PAPER TASK FORCE

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

WHITE PAPER NO. 10B

ENVIRONMENTAL COMPARISON - MANUFACTURING TECHNOLOGIES FOR VIRGIN AND RECYCLED CORRUGATED BOXES

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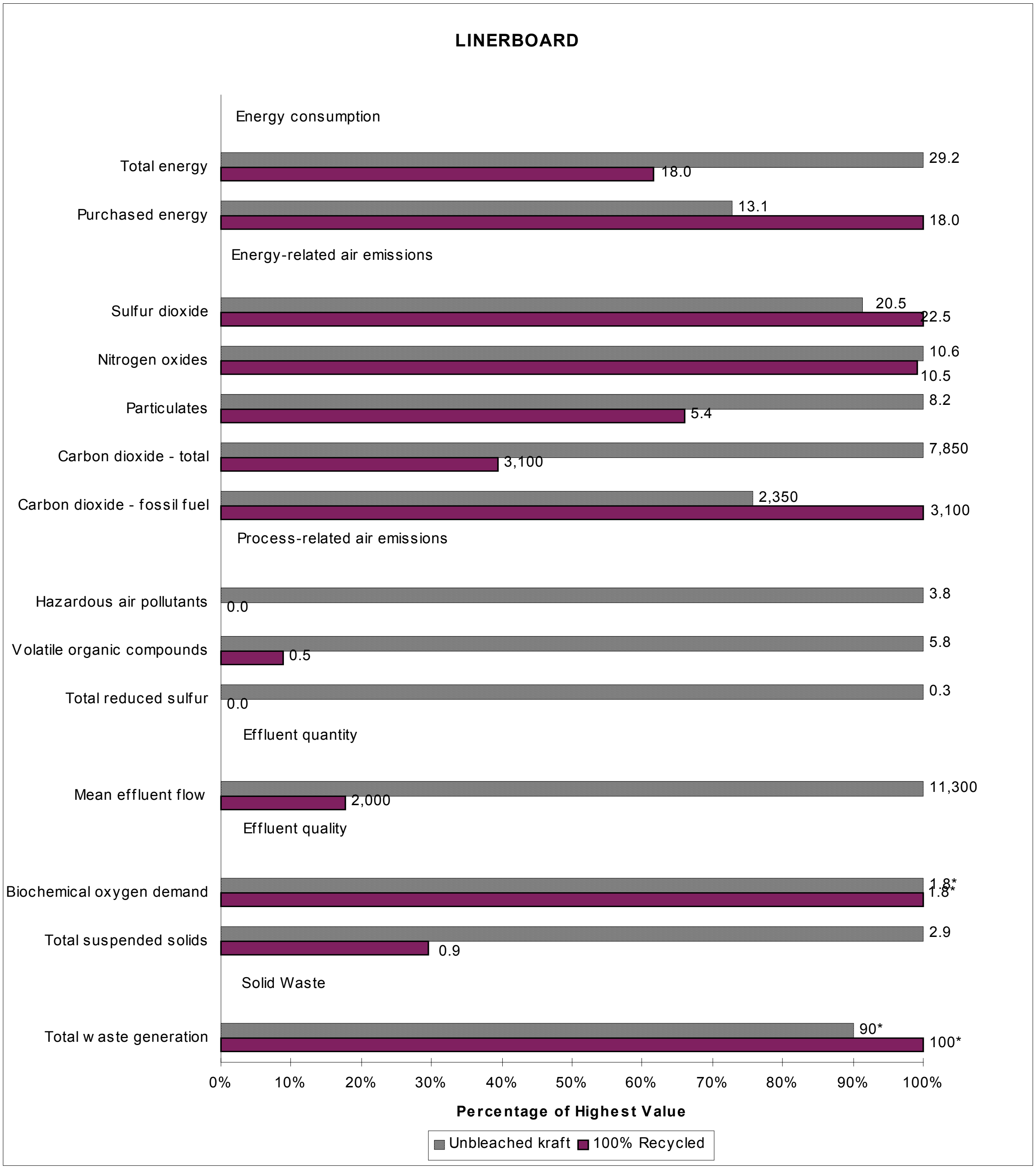
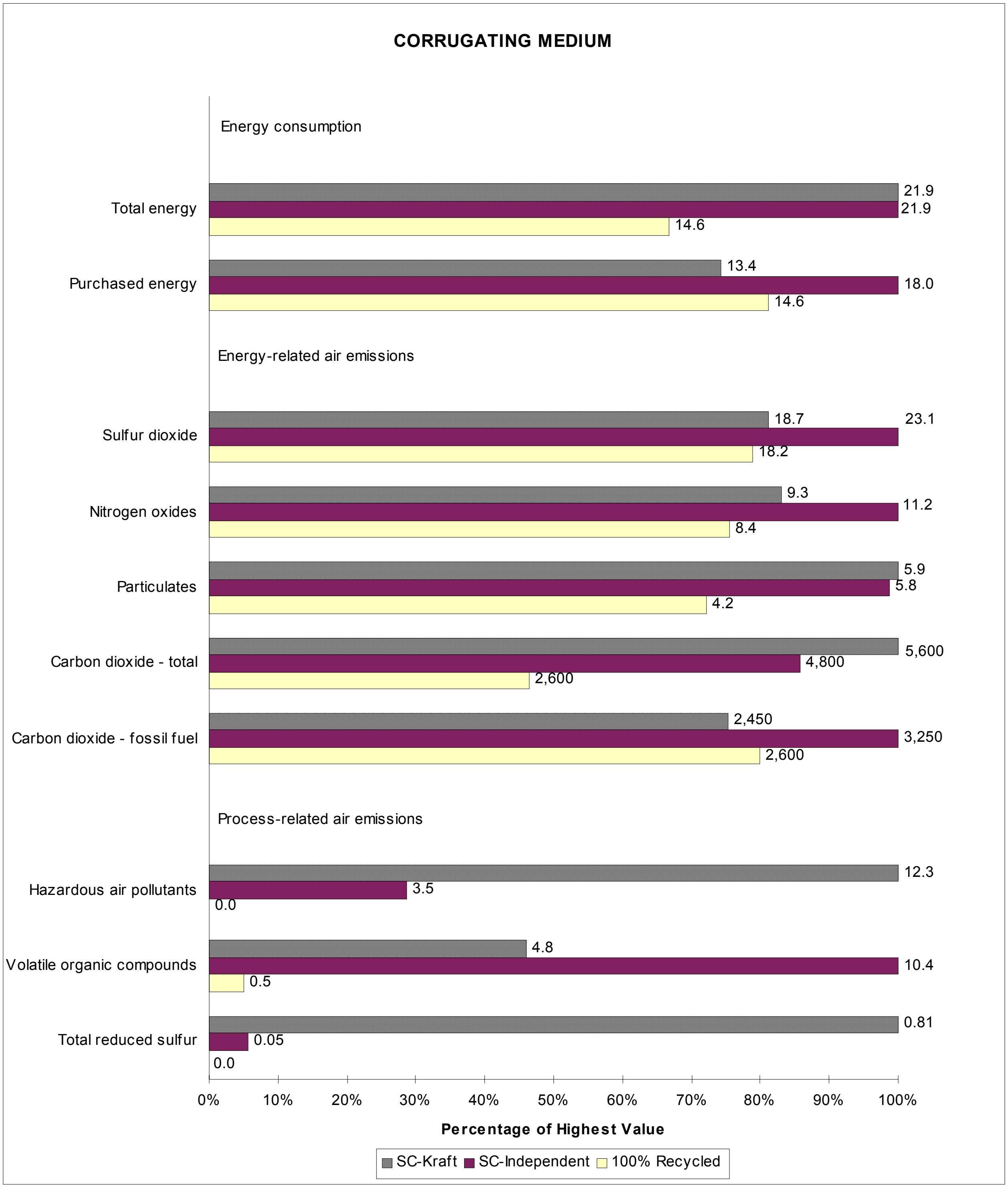
Environmental parameters	Unbleached kraft pulp	Recovered fiber pulp	Semichemical SC-kraft	Semichemical SC-independent
ENERGY CONSUMPTION (millions of BTUs per air dried ton of product)				
Total	17.0 - 18.8	5.9	13.7	13.7
Purchased	(2.7) - 4.2	5.9	3.2 - 6.1	8.7 - 10.5
ENERGY-RELATED AIR EMISSIONS (pounds per air dried ton of product)				
Sulfur dioxide (SO_2)	1.7 - 9.2	7.4	6.5 - 10.7	11.5 - 13.6
Nitrogen oxides (NO_x)	2.5 - 5.1	3.6	4.1 - 5.3	5.9 - 6.7
Particulates	5.3	2.2	3.9 - 4.1	3.5 3.8
Carbon dioxide (CO_2) - total	6,200 - 7,200	1,000	4,000 - 4,200	2,200 - 2,700
Carbon dioxide (CO_2) - fossil fuel	(500) - 800	1,000	600 - 1,200	1,500 - 1,800
PROCESS-RELATED AIR EMISSIONS (pounds per air dried ton of product)				
Hazardous air pollutants (HAP)	2.0	0.0	12.6	3.3
Volatile organic compounds (VOC)	5.0	0.6	4.3	10.2
Total reduced sulfur (TRS)	0.2	0.0	0.7	0.0
EFFLUENT QUANTITY (gallons per air dried ton of final product)				
Mean effluent flow	4,200	700	4,200	1,700
EFFLUENT QUALITY (kilograms per air dried metric ton of final product)				
Biochemical oxygen demand (BOD)	0.2 - 2.8	0.2 - 2.8	0.2 - 2.8	0.4 - 9.4
Total suspended solids (TSS)	0.7 - 6.1	0.2 - 4.0	0.7 - 6.1	0.6 - 8.8
SOLID WASTE (kilograms per air dried metric ton of final product)				
Total waste generation	0	100	90	130

Figure 1. Environmental parameters for linerboard



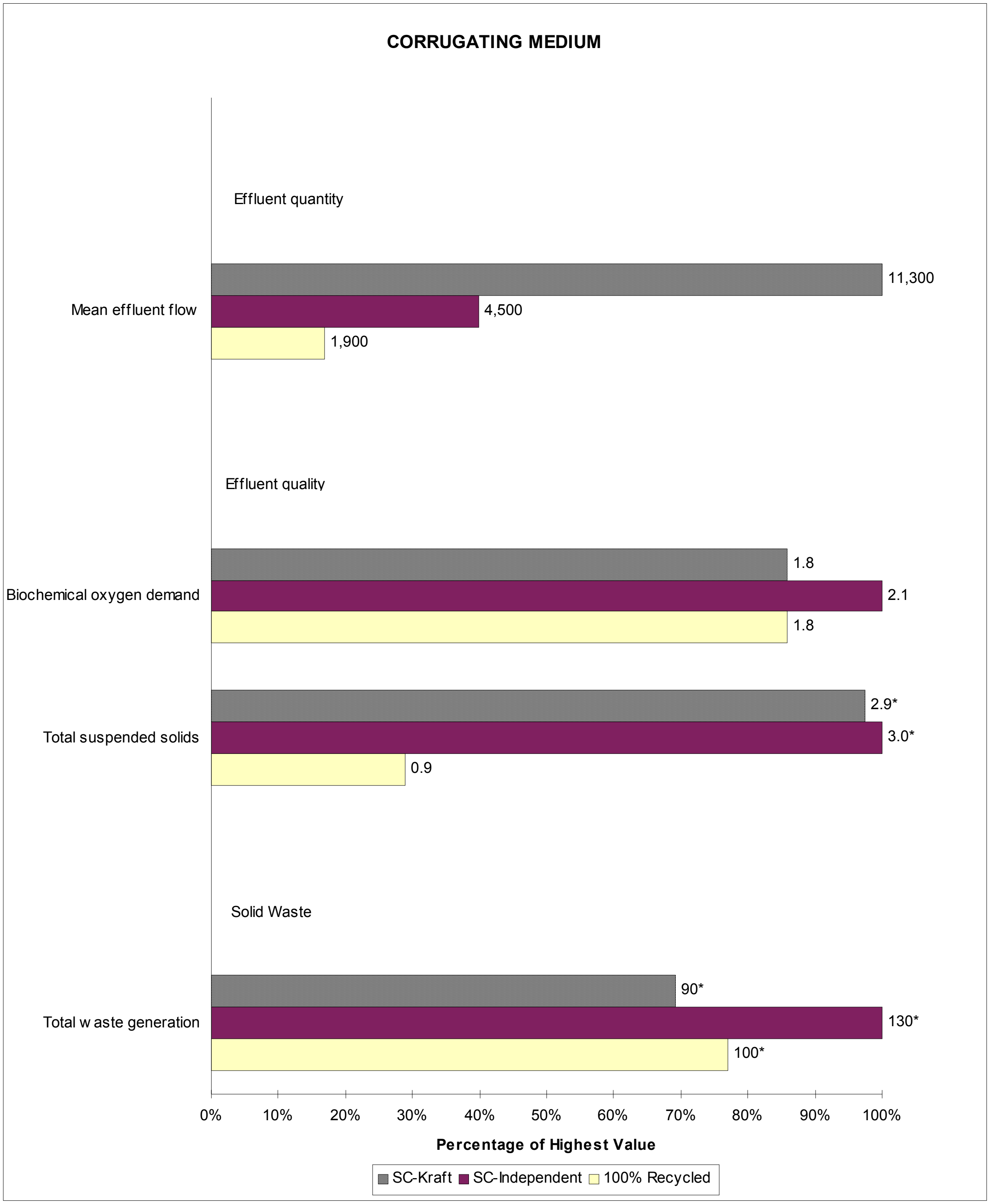
Note: * Statistically not different
Energy consumption: millions of BTU per air dried ton of product
Air emissions: pounds per air dried ton of final product
Effluent flow: gallons per air dried ton of final product
Effluent quality and solid waste: kilograms per air dried metric ton of final product

Figure 2a. Environmental parameters for corrugating medium



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

Figure 2b. Environmental parameters for corrugating medium



Note: * Statistically not 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 2. Environmental parameters for linerboard and corrugating medium

Environmental parameters	Linerboard: Unbleached Kraft	Linerboard: with 100% recycled content	Corrugating Medium: Integrated with kraft mill	Corrugating Medium: Independent	Corrugating Medium: with 100% recycled content
ENERGY CONSUMPTION (millions of BTU per air dried ton of product)					
Total	28.3 - 30.1	18.0	21.9	21.9	14.6
Purchased	9.8 - 16.3	18.0	12.0 - 14.7	17.1 - 18.8	14.6
ENERGY-RELATED AIR EMISSIONS (pounds per air dried ton of product)					
Sulfur dioxide (SO_2)	17.0 - 24.1	22.5	17.3 - 20.2	22.1 - 24.1	18.2
Nitrogen oxides (NO_x)	9.4 - 11.8	10.5	8.8 - 9.8	10.9 - 11.4	8.4
Particulates	8.2 - 8.3	5.4	5.8 - 5.9	5.7 - 5.9	4.2
Carbon dioxide (CO_2) - total	7,600 - 8,100	3,100	5,300 - 5,900	4,600 - 5,000	2,600
Carbon dioxide (CO_2) - fossil fuel	1,700 - 3,000	3,100	2,200 - 2,700	3,100 - 3,400	2,600
PROCESS-RELATED AIR EMISSIONS (pounds per air dried ton of product)					
Hazardous air pollutants (HAP)	3.3	0.0	12.3	3.5	0.0
Volatile organic compounds (VOC)	5.8	0.5	4.8	10.4	0.5
Total reduced sulfur (TRS)	0.30	0.00	0.81	0.05	0.00
EFFLUENT QUANTITY (gallons per air dried ton of final product)					
Mean effluent flow	11,300	2,000	11,300	4,500	1,900
EFFLUENT QUALITY (kilograms per air dried metric ton of final product)					
Biochemical oxygen demand (BOD)	1.8	1.8	1.8	2.1	1.8
Total suspended solids (TSS)	2.9	0.9	2.9	3.0	0.9
SOLID WASTE (kilograms per air dried metric ton of final product)					
Total waste generation	90	100	90	130	100

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 of corrugated packaging. 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 industry, relevant documents from the U.S. Environmental Protection Agency (EPA), information gathered during technical visits and other presentations from experts.

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

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

A. Paperboard Grades

The task force decided to study two paperboard products: corrugated containers consisting of linerboard and corrugating medium, and folding cartons. This paper examines corrugated containers; White Paper 10C examines coated paperboard used in folding cartons.

1. Linerboard

Linerboard mills use unbleached virgin kraft pulp, non-deinked recovered fiber, or a combination of the two as the furnishes in their product.

- **Unbleached kraft pulp** has the highest tear resistance of all chemical fiber pulp produced today. To maintain its strength, mills remove less lignin from unbleached kraft pulp used in linerboard than they do from unbleached kraft pulp that is eventually used in bleached paper products. Some mills differentiate between the top and bottom layers of the linerboard, using a brighter, more delignified unbleached kraft pulp on the top layer.[1]

- **Non-deinked recovered fiber pulp**: Postconsumer recycled fiber furnishes for linerboard consist mainly of repulped old corrugated containers (OCC). We will refer to the manufacturing process of non-deinked recovered fiber pulp as "recovered fiber" pulp manufacturing. OCC comprises 91% of the recovered fiber used to produce linerboard;

mixed waste paper comprises 4.5%.[2] To produce OCC pulp, the mill mixes the waste paper with water, uses mechanical energy and sometimes adds steam to repulp the paper. Non-volatile sizing agents and retention aids may be added at this stage.[3]

2. Corrugating medium

Mills produce corrugating medium from semichemical pulp, non-deinked recovered fiber pulp, or a combination of the two. OCC also accounts for most of the recovered fiber used in corrugating medium.

The production process for semichemical pulps combines chemical and mechanical processing of wood chips. First chips are partially delignified in a pressurized digester using the green liquor from the chemical recovery system of a kraft pulp mill, sodium carbonate, or neutral sodium sulfite (NSSC). The chips pass through a washer, then a refiner mechanically separates the fibers.

At kraft mills, the most commonly used process is the green liquor process, although there are still some NSSC processes in use at kraft mills. Of the 14 operating stand-alone semichemical pulp mills, 11 use the sodium carbonate process and only 3 use the NSSC process.[4] Ten years ago, most semichemical pulp mills used the NSSC process; today, 40% of the mills producing semichemical pulp use this process, while 60% have switched to green liquor and caustic-carbonate pulping.[5] Overall, the sodium carbonate process accounts for almost half of the semichemical pulp capacity in the U.S. today.[6] A brief description of the two major semichemical processes follows.

- **Green liquor semichemical pulping**. Many kraft pulp mills use the green liquor from the chemical recovery process as the cooking chemical in the digester. Green liquor contains sodium sulfide and sodium carbonate.

- **Caustic-Carbonate semichemical pulping**. Most non-integrated semichemical pulp mills use sodium carbonate (soda ash) with a small amount of sodium hydroxide (caustic soda) to partially delignify the pulp before mechanical refining.

All but one U.S. semichemical mill recover the chemicals from their spent liquor to minimize the organic loading in the effluent. Some NSSC mills and all semichemical pulp mills that use green liquor are co-located with kraft pulp mills. A large non-integrated semichemical pulp mill that uses the caustic-carbonate process recovers its liquor with a fluidized bed reactor on site.[7] We refer to the semichemical pulp mills co-located with kraft mills as "*SC-kraft*" and the stand-alone semichemical mills as "*SC-independent*" throughout the paper.

B. Major Topics

This paper compares the environmental profiles of linerboard produced with unbleached kraft and recovered fiber pulps, and corrugating medium produced with semichemical and recovered fiber pulps.

We present the environmental comparison research in two parts. First we examine the energy consumption and releases to the environment associated with unbleached kraft pulp, semichemical pulp and recovered fiber pulp manufacturing processes. We also consider the contribution from the paper machine associated with the production of the paperboard grades. Then we compare the environmental parameters for virgin and 100%-recycled linerboard and virgin and 100%-recycled corrugating medium.

The environmental comparison has two components as well: energy consumption, and releases to the environment associated with the production of these packaging grades. The examination of energy consumption focuses on the total and purchased energy required to produce these packaging grades. Total energy includes the electricity and steam required to produce the bleaching chemicals (where relevant) and to run the equipment at the mill. Purchased energy refers to the electricity and fossil fuels that mills purchase. Releases to the environment include air emissions, effluent 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

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, that are measured per ton of *pulp*, we based the contribution of each pulp on its percent of the total weight of the paper. For effluent and solid waste parameters that are measured per ton of final product, we calculated the contribution of each pulp as a percent of the fiber weight. Both corrugating medium and linerboard contain 94% pulp and 6% moisture; neither contain fillers.[8] For effluent and solid waste parameters that are measured per ton of final product, we based the contribution of each pulp as a percent of the fiber weight.

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

2. Using Averages

We consider both the mean, the ranges and the variability 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. Data to develop rankings of the magnitude of the environmental releases and energy consumption associated with the production of linerboard and corrugating medium.

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. **Table 1** presents ranges for all of the environmental parameters associated with unbleached kraft, semichemical and recovered fiber pulp manufacturing processes where the information is available. We perform statistical analyses to compare the means when enough data are available.

The final section compares the environmental profiles of virgin and 100%-recycled linerboard and corrugating medium. All recycled-content is by fiber weight. We present the ranges of the parameters for the virgin and 100%-recycled linerboard and corrugating medium in **Table 2**. These tables follow the list of tables and figures at the beginning of the paper.

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. **Table 1** presents ranges for all of the environmental parameters associated with unbleached kraft, semichemical and recovered fiber pulp manufacturing processes where the information is available. We 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 per ton of oven-dried pulp or air-dried final product, respectively. We present effluent and solid waste data in metric units: kilograms per metric ton of oven-dried pulp (kg/ODMTP) or in kilograms per metric ton of off -machine product (kg/ADMTFP).

A. Energy Consumption Associated with Pulp and Paper Manufacturing Processes

We have examined the total and purchased energy consumed by the pulp and paper manufacturing processes used to produce linerboard and corrugating medium. We present ranges of energy consumption for the unbleached kraft and semichemical pulping processes in **Table 1**.

- **The *total* energy consumed to produce an oven-dried ton of recovered fiber pulp is lower than the total energy consumption to produce unbleached kraft pulp for linerboard.**

- **On average, the *purchased* energy consumed to produce an oven-dried ton of unbleached kraft pulp is lower than the purchased energy consumed to produce an oven-dried ton of recovered fiber pulp.**

- **The *total* energy consumed in the production of semichemical pulp is higher than that consumed in the production of recovered fiber pulp.**

- **The *purchased* energy to produce an oven-dried ton of semichemical pulp at an SC-kraft mill and recovered fiber pulp are similar; whereas, the purchased energy to produce an oven-dried ton of semichemical pulp at an SC-independent mill is higher than that consumed to produce an oven-dried ton of recovered fiber pulp.**

- **Paper machines consume about 3.4 million Btu's per ADTFP more to produce a ton of linerboard than to produce a ton of corrugating medium.**

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

We compared emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), particulates, and carbon dioxide (CO_2) in this section. To develop estimates of the emissions of air pollutants associated with energy generation, we used the 1992 industry average fuel mix and the national grid fuel mix for electricity. The emissions of the energy-related air pollutants such as SO_2, NO_x, and CO_2 will vary depending on the fuel mix available to a particular mill. **In Table 1**, we present ranges of emissions of SO_2, NOx, particulate and CO_2 emissions from unbleached kraft and semichemical pulp manufacturing processes, based our knowledge of the range of energy use of the processes.

- **With the exception of sulfur dioxide and fossil fuel based carbon dioxide emissions, the magnitude of the average releases of energy-related air pollutants associated with the production of recovered fiber pulps are lower than are those associated with the production of unbleached kraft pulp**. The recovered fiber pulping process consumes more purchased energy and relies more on electrical energy than does the unbleached kraft mill. The unbleached kraft processes satisfy almost all of their energy with wood-based fuels. The uptake of CO_2 by young, fast-growing trees almost balances the CO_2 emissions associated with the wood-based fuel.

- **The recovered fiber pulping process has comparable NO_x emissions and lower emissions of particulates and total carbon dioxide than does the unbleached kraft pulping process.** The lower total energy consumption and use of wood-based fuel of the recovered fiber pulping process accounts for this result.

- **The magnitude of the energy-related air pollutants for the semichemical pulping processes is higher than that of the recovered fiber pulping process.** On average, semichemical processes consume more total and purchased energy than do the recovered fiber processes.

- **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 1 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.

- **Methanol constitutes almost 90% of the total HAP emissions associated with unbleached kraft SC-kraft semichemical pulping processes.** It accounted for about 48% of the total HAP emissions of the SC-independent semichemical pulping process.

- **Recovered fiber pulping processes do not generate HAP emissions, and thus have the lowest emissions of the three pulping processes.**

- **Energy-related VOC emissions account for the VOC emissions from recovered fiber pulp mills. We found no process-related VOC emissions**.

- **The VOC emissions associated with the SC-independent semichemical pulping process more than twice as high as those associated with the SC-kraft semichemical process.** The chemical recovery system of the SC-independent process contributes over 80% of the total VOC emissions. Process-related VOC emissions account for about 67% of the VOC emissions associated with the SC-kraft process.

- **The unbleached kraft and SC-kraft semichemical pulping processes generate emissions of TRS compounds.** Both of these pulping processes use sodium sulfide as a pulping chemical.

D. Effluent Associated with Pulp and Paper Manufacturing Processes

Both effluent quantity and quality differ for linerboard and corrugating medium mills. We present the ranges of the magnitude of effluent flow, biochemical oxygen demand (BOD), and total suspended solids (TSS) for unbleached kraft, semichemical and recovered fiber pulping processes in **Table 1.** We do not consider releases of either AOX or dioxins because these substances are generated during bleaching processes where the pulp is exposed to elemental chlorine. We also do not consider chemical oxygen demand (COD) in the comparison of packaging grades. Insufficient data on the COD loading in the final effluent associated with recovered fiber pulping processes precluded this comparison. None of the pulps that comprise the furnish of linerboard or corrugating medium are bleached.

- **Effluent flow and the TSS loading in the final effluent are statistically lower for the recovered fiber pulping processes than for either unbleached kraft or SC-independent semichemical pulping processes.**

- **There is no statistical difference in the BOD loading in the final effluent for the three pulping processes.**

E. Solid Waste Generation Associated with Pulp and Paper Manufacturing Processes [Section VII]

We have developed estimates of the quantity of solid waste associated with unbleached kraft, recovered fiber and semichemical pulping processes. **Table 1** contains estimates of total solid waste generation for the pulping processes.

- **Statistical analysis of the quantities of solid waste generated by unbleached kraft mills and recovered fiber mills indicates that there is no statistical difference in the quantity of total solid waste generated at these mills.**

- **Statistical analysis of the quantities of solid waste generated by semichemical mills and recovered fiber mills indicates that there is no statistical difference in the quantity of total solid waste generated at these mills.**

- **Using a ton of recovered fiber to produce linerboard or corrugating medium removes 1.07 tons or 2.7 cubic yards of material from the solid waste stream.**

F. Comparisons of the Packaging Grades

In this section we summarize the environmental comparisons of the corrugated packing grades. These comparisons compare the magnitude of energy consumption and releases to the environment associated with the production of virgin and 100%-recycled linerboard and corrugating medium.

Comparison I: Virgin and 100%-Recycled Linerboard

Figure 1 and **Table 2** present the average and the ranges, respectively, for energy consumption and releases to the environment generated during the production of these grades of linerboard.

- **On average, producing virgin linerboard requires about 27% less purchased energy than does producing 100%-recycled linerboard. This difference in purchased energy consumption leads to increased sulfur dioxide emissions and fossil-fuel based carbon dioxide emissions associated with the production of 100%-recycled linerboard.**

- **Nitrogen oxide emissions, the BOD loading in the final effluent and the generation of total solid waste are about the same.**

- **Producing 100%-recycled linerboard results in significantly lower emissions of particulates and total carbon dioxide emissions than does producing virgin linerboard. Process-related air emissions are also significantly lower.**

- **Effluent flow and the TSS loading in the final effluent of 100%-recycled linerboard mills is significantly lower than that of virgin linerboard mills.**

Comparison II: Virgin and 100%-recycled Corrugating Medium

Figure 2a-b and **Table 2** present the average and the ranges, respectively, for energy consumption and releases to the environment generated during the production of these grades of corrugating medium.

- **On average, producing 100% recycled medium results in lower energy consumption and releases to the environment for all parameters except BOD and total solid waste generation than does producing semichemical medium.**

- **There is no statistical difference in the BOD loading in the final effluent or total solid waste generation for the two medium grades**.

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 unbleached kraft pulp, recovered fiber, and semichemical pulp and to make a ton of linerboard and corrugating medium on the paper machine. This information forms the basis for estimates of the energy consumption associated with the production of virgin and recovered fiber linerboard and medium. The *total* energy requirement consists of the electricity and steam required to produce the bleaching chemicals (where relevant) and to operate the equipment at the mill. The *purchased* energy consists of the electricity[9] 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, nor does it include the energy consumed to produce chemicals off-site. 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.[10] White Paper No. 3 includes this 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).[11]

- A 1993 study prepared by Simons Strategic Division for the Electric Power Research Institute (the EPRI study, hereafter).[12] 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.[13]

C. Energy Consumption of the Pulp and Paper Manufacturing Processes

1. Unbleached Kraft Pulp

In **Table 3**, we present the total and purchased energy estimates for the average mill and the modern mill. Mills built in the 1980s and the 1990s represent the high and low ends, respectively, of the range of energy use to produce a ton of unbleached kraft pulp today.[14] **Table B-6** in Appendix B contain the calculation of the total, self-generated and purchased energy consumption.

Table 3. Total and purchased energy requirements to produce unbleached kraft and recovered fiber pulps

(Millions of Btu's per oven-dried ton of pulp)	**Unbleached kraft pulping**		**Non-deinked recovered fiber pulping**
	Low [1]	High [2]	
Total Energy			
Process energy	17.0	18.8	5.9
Total	**17.0**	**18.8**	**5.9**
Self -generated energy			
Black liquor	16.1	12.9	0.0
Wood waste	3.5	1.8	0.0
Total	**19.6**	**14.7**	**0.0**
Purchased energy	**(2.7)**	**4.2**	**5.9**

[1] High energy consumption mills were built in the early 1980s.
[2] Low energy consumption mills were built in the late 1980s to early 1990s.

While 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.[15] This estimate includes some mills that purchase all of their energy. Kraft pulp mills have further reduced their energy consumption by employing cogeneration to produce both electricity and process steam from their boilers.

The older unbleached kraft pulping process provides about 80% of its energy by burning black liquor, bark and other wood residues. The modern mill actually generates a surplus of about 2.7 million Btus of energy per ton of oven-dried pulp which it can sell back to the local utility as electricity.[16]

2. Recovered Fiber Pulp

We present the total and purchased energy required to produce a ton of recovered fiber pulp in **Table 3**. We present additional information about the energy consumption calculations in **Table B-5 of** Appendix B. The total energy requirement for recovered pulps ranges from 31-35% of the total energy consumed by unbleached kraft pulp mills. Recovered fiber pulp mills, however, do purchase more energy than unbleached kraft pulp mills because the recovered fiber mills have no source of self-generated energy.

3. Semichemical Pulp

We present the total and purchased energy required to produce a ton of semichemical pulp in **Table 4**. We present additional information about the energy consumption calculation in **Table B-7** of Appendix B. David Knoll at Jacobs Sirrine Inc., an engineering consulting firm provided estimates of total and purchased energy consumption for the SC-kraft and SC-independent pulping processes.[17]

The SC-Kraft semichemical mills, on average, generate about one-third of the steam by burning black liquor as do bleached kraft pulp mills. Energy recovery from spent pulping liquor at the SC-independent mills is about 10% of that of a bleached kraft mill. With an average yield of 75%,[18] semichemical mills generate about from 1.3 to 2.7 million Btus per ODTP from burning bark and other wood residue

Table 4. Total and purchased energy requirements to produce semichemical pulp

(Millions of Btu's per oven-dried ton of pulp)				
	SC-Kraft		SC-Independent	
	low [1]	high [2]	low [1]	high [2]
Total Energy				
Process energy	13.72	13.72	13.72	13.72
Total	**13.72**	**13.72**	**13.72**	**13.72**
Self -generated energy				
Black liquor	7.84	6.27	2.38	1.90
Wood waste[19]	2.67	1.33	2.67	1.33
Total	**10.51**	**7.61**	**5.04**	**3.23**
Purchased energy	**3.21**	**6.11**	**8.67**	**10.48**

[1] High energy consumption mills were built in the early 1980s.
[2] Low energy consumption mills were built in the late 1980s to early 1990s.

4. Papermaking-Linerboard and Corrugating Medium

Table 5 contains estimates of the electricity and steam required to produce the paper grades considered in this white paper.[20] The energy consumption data in **Table 5** indicate that the energy consumed to produce linerboard is higher than the energy consumed to produce corrugating medium. The 1988 Energetics Report demonstrated that about 75% of the energy consumed by paper machines in 1985 was steam.[21] The typical paper machine operating today has realized the steam savings that the report identified.

Table 5. Paper machine energy consumption to produce packaging grades

(Millions of Btu's per ADTFP)	**Electricity [1]**	**Steam**	**Total Energy**
Linerboard	580	6.3	12.35
Corrugating medium	350	5.3	8.98

kWh/ADFTP = kilowatt-hours per air-dried ton of final product
MM Btu/ADTFP = millions of Btu's per air-dried ton of final product

[1] The conversion of kilowatt-hours to Btu's includes the transmission loss at the electric utility. Therefore, the conversion factor used is 1 kWh = 10,500 Btu.

D. Summary

- **The total energy consumed to produce an oven-dried ton of recovered fiber pulp is lower than the total energy consumption to produce either unbleached kraft pulp for linerboard or semichemical pulp for corrugating medium.**

- **The range of purchased energy consumed to produce an oven-dried ton of unbleached kraft pulp is lower than the purchased energy consumed to produce an oven-dried ton of bleached kraft pulp.**

- **The purchased energy to produce an oven-dried ton of semichemical pulp at an SC-kraft mill and recovered fiber pulp is similar; whereas, the purchased energy to produce an oven-dried ton of semichemical pulp at an SC-independent mill is higher than that consumed to produce an oven-dried ton of recovered fiber pulp.**

- **Paper machines consume about 3.4 million Btu's per ADTFP more to produce a ton of linerboard than to produce a ton of corrugating medium.**

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 pollutants. These sources release sulfur dioxide (SO_2), nitrogen oxides (NOx), particulates and carbon dioxide (CO_2) as they generate energy. 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, therefore, estimate the emissions of these pollutants associated with the production of the linerboard and corrugating medium from the mix of fuels used to produce the steam and electricity used at the mill. We consider emissions of these pollutants for the range of mills because of the differences in energy consumption..

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

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.[22] 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.[23] We have used estimates of particulate emissions from EPA's AP-42 summary of emission factors[24] and NCASI estimates for coal and oil boilers.[25] Zerbe published CO_2 emission factors for all of the fuels of interest except black liquor.[26] We estimated CO_2 emissions for black liquor using a method described by Takeyama and Otsuka.[27]

2. Fuels

The analysis of energy consumption provided estimates of the energy produced from self-generated fuels for unbleached kraft, semichemical and recovered fiber 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.[28] 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.[29] Recovery boilers accounted for 14% of the SO_2 generated by pulp and paper mills in the U.S. in 1990.[30] 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.[31] 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.[32]

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%.[33]

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.[34]

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.[35] 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.[36]

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.[37]

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

CO_2 is a greenhouse gas that is associated with global climate change.[38] 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 6**. Several trends emerge from the comparison of these emissions.

Table 6. Emissions of energy-related air pollutants associated with unbleached kraft, recovered fiber and semichemical pulping processes

(pounds/ADFTP)	**Sulfur dioxide (SO_2)**		**Nitrogen oxides (NO_x)**		**Particulates**		**Carbon dioxide (CO_2)– Total**		**Carbon dioxide (CO_2)–Fossil fuel**	
Pulp	Low [1]	High[2]	Low	High	Low	High	Low	High	Low	High
Unbleached kraft pulp	1.68	9.20	2.51	5.09	5.15	5.29	7,200	6,200	(500)	800
Recovered fiber pulp		7.35		3.63		2.20		1,000		1,000
Semichemical pulp										
SC-kraft	6.46	10.70	4.10	5.27	3.90	4.14	4,200	4,000	600	1,200
SC independent	11.45	13.58	5.95	6.67	3.52	3.82	2,200	2,700	1,500	1,800

pounds/ADTFP = pounds per air-dried ton of final product
[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.* On average, the total energy for the semichemical pulp manufacturing processes is higher than that of the unbleached kraft pulping processes. However, the reliance on purchased electricity of the semichemical pulping processes results in higher emissions of sulfur dioxide, nitrogen oxides, particulates and fossil fuel 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 has a high percentage of coal and oil. Both of these fuels have relatively high sulfur dioxide and nitrogen oxide emissions upon combustion. Mills and utilities that use a larger percentage of oil and natural gas will have lower emissions.

- *The total carbon dioxide emissions associated with semichemical pulp and 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 on 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 semichemical and the recovered fiber pulp manufacturing processes.* Unbleached kraft mills generate most of their energy from renewable wood-based fuels. The more energy-efficient processes received a credit for these emissions to reflect the small surplus of energy they generate on-site.

E. Emissions Associated with Papermaking

Table 7 illustrates the range of emissions associated with the papermaking process for linerboard and corrugating medium. Paper machines generate no energy on-site; thus, we assumed that they consume purchased electricity and fossil fuels. Thus, the magnitude of the emissions corresponds to the total energy consumed to produce linerboard and corrugating medium. There also is no difference between the total and fossil fuel-based carbon dioxide emissions.

Table 7. Emissions of energy-related air pollutants associated with papermaking processes

Paper grade (pounds/ADFTP)	**Sulfur dioxide (SO_2)**	**Nitrogen oxides (NO_x)**	**Particulates**	**Carbon dioxide (CO_2)– Total**
Linerboard	16.10	7.39	3.62	2,300
Corrugating medium	19.07	8.72	4.20	2,200

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

F. Summary

- **With the exception of sulfur dioxide and fossil fuel based carbon dioxide emissions, the magnitude of the average releases of energy-related air pollutants associated with the production of recovered fiber pulps are lower than are those associated with the production of unbleached kraft pulp**. The recovered fiber pulping process consumes more purchased energy and relies more on electrical energy than does the unbleached kraft mill. The unbleached kraft processes satisfy almost all of their energy with wood-based fuels. The uptake of CO_2 by young, fast-growing trees almost balances the CO_2 emissions associated with the wood-based fuel.

- **The recovered fiber pulping process has comparable NO_x emissions and lower emissions of particulates and total carbon dioxide than does the unbleached kraft pulping process.** The lower total energy consumption and use of wood-based fuel of the recovered fiber pulping process accounts for this result.

- **The magnitude of the energy-related air pollutants for the semichemical pulping processes is higher than that of the recovered fiber pulping process.** On average, semichemical processes consume more total and purchased energy than do the recovered fiber processes.

- **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 BOARD 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.[39]

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 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 a small amount of dissolving kraft pulp, another produces TMP. One unbleached kraft pulp mill also produces semichemical pulp.[40] In Appendix C, we present a summary of the emissions of ten HAPs from sources at unbleached kraft and semichemical pulp mills included in the study in **Table C-14**, and VOCs and TRS emissions in **Table C-15**.

NCASI tested emissions from an SC-kraft mill and an SC-independent mill that recovers the pulping chemicals on the site in a fluidized bed reactor. We present more detail on the HAP emissions from these semichemical mills in **Table C-8** and on VOC and TRS emissions in **Table C-9** in Appendix C.

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.[41] 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 associated with the unbleached kraft and semichemical pulp manufacturing processes are from process sources. The energy-related HAPs are about two orders of magnitude lower than those from process sources.[42] 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-7** of Appendix C.

1. Unbleached Kraft Pulping Processes

Major unbleached kraft mill sources include the pulp plant, storage tanks and the chemical recovery system. The unbleached kraft mills discussed in this paper use a continuous digester, and diffusion and vacuum drum brownstock washing. Methanol and acetaldehyde account for over 90% of the HAPs emitted by these mills. On average, the pulping processes and chemical recovery system account for 99% of the organic HAP emissions from pulp mill sources. We present the major HAP emissions from the process and combustion sources at unbleached kraft pulp mills in **Table 8.**

Table 8. HAP emissions from unbleached kraft pulp mill sources

Unbleached kraft pulp		
HAP	**Quantity** (lb/ODTP)	**Percent of total**
Total	**2.00**	
Methanol	1.79	89.5%
Acetaldehyde	0.08	4.0%
		93.5%

2. Semichemical Pulping Processes

We present the major components of the organic HAP emissions for the SC-kraft and SC-independent semichemical pulp mills in **Table 9.** Methanol accounts for 88% to 95% of total HAP emissions from the SC-kraft mill and 48% for the SC-independent. The emissions from the chemical recovery system account for about 97% of the total HAP emissions from the SC-kraft mill and about 57% from the SC-independent semichemical pulp mills. HAP emissions associated with combustion sources account for less than 1% of total HAP emissions.

Table 9. HAP emissions from semichemical pulp mill sources

SC-Kraft semichemical pulp			SC-Independent semichemical pulp		
HAP	**Quantity** (lb/ODTP)	**Percent of total**	**HAP**	**Quantity** (lb/ODTP)	**Percent of total**
Total	**12.60**		**Total**	**3.27**	
Methanol	11.48	91.1%	Methanol	1.58	48.3%
Acetaldehyde	0.32	2.5%	Acetaldehyde	0.46	14.1%
			Formaldehyde	0.55	16.8%
		93.6%			**79.2%**

3. Non-Deinked Recovered Fiber Pulping Processes

NCASI did not report any estimates for air emissions from the repulping process.[43] Given that no chemical degradation of the pulp occurs during this process, one would not expect to see releases of HAPs.

4. Paper Machines

We present the organic HAP emissions released by paper machines that produce unbleached kraft linerboard and semichemical corrugating medium in **Table 10**. Methanol and acetaldehyde account for 94.2% and 82.2% of the total HAP emissions from the linerboard and corrugating medium paper machines respectively The concentration of methanol in the white water of the paper machine accounts for most of the HAP emissions from this source. The higher HAP emissions may result from increased water reuse at linerboard mills.[44]

Table 10. HAP emissions from paper machine sources

Paper machine producing unbleached kraft linerboard			Paper machine producing semichemical corrugating medium		
HAP	**Quantity** lb/ODTP	**Percent of total**	**HAP**	**Quantity** lb/ODTP	**Percent of total**
Total	**1.40**		**Total**	**0.45**	
Methanol	1.21	86.4%	Methanol	0.29	64.4%
Acetaldehyde	0.11	7.9%	Acetaldehyde	0.08	17.8%
		94.2%			**82.2%**

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 (NOx) to form ozone in the atmosphere, the major component of photochemical smog.[45] 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; it is not a HAP. We present the HAP emissions from all sources at the mill in **Table C-9** 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).[46]

1. Unbleached Kraft Pulping Processes

We present total VOC emissions for unbleached kraft pulp mills in **Table 11**. Pulping and chemical recovery sources account for about 64% of the VOC emissions from unbleached kraft pulp mills.

Table 11. VOC emissions for unbleached kraft pulp mills

Unbleached kraft pulp mill	
Source	**Quantity** lb C/ODTP
Pulping	2.34
Chemical Recovery	0.96
Energy	1.84
Total	**5.14**

2. Semichemical Pulping Processes

We present total VOC emissions for SC-kraft and SC-independent semichemical pulping processes in **Table 12**. The VOC emissions from the pulping process account for almost 95% of the VOC emissions from all mill sources.

Table 12. VOC emissions from semichemical pulp mill sources

SC-Kraft semichemical pulp		SC-Independent semichemical pulp	
Source	**Quantity** lb C/ODTP	**Source**	**Quantity** lb C/ODTP
Pulping	2.87	Pulping	0.73
Chemical Recovery	0.13	Chemical Recovery	8.43
Energy	1.25	Energy [1]	1.04
Total	**4.25**		**10.2**

3. Recovered Fiber Pulping Processes

As with HAP emissions, VOC emissions are expected to be very low because no chemical degradation of lignin occurs during the production of recovered fiber pulp. Thus, combustion sources account for the 0.59 lb C/ODTP VOC released recovered fiber pulp mills.

4. Paper Machines

We present the VOC emissions from paper machines used to produce linerboard and corrugating medium in **Table 13**. Energy-related VOC emissions account for over 90% of the VOC emissions from paper machines.

Table 13. VOC emissions from paper machine sources

Paper machine producing unbleached kraft linerboard		Paper machine producing semichemical medium	
Source	**Quantity** lb C/ODTP	**Source**	**Quantity** lb C/ODTP
Machine	0.51	Machine	0.25
Energy	0.51	Energy	0.51
Total	**1.02**	**Total**	**0.76**

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 reduced sulfur compounds in the cooking process produce these malodorous compounds, thus TRS emissions are higher for unbleached kraft pulping process. Neither the semichemical nor the recovered fiber pulping 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.[47]

1. Unbleached Kraft Pulping Processes

The pulping and chemical recovery processes generate the TRS emissions at an unbleached kraft pulp mill. Installation of low odor recovery boilers has reduced TRS emissions.

2. Recovered Fiber Pulping Processes

Recovered fiber mills use no sulfur compounds in the pulping process, and thus one would not expect these mills to have TRS emissions. Some TRS emissions can result during the repulping process of OCC as TRS compounds that remained in the corrugated packaging is released.[48]

3. Semichemical Pulping Processes

According to the NCASI study, a semichemical mill with an SC-kraft process released 0.7 lbs TRS/ODTP,[49] The caustic-carbonate semichemical process does not use sodium sulfide; the NCASI study did not find detectable levels of TRS emissions from process sources at this type of mill.[50]

4. Paper Machines

NCASI found no detectable emissions of TRS compounds from paper machine sources.[51]

F. Summary

- **Methanol constitutes almost 90% of the total HAP emissions associated with unbleached kraft SC-kraft semichemical pulping processes.** It accounted for about 48% of the total HAP emissions of the SC-independent semichemical pulping process.

- **Recovered fiber pulping processes do not generate HAP emissions, and thus have the lowest emissions of the three pulping processes.**

- **Energy-related VOC emissions account for the VOC emissions from recovered fiber pulp mills. We found no process-related VOC emissions**.

- **The VOC emissions associated with the SC-independent semichemical pulping process more than twice as high as those associated with the SC-kraft semichemical process.** The chemical recovery system of the SC-independent process contributes over 80% of the total VOC emissions. Process-related VOC emissions account for about 67% of the VOC emissions associated with the SC-kraft process.

- **The unbleached kraft and SC-kraft semichemical pulping processes generate emissions of TRS compounds.** Both of these pulping processes use sodium sulfide as a pulping chemical.

VI. EFFLUENT ASSOCIATED WITH CORRUGATED PACKAGING PRODUCTION PROCESSES

A. Scope

We examine the quantity and quality of the effluent for linerboard and corrugating medium in this section. We compare effluent flow along with three parameters that describe effluent quality: biochemical oxygen demand (BOD), and total suspended solids (TSS). We do not examine adsorbable organic halogens (AOX) or dioxins in this study because neither furnish contains bleached pulps. We also have eliminated chemical oxygen demand (COD) in this comparison.[52] We examine the variability of the data for each parameter in the comparisons as well.

Note of caution: Mills that comprise broad categories such as unbleached kraft pulp mills or non-deinked fiber pulp mills may make more than one product or may produce more than one type of pulp.

- **Unbleached kraft pulp mills** may take advantage of the chemical recovery system to produce semichemical pulp on-site. Unbleached kraft pulp mills produce linerboard with a range of zero to 100% OCC.

- **Integrated semichemical pulp mills.** EPA has proposed to consider semichemical mills that are integrated with unbleached kraft mills and unbleached kraft mills in one subcategory because there is no difference in the BOD loading in the final effluent of these mills.[53] With the exception of effluent flow, we assume that the BOD, TSS and COD loading in the final effluent in an integrated semichemical mill are the same as those .in the final effluent of an unbleached kraft pulp mill.

- **Recovered fiber pulp mills** produce linerboard, corrugating medium and coated paper board for folding cartons. Although these mills use different types of recovered medium in their products, the production processes are very similar. A recent statistical comparison of effluent flow, mean BOD and TSS loadings in raw effluent of four mills that produce linerboard or corrugating medium and seven mills that produce recycled cartons[54] shows a statistical difference between mean BOD loadings for corrugated packaging and coated paperboard grades. The differences in effluent flow and TSS loading were not statistically different.[55] Analysis of the BOD loading supports NCASI's earlier finding that the BOD loading in the final effluent of mills that produce virgin and 100% recycled linerboard are similar in magnitude.[56]

B. Sources

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

- EPA's 1990 industry questionnaire provides information on mean effluent flow, along with final BOD and TSS loadings for 20 unbleached kraft pulp mills, 27 non-deinked recovered fiber pulp mills, and 15 semichemical pulp mills in the background document for the proposed effluent limitation guidelines.[57] EPA also provides COD loadings in final effluent for 3 unbleached kraft mills.

- A 1991 NCASI study that surveyed available information on the environmental releases from both deinked and non-deinked recovered fiber pulp mills.[58] This study contains data from 11 non-deinked recovered fiber pulp mills for effluent flow and BOD and TSS loadings in the raw effluent.

- A 1993 NCASI recently survey of 16 unbleached kraft pulp mills and 13 semichemical mills provides data on effluent flow, BOD, TSS and COD loadings in the raw and final effluent.[59]

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. Recycled fiber mills can also come from municipal systems, especially for mills located near urban areas. 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;[60] 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.[61]

We present estimates of effluent flow for unbleached kraft pulp mills, non-integrated semichemical pulp mills, recovered fiber pulp mills that produce paper and paperboard in **Table 14**. Generally, the contribution of the pulping process of the unbleached, semichemical and recovered fiber pulping processes is about 35% of the total effluent flow.[62]

Table 14: Estimates of effluent flow (Gallons per air-dried ton of final product)

Process	% OCC	Mean	Range [2] low	Range [2] high	Number of mills	Reference
Unbleached kraft [1]	0%-100%	11,300	6,900 (39%)	26,300 (22%)	15	NCASI 1993[59]
Unbleached kraft		11,700				EPA 1993[57]
Recovered fiber	100%	1,930	0 (100%)	7,350 (100%)	11	NCASI 1991[58]
Recovered fiber	100%	8,000				EPA 1993[57]
Semichemical	2% - 75%	4,454	1,190 (60%)	6,260 (30%)	13	NCASI 1993[59]
Semichemical		5,200				EPA 1993[57]

[1] Effluent flow for unbleached kraft pulp mills that produce over 500 metric tons per day of product.
[2] Recycled content as a percent of fiber weight follows the estimate of mean flow.

1. Unbleached Kraft and Recovered Fiber Pulping Processes

A statistical analysis of the flow data shows that the effluent flow associated with the recovered fiber pulping processes is significantly lower than the flow associated with unbleached kraft production processes. We present the individual mill data in **Table E-2** and the statistical analysis in **Table E-9**.

Some non-deinked recovered fiber mills operate without effluent discharge. Green Bay Packaging, for example, has produced 300 ton per day of linerboard and corrugating medium without any effluent discharge since 1991. EPA found that there were few differences in the process technology or operations for mills that completely recycled the wastewater and those that did not;[63] thus, there appear to be no technological barriers preventing these mills from moving to complete recirculation of the wastewater. Jeffrey Walch, vice president of Green Bay Packaging, confirmed this observation.[64] These mills may, however, have to install sophisticated water treatment systems to produce high-quality products at a zero-discharge mill.[65]

2. Semichemical Pulping Processes

A statistical analysis shows that the effluent flow from recovered fiber pulping processes is significantly lower than the flow from SC-independent semichemical pulping processes. We present the individual mill data in **Table E-2** and the statistical analysis in **Table E-9**.

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.[66] The employ secondary treatment systems to remove over 95% of the BOD from the raw effluent. For environmental impacts for BOD 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."[67] These limits keep BOD discharges below the assimilative capacity to protect aquatic communities.

In **Table 15**, we present a summary of the available data on BOD loadings in the final effluent associated with unbleached kraft , and SC-independent semichemical pulping processes. NCASI scientists have shown that there is no statistical difference in the BOD loading in the final effluent of recovered fiber pulping processes and unbleached kraft or SC-independent semichemical pulping processes.[68]

Table 15: Estimates of BOD in the final effluent (kg/ADMTFP)

Process	**% OCC**	**Mean**	**Range [2] low**	**Range [2] high**	**Number of mills**	**Reference**
Unbleached kraft [1]	0%-39%	1.69	0.73 (15%)	2.54 (0%)	14	NCASI 1993[59]
Unbleached kraft		1.79	0.24	2.80	20	EPA 1993[57]
Semichemical	2% - 75%	1.10	0.28 (23.7%)	2.44 (68%)	12	NCASI 1993[59]
Semichemical		2.09	0.37	9.41	15	EPA 1993[57]

[1] BOD loading in final effluent for unbleached kraft pulp mills that produce over 500 metric tons per day of product.
[2] Recycled content as a percent of fiber weight follows the estimate of mean BOD loading.

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 stationery 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.[69] Mills use primary treatment to remove all solids that might settle from the effluent. Treated mill effluent contains minimal amounts of settleable solids.[70]

We present a summary of the data on mean TSS loading in the final effluent of unbleached kraft pulp, semichemical pulp and recovered mills in **Table 16.**

Table 16: Estimates of TSS in the final effluent (kg/ADMTFP)

Process	% OCC	Mean	Range [2] low	Range [2] high	Number of mills	Reference
Unbleached kraft [1]	0%-39%	3.17	1.48 (12.8%)	5.95 (22%)	15	NCASI 1993[59]
Unbleached kraft		2.93	0.68	6.06	20	EPA 1993[57]
Recovered fiber		0.87	0.17	4.02	28	EPA 1993[57]
Semichemical	2% - 75%	1.95	0.45 (23.7%)	3.49 (68%)	12	NCASI 1993[59]
Semichemical		3.00	0.55	8.80	15	EPA 1993[57]

[1] TSS loading in final effluent for bleached kraft pulp mills that produce over 500 metric tons per day of product.
[2] Recycled content as a percent of fiber weight follows the estimate of mean TSS loading.

A statistical analysis of the EPA data showed that the mean TSS loadings in the final effluent of mills producing recovered fiber is significantly lower than the TSS loading in the final effluent of mills that produce unbleached kraft pulp. Statistical analysis also demonstrated that the mean TSS loading in the final effluent of the unbleached kraft pulp mills surveyed by NCASI and EPA is not significantly different. We present this analysis in **Table E-9**.

A statistical analysis of the EPA data shows that the mean TSS loading in the final effluent of recovered fiber medium mills is significantly lower than the mean TSS loading in the final effluent of SC-independent semichemical medium mills. We present this analysis in **Table E-9** in Appendix E.

E. Summary

- **Effluent flow and the TSS loading in the final effluent are statistically lower for the recovered fiber pulping processes than for either unbleached kraft or SC-independent semichemical pulping processes.**

- **There is no statistical difference in the BOD loading in the final effluent for the three pulping processes.**

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

A. Scope

In this section we examine the quantity of the solid waste associated with the production of unbleached kraft, semichemical and recovered fiber pulp. We also examine the effect of using recovered fiber in corrugating packaging 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 found no published information on environmental issues associated with sludge from mills that produce pulp for corrugated packaging. Unlike sludge generated during bleached kraft pulp production, one would not expect sludge from unbleached kraft pulp mills to contain dioxins because dioxins are generated during the bleaching process, and these pulps are not bleached. Sludge from non-deinked recovered fiber mills should have low concentrations of heavy metals because unprinted OCC makes up the bulk of the raw material.

B. Sources

A 1992 NCASI study provides information on the total quantity of solid waste generated by different types of mills.[71] NCASI's characterization of the wastes from mills using recovered fiber provides more detailed information on the solid waste generated at mills that use recycled fiber.[72]

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.[73] Currently, primary and secondary sludge from wastewater treatment systems account for the largest portion of the solid waste stream.[74] 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,[75] 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.[76] Mills usually generate larger quantities of primary sludge.[77]

1. Unbleached Kraft Pulp Mills

We present data on solid waste generation for unbleached kraft pulp mills in **Table 17**, and more detail on the calculation of total sludge quantity in **Table E-4** of Appendix E.

Table 17. Solid waste from unbleached kraft pulp mills (kg/ADMTFP)

Solid Waste	Mean	Std. Dev.	No. of Mills
Sludge			
Primary	24.0	16.8	23
Secondary	7.5	3.4	8
Dredged	8.0	1.3	14
Total [1]	**32.0**		
Misc. Solid Waste [2]	**43**	**48.6**	**27**
Total Solid Waste	**91**	**61.0**	**27**

[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. Recovered Fiber Pulp Mills

We present data on total solid waste generated by recovered fiber pulp mills in **Table 19** and more detail on the calculation of the total sludge quantity in **Table E-4**.

Table 19. Solid waste from recovered fiber mills (kg/ADMTFP)

Solid Waste	Mean	Std. Dev.	No. of Mills
Sludge			
Primary	33.0	53.5	8
Secondary	7.0		1
Dredged	5.5	3.8	2
Total [1]	**39**		
Misc. Solid Waste [2]	**66.0**	**75.2**	**13**
Total Solid Waste [3]	**105**	**109.4**	**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. The difference between the total and the miscellaneous solid waste and the sludge is ash from the recovery furnace and other boilers.

3. Semichemical Pulp Mills

We present data on total solid waste generated by SC-independent semichemical pulp mills in **Table 18** and more detail on the calculation of the total sludge quantity in **Table E-4**.

Table 18. Solid waste from semichemical pulp mills (kg/ADMTFP)

Solid Waste	Mean	Std. Dev.	No. of Mills
Sludge			
Primary	18.5	17.2	7
Secondary	18.5	15.2	5
Dredged	4.0	3.5	4
Total [1]	**33**		
Misc. Solid Waste [2]	**45.5**	**81.9**	**8**
Total Solid Waste	**133**	**117.0**	**8**

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

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

A statistical analysis of the quantities of primary sludge generated by 23 unbleached kraft pulp mills and the 8 recovered fiber 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 27 unbleached kraft mills and 13 recovered fiber mills. We present the results of this analysis in **Table E-10** of Appendix E.

A statistical analysis of mean primary sludge generation rates at 8 semichemical mills and 13 recovered fiber mills shows no significant difference in the quantities of primary sludge generated at these types of mills. There is also no statistical difference in the mean quantity of solid waste generated at medium mills. We present the statistical analysis in **Table E-10**.

D. Recovered and Solid Waste Generation Associated with the Manufacture, Use and Disposal of Corrugated Packaging

When we examine the generation of solid waste in terms of the manufacture, use and disposal of paper products, a different picture emerges. Producing a ton of recovered fiber from OCC removes discarded corrugated boxes as well as the sludge and other solid waste generated during the production of the virgin pulp that the recovered fiber replaces. Because there is no statistical difference in the amount of solid waste generated during the production of a ton of virgin or 100% recycled linerboard, producing a ton of recovered fiber from OCC removes 1.07 tons of material from the waste stream. This estimate assumes a 93% yield for recovered fiber pulping.[78]

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.[79] Assuming a density of 0.4 tons/cubic yard for discarded OCC, producing one ton of recovered fiber removes 2.7 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.

E. Summary

- **Statistical analysis of the quantities of solid waste generated by unbleached kraft mills and recovered fiber mills indicates that there is no statistical difference in the quantity of total solid waste generated at these mills.**

- **Statistical analysis of the quantities of solid waste generated by semichemical mills and recovered fiber mills indicates that there is no statistical difference in the quantity of total solid waste generated at these mills.**

- **Using a ton of recovered fiber to produce linerboard or corrugating medium removes 1.07 tons or 2.7 cubic yards of material from the solid waste stream.**

VIII. ENVIRONMENTAL COMPARISONS OF VIRGIN AND 100%-RECYCLED PACKAGING GRADES

A. Scope

In this section we summarize the environmental comparisons of the corrugated packing grades. These comparisons compare the magnitude of energy consumption and releases to the environment associated with the production of virgin and 100%-recycled linerboard and corrugating medium.

B. Comparison I: Virgin and 100%-Recycled Linerboard

Figure 1 and **Table 2** present the average and the ranges, respectively, for energy consumption and releases to the environment generated during the production of these grades of linerboard.

On average, producing virgin linerboard requires about 27% less purchased energy than does producing 100%-recycled linerboard. This difference in purchased energy consumption leads to increased sulfur dioxide emissions and fossil-fuel based carbon dioxide emissions associated with the production of 100%-recycled linerboard. Nitrogen oxide emissions, the BOD loading in the final effluent and the generation of total solid waste are about the same.

Producing 100%-recycled linerboard results in significantly lower emissions of particulates and total carbon dioxide emissions than does producing virgin linerboard. Process-related air emissions are also significantly lower. Effluent flow and the TSS loading in the final effluent of 100%-recycled linerboard mills is significantly lower than that of virgin linerboard mills.

C. Comparison II: Virgin and 100%-Recycled Corrugating Medium

Figures 2a-b and **Table 2** present the average and the ranges, respectively, for energy consumption and releases to the environment generated during the production of these grades of corrugating medium.

On average, producing 100% recycled medium results in lower energy consumption and releases to the environment for all parameters except BOD and total solid waste generation than does producing semichemical medium. There is no statistical difference in the BOD loading in the final effluent or total solid waste generation for the two medium grades.

IX. ENDNOTES

[1] Terry Campbell, manager, Technology Support, International Paper, personal communication, February 24, 1995.

[2] American Forest & Paper Association, *Pulp, Paperboard, Pulp Capacity and Fiber Consumption 1992 - 1996: 34th Annual Survey* (Washington: American Forest & Paper Association, September 1993), p. 26.

[3] NCASI, "Characterization of Wastes and Emissions from Mills Using Recycled Fiber," *Technical Bulletin No. 613*, September 1991, p. 21.

[4] Richard Storat, vice president, economics and materials, American Forest & Paper Association, "Comments on White Paper No. 10B," letter to Linda Fransen, Perseco, 5 June 1995, 4.

[5] Mark Weintraub, Willard Mies, Debra Garcia, Rob Galin, Carl Espe, Noel DeKing, Sophie Wilkinson, Marta Dils, Jim McLaren, William McClanahan, Virginia Stefan, "Corrugating Medium," 1994 North American Pulp and Paper Factbook (San Francisco: Miller Freeman Inc., 1993), p. 261-262.

[6] Richard Storat, letter to Linda Fransen, 4.

[7] NCASI, "Volatile Organic Emissions from Pulp and Paper Mill Sources Part IX: Semichemical mills," *Technical Report No. 683*, November 1994.

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

[9] *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.

[10] 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.

[11] 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.)

[12] 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).

[13] 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).

[14] 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 1980 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 1990 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.

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

16 Kenneth Gilbreath, *Chesapeake Paper Products Company's Use of LCA for Manufacturing Process Improvements.*

17 David Knoll, Jacob Sirrine Inc., telephone interview, 6 October 1995.

18 NCASI, "Volatile Organic Emissions from Pulp and Paper Mill Sources Part IX: Semichemical Mills, *Technical Bulletin No. 683*, September 1994, p.8.

19 We have assumed that the low energy consumption mills burn 10% of the weight of dry-wood as hog-fuel, while the high energy consumption mills burn 5% of the weight of dry-wood as hog-fuel. K.R. Gilbreath, et. al., "Background Paper on Energy Efficiency in the Pulp and Paper Industry," p. 52.

20 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.

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

22 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.)

23 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.

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

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

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

27 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.

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

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

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

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

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

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

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

[35] Ibid., 530 - 531.

[36] 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.

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

[38] 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.

[39] 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.

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

[41]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.)

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

[43] NCASI, *Technical Bulletin Nos. 675 - 683*.

[44] Ashok Jain, Robert Crawford, David Rovell-Rixx, David Dillard and Steven Jett, "Impact of Water Reuse on Chemical Pulp and Paper Mill Emissions," *Proceedings of the 1995 Non-Chlorine Bleaching Conference* (San Francisco: Miller Freeman, Inc., March 1995).

[45] U.S. EPA, *Regulatory Impact Assessment,* 7-8.

[46] 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.

[47] U.S. EPA, *Regulatory Impact Assessment,*. 7-11.

48 Richard Storat, “Comments on White Paper No. 10C,” letter to Linda Fransen, Perseco, 5 June 1995,12.

49 NCASI, “Volatile Organic Emissions From Pulp and Paper Mill Sources Part IX: Semi-Chemical Mills,” *Technical Bulletin No. 683*, November 1994, 50, 53, 56.

50 Ibid.

51 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.

52 Increasing the recycled content of linerboard or medium at mills that produce unbleached kraft pulp or semichemical pulp does not appear to affect the magnitude of the BOD, TSS, and COD loadings in the final effluent of these mills. NCASI studied 15 unbleached kraft linerboard mills and 12 semichemical medium mills in its 1993 survey to see if there was a correlation between the loading of BOD, TSS and COD in the final effluent and the amount of OCC used in the final product. [52] They found no correlation between recovered fiber content and these loadings for unbleached kraft linerboard mills that incorporate up to 39% recovered fiber into the linerboard or for semichemical medium mills that incorporate up to 68% recovered fiber into medium. This finding indicates that the contribution of BOD, TSS and COD from the OCC pulping process is similar to that of the virgin pulp. If the loadings from the OCC were lower, the BOD loading should decrease as the percentage of recycled content increases. Differences in technology and operating processes may account for the significantly difference BOD, TSS and COD loading between recovered fiber mills and virgin mills. NCASI, "The Effects of Recovered Fiber Reuse on Raw and Final Effluent BOD, TSS, and COD Loads from Unbleached kraft and Semi-Chemical Mills," *Technical Bulletin No. 670*, July 1994.

Given these findings, the work of Barton and Ahearn (See endnote 56) that support the finding for BOD loading for 100%-recycled linerboard and corrugated medium mills, and the sparseness of COD data for the recovered fiber processes, we decided to eliminate this parameter from the evaluation. The NCASI work suggests that there would be no difference in the COD loadings associated with recovered fiber, semichemical and unbleached kraft pulping processes. Additional data needs to be collected from recovered fiber mills to confirm this observation.

53 U.S. EPA, *Development Document for Proposed Effluent Limitations Guidelines*, p. 5-9.

54 NCASI, " Characterization of Wastes and Emissions from Mills Using Recycled Fiber," *Technical Bulletin No. 613*, September 1991, p. 6.

55 D.A. Barton and P.S. Ahearn, “Effects of Recovered Fiber Furnish and Final Product Grade Structure on Wastewater Characteristics at Recycled Paper Mills,” *TAPPI Proceedings of the 1995 International Environmental Conference* (Atlanta: TAPPI Press, 1995), 233-240.

56 NCASI, *Technical Bulletin No. 670*, 5.

57 U.S. EPA, *Development Document for the Proposed Effluent Limitations Guidelines*, 6-48-6-49, 9-81-9-84.

58 NCASI, *Technical Bulletin No. 613*, p. 6.

59 NCASI, *Technical Bulletin No. 670*.

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

61 Jerry W. Garner, "Water, water everywhere and not a drop to waste," *Papermaker*, **56**, October 1993, p. 18; NCASI, *Technical Bulletin No.* 603, 3.

[62] U.S. EPA, *Development Document for the Proposed Effluent Limitations Guidelines*, 6-48-6-49.

[63] Ibid., 6-12.

[64] Jeffrey Walch, vice president operations, Green Bay Packaging, technical visit, October 6, 1993.

[65] Richard Storat, "Comments on White Paper No. 10B,"letter to Linda Fransen, 12.

[66] 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.

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

[68] NCASI, *Technical Bulletin No. 670.*

[69] U.S. EPA, *Regulatory Impact Assessment of Proposed Effluent Guidelines and NESHAP*, pp. 7-27 - 7-28.

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

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

[72] NCASI, *Technical Bulletin No. 613*, 35.

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

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

[75] A. Springer, *Industrial Pollution Control*, 484.

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

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

[78] Neil McCubbin and Jens Folke, "Is Deinking Environmentally Preferable?" *TAPPI Proceedings of the 1994 International Environmental Conference* (Atlanta, GA: TAPPI Press, 1994), 327.

[79] 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.