mills that produce DIP from office waste are using hydrogen peroxide and other non-chlorine based chemicals to brighten the pulp and remove colors. For example, James River at its plant in Halsey, OR and Union Camp in Franklin, VA operate 300 ton-per-day deinked recovered fiber pulp mills that brighten pulp without the use of chlorine compounds. Ponderosa Fibres plans to install an ozone system at one of its market deinked pulp mills,[5] and Intercontinental Recycling Corporation is building a 300 ton-per-day deinked market pulp mill that will use oxygen bleaching.[6]

B. Major Topics

This paper examines the effect of incorporating deinked recovered fiber pulp (DIP) made from office paper into coated and uncoated printing and writing papers. This paper also illustrates the effect of substituting mechanical pulp for bleached kraft pulp in virgin publication papers in a comparison of the environmental profiles of lightweight coated groundwood and coated freesheet paper. Thus, we consider the effect of four pulp substitutions on the environmental parameters associated with the production of three grades of business and publication papers:

- *Business paper*: DIP replaces hardwood bleached kraft pulp in uncoated freesheet paper

- *Coated publication papers*: DIP replaces an equal mix of softwood kraft and groundwood pulp in lightweight coated groundwood paper; mechanical pulp replaces hardwood bleached kraft pulp in coated freesheet paper.[a]

- *Uncoated publication papers*: DIP replaces groundwood pulp in uncoated book papers

We present the environmental comparison in two parts. First we examine the energy consumption and releases to the environment associated with bleached kraft pulp, mechanical pulp and deinked recovered fiber pulp manufacturing processes. We also consider the contribution from the paper machine associated with the production of the paper grades. Then we examine the impact on the environmental parameters of incorporating deinked recovered fiber into uncoated freesheet, lightweight coated groundwood paper and uncoated groundwood text paper. We also compare the environmental profiles of virgin coated freesheet and lightweight coated groundwood papers.

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 energy- and process-related air emissions, effluent quantity and waterborne wastes, and solid waste generation.

C. *Methodology*

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 mill[7] during the production of virgin UCFS (bleached kraft pulp), virgin uncoated groundwood (mechanical pulp) and UCFS with 100% recovered fiber (DIP). To obtain estimates of environmental releases and energy consumption associated with the production of LWC with 0% and 10% recovered fiber, UCFS with 20% recovered fiber and uncoated groundwood with 15% recovered fiber, we calculate these parameters by using a weighted average of the pulps that comprise the furnish. We present the composition of the paper grades studied in this analysis in **Table 1**.

[a] We have included the substitution of mechanical pulps for hardwood bleached kraft pulp in coated freesheet paper in this paper, because of the relevance of this substitution of different virgin pulps to the environmental comparison of coated publication papers.

Table 1. Printing and writing paper grade formulations (as a percent of total paper weight)

Paper Grade	Fiber			Coatings & Fillers	Moisture
	Bleached kraft	Mechanical [2]	DIP [3]		
Uncoated free sheet [1]					
Virgin - 50% - 70% D	78%		0%	16%	6%
Virgin - 100% D	78%		0%	16%	6%
Virgin - OD + 100% D	78%		0%	16%	6%
20% DIP	62%		16%	16%	6%
text - 100% DIP	0%		78%	16%	6%
Groundwood Papers					
Virgin LWC	32%	32%	0%	30%	6%
LWC - 10% DIP	29%	29%	6%	30%	6%
Uncoated groundwood text	0%	94%	0%	0%	6%
Uncoated gwd with 15% recovered fiber	0%	80%	14%	0%	6%

Note: [1] About 16% of the total weight of alkaline paper is filler. Most paper and paperboard have 6% moisture[8];
[2] Mechanical pulps include stone groundwood (SGW), pressurized groundwood (PGW) and thermomechanical pulps (TMP)
[3]Percentage of recovered fiber is by fiber weight.

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.[9]

The summary tables, **Tables 2-6**, reflect this difference. **Table 2** summarizes the data on the environmental parameters associated with producing bleached kraft, mechanical and deinked recovered fiber pulps, while **Tables 3-6** summarize the data for the different paper grades. The data for energy consumption, air emissions and mean effluent flow are different in **Table 2** as compared with **Tables 3-6**. 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 all 5 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 2** 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 2** include the pulping and chemical recovery stages as well. We present **Tables 2-6** 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 six sections. The first five sections examine the energy consumption and releases to the environment associated with different pulp and paper manufacturing processes. The final section compares the environmental profiles of four grades of paper:

- Business papers: Uncoated free sheet paper with 0%, 20% and 100% deinked recovered fiber pulp (DIP)
- Coated publication papers: Lightweight coated groundwood paper with0% and 10% DIP
- Uncoated publication papers: Uncoated groundwood text paper with 0% and 15% DIP
- Coated publication papers: Virgin coated freesheet and virgin lightweight coated groundwood papers

All recycled-content is by fiber weight. We present the ranges of the parameters for the paper grades in **Tables 3 - 6,** respectively. These tables follow the lists of tables and figures at the beginning of the paper. The section of the paper that contains the supporting research is indicated in bold type at the beginning of each section of the findings.

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. Most of the comparisons begin with mean values for key environmental parameters. We discuss ranges where the information is available and perform statistical analyses to compare the means when enough data are available.

We have also 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 ton of final product produced (lb/ADTFP), and millions of Btu's/oven-dried ton, respectively. We present effluent and sludge data in metric units: kilograms per metric ton of oven-dried pulp (kg/ODMTP) or in kilograms per 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%.

A. Energy Consumption Associated with Pulp and Paper Manufacturing Processes

We examined the total and purchased energy consumed by bleached kraft, mechanical and deinked recovered fiber pulping processes as well as the energy consumed by the paper machines to produce coated and uncoated freesheet, lightweight coated groundwood and uncoated groundwood text papers. We examined a range of energy requirements for bleached kraft and deinked recovered fiber pulping processes. **Table 2** contains the total and purchased energy consumed to produce an oven-dried ton of pulp. **[Section III C - Section III F]**

- **Bleached kraft pulp manufacturing processes consume the largest quantity of total energy as compared to mechanical pulp and DIP processes. The purchased energy requirements of the bleached kraft processes, however, are the lowest of the three pulp manufacturing processes, because these processes generate almost all of their energy requirements from black liquor solids and wood residues.**

- **Bleached kraft pulp manufacturing processes consume more bleaching chemicals than do the mechanical or DIP processes.** The energy consumed to manufacture the bleaching chemicals accounts for about 17-31% of the total energy consumed by the bleached kraft pulping processes. Whereas, the energy consumed to manufacture the bleaching chemicals used in mechanical and DIP processes accounts for about 5% of the total energy consumption.

- **Mechanical pulping processes consume the most purchased energy of the three pulping processes.** These processes, however, convert over 88% of the wood into usable pulp, about twice the amount of pulp that a bleached kraft pulping process produces per ton of wood.

- **Both mechanical pulping and DIP pulping processes depend primarily on purchased electricity in their processes.**

- **Paper machines consume more energy to produce coated papers than they do to produce uncoated papers;and they consume more energy to produce freesheet than groundwood papers..** This difference in energy consumption is primarily relevant for coated freesheet and lightweight coated groundwood papers, because these papers can substitute for each other in magazines and catalogues.

B. Energy-Related Air Emissions Associated with Pulp and Paper Manufacturing Processes

We compared emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), particulates, and carbon dioxide (CO_2) in this section. To develop estimates of the emissions of air pollutants released in generat 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 2**, we present ranges of emissions of SO_2, NOx, particulate and CO_2 emissions from bleached kraft and DIP mills based on our knowledge of the range of energy use of different processes. **[Section IV D, section IV E]**

- **Emissions of sulfur dioxide, nitrogen oxides and particulates depend on the fuel mix used at the mill to produce electricity and steam.** Processes that use more electricity tend to have higher emissions of these pollutants, e.g., the mechanical pulping processes consume less total energy than do bleached kraft pulping processes, but have higher emissions of sulfur dioxide and nitrogen oxides.

- **Total carbon dioxide emissions depend both on the total energy and the fuel mix.** Mechanical and deinked recovered fiber pulping processes generate less total carbon dioxide because they consume less total energy than do bleached kraft pulping processes. These processes also use larger quantities of electricity and natural gas, two fuels with relatively low CO_2 emissions.

- **On average, the fossil fuel-based carbon dioxide emissions for bleached kraft pulp mills are lower than those of mechanical or deinked recovered fiber processes because of the large quantities of wood-waste fuel burned at the kraft mills. The uptake of CO_2 by young, fast-growing trees almost balances the CO_2 emissions associated with the wood-based fuel.**

- **Energy-related air emissions associated with papermaking vary with the energy required to produce each grade, because the electricity and fossil fuels are generally purchased.**

C. Process-Related Air Emissions Associated with Pulp and Paper Manufacturing Processes

Table 2 also contains estimates of the magnitude of three process-related air emissions generated during the production of bleached kraft, mechanical and deinked recovered fiber pulp: hazardous air pollutants (HAPs), volatile organic compounds (VOCs) and total reduced sulfur compounds (TRS). We do not present a range for these emissions because the contribution from combustion sources has little effect on the magnitude of these parameters. **[Section V. C - section V, F]**

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

- **Bleached kraft pulping processes generate the highest releases of process-related air emissions of the three pulping processes.** Pulping, bleaching and chemical recovery systems account for all of the emissions of HAPs and TRS, and about 50% of the emissions of VOCs at bleached kraft mills. Mechanical and deinked recovered fiber pulping processes mostly use mechanical energy; process-related air emissions are lower, as a result.

- **Paper machines release small amounts of HAPs and VOCs as compared to bleached kraft pulping processes.**

D. Effluent Associated with Pulp Manufacturing Processes

Both effluent quantity and quality differ among current bleached kraft, mechanical and deinked recovered fiber pulp processes. We evaluated five parameters of effluent quality:

biochemical oxygen demand (BOD), total suspended solids (TSS), chemical oxygen demand (COD), adsorbable organic halogens (AOX) and dioxins. **Table 2** contains the ranges of these parameters for the pulping processes. We have not included a comparison of dioxin loadings in this analysis. Most DIP manufacturing processes do not use elemental chlorine or chlorine dioxide to brighten the pulp; thus, dioxins are not expected to be generated. See White Paper No. 5, "Environmental Comparison of Bleached Kraft Pulp Manufacturing Technologies," for a detailed discussion of the dioxin loading in the final effluent from bleached kraft mills.

- **The mean effluent flow associated with the DIP pulp manufacturing is ranges from about 20%-60% lower than that associated with bleached kraft pulp manufacture, depending on the bleaching process used to produce the bleached kraft pulp.** The O+100%D process discharges about half the quantity of effluent as the 50%D and 100%D processes. Several DIP mills use no fresh water in their production processes. They use whitewater from paper machines.

- **Statistical analysis shows no difference between the loadings of BOD and TSS in the final effluents of bleached kraft and DIP mills.**

- **The mean COD loading of DIP mills is about 70% lower than that of bleached kraft mills.** Insufficient data precluded statistical analysis.

- **AOX loading in the final effluent associated with bleached kraft pulp production are higher that in the final effluent associated with the production of DIP.**

- **The mean effluent flow of mechanical pulping processes is about the same as that of DIP processes.**

- **Statistical analysis demonstrated that the BOD loading in final effluent associated with the mechanical pulp manufacturing process was statistically lower from the BOD loading in associated with DIP manufacturing process. The TSS loading in the final effluent of the two pulp manufacturing processes was not statistically different.**

- **The mean COD loading in DIP mill final effluent is about 22% lower than the COD loading in mechanical pulp mill effluent.**

- **Neither DIP nor mechanical pulp mills are expected to have loadings of AOX or dioxins in their effluent.** Neither manufacturing process uses chlorine compounds in the bleaching process.

- **The mean effluent associated with from mechanical pulp mills ranges from about 17%-59% lower than that from bleached kraft mills, depending on the bleaching process used at to produce the bleached kraft pulp.** The O+100%D process generates half the effluent flow per oven-dried ton of pulp as do the 50%D and 100% processes. Mechanical pulp mills use no fresh water in their production processes. They use whitewater from paper machines.

- **Statistical analysis shows that the loadings of BOD and TSS in the final effluent associated with mechanical pulp manufacture are statistically lower than the loadings in the final effluent associated with bleached kraft pulp manufacture.**

- **The mean COD loading in the final effluent associated with of mechanical pulp manufacture is about 60% lower than that associated with the production of bleached kraft pulp.** Insufficient data precluded statistical analysis.

- **AOX loadings are higher and dioxin loadings are likely to be higher, on average, in bleached kraft mill effluent than in the final effluent from mechanical pulp mills.** Mechanical pulp mills do not use elemental chlorine or chlorine dioxide to brighten the pulp; thus, dioxins are not expected to be generated.

E. Solid Waste Generation Associated with Pulp and Paper manufacturing Processes

We have developed estimates of the quantity of solid waste and quality of wastewater sludge from bleached kraft, deinked recovered fiber and mechanical pulping processes. **Table 2** contains estimates of total solid waste generation for the pulping processes. The variability of the sludge quality data precluded its quantification. We have not included a comparison of dioxin loadings in this analysis. Most DIP manufacturing processes do not use elemental chlorine or chlorine dioxide to brighten the pulp; thus, dioxins are not expected to be generated. See White Paper No. 5, "Environmental Comparison of Bleached Kraft Pulp Manufacturing Technologies," for a detailed discussion of the dioxin loading in the final effluent from bleached kraft mills.

Sludge quantity [Section VII.C]:

- **Deinked recovered fiber pulp manufacturing processes produce about twice as much wastewater sludge as do mechanical and bleached kraft pulp manufacturing processes**.

- **A statistical analysis indicates that there is no statistical difference in the amount of solid waste generated by bleached kraft processes and mechanical processes.**

- **Producing one ton of deinked recovered fiber pulp removes 0.92 tons and 2.97 cubic yards of material from the solid waste stream.** Producing DIP removes the discarded paper and solid waste associated with the production of a ton of virgin bleached kraft pulp from the waste stream and adds the solid waste associated with the production of the DIP.

Sludge quality - metals content [Section VII.D.1]:

- **The variability in the metals content of the sludge of bleached kraft pulp and DIP mills precludes a comparison of the magnitude of the metals content in the sludge associated with the different pulping processes..**

F. Comparisons of the Paper Grades

In this section we summarize the environmental comparisons of the paper grades. Generally, these comparisons evaluated the effect on the magnitude of energy consumption and releases to the environment associated with incorporating recycled-content into printing and writing grades as well as the effects of incorporating mechanical pulp into virgin coated freesheet publication papers.

Comparison I: Business papers: Uncoated freesheet paper with 0%, 20% and 100% recycled-content.

We examine the effect on the magnitude of the environmental parameters as deinked recovered fiber pulp replaces 20% and all of the bleached kraft pulp in this grade of paper. In this case, we use the weighted average of the three bleached kraft pulp manufacturing processes to assess the contribution of the bleached kraft pulp to the energy consumption and releases to the environment for all three uncoated freesheet papers. **Figures 1a and b** and **Table 3** present the average and the ranges, respectively, for energy consumption and releases to the environment generated during the production of these grades of paper.

- **With the exception of purchased energy, CO_2 from fossil fuels and total solid waste generation, incorporating deinked fiber into uncoated freesheet paper generally reduces the magnitude of the environmental parameters.**

- **On average, the purchased energy associated with the production of UCFS with bleached kraft pulp is 18% lower than UCFS that contains 100% DIP.**

- **Incorporating DIP has no effect on the BOD or TSS loading in the final effluent generated during the production of UCFS, because the parameters for the two pulping processes are not statistically different.**

Comparison II: Publication paper: Lightweight coated groundwood paper with 0% and 10% recycled-content

Figure 2 and **Table 4** present the average and the ranges, respectively, for energy consumption and releases to the environment generated during the production of these grades of paper.

- **The magnitudes of the energy consumption and releases to the environment reflect the fact that incorporating 10% deinked recovered fiber by fiber weight is the same as 6% of the total weight of the sheet.**

- **While incorporating DIP into LWC increases mean effluent flow, mean BOD loading in the final effluent, and total waste generation, the difference in the magnitude of all of these parameters is at most 10%. Given the variability of individual mechanical**

pulp and DIP mills, it is unlikely that the difference in magnitude of these parameters is significant.

- **The remaining environmental parameters decrease with the incorporation of deinked recovered fiber pulp into the paper furnish.**

Comparison III: Uncoated groundwood text paper with 0% and 15% recycled-content

Figure 3 and **Table 4** present the average, respectively, for energy consumption and releases to the environment generated during the production of these grades of paper.

- **With the exception of the BOD loading in the final effluent and total waste generation, where incorporating deinked recovered fiber pulp increases the magnitude of the parameters, the addition of deinked recovered fiber pulp to uncoated groundwood papers generally reduces the magnitude of the energy consumption and releases to the environment by about 5%. Given the variability of individual mechanical pulp and DIP mills, it is unlikely that the difference in magnitude of these parameters is significant.**

Comparison IV: Publication Papers: Coated freesheet and lightweight coated groundwood papers

Coated publication papers generally contain about 30% coating, 64% pulp and 6% moisture. Coated freesheet papers contain a mixture of hardwood and softwood kraft pulps, while coated lightweigh groundwood papers generally contain a 50:50 mix of groundwood and softwood bleached kraft pulp.

Table 5 presents the ranges of the magnitude of energy consumption and releases to the environment for these coated publication papers. We use the weighted average of the three bleached kraft pulping processes to estimate the contribution of the bleached kraft pulp to the magnitude of the environmental parameters for LWC in **Table 5** and for both grades in **Figure 4**. **Figure 4** compares the mean values of these parameters for the "average" coated freesheet and lightweight coated groundwood papers.

- **Substituting mechanical pulp for bleached kraft pulp increases the purchased energy consumption because mechanical pulping processes do not generate much wood-waste.**

- **Substituting mechanical pulps for bleached kraft pulp increases the emissions of sulfur dioxide, nitrogen oxides and carbon dioxide from fossil fuels.** Lightweight coated groundwood paper production processes consume more purchased electricity and less wood-based fuels than do coated freesheet papers.

- **Process-related air emissions and releases to water are lower for LWC than they are for coated freesheet, because the higher-yield groundwood process converts more wood into pulp than does the kraft process.**

III. ENERGY CONSUMPTION ASSOCIATED WITH PULP AND PAPER MANUFACTURING PROCESSES

A. Scope

We examine the total and purchased energy consumed at the mill to produce a ton of bleached kraft pulp, mechanical pulp, and DIP along with the energy consumed by the paper machine to make a ton of fine paper. The *total* energy requirement consists of the electricity and steam required to produce the bleaching chemicals off-site and to operate the equipment at the mill. The *purchased* energy consists of the electricity[10] 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. A 1992 Tellus Institute study found that the energy consumed in the transport of wood or recovered paper to the mill is small compared to the energy required to manufacture a ton of paper.[11] White Paper No. 3 includes this transportation energy consumption in its analysis of virgin and recycled paper systems.

B. 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).[12]

- A 1993 study prepared by Simons Strategic Division for the Electric Power Research Institute (the EPRI study, hereafter).[13] 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.[14]

C. Bleached Kraft Pulp Production

Table 6 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.[15] **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 6. 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.[16]

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.[17] 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 6** 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.[18] 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).[19]

D. Mechanical Pulps

The amount of energy consumed to produce a ton of mechanical pulp depends on the process. We present the energy required to produce one oven-dried ton of stone groundwood (SGW), pressurized groundwood (PGW) thermomechanical pulp (TMP) in **Table 7**. We present the calculation of the energy consumption to produce mechanical pulps in **Table B-4**.

Table 7. Total and purchased energy requirements to produce mechanical pulps

(Millions of Btu's per oven-dried ton of pulp)	**Stone groundwood/ Pressurized groundwood**	**Thermomechanical (TMP)**
Total Energy		
Process energy	22.43	26.11
Bleaching chemical energy[20]	1.04	1.50
Total	**23.47**	**27.61**
Self -generated energy		
Recovered steam	1.90	1.90
Wood waste	1.56	1.61
Total	**3.46**	**3.51**
Purchased energy	**20.01**	**24.09**

1. Stone Groundwood Pulp

Stone groundwood processes use electricity to grind logs against a stone; water cools the stone and flushes the pulp from the grinder. There is no steam requirement.[21] Modern stone groundwood mills have installed steam recovery systems to reduce the energy requirement by about 9%.[22] Because stone groundwood mills use whole logs in the pulping process, we have assumed that these mills meet some of their energy needs by burning the bark and other wood residue in a hog fuel boiler.[23] These mills also recover about 1.9 million Btu's of steam from the pulping process that is used in the paper machine dryers.[24] We have assumed that this mill generates half as much energy from its bark on a per ton basis as a kraft mill and consumes about half the debarking/chipping energy because the groundwood pulp mill uses half the wood to produce a ton of pulp.

2. Pressurized Groundwood Pulp

Pressurized groundwood (PGW) grinds the logs under pressure using compressed air. This process produces stronger pulp than stone groundwood processes using the same amount of energy. In 1984, the reported energy consumption of the pulping process was 14.4 million Btu's per ODTP.[25] PGW mills also consume energy debarking the logs and generate some energy by burning the bark. These mills also recover steam from the pulping process.

3. Thermomechanical Pulp

Thermomechanical pulp mills consume more energy to produce a ton of pulp than do either of the groundwood processes. Electricity to run the refiners accounts for 96% of the total energy.[26] Modern TMP mills employ heat recovery techniques to reduce the energy requirement by about 20%.[27] We have assumed that TMP mills purchase all of the wood chips and take wood-residues from the chip suppliers to burn in a hog-fuel boiler,[28] thus, they also generate some energy by burning wood waste and recovering steam from the pulping process.

E. Deinked Recovered Fiber Pulp (DIP)

Table 8 provides a range of estimates of total and purchased energy consumption for existing DIP mills. Mills built in the 1980s[29] have higher energy consumption than mills built since 1993.[30] The newer DIP mills consume 7.85 million Btu's of energy to produce an oven-dried ton of deinked recovered fiber;[31] 93% of this energy consumed is electricity, the rest is thermal energy. The older DIP mills, consume about 10.7 million Btu of energy to produce an oven-dried ton of deinked recovered fiber with electricity accounting for 91% of the energy requirement and thermal energy accounting for the remainder. Researchers at the Tellus Institute reported total energy consumption of 7.5 million Btu to produce a ton of deinked recovered fiber from both old newspapers and office waste.[32] DIP mills purchase all of their energy. It is interesting to note that the purchased energy consumed to produce a ton of *pulp* at a DIP mill is lower than that of the older bleached kraft pulp mill. We present the calculation of the energy consumption to produce DIP in **Table B-5** of Appendix B.

Table 8. Total and purchased energy consumption for deinked recovered fiber pulp mills

(Millions of Btu's per oven-dried ton of pulp)		
	Deinked recovered fiber	
	High [1]	Low [2]
Total Energy		
Process energy	10.15	7.29
Bleaching chemical energy	0.56	0.56
Total	**10.71**	**7.85**
Self -generated energy		
Recovered steam	0.00	0.00
Wood waste	0.00	0.00
Total	**0.00**	**0.00**
Purchased energy	**10.71**	**7.85**

[1] High energy-use DIP mills were built in the 1980s
[2] Low energy-use DIP mills are being built today

F. Papermaking – Printing and Writing Papers

Table 9 contains estimates of the electricity and steam required to produce the paper grades considered in this white paper.[33]

Table 9. Paper machine energy consumption to produce printing and writing papers

Paper Grade	**Electricity [1]** (kWh/ADTFP)	**Steam** (MM Btu/ADTFP)	**Total Energy** (MM Btu/ADTFP)
Uncoated freesheet	640	6.2	**12.9**
Coated freesheet	740	7.5	**15.3**
Lightweight coated groundwood	640	6.7	**13.5**
Uncoated groundwood text	540	5.4	**11.1**

kWh/ADTFP = kilowatt-hours per air-dried ton of final product
MM Btu/ADTFP = millions of Btu's per air-dried ton of final product
[1] 1 kWh = 10,500 Btu's

The energy consumption data in **Table 9** indicate that the energy consumed to produce coated paper is higher than the energy consumed to produce uncoated paper. Similarly, groundwood papers require less energy on the paper machine than do freesheet papers. Unlike the mechanical and DIP pulping processes which have high electricity requirements, about 50% of the energy consumed by this paper machine is steam; the rest is electricity. 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.

G. Summary of Energy Consumption Associated with Pulp and Paper Manufacturing Processes

- **Bleached kraft pulp manufacturing processes consume the largest quantity of total energy as compared to mechanical pulp and DIP processes. The purchased energy requirements of the bleached kraft processes, however, are the lowest of the three pulp manufacturing processes, because these processes generate almost all of their energy requirements from black liquor solids and wood residues.**

- **Bleached kraft pulp manufacturing processes consume more bleaching chemicals than do the mechanical or DIP processes.** The energy consumed to manufacture the bleaching chemicals accounts for about 17-31% of the total energy consumed by the bleached kraft pulping processes. Whereas, the energy consumed to manufacture the bleaching chemicals used in mechanical and DIP processes accounts for about 5% of the total energy consumption.

- **Mechanical pulping processes consume the most purchased energy of the three pulping processes.** These processes, however, convert over 88% of the wood into usable pulp, about twice the amount of pulp that a bleached kraft pulping process produces per ton of wood.

- **Both mechanical pulping and DIP pulping processes depend primarily on purchased electricity in their processes.**

- **Paper machines consume more energy to produce coated papers than they do to produce uncoated papers;and they consume more energy to produce freesheet than groundwood papers..** This difference in energy consumption is primarily relevant for coated freesheet and lightweight coated groundwood papers, because these papers can substitute for each other in magazines and catalogues.

IV. ENERGY-RELATED AIR EMISSIONS ASSOCIATED WITH PULP AND PAPER MANUFACTURING PROCESSES

A. Scope

In this section, we estimate the emissions of four energy-related air pollutants. As they generate energy, combustion sources 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 and DIP 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.

B. Sources

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

1. 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]

2. Fuels

The analysis of energy consumption provided estimates of the energy produced from self-generated fuels for bleached kraft, mechanical and DIP 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.

C. Descriptions of the Energy-Related Air Pollutants

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

1. 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 levels 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, although acid sensitive areas are confined to only certain areas of the country. Mills control SO_2 releases with chemical scrubbers and by burning fossil fuels with low sulfur content.

2. 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.

3. 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 of the air 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]

4. 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 illustrate one impact 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 biomass fuels is smaller than that for 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.

D. Emissions Associated with Pulp Manufacturing

We present the releases of energy-related air emissions associated with the production of bleached kraft, mechanical and deinked recovered fiber pulps in **Table 10**. Several trends emerge from the comparison of these emissions.

Table 10. Emissions of energy-related air pollutants associated with bleached kraft, mechanical and deinked recovered fiber pulping processes

	Sulfur dioxide (SO_2) (pounds/ODTP)		**Nitrogen oxides (NO_x)** (pounds/ODTP)		**Particulates** (pounds/ODTP)		**Carbon dioxide (CO_2) – Total** (pounds/ODTP)		**Carbon dioxide (CO_2)–Fossil fuel** (pounds/ODTP)	
Pulp	Low [1]	High[2]	Low [1]	High[2]	Low [1]	High[2]	Low [1]	High[2]	Low [1]	High[2]
Bleached kraft - 50%D	9.32	18.96	7.28	10.55	10.39	10.39	10,600	9,600	0	1,700
Bleached kraft - 100%D	12.58	22.23	8.96	12.24	11.54	11.54	11,000	9,800	400	2,100
Bleached kraft - O + 100%D	3.99	13.64	4.79	8.06	9.44	9.45	10,500	9,400	(800)	900
Bleached kraft - average	8.68	18.32	7.01	10.29	10.38	10.38	10,600	9,400	(100)	1,600
Groundwood		25.16		13.71		9.61		3,600		3,000
Thermomechanical		31.01		16.33		11.12		4,300		3,700
Deinked recovered fiber	9.21	13.44	4.76	6.96	3.25	4.77	1,100	1,600	1,100	1,600

pounds/ODTP = pounds per oven-dried ton of pulp
[1] Low energy-use mills are being built in the 1990s
[2] High energy-use mills were built in the 1980s

- *The magnitude of the releases depends on the fuel mix of the mill.* Both the groundwood and TMP processes have lower total energy than do the bleached kraft pulping processes, but their reliance on purchased electricity results in high emissions of sulfur dioxide, nitrogen oxides, particulates and fossil fuel- based carbon dioxide. The emissions associated with purchased electricity are higher than those for wood, coal and oil because the emission factors include the emissions associated with extracting, refining and transporting the fuels to the utility. The fuel mix of the national grid also has a high percentage of coal and oil. Both of these fuels generate relatively high sulfur dioxide and nitrogen oxide emissions upon combustion. Mills and utilities that use a larger percentage of natural gas will have lower emissions.

- *The total carbon dioxide emissions associated with mechanical pulp and deinked recovered fiber 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 mechanical and the deinked recovered fiber pulp manufacturing processes.* 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.

E. Emissions Associated with Papermaking

Table 11 illustrates the range of emissions associated with the papermaking process for coated and uncoated freesheet paper, lightweight coated groundwood paper and uncoated groundwood text paper. Paper machines generate no energy on-site; thus, we assumed that they consume purchased electricity and fossil fuels. The magnitude of the emissions corresponds to the total energy consumed to produce each type of paper, as a result. There also is no difference between the total and fossil fuel-based carbon dioxide emissions.

Table 11. Emissions of energy-related air pollutants associated with papermaking processes

(pounds/ADTFP)	**Sulfur dioxide (SO_2)**	**Nitrogen oxides (NO_x)**	**Particulates**	**Carbon dioxide (CO_2)– Total**
Paper grade				
Uncoated freesheet	16.10	7.39	3.62	2,300
Coated freesheet	19.07	8.72	4.20	2,200
Lightweight coated groundwood	16.81	7.66	3.65	2,400
Uncoated groundwood	13.84	6.34	3.06	2,000

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

F. Summary of Energy-Related Air Emissions Associated with Pulp and Paper Manufacturing

- **Emissions of sulfur dioxide, nitrogen oxides and particulates depend on the fuel mix used at the mill to produce electricity and steam.** Processes that use more electricity tend to have higher emissions of these pollutants, e.g., the mechanical pulping processes consume less total energy than do bleached kraft pulping processes, but have higher emissions of sulfur dioxide and nitrogen oxides.

- **Total carbon dioxide emissions depend both on the total energy and the fuel mix.** Mechanical and deinked recovered fiber pulping processes generate less total carbon dioxide because they consume less total energy than do bleached kraft pulping processes. These processes also use larger quantities of electricity and natural gas, two fuels with relatively low CO_2 emissions.

- On average, the fossil fuel-based carbon dioxide emissions for bleached kraft pulp mills are lower than those of mechanical or deinked recovered fiber processes because of the large quantities of wood-waste fuel burned at the kraft mills. The uptake of CO_2 by young, fast-growing trees almost balances the CO_2 emissions associated with the wood-based fuel.

- **Energy-related air emissions associated with papermaking vary with the energy required to produce each grade, because the electricity and fossil fuels are generally purchased.**

V. PROCESS-RELATED AIR EMISSIONS ASSOCIATED WITH PULP AND PAPER MANUFACTURING PROCESSES

A. 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.

B. 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.[52]

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 in small volumes. One bleached kraft mill produces dissolving kraft pulp, while another produces TMP. One unbleached kraft pulp mill also produces semichemical pulp. [53]. 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**.

C. 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.[54] 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.[55] 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-6** of Appendix C.

1. Bleached Kraft Pulp Mills

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 12.**

The chloroform emissions of the three mills in **Table 12**, 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.[56] 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.[57]

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.[58] 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.

Table 12. 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).

2. Mechanical Pulping Processes

Air emissions of HAPs from non-combustion sources of mechanical pulp mills are an order of magnitude lower than those from a bleached kraft pulp mill. We have assumed that the HAP emissions from a stone groundwood process are similar to those from a TMP process. The emissions differ because the stone groundwood mill burns some bark as fuel. We present the major components of the organic HAP emissions from process sources at the mechanical pulp mills in **Table 13.**

Table 13. HAP emissions from mechanical pulp mill sources

Stone groundwood pulp mill			**Thermomechanical pulp mill**		
HAP	**Quantity** (lb/ODTP)	**Percent of total**	**HAP**	**Quantity** (lb/ODTP)	**Percent of total**
Total	**0.3061**		**Total**	**0.2876**	
Methanol	0.1556	50.8%	Methanol	0.1500	52.2%
Acetaldehyde	0.0017	0.6%	Acetaldehyde	0.0006	0.2%
Formaldehyde	0.1322	43.2%	Formaldehyde	0.1301	45.2%
Chloroform	0.0004	0.1%	Chloroform	0.0003	0.1%
		94.7%			**97.7%**

Air release data from EPA's 1991 Toxics Release Inventory (TRI) database support the finding about the relative magnitude of the releases of bleached kraft pulp mills and mechanical pulp mills. Mechanical pulp mills reported no air releases of toxic substances associated with the pulping process to the air, while the mean air emissions from 13 bleached kraft pulp mills was 0.21 lb/ton. We present a more detailed discussion of the information in the TRI database and its use in the comparison of air emissions from different manufacturing processes in **Appendix D**.

3. Deinked Recovered Fiber Pulping Processes

Very little published information on the emissions of HAPs from non-combustion sources at deinked recovered fiber mills currently exists. One would not expect deinked recovered fiber mills to release significant amounts of organic HAPs because deinked recovered fiber manufacturing resembles a mechanical pulping process in that the process focuses on separating and cleaning the fibers rather than chemically degrading a specific component. Deinked recovered fiber pulp mills that have brightened the pulp with sodium hypochlorite released significant amounts of chloroform. At 0.76 pounds per ton of pulp, the mean air releases of chloroform from these mills are actually significantly higher than the per ton emissions from bleached kraft pulp mills.[59] TRI data from mills that do not use sodium hypochlorite report no emissions of HAPs associated with the deinked recovered fiber manufacturing process. We present a summary of these releases in **Table D-2** in Appendix D.

4. Paper Machines

We present the organic HAP emissions released from process sources at paper machines that produce uncoated and coated paper at a bleached kraft pulp mill in **Table 14**. These emissions are low compared with those from the pulp and bleach plants at bleached kraft pulp mills. HAP emissions may increase at mills that produce recycled-content paper if operators use organic solvents to remove stickies from the paper machine wire.[60]

Table 14. HAP emissions from paper machine sources

Paper machine producing uncoated paper			**Paper machine producing coated paper**		
HAP	**Quantity** lb/ODTP	**Percent of total**	**HAP**	**Quantity** lb/ODTP	**Percent of total**
Total	**0.1513**		**Total**	**0.1743**	
Methanol	0.0410	27.1%	Methanol	0.0484	27.8%
Acetaldehyde	0.0482	31.9%	Acetaldehyde	0.0485	27.8%
Formaldehyde	0.0102	6.8%	Formaldehyde	0.0102	5.9%
Chloroform	0.0180	11.9%	Chloroform	0.0208	11.9%
		77.6%			**73.4%**

D. 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 be 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 VOC emissions from all sources at the mill in **Table C-7** 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]

1. Bleached Kraft Pulp Mills

We present total VOC emissions for bleached kraft pulp mills using three different bleaching sequences and a TMP mill in **Table 15**. As with HAPs the age of the mill has little impact on the magnitude of the VOC releases.

Pulping and chemical recovery sources account for about 60% 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.

Table 15. 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	**6.02 (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).

2. Mechanical Pulp Mills

We present total VOC emissions for a stone groundwood mill and a thermomechanical pulp mill in **Table 16**. We have assumed that the VOC emissions from the non-combustion process sources at the stone groundwood mill are the same as the emissions from the TMP mill.

Table 16. VOC emissions from mechanical pulp mill sources

Stone groundwood/Pressurized groundwood		**Thermomechanical**	
Source	**Quantity** lb C/ODTP	**Source**	**Quantity** lb C/ODTP
Pulping	0.31	Pulping	0.31
Bleaching	0.00	Bleaching	0.00
Chemical Recovery	0.00	Chemical Recovery	0.00
Energy	2.70	Energy	3.10
Total	**3.01**		**3.41**

Total VOC emissions for the mechanical pulp mills are about half the magnitude of the releases from bleached kraft pulp mills, and combustion sources account for over 85% of the emissions.

3. DIP Mills

As with HAP emissions, VOC emissions are expected to be very low because no chemical degradation of lignin occurs during the production of DIP. Potential air emissions from process sources include VOCs resulting from the deinking solvents.[63] Thus, combustion sources account for the 0.90 lb C/ODTP VOC released by modern DIP mills. Energy consumption at older DIP mills accounts for the VOC emissions of 1.32 lb C/ODTP.

4. Paper Machines

We present the VOC emissions from paper machines used to produce uncoated and coated paper in **Table 17**. Energy-related VOC emissions account for over 90% of the VOC emissions from paper machines. VOC emissions may increase at mills that produce recycled-content paper if operators use organic solvents to remove stickies from the paper machine wire.[64]

Table 17. 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**

E. 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.[65]

1. 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.

2. Mechanical Pulp Mills

NCASI found no detectable emissions of TRS at the TMP mill.[66] Mechanical pulping processes do not generate these compounds, because they do not use any sulfur compounds in the production process.

3. DIP Mills

DIP mills do not release TRS compounds because they do not use any sulfur compounds in the pulping process.

4. Paper Machines

NCASI found no detectable emissions of TRS compounds from paper machine sources.[67]

F. Summary of Process-Related Air Emissions from Pulp and Paper Manufacturing Processes

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

- **Bleached kraft pulping processes generate the highest releases of process-related air emissions of the three pulping processes.** Pulping, bleaching and chemical recovery systems account for all of the emissions of HAPs and TRS, and about 50% of the emissions of VOCs at bleached kraft mills. Mechanical and deinked recovered fiber pulping processes mostly use mechanical energy; process-related air emissions are lower, as a result.

- **Paper machines release small amounts of HAPs and VOCs as compared to bleached kraft pulping processes.**

VI. EFFLUENT ASSOCIATED WITH PULP AND PAPER MANUFACTURING PROCESSES

A. Scope

We examine the quantity and quality of the effluent for UCFS, LWC and uncoated groundwood papers in this section. We compare effluent flow along with five parameters that describe effluent quality: biochemical oxygen demand (BOD), total suspended solids (TSS), chemical oxygen demand (COD), adsorbable organic halogens (AOX). We examine the variability of the data for each parameter in the comparisons as well.

We have not included a comparison of dioxin loadings in this analysis. Most DIP manufacturing processes do not use elemental chlorine or chlorine dioxide to brighten the pulp; thus, dioxins are not expected to be generated. See White Paper No. 5, “Environmental Comparison of Bleached Kraft Pulp Manufacturing Technologies,” for a detailed discussion of the dioxin loading in the final effluent from bleached kraft mills.

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 an uncoated groundwood text paper with 15% recycled-content, for example, we have estimated the effluent quality parameters based on an 85% contribution from the groundwood and 15% contribution from the DIP.

B. 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.[68] 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, 9 mechanical pulp mills and 14 DIP mills. EPA also provides COD loadings in final effluent for 13 bleached kraft pulp 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, 11 mechanical pulp mills and 8 deinked recovered fiber 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.[69]

C. Effluent Flow

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, starch solutions are 90% water and purchased wetlap deinked market pulp contains 50% to 55% water by weight. 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;[70] 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.[71]

We present estimates of effluent flow for bleached kraft pulp mills, mechanical pulp mills, deinked recovered fiber pulp mills that produce paper and paperboard in **Table 18**.

Table 18: Estimates of effluent flow

Gallons per ton of final product Process	Mean	Range low	 high	# of mills	Reference
Bleached kraft	24,800			40	NCASI 1989[69]
Bleached kraft	22,000				EPA 1993[68]
Bleached kraft	17,000	15,500	35,500		Garner[71]
Bleached kraft		12,000			Raymond[70]
Mechanical	14,800			11	NCASI 1989[69]
Mechanical	14,200				EPA 1993[68]
Deinked recovered fiber	16,400			8	NCASI 1989[69]
Deinked recovered fiber	19,300				EPA 1993[68]

EPA has estimated the contribution to the effluent flow from the components of the manufacturing processes for bleached kraft, mechanical and DIP mills.[72] 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.[73] We present these estimates of effluent flow for the pulping and papermaking processes in **Table 19**.

Table 19. Contribution of mill processes to the total effluent flow

Process	Mean	Range low	 High	Reference
Paper machine (gallons per ton of *final product*)				EPA 1993[68]
Bleached kraft	7,400			
Mechanical	9,500			
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[73]
Average [2]	16,800			
Mechanical [3]	4,900	0		Walkush[79]
Deinked recovered fiber [3]		0	7500	Breed[74]; Pekovitch[75]; McBride[76]

[1] We have divided the effluent from the mill into paper making 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.
[3] The water consumption of the mechanical and deinked recovered fiber pulping process is low enough that the mill can use waste water from the paper machine, and thus avoid consuming any fresh water.

1. Bleached Kraft Pulping 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.[77] 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.[78] 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.

2. Mechanical Pulping Processes

With the exception of mills that produce high quality grades of bleached CTMP market pulp, virgin mechanical pulp mills are integrated with paper machines. These mills use the white water from the paper machine as process water, and do not increase the total water consumption of the mill.[79]

3. Deinked Recovered Fiber Pulping Processes

DIP mills that are integrated with paper machines can follow the same strategy employed by mechanical pulp mills. SRFI obtains all of its process water to produce deinked market pulp from white water from a nearby paper machine.[80] Union Camp designed its deinking process at its Franklin, VA mill to operate without steam and to use white water from its paper machines as process water.[81] Non-integrated mills that produce deinked market pulp from office waste may use 3,000 to 7,500 gallons of fresh water.[82] Thus the deinked recovered fiber pulping process can contribute from 0 to 7500 gallons to the effluent on a per ton basis.

D. Effluent Quality

1. Biochemical Oxygen Demand (BOD)

BOD is a measure of the tendency of an effluent to consume dissolved oxygen from receiving waters. 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.[83] Mills employ secondary 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.”[84] These limits keep BOD discharges below the assimilative capacity to protect aquatic communities.

In **Table 20**, we present a summary of the available data on BOD loadings in the final effluent of bleached kraft pulp mills, mechanical pulp mills and deinked recovered fiber pulp mills.

Table 20. BOD data for bleached kraft, mechanical and deinked recovered fiber pulp 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[85]
Mechanical	1.6			11	NCASI 1989[69]
Mechanical	1.27	0.16	3.60	9	EPA 1993[85]
Deinked recovered fiber	4.0			8	NCASI 1989[69]
Deinked recovered fiber	3.03	0.89	7.63	14	EPA 1993[85]

A statistical analysis of the EPA data on BOD loading in the final effluent for 33 bleached kraft pulp mills, 14 DIP mills and 9 mechanical pulp mills,[86] indicates that the mean BOD loading of mechanical pulp mill final effluent is significantly lower than that of bleached kraft mill final effluent and that of DIP mill final effluent. We present the data from the individual mills in **Table E-1** and the statistical analyses in **Table E-7** in Appendix E.

2. 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. Fiber mats on the bottom of the rivers or lakes can decompose to reduce the dissolved oxygen levels in the water column.[87] Mills use primary treatment to remove all solids that might settle from the effluent. Treated mill effluent contains minimal amounts of settleable solids.[88]

We present a summary of the data on mean TSS loading in the final effluent of bleached kraft pulp, mechanical pulp and DIP mills in **Table 21.**

A statistical analysis of the EPA data for 33 kraft mills, 14 deinked recovered fiber mills and 9 mechanical pulp mills showed that the mean TSS loadings in the final effluent of mechanical pulp is statistically lower than that for bleached kraft pulp mills. The analysis also showed that neither the mean TSS loadings of bleached kraft pulp mills and DIP mills, nor the TSS loadings of mechanical pulp mills and DIP mills are significantly different. We present the data from the individual mills in **Table E-1** and the statistical analyses in **Table E-7** in Appendix E.

Table 21. TSS loading in the final effluent of bleached kraft pulp, mechanical pulp and deinked recovered fiber pulp mills

kg/ADMTFP Process	Mean	Range low	high	# of mills	Reference
Bleached kraft	7.5			41	NCASI 1989[69]
Bleached kraft	4.92	0.24	9.79	33	EPA 1993[85]
Mechanical	3.2			11	NCASI 1989[69]
Mechanical	2.42	0.46	6.69	9	EPA 1993[85]
Deinked recovered fiber	3.7			8	NCASI 1989[69]
Deinked recovered fiber	3.45	0.42	10.70	14	EPA 1993[85]

3. 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.[89] 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.[90] 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.[91]

Fewer data exist on COD loadings in the final effluent of pulp and paper mills. While the EPA presents data for bleached kraft pulp mills from the 1990 industry questionnaire[92] and from short-term mill effluent studies[93] in the Development Document for Effluent Limitations Guidelines, neither EPA nor NCASI have published data on COD loadings in the final effluent of deinked recovered fiber mills or mechanical pulp mills. McCubbin and Folke estimated the range of COD loadings for effluent that has undergone secondary treatment.[94] We present the estimates of COD loading in effluent that has undergone secondary treatment for bleached kraft pulp mills, mechanical pulp mills and DIP mills in **Table 22**.

While the mean COD loadings in the final effluent of the mechanical pulp and DIP mills is lower than that of bleached kraft pulp mills, the ranges of the COD loadings of all three processes overlap.

Table 22. Estimates of COD loading in the final effluent of bleached kraft pulp mills, mechanical pulp mills and deinked recovered fiber pulp mills

kg/ODTMP Process	Mean [1]	Range low	Range high	# of mills	Reference
Bleached kraft	44.5	15.8	79.5	13	EPA 1993[92]
Bleached kraft		12.1	84.7	12	EPA 1993[83]
Mechanical	18.2	4	33		McCubbin[94]
DIP	13.8	11	17		McCubbin[94]

[1] We used the mid-point of the range for mechanical pulp and DIP mills.

4. Composition Of BOD And COD

The composition of the organic substances measured by COD differs for the three pulping processes.

a) Bleached Kraft Pulp Mills

Most of the organic material in the effluent of bleached kraft pulp mills is soluble degraded lignin by-products. Most of the extractives and hemicelluloses are removed during the pulping process and are burned in the recovery furnace.

b) Mechanical Pulp Mills

Untreated effluent from mechanical pulp manufacturing processes contains extractives, terpenes and resin and fatty acids. Effluent from mechanical pulp mills in Ontario without biological treatment contains as much as 550 grams of resin acids per oven-dried metric ton of pulp produced. Scientists have found that this effluent can be acutely toxic to fish at more than 90% dilution. Secondary treatment reduces the concentrations of resin acids in the final effluent to about 1 gram per oven-dried metric ton of pulp and removes the source of acute toxicity.[95]

c) DIP Mills

Because no additional delignification occurs during the production of deinked pulps, there are no dissolved lignin by-products present in the effluent. Starch sizing, coatings and other additives are the major contributors to BOD and COD from a deinked recovered fiber pulp mill.

d) Alkylphenol-Based Surfactants

Components of particular interest are the degradation products of alkylphenol-based surfactants. Cleaning solutions for equipment at all pulp and paper mills may contain these surfactants. DIP mills, however, may use larger quantities of these surfactants because they are often used in deinking flotation cells. Recent research suggests that nonylphenol, a degradation product of the alkylphenol-based surfactants, is an environmental estrogen. A British researcher found that nonylphenol from municipal sewage caused male fish to exhibit female sexual behavior[96]. Van der Kraak also found that nonylphenol competes for estrogenic receptors from female rainbow trout.[97]

5. Adsorbable Organic Halogens: AOX

AOX is a summary parameter that measures the approximate amount of chlorine present in organic material 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."[98]

a) 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 23**. 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.

b) Mechanical pulp and DIP mills

Releases of AOX are not expected to be associated with virgin mechanical pulp or DIP 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. In the past, deinked office waste has been brightened with chlorine compounds, but the newer deinking processes are using hydrogen peroxide and other non-chlorine bleaching agents to brighten the pulp and remove color. We have not found any published reports of AOX levels in the biologically treated effluent from deinked recovered fiber mills that brighten the pulp with either chlorine and/or sodium hypochlorite.

Table 23. AOX loading in the final effluent of bleached softwood kraft pulp mills

kg/ODMTP Process	Mean [1]	Range low	Range high	# of mills	Reference
50% D	1.8			1	Morgan[99]
50 % D	1.5			1	Stinchfield[100]
50% D	1.6			1	Phillips[101]]
100% D [1]	0.59			4	NCASI[102]
O + 100% D [2]	0.18	0.14	0.22	5	NCASI[102]
O + 100% D	0.15				EPA 1993[103]

[1] The mills with 100%D bleaching sequences generally produced a mix of softwood and hardwood pulps.
[2] Four of the five mills with oxygen delignification systems produced bleached softwood pulp; the other produced a mix of softwood and hardwood pulps.

E. Summary of Effluent Associated with Pulp and Paper Manufacturing Processes

- **The mean effluent flow associated with the DIP pulp manufacturing is ranges from about 20%-60% lower than that associated with bleached kraft pulp manufacture, depending on the bleaching process used to produce the bleached kraft pulp.** The O+100%D process discharges about half the quantity of effluent as the 50%D and 100%D processes. Several DIP mills use no fresh water in their production processes. They use whitewater from paper machines.

- **Statistical analysis shows no difference between the loadings of BOD and TSS in the final effluents of bleached kraft and DIP mills.**

- **The mean COD loading of DIP mills is about 70% lower than that of bleached kraft mills.** Insufficient data precluded statistical analysis.

- **AOX loadings are higher and dioxin loadings in the final effluent associated with bleached kraft pulp production are likely to be higher, on average, that in the final effluent associated with the production of DIP.** Most DIP manufacturing processes do not use elemental chlorine or chlorine dioxide to brighten the pulp; thus, dioxins are not expected to be generated. Dioxins (TCDF) have been detected at a detection limit of 10 ppq in the untreated bleach plant effluent of some bleached kraft pulp mills, including some that use 100% chlorine dioxide substitution; thus, dioxins might be present in any untreated bleach plant effluent at a mill that uses elemental chlorine or chlorine dioxide in the bleaching process. Dioxins have not been detected at a detection limit of 10 ppq in the final effluent of bleached kraft pulp mills that use 100% chlorine dioxide.

- **The mean effluent flow of mechanical pulping processes is about the same as that of DIP processes.**

- **Statistical analysis demonstrated that the BOD loading in final effluent associated with the mechanical pulp manufacturing process was statistically lower from the BOD loading in associated with DIP manufacturing process. The TSS loading in the final effluent of the two pulp manufacturing processes was not statistically different.**

- **The mean COD loading in DIP mill final effluent is about 22% lower than the COD loading in mechanical pulp mill effluent.**

- **Neither DIP nor mechanical pulp mills are expected to have loadings of AOX in their effluent.** Neither manufacturing process uses chlorine compounds in the bleaching process.

- **The mean effluent associated with from mechanical pulp mills ranges from about 17%-59% lower than that from bleached kraft mills, depending on the bleaching process used at to produce the bleached kraft pulp.** The O+100%D process generates half the effluent flow per oven-dried ton of pulp as do the 50%D and 100% processes. Mechanical pulp mills use no fresh water in their production processes. They use whitewater from paper machines.

- **Statistical analysis shows that the loadings of BOD and TSS in the final effluent associated with mechanical pulp manufacture are statistically lower than the loadings in the final effluent associated with bleached kraft pulp manufacture.**

- **The mean COD loading in the final effluent associated with of mechanical pulp manufacture is about 60% lower than that associated with the production of bleached kraft pulp.** Insufficient data precluded statistical analysis.

VII. SOLID WASTE GENERATION ASSOCIATED WITH PULP AND PAPER MANUFACTURING PROCESSES

A. Scope

In this section we examine the quantity of the solid waste generated at bleached kraft pulp, mechanical pulp and DIP mills. We also examine the effect of using deinked recovered fiber on the solid waste stream associated with the manufacture and use of paper. The discussion of the quality of solid waste focuses on sludge quality because of the interest in using sludge as a land amendment.

We have not included a comparison of dioxin loadings in this analysis. Most DIP manufacturing processes do not use elemental chlorine or chlorine dioxide to brighten the pulp; thus, dioxins are not expected to be generated. See White Paper No. 5, "Environmental

Comparison of Bleached Kraft Pulp Manufacturing Technologies, for a detailed discussion of the dioxin loading in wastewater sludge from bleached kraft mills.

B. Sources

The 1989 NCASI mill survey provides estimates of the mean quantity of sludge generated per ton of final product for bleached kraft pulp, mechanical pulp and DIP mills, [104] while a more recent NCASI study provides additional information on total quantity of solid waste generated by different types of mills.[105] Data sources for wastewater sludge quality include EPA's short and long-term mill sampling of wastewater sludges at 14 mills[106] and NCASI's characterization of the wastes from mills using recovered fiber.[107]

C. 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.[108] Currently, primary and secondary sludge from wastewater treatment systems account for the largest portion of the solid waste stream.[109] 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,[110] and a growing number of mills are exploring beneficial uses for sludge including land-spreading, and landfill capping material.

All mills that treat their effluent 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.[111] Mills usually generate larger quantities of primary sludge.[112]

1. Bleached Kraft Pulp Mills

.We present data on solid waste generation for bleached kraft pulp mills in **Table 24**, and more detail on the calculation of total sludge quantity in **Table E-3** of Appendix E.

Table 24. 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.

2. Mechanical Pulp Mills

We present data on total solid waste generated by mechanical pulp mills in **Table 25** and more detail on the calculation of the total sludge quantity in **Table E-3**.

Table 25. 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**		
Misc. Solid Waste [2]	**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. We then calculated a weighted average.

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

A statistical analysis of the quantities of primary sludge generated by 43 bleached kraft pulp mills and the 13 mechanical pulp mills in the NCASI survey shows no significant difference in the quantity of primary sludge generated by the two types of mills. A statistical analysis of total solid waste yielded a similar result for 51 bleached kraft pulp mills and 13 mechanical pulp mills in the NCASI study. We present the results of this analysis in **Table E-3** of Appendix E.

3. Deinked Recovered Fiber Pulp Mills

We present data on total solid waste generated by DIP mills in **Table 26** and more detail on the calculation of the total sludge quantity in **Table E-3**.

Table 26. Solid waste from DIP mills (kg/ADMTFP)

Solid Waste	**Mean**	**Std. Dev.**	**No. of Mills**
Sludge			
Primary	269.5	143	9
Secondary	25.0	11	8
Dredged	0.5	0.02	1
Total [1]	**292**		
Misc. Solid Waste [2]	**87.0**	**88.7**	**9**
Total Solid Waste [3]	**376**	**207**	**9**

[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.

[3] Mean total solid waste is the total of mean sludge and misc. solid waste generated at DIP mills; the standard deviation is from the NCASI study.

Sludge levels depend both on the type of recovered paper furnish used and the final products produced. Using coated paper as a furnish for deinked pulp will generate higher sludge levels, because the coating and fillers, the non-recyclable component of the paper, account for 20% - 30% of the total weight of coated paper while uncoated free sheet produced with an acid process contains about 8% filler.[113] Recovered fiber yields for business papers are higher than those for tissue, because mills do not need to remove all of the filler during the production of recovered fiber pulps for fine paper.

DIP mills produce more sludge per ton of pulp than do either of the virgin pulping processes. The yield of deinking processes that use deinked office waste is about 75%. Thus, a DIP mill uses 1.33 metric tons of discarded office paper to produce 1 metric ton of deinked pulp, and generate 0.33 metric tons dry weight of primary sludge. With an additional 15 to 25 kg dry weight of secondary sludge,[114] a DIP mill with a 75% yield can produce as much as 355 kg dry weight of wastewater sludge per metric ton of pulp produced. These values are consistent with NCASI estimates. Based on a survey of six fine paper mills, NCASI reported a mean sludge discharge for deinked fine paper mills was 300 kg dry weight/metric ton; in both cases, 90% was primary sludge.[115]

NCASI's 1989 survey of 9 DIP mills found a mean total solid waste generation rate of 440 kg/ADMTFP.[116] NCASI developed this estimate of total solid waste based on the mills' estimates of their total waste. The estimate of the quantity of total solid waste presented in Table 20 is consistent with an estimate of 360 kg/ADMTFP that NCASI derived from actual mill data in a study that focused on the emissions and wastes associated with the use of recovered fiber.[117]

4. DIP and Solid Waste Generation Associated with the Manufacture, Use and Disposal of Paper

DIP mills generate 3.7 times as much sludge (kg dry weight/ADMTFP) as do bleached kraft pulp mills, and about twice as much total solid waste. A statistical comparison of the primary sludge and total solid waste generated by DIP mills, bleached kraft and mechanical pulp mills showed that DIP mills generate higher quantities of both primary sludge and total solid waste than do either bleached kraft pulp or mechanical pulp mills. We present the statistical analysis in **Table E-8**. According to EPA, sludge handling and disposal operations may account for more than half of the costs of operating an effluent treatment system.[118] Thus, disposing of the large quantities of sludge generated during the production of deinked recovered fiber pulps adds to the operating costs of the mills that produce this pulp.

When we examine the generation of solid waste in terms of the manufacture, use and disposal of paper, a different picture emerges. Producing a ton of DIP removes discarded paper as well as the sludge and other solid waste generated during the production of the virgin pulp that the DIP replaces. Producing one ton of DIP from recovered office paper generates sludge and other solid waste. Based on calculations presented in **Table 27**, producing one ton of DIP removes 1.15 tons of material from the solid waste stream, assuming that DIP would be replaced by virgin bleached kraft pulp if the DIP were not available.

Landfills fill up by volume of the disposed material rather than by mass; thus, comparisons of tonnage underestimate the impact of paper recycling on landfills. The volume of material removed from the waste stream is larger, because the density of the wastewater sludge is 2 to 2.5 times that of discarded paper.[119] Producing one ton of DIP removes 3.16 cubic yards of material from the solid waste stream. By recycling paper, however, the burden of disposing of some paper waste shifts from municipal solid waste management to the paper industry. White Paper No. 3 describes the system-wide impacts of recycling for solid waste and other environmental parameters.

D. Solid Waste Quality (Composition)

In this section, we will focus on the quality of wastewater sludge because of its potential use as a soil amendment. The composition of sludges differs for the three pulp manufacturing processes. Hydrophobic substances (substances that do not dissolve in water) present in wastewater tend to bind to the suspended organic solids in the effluent which become associated with the sludge during treatment. The loadings of metals and dioxin in the sludge are two important measures of sludge quality.

Table 27. DIP and the solid waste associated with the manufacture, use and disposal of paper

Density - waste paper [1]	0.4	ton/cu.yd		
Density - sludge [2]	0.9	ton/cu.yd		
Density-other waste	0.4	ton/cu.yd		
			Mass	**Volume**
Materials removed from the waste stream			tons	cu. yd
discarded paper [3]			1.33	3.33
solid waste associated with the production of 1 ton of virgin pulp				
sludge [4]			0.08	0.09
other solid waste [4]			0.11	0.28
TOTAL REMOVED			**1.52**	**3.70**
Material added to the waste stream				
Deinking sludge			0.29	0.32
Other solid waste [7]			0.09	0.22
TOTAL ADDED			**0.38**	**0.54**
NET MATERIAL REMOVED FROM THE WASTE STREAM			**1.15**	**3.16**

Notes:
[1] We have assumed that the water content of the disposed sludge is 50%.
[2] Franklin Associates, "Characterization of Municipal Solid Waste in the United States: 1994 Update", (Washington: U.S. EPA Report No. EPA-530-2-94-042), p. 135.
[3] Jack Firkins, Boise Cascade, Paper Task Force panel discussion, November 3, 1994.
[4] The mass of discarded paper includes the deinked pulp, the sludge (dry weight) and other solid waste from the deinking process.
[5] NCASI, "Progress in Reducing Water use and Wastewater loads in the U.S. Paper Industry," Technical Bulletin No. 603, February 1991, p. A8.
[6] Allan M. Springer, Industrial Environmental Control: Pulp and Paper Industry, 2nd. Ed. (Atlanta: TAPPI Press, 1993), p. 459.
[7] 'NCASI, "Characterization of Emissions and Wastes from Mills that Use Recycled Fiber," Technical Bulletin No. 613, September 1991, p. 35.

1. Metals

Loadings of heavy metals may prevent mills from using sludge as a soil amendment.

a) Bleached Kraft Pulp And DIP Mills

We present a comparison of the metals content in sludge from bleached kraft mills and DIP mills in 1989 and 1994 and, for reference, municipal sewage sludge in **Table 28**. DIP mill sludges contain small fibers, inorganic fillers, ink and surfactants from the flotation process. The inorganic portion varies with the amount of fillers and coating in the waste paper. SRFI's sludge from a deinked office waste pulp mill, for example, contains almost 60% inorganic filler.[120] A high inorganic filler content makes the sludge difficult to dewater and a poor fuel.[121] In 1989, the inks in the DIP mill sludge contributed to significantly higher maximum metal concentrations for cadmium, chromium, cobalt, copper, and lead compared with bleached kraft pulp mill sludge. Many deinked pulp mills had high zinc levels because they used zinc hydrosulfite as a brightening agent. The 1994 data show that with the exception of calcium,(a result of the industry's shift to alkaline papermaking) concentrations of most metals in deinked recovered fiber sludge for a deinking mill have moved closer to the previously reported minimums. With the removal of heavy metals from most inks, deinked recovered fiber sludges have few sources of toxicity. Metals content in both DIP and bleached kraft pulp mill sludges are generally lower than that in municipal sewage sludges.[122]

Table 28. Metal loadings in DIP and bleached kraft mill wastewater sludges

Metal (1)	**Deinking 1989 (2) [1]**		**Deinking 1994 (3) [2]**	**Bleached kraft 1992-93 (4) [3]**	
	Min	Max	(ppm dry weight) (5)	Min	Max
Aluminum	119.0	37,800.0	3,309.0	3.6	5,850.0
Arsenic	ND(0.1)	0.0	4.2	ND(0)	ND(3.00)
Barium	ND	88.0	ND(48)	0.5	262.0
Boron	11.0	28.0	3.5	ND(5.00)	0.0
Cadmium	**ND**	**7.7**	**ND(0.8)**	**ND(3.00)**	**0.0**
Calcium	2,700.0	40,600.0	100,000.0	263.0	95,200.0
Chromium	**ND(0.005)**	**300.0**	**7.7**	**0.1**	**14.0**
Cobalt	ND(5)	21.7		ND(12)	0.0
Copper	**7.5**	**920.0**	**26.0**	**0.1**	**36.0**
Iron	37.3	1,940.0	958.0	2.6	7,640.0
Lead	**ND**	**880.0**	**18.0**	**ND(0.01)**	**ND(25)**
Manganese	**ND(0.005)**	**63.0**	**20.0**	**1.1**	**1,020.0**
Mercury	0.0	2.4	0.1	ND(0.0)	ND(0.5)
Nickel	**ND(0.1)**	**85.0**	**8.5**	**ND(11)**	**0.1**
Phosphorus	0.4	739.0		ND	1.1
Potassium	202.0	1,085.0		ND	ND
Selenium	ND(0.8)	5.3		ND(0.0)	ND(1.50)
Silver	ND(0.005)	3.7		ND(3.0	0.0
Sodium	332.0	11,828.0	497.0	4.3	4,250.0
Sulfate	97.2	17,200.0	420.0		
Sulfur	848.0	8,914.0		14.8	2,500.0
Zinc	**0.2**	**1,400.0**	**170.0**	**0.2**	**184.0**

Notes:
(1) To facilitate comparisons, metals that are present in all three types of sludge are printed in boldface type
(2) Includes data from 8 deink fine, 5 deink tissue and 2 deink newsprint manufacturers.
(3) May 1994 data from Superior Recycled Fiber Corp. for high quality deinked office waste market pulp
(4) Primary, biological and combined sludges from 14 bleached kraft pulp mills
(5) Non-detectable loadings of a given metal are presented as ND(detection limit).

Sources:
[1] NCASI, "Progress in Reducing Water use and Wastewater loads in the U.S. Paper Industry," *Technical Bulletin No. 613*, February 1991, p. A8.
[2] Tony Pekovitch, Superior Recycled Fiber Corp., personal communication, September 26, 1994.
[3] 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.

E. Summary

Sludge quantity [Section VII.C]:

- **Deinked recovered fiber pulp manufacturing processes produce about twice as much wastewater sludge as do mechanical and bleached kraft pulp manufacturing processes**.
- **A statistical analysis indicates that there is no statistical difference in the amount of solid waste generated by bleached kraft processes and mechanical processes.**
- **Producing one ton of deinked recovered fiber pulp removes 0.92 tons and 2.97 cubic yards of material from the solid waste stream.** Producing DIP removes the discarded paper and solid waste associated with the production of a ton of virgin bleached kraft pulp from the waste stream and adds the solid waste associated with the production of the DIP.

Sludge quality - metals content [Section VII.D.1]:

- **The variability in the metals content of the sludge of bleached kraft pulp and DIP mills precludes a comparison of the magnitude of the metals content in the sludge associated with the different pulping processes..**

VIII. ENVIRONMENTAL COMPARISONS OF PRINTING AND WRITING PAPERS

A. Comparison I: Uncoated Freesheet Paper With 0%, 20% And 100% Recycled-Content.

Uncoated freesheet paper produced with an alkaline papermaking process contains 16% precipitated calcium carbonate filler, 78% pulp and 6% moisture. We examine the effect on the magnitude of the environmental parameters as deinked recovered fiber pulp replaces first 20% and second all of the bleached kraft pulp in this grade of paper. We calculate the magnitude of the the midpoint of the ranges for the “average” uncoated freesheet. **Figures 1a-b** and **Table 3** present the average and the ranges, respectively, for energy consumption and releases to the environment generated during the production of these grades of paper.

- **With the exception of purchased energy, CO_2 from fossil fuels and total solid waste generation, incorporating deinked fiber into uncoated freesheet paper generally reduces the magnitude of the environmental parameters.**

- **On average, the purchased energy associated with the production of UCFS with bleached kraft pulp is 18% lower than UCFS that contains 100% DIP.**

- **Incorporating DIP has no effect on the BOD or TSS loading in the final effluent generated during the production of UCFS, because the parameters for the two pulping processes are not statistically different.**

B. Comparison II: Lightweight Coated Groundwood Paper With 0% And 10% Recycled-Content

Lightweight coated groundwood paper contains 30% coating by weight, about an equal mix of softwood bleached kraft and groundwood pulps, and about 6% water. The deinked recovered fiber replaces an equal quantity of kraft and groundwood pulp. **Figure 2** and **Table 4** present the average and the ranges, respectively, for energy consumption and releases to the environment generated during the production of these grades of paper.

- **The magnitudes of the energy consumption and releases to the environment reflect the fact that incorporating 10% deinked recovered fiber by fiber weight is the same as 6% of the total weight of the sheet.**

- **While incorporating DIP into LWC increases mean effluent flow, mean BOD loading in the final effluent, and total waste generation, the difference in the magnitude of all of these parameters is at most 10%. Given the variability of individual mechanical pulp and DIP mills, it is unlikely that the difference in magnitude of these parameters is significant.**

- **The remaining environmental parameters decrease with the incorporation of deinked recovered fiber pulp into the paper furnish.**

C. Comparison III: Uncoated Groundwood Text Paper With 0% And 15% Recycled-Content

Uncoated groundwood text paper contains no fillers, 94% groundwood pulp, and about 6% moisture. In this case, we assess the impact on the energy consumption and releases to the environment associated with incorporating 15% deinked recovered fiber pulp into the furnish. **Figure 3** and **Table 4** present the average and the ranges, respectively, for energy consumption and releases to the environment generated during the production of these grades of paper.

With the exception of the BOD loading in the final effluent and total waste generation, where incorporating deinked recovered fiber pulp increases the magnitude of the parameters, the addition of deinked recovered fiber pulp to uncoated groundwood papers generally reduces the magnitude of the energy consumption and releases to the environment by about 5%. Given the variability of individual mechanical pulp and DIP mills, it is unlikely that the difference in magnitude of these parameters is significant.

D. Comparison IV: Coated Freesheet And Lightweight Coated Groundwood Publication Papers

Coated printing and writing papers generally contain about 30% coating by weight. Coated freesheet (CFS) paper contains approximately 64% bleached kraft hardwood and softwood pulps; lightweight coated groundwood (LWC) papers usually contain a 50:50 mix of bleached softwood kraft pulp and groundwood pulp. **Figure 4** and **Table 5** present the average and the ranges, respectively, for energy consumption and releases to the environment generated during the production of these grades of paper.

Comparison IV: Publication Papers: Coated freesheet and lightweight coated groundwood papers

Coated publication papers generally contain about 30% coating, 64% pulp and 6% moisture. Coated freesheet papers contain a mixture of hardwood and softwood kraft pulps, while coated lightweigh groundwood papers generally contain a 50:50 mix of groundwood and softwood bleached kraft pulp.

Table 5 presents the ranges of the magnitude of energy consumption and releases to the environment for these coated publication papers. We use the weighted average of the three bleached kraft pulping processes to estimate the contribution of the bleached kraft pulp to the magnitude of the environmental parameters for LWC in **Table 5** and for both grades in **Figure 4**. **Figure 4** compares the mean values of these parameters for the "average" coated freesheet and lightweight coated groundwood papers.

- **Substituting mechanical pulp for bleached kraft pulp increases the purchased energy consumption because mechanical pulping processes do not generate much wood-waste.**

- **Substituting mechanical pulps for bleached kraft pulp increases the emissions of sulfur dioxide, nitrogen oxides and carbon dioxide from fossil fuels.** Lightweight coated groundwood paper production processes consume more purchased electricity and less wood-based fuels than do coated freesheet papers.

- **Process-related air emissions and releases to water are lower for LWC than they are for coated freesheet, because the higher-yield groundwood process converts more wood into pulp than does the kraft process.**

IX. ENDNOTES

[1] Thermomechanical pulp (TMP) is used mainly in newsprint in the United States. Some manufacturers of lightweight coated papers use TMP in place of groundwood pulp. We present a comparison of environmental parameters for virgin newsprint and newsprint made with 100% deinked recovered fibers in Appendix B. While the Paper Task Force did not include newsprint in the types of paper studied, recycled newsprint comprises a significant part of the paper recovered in residential recycling programs. The environmental comparison of virgin and recycled newsprint manufacturing is a component of the analysis in White Paper No. 3, Lifecycle Environmental Comparison – Virgin Paper and Recycled Paper-Based Systems.

[2] R. T. Campbell, Manager, Technology Support, International Paper, personal communication, February 24, 1995.

[3] Neil McCubbin, Howard Edde, Ed Barnes, Jens Folke, Eva Bergman, Dennis Owen, *Best Available Technology for the Ontario Pulp and Paper Industry. Report prepared for the Water Resources Branch, Ontario Ministry of the Environment* (Ontario: Queen's Printer for Ontario, February 1992), p. 102.

[4] Seven DIP mills in the Great Lakes region currently use elemental chlorine or sodium hypochlorite to brighten pulp used in printing and writing papers. (Joyce Rosenthal, Center for Biology and Natural Science, Queens College, Brooklyn, NY, personal communication, March 1, 1995.)

[5]. "Mill Operations News Scan," *Pulp & Paper*, **68**, December 1994, p. 27.

[6] "Intercontinental Recycling begins building deinking mill; partners eye other projects," *Pulp & Paper Week*, **16**, October 17, 1994, p. 4.

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

[9] 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.

[10] *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.

[11] Tellus Institute, *Energy Implications of Integrated Solid Waste Management Systems*, a report prepared for the New York State Energy Research and Development Authority (Albany: Energy Authority, report no. 94-11, July 1994), chapter 6.

[12] 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.)

[13] 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).

[14] 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).

[15] 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-2** contains the calculations of the total and purchased energy for the three bleached kraft pulp manufacturing processes.

[16] See Figure 11 in Chapter 5, Volume I for a breakdown of 1994 bleached kraft pulp production by manufacturing process.

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

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

[19] 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.

[20] Stone groundwood mills use 3-5% hydrogen peroxide to brighten a ton of pulp. Alan Bird, manager of pulp and paper chemicals and hydrogen peroxide, DuPont Canada, telephone interview, August 8, 1995. TMP mills use about 1.6 million Btu's of energy to brighten a ton of pulp. F. Stodolsky and M.M Mintz, *Energy Life-Cycle Analysis of Newspaper*, (Argonne IL: report prepared by the Energy Systems Division, Argonne National Laboratory, May 1993), 6.

[21] A. Elaahi and H.E. Lowitt, *1988 Energetics Report*, 2.29.

[22] *Ibid*, 4.3.

[23] Howard J. Herzog, Jefferson W. Tester, "Energy Management and Conservation in the Pulp and Paper Industry," *Energy and the Environment in the 21st Century: Proceedings of the Conference held at the Massachusetts Institute of Technology*, March 26-28, 1990, p. 438..

[24] K. R. Gilbreath, et. al., "Background Paper on Energy Efficiency in the Pulp and Paper Industry," p. 52.

[25] A. Elaahi and H.E. Lowitt, *1988 Energetics Report*, 3.24.

[26] *Ibid.*, 2.31.

[27] *Ibid.,* p. 4.3.

28 Most mills that purchase wood chips also take bark and wood residue from the sawmills as part of their purchase agreement. Neil McCubbin, president, N. McCubbin Consultants, Inc., personal communication, DATE.

29 Edward Kelleher, Champion International, Paper Task Force Technical Meeting, Champion International Technical Center, West Nyack, NY, 7 January 1994.

30 Don McBride, "Deinking Systems for Office Waste Offer "Pay Now/Pay Later" Choices," *Pulp & Paper*, **68(4):** 49 (1994).

31 Ibid.

32 This estimate includes energy for the pulping process only and is consistent with the energy consumption of 7.7 million Btu's for the 1980s DIP mill. Tellus Institute, *Energy Implications of Integrated Solid Waste Management Systems*," pp. III-A-17, III-A-23.

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), 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 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.

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

54 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.)

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

56 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.

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

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

59 In Appendix D we present data on 1991 releases from the on-line TRI database for 13 producers of deinked recovered pulps that have been brightened. Of these, 7 report releases of chloroform. The average release from these mills is 0.76 lbs per ton of pulp produced. The average chloroform release for the 13 bleached kraft pulp

mills was 0.6 lbs of chloroform per ton of pulp produced. These data are consistent with TRI emissions of chloroform for 1988 and 1989 as reported by NCASI in Technical Bulletin No. 613. In 1989, nine deinking mills reported releases of chloroform to air that ranged from 0.11 to 1.51 lbs/ton of product produced.

60 Richard Storat, vice president, economics and materials, American Forest & Paper Association, letter to Linda Fransen, 5 June 1995,

61 U.S. EPA,. *Regulatory Impact Assessment,* 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 NCASI, "Characterization of Wastes and Emissions from Mills Using Recycled Fiber," *Technical Bulletin No. 613*, September 1991, p. 21.

64 Richard Storat, letter to David Refkin, 26 May 1995, 10.

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

66 NCASI, "Volatile Organic Emissions from Pulp and Paper Mill Sources: Part III - Miscellaneous Sources at Kraft and TMP Mills," *Technical Bulletin No. 676*, p. 170.

67 NCASI, "Volatile Organic Emissions from Pulp and Paper Mill Sources: Part VII - Pulp Dryers and Paper Machines at Integrated Chemical Pulp Mills," *Technical Bulletin No. 681*, October 1994, p. 66.

68 U.S. EPA, *(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). We will refer to this document as the EPA *Development Document For Effluent Limitations Guidelines for Effluent Limitations Guidelines* throughout the paper.

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

70 Dale Raymond, Director of Quality and Technology, Union Camp Corporation, letter to Lauren Blum, Environmental Defense Fund, November 21, 1994.

71 Jerry W. Garner, "Water, water everywhere and not a drop to waste," *Papermaker*, **56**, October 1993, p. 18; NCASI, *op. cit.*, p. 3.

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

73 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.

74 David Breed, mill manager, deinking plant, Union Camp Corp., personal communication, September 29, 1994.

75 Tony Pekovitch, Environmental Manager, Superior Recycled Fiber Corporation, personal communication,

September 26, 1994.

[76] Don McBride, "Deinking Systems for Office Waste Offer "Pay Now/Pay Later" Choices," 49.

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

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

[79] John Walkush, mill manager and vice president, NORPAC, telephone interview, October 10, 1994.

[80] Tony Pekovitch, Superior Fiber Recycled Corporation, personal communication, September 26, 1994.

[81] David Breed, mill manager, recovered fiber, Union Camp, Franklin, VA, personal communication, September 26, 1994.

[82] Don McBride, "Deinking Systems for Office Waste Offer "Pay Now/Pay Later" Choices," 49; Terry Campbell, presentation to the Paper Task Force, September 1, 1994.

Tony Pekovitch, SRFI, personal communication, September 26, 1994.

[83] 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, 1993), p. 2-4.

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

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

[86] Ibid., 9-81 - 9-84.

[87] U.S. EPA, *Regulatory Impact Assessment*, 7-27 - 7-28.

[88] Dale Raymond, letter to Lauren Blum, November 21, 1994.

[89] 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.

[90] 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.

[91] Ibid., 12-13.

[92] U.S. EPA, *Development Document For Effluent Limitations Guidelines*, 10-42.

[93] Ibid., 3-2, 6-35.

[94] 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. 117.

[95] Neil McCubbin, Howard Edde, Ed Barnes, Jens Folke, Eva Bergman, Dennis Owen, *Best Available Technology for the Ontario Pulp and Paper Industry. Report prepared for the Water Resources Branch, Ontario Ministry of the Environment* (Ontario: Queen's Printer for Ontario, February 1992), pp. 149 -154.

[96] Bette Hileman, "Environmental Estrogens Linked to Reproductive Abnormalities, Cancer," *Chemical & Engineering News*, January 31, 1994, p. 22.

[97] L.A. Tremblay and G.J. Van der Kraak, "Development of assays to determine the estrogenic activity of xenobiotic compounds in fish," presented at the 2nd International Conference on the Environmental Fate and Effects of Bleached Pulp Mill Effluents, Vancouver, BC, November 6 - 10, 1994.

[98] U.S. EPA, *Regulatory Impact Assessment,* 7-25 - 7-26.

[99] 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), 5.

[100] 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, DC, February 17, 1994, p. 6.

[101] 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), p. 200.

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

[103] U.S. EPA, *Development Document For Effluent Limitations Guidelines,* 9-27.

[104] NCASI, *Technical Bulletin No. 603*, p. A8.

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

[106] U.S. EPA, *Development Document For Effluent Limitations Guidelines,* Appendix C, pp. 112 - 120.

[107] NCASI, *Technical Bulletin No. 613*, p 35.

[108] NCASI, *Technical Bulletin No. 641*, 2.

[109] 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), 269.

[110] A. Springer, *Industrial Environmental Control*, 484.

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

[112] EPA *Development Document For Effluent Limitations Guidelines*, 8-46.

[113] Edward Kelleher, Champion International, personal communication, January 5, 1995.

[114] NCASI, *Technical Bulletin No. 613*, p. 32.

[115] Ibid.

[116] NCASI, *Technical Bulletin No. 641*, 16.

[117] NCASI, *Technical Bulletin No. 613*, pp. 30-31.

[118] EPA *Development Document For Effluent Limitations Guidelines*, 8-46.

[119] Jack Firkins, Boise Cascade Corporation, Paper Task Force expert panel discussion on the environmental comparison of virgin and recovered fiber pulp manufacturing technologies, New York, NY, November 3, 1994.

[120] Tony Pekovitch, SRFI, telephone interview, September 26, 1994.

[121] Allan Springer, *Industrial Environmental Control* ,459.

[122] Judy Usherson, "Recycled Paper and Sludge," *Resource Recycling*, **9**, March 1992, p. 98.