BACKGROUND DOCUMENT B

Background Data
Submitted by the Tellus Institute

PREFACE TO THE TELLUS REPORT ON METHODOLOGY

The attached report was prepared by the Tellus Institute to describe its methodology for estimating the amounts and types of energy consumed in raw materials acquisition and manufacturing of eight different materials. The materials considered were: newspaper, office paper, corrugated cardboard, aluminum cans, steel cans, and three types of plastic (HDPE, LDPE, and PET). For each material, Tellus provided separate estimates for the amount of energy consumed when virgin inputs are used, and the amount of energy used when recycled inputs are used.

The Tellus report consists of an introductory section and a section on each material. The sections for the respective materials show (1) how Tellus estimated the amount and types of energy consumed in manufacturing the material (including flow diagrams and data tables), and (2) what data sources were used in making the estimates.

The introduction to the Tellus report discusses the sources that Tellus used in its analysis. The major source was a report that Tellus had previously prepared for the New York State Energy Research and Development Authority (NYSERDA). In its discussion of this report, Tellus describes the methodology and limitations of the NYSERDA study. In addition, Tellus notes that in its analysis it also used standard reference works, primarily U.S. government publications.

Note that when modeling the effects of recycling on production, the energy difference between virgin and recycled production must be divided by the number of tons of recyclables required to produce one ton of materials from recycled inputs. There are process losses during processing at a MRF, and some of the weight of the recyclables consists of water, paints, labels or other materials. These divisors were calculated and transmitted to ICF separately.

System Boundaries

The chain of impacts associated with a production system may be traced far upstream and downstream in the product lifecycle. The NYSERDA framework set four basic boundary conditions:

- Exclude Energy Value of Raw Materials
- Stop at Energy Convergence Point Rather than the Final Manufacturing Step
- Stop at One Step Back
- Include only if Greater than 2.5% of Material Inputs

Exclude Material Energy: The energy value of raw materials, or "inherent energy," represents the energy value of materials themselves - the oil and gas embodied in plastics, the wood embodied in paper, etc. In the NYSERDA project, it was decided not to include material energy because of the study's focus on manufacturing processes and process steps.

Energy Convergence Point versus Final Manufacturing Step: Since NYSERDA's interest was in calculating the difference in energy use between virgin and recycled manufacturing systems, in some cases NYSERDA chose to model the production of an intermediate product (such as molten steel or LDPE pellets), rather than final products, such as steel cans or LDPE containers. This occurred in cases where no significant difference in energy use exists for the two systems in steps subsequent to intermediate product manufacturing. The energy convergence concept applies to both process and transportation energy.

The NYSERDA methodology does not apply adequately to source reduction, since when a material is source reduced, energy use both during the modeled steps and the final manufacturing steps is avoided. Since this project considered source reduction effects in addition to recycling effects, Tellus was asked by ICF to provide estimates of the energy used during final manufacturing steps. We were unable to obtain directly energy use during the final manufacturing steps from manufacturers, associations, or reference works. We were also unable to obtain estimates of final transportation energy. Energy use and production data from the most recent U.S. Government Census of Manufacturers (1987) were used as a proxy for the energy use during the final manufacturing steps. This information is nearly one decade old, is based on voluntary reporting rather than systematic data collection, is aggregated at the 4-digit SIC code level, and only shows electricity use, and not total energy use. It was our opinion from the beginning that the calculations made based on the Census of Manufacturers information would be replaced by better data as they became available. After the October 27th meeting it was decided that Franklin Associates data would replace Tellus data for aluminum, LDPE, HDPE and PET, although Tellus offered to have all of its final manufacturing data replaced by Franklin Associates data. Tellus data remained for newsprint, corrugated boxes, and steel cans (NYSERDA included final manufacturing data for printing and writing paper). We were not able to obtain the Franklin information to include in this report; the process spreadsheets therefore show only Tellus data even for the materials where Franklin data were used.

One Step Back: Energy inputs were counted for processes one step back from the main production chain, but not for processes two or more steps back. For example, the energy inputs associated with mining raw

Methodology, Flow Diagrams and Data Listings

Introduction

Tellus' study for the New York State Energy Research and Development Authority, entitled *Energy Implications of Solid Waste Management Systems* (hereafter NYSERDA[1]), incorporated two types of information. A vital part of the study was its peer review panel, called the Technical Advisory Group (TAG). The TAG included industry representatives from all of the industries studied, as well as government and academic representatives. The TAG met with the study's authors to discuss methodological issues, reviewed drafts, and provided information to the authors wherever possible. Much of the information used in the report came from the TAG. However, when the representatives communicated with Tellus, they did not necessarily cite detailed sources of their information. We cannot report the number of data points, or the age of the data, that the TAG members provided to Tellus. Attempting to obtain that information was beyond the time and scope of this project.

A second source of information was standard reference works, primarily US government publications. These publications also do not necessarily cite the number of sources relied upon or the age and quality of data. NYSERDA's authors realized that the information in these publications did not necessarily reflect current industry practice. Information from reference materials was submitted to the TAG as part of the peer review process, and TAG members were asked to comment on the data and provide more recent information wherever possible. In many cases, TAG members were able to provide energy use information which better reflected current practices. However, in some cases they were not able to do so; in those cases NYSERDA used the reference information.

NYSERDA Modeling Approach[2]

The objective of the NYSERDA project was to develop energy coefficients for recyclable materials. These coefficients embody the difference between the energy required to manufacture an intermediate or final product from virgin materials and the energy needed to manufacture the same intermediate or final product from recycled materials. This energy coefficient could then be used to estimate the energy impact associated with the diversion of each ton of recyclables from the waste stream.

To perform the comparative analysis, NYSERDA made the simplifying assumption that recyclable materials extracted from the waste stream to produce a certain quantity of new product displace an equal quantity of virgin-based product. This means that the virgin raw materials required to produce that quantity of product will not be mined, processed, transported to a manufacturing plant, or processed into product.

NYSERDA was concerned primarily with the effects of increased recycling on production systems, and was not concerned with the effects of source reduction. To model source reduction for this report, we assumed that each ton of material source reduced displaced one ton of virgin material. The energy coefficient for source reduction, therefore, is equal to the energy required to manufacture an intermediate or final product from virgin materials.

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[1] Throughout the document, "NYSERDA" or "NYSERDA's authors" refers to the work performed for the *Energy Implications* report. "We, " "Tellus" or "our" refers to work performed for ICF as part of this report.

[2] The text of the following sections is based upon Tellus Institute, *Energy Implications of Integrated Solid Waste Management Systems*, prepared for the New York State Energy Research and Development Authority, April 1994, Section 3.

materials for the main production sequence were included, whereas the energy inputs associated with the production of explosives or mining equipment were not.

Most manufacturing processes require the use of additives in addition to the major raw material. In applying this rule to additives, NYSERDA considered the energy inputs associated with the production of additives, but not those associated with additives needed for the manufacture of a direct additive. For example, chlorine (an additive in paper production) production requires sulfuric acid as an additive. By the one step back rule, the energy inputs associated with sulfuric acid production were not included when assessing the energy requirements of chlorine.

In applying the one step back rule to electricity production, NYSERDA considered the energy required to make energy - the Btu value of the fuel input versus the Btu value of the energy output. During the October 27th meeting involving Tellus, Franklin Associates, ICF and EPA, it was decided, for consistency, to use a common set of Btu values for fuels which incorporated this "precombustion" energy.

Greater than 2.5% Material Inputs: Additives were included in the production system if the additive comprises more than 2.5% of the total material input required to manufacture a final/intermediate product. NYSERDA used a cut-off since many additives are used in very small quantities, and it was assumed that the energy required to produce these additives would also be small compared with the total energy required.

Other assumptions used in the development of the energy requirements of virgin and recycled materials include:

- In the comparison of virgin and secondary systems, NYSERDA assumed closed loop recycling of materials diverted for the waste stream.
- Electricity was assumed to be generated from a generic national average mix.
- Where technically possible, energy requirements for virgin production systems were calculated using 100% virgin raw materials, and energy requirements for secondary production systems were calculated using 100% recycled materials. Production of steel and virgin glass are the exceptions.
- Indirect energy requirements for manufacturing processes, such as operation of pollution control devices, were not included in the energy analysis.
- In the transportation analysis, bulk densities for all materials were assumed to be the same.
- When a manufacturing processes creates coproducts in addition to the primary product (such as oil processing as part of virgin plastics manufacturing), energy use was allocated to the products according to weight.

NYSERDA Transportation Methodology

Virgin Manufacturing Systems: Transportation in virgin manufacturing systems involves a complex network linking raw materials mining, intermediate, and ancillary materials production and the final (point of energy convergence in this case) production process. Some virgin manufacturing systems involve the production of intermediate materials at locations different from those of the final product manufacturing process.

To calculate the energy impacts associated with materials transport for each production process, three variables must be quantified:

- The average distance each material travels
- The mode of transport for each material

- The fuel efficiency for each mode[3]

For each commodity examined there are many, often dispersed locations where raw materials are mined and processed, where intermediate and ancillary inputs are produced, and where the main production process takes place.

Each transport link has an origin and a destination. To estimate transport distances for materials used in virgin manufacturing, NYSERDA used census data and statistical surveys to determine the dominant geographic routes along which each material input flows. The dominant route was defined as the route from the nearest geographic concentration of mining of each raw material or intermediate/ancillary product manufacture -- the origin -- to the dominant locations of the main production process in the United States -- the destination.

The methodology consists of three steps. First, NYSERDA identified the predominant locations of intermediate and final product processing facilities. To define the dominant transportation routes of materials for each production process, NYSERDA identified the regions accounting for approximately 70% of final product production, although a 65% target was applied in instances where accounting for 70% would have added unwarranted complexity to the analysis. Second, NYSERDA matched to those destinations the geographical origins of either raw materials or intermediate products, based on geographic proximity. The methodology assumed that intermediate and final processing plants draw their raw materials and intermediate products from the closest source.

In the final step NYSERDA calculated actual transportation energy use. The contributing regions were normalized to 100%, to make the analysis representative of the entire industry. Then, the percentage of normalized material inputs traveling along each route was multiplied by the distance between the origin and the destination, and by the energy intensity of transportation. Summing the energy use per route across all routes yielded the total transportation energy, in MMBtu/ton transported.

<u>Recycled Manufacturing Systems:</u> Capturing the energy impacts of transportation in recycling systems involves quantifying the distance traveled, method of transport, and fuel efficiency for each recycled material, just as in virgin systems.

Recyclables are collected at MRFs, redemption centers, and other recycling facilities throughout the nation; there are numerous, dispersed origins of secondary materials. NYSERDA estimated the distance traveled by recycled materials based upon the number of secondary production and processing facilities in the United States.

NYSERDA began with the assumption that the distance recyclable materials had to travel to reach a manufacturing facility was inversely proportional to the number of facilities. NYSERDA developed guidelines for assigning a travel distance to recyclable materials according to the number of manufacturing facilities in the United States using them. The distance estimates were:

- 5 facilities or less:	750 miles
- 6 to 15 facilities:	500 miles

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[3] Energy intensity of transportation (Btu per ton-mile) of rail, truck and ship taken from The Aluminum Association, "Energy Content in Aluminum Cans: Historical Performance and Future Potential," June 29, 1984, page 13. Energy intensity of ship transportation taken from the U.S. Department of Energy, *Energy Technology Characterizations Handbook: Environmental*

- 16 to 99 facilities: 250 miles
- 100 or more facilities: 100 miles

Once again, distances traveled were multiplied by the energy intensity of transportation, based upon the transportation type.

Recyclables Acquisition Energy: One final category of energy use in secondary manufacturing systems, not accounted for in the transportation methodology, is the energy required to collect and process recyclables. NYSERDA analyzed four solid waste management scenarios for New York City using its WastePlan© software. For each scenario, WastePlan estimated the quantity of recyclables collected, by type, and the total quantity of fuel used to collect the recyclables. Dividing the total energy content of the fuels used by the total quantity of recyclables collected yielded the average energy used per ton of recyclables collected, which was 0.07 MMBtu/ton. All of the collection energy is diesel fuel. Tellus also obtained information on energy used in two types of recycling facilities - commercial paper processors and MRFs. Energy use varied between 0.23 - 0.34 MMBtu/ton of recyclables collected; the average was 0.29 MMBtu/ton recyclables collected. Of that energy, 0.25 MMBtu/ton was electricity and 0.04 MMBtu/ton was diesel. The recyclables acquisition energy, therefore, was set at 0.36 (0.07 + 0.29) MMBtu per ton of recyclables collected. This recyclables acquisition energy is shown in each of the process spreadsheets for recycled materials.

Report Format

Below we present data for the following materials:

- Newspaper
- Aluminum Cans
- Office Paper
- Steel Cans
- Corrugated Boxes
- LDPE
- HDPE
- PET

ICF used our office paper information as a proxy for tissue paper, and our corrugated box information as a proxy for folding boxes; since NYSERDA did not examine these materials, we have not presented data for them separately here. Since NYSERDA did not develop data for corrugated boxes directly, we used the average of the energy values for NYSERDA's linerboard and folding boxboard systems.

For each material, we have provided the following data, for both recycled input and 100% virgin manufacturing:

- A flowchart showing the extent of the lifecycle and major processing steps considered in estimating the energy and non-energy data for manufacturing the material.
- A description of the fundamental raw material and manufacturing process.
- A listing of the data elements used to estimate the quantities and types of fuels used for both the manufacturing process and for transportation. That listing consists of a spreadsheet showing the

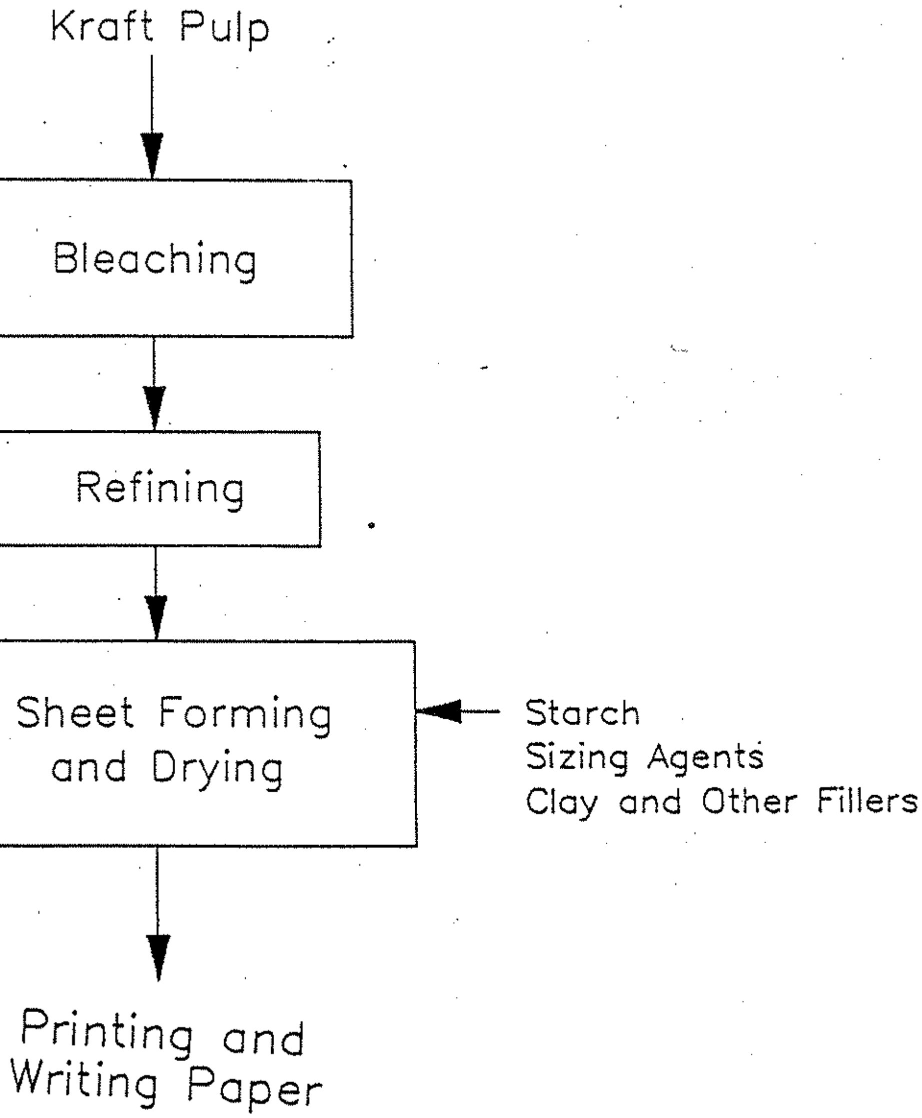
materials and energy requirements for each process step, and a discussion of those steps, which shows data sources and assumptions, on the following pages. These listings are in the same format for each material. In some cases, despite our review of the data sources, we were not able to fully reconstruct the assumptions that were made.

There is one appendix; kraft pulp production is the first stage in the manufacture of several paper types and is complex enough to merit a separate listing; we show the spreadsheet, as taken from the NYSERDA document.

For corrugated boxboard manufacture, we present only the linerboard flowchart and process description, as the processes for linerboard and folding boxboard production are quite similar.

Office Paper

VIRGIN PRINTING AND WRITING PAPER PRODUCTION



Virgin Printing and Writing Paper Production

Virgin printing and writing paper is produced using the following processes: Pulpwood Harvesting; Debarking; Chipping; Kraft Pulping; Bleaching; Refining; and Sheet Forming & Drying for use in the final product.

Pulpwood Harvesting Typically trees are severed from the stump by one person using a chain saw. The trees are then skidded, or dragged, by a tractor to a truck road. At the roadside they are cut into bolts (i.e. transportable sized logs) and loaded onto a truck with either a crane, hydraulic loader or a fork-lift attachment on a tractor. The wood is commonly trucked directly to a mill.

Debarking When the wood arrives at the mill it is usually stored for days or months in a woodyard, and then loaded onto a mechanized conveyor system or water flume for transport to the debarker. Mechanical conveyance, the more common transport mode, requires washing of the logs before debarking to reduce equipment wear.

Debarking is generally done by one of three methods, dry debarking by friction, wet debarking by friction, or hydraulic debarking. The process used depends on the size of the logs handled. Since most pulpwood used today is small in diameter, most debarking is done in dry drum barkers. A dry drum barker consists of a slotted drum with internal staves that remove the bark from the pulpwood as the drum rotates. The bark sifts out of the slots and the debarked logs travel out the end of the drum and fall onto a conveyor belt.

Chipping Debarked logs or sawmill wastes are cut into chips by means of a rotating flywheel face with bars which act as cutting blades. The chips are then screened, and the screened out fines are sent to a boiler for combustion.

Kraft Pulping Wood consists of hollow cellulosic fibers and other cells cemented together by lignin and hemicelluloses into a rigid and strong material. Pulping separates the wood into its cell components; paper and paperboard are formed when these cells are reunited in a mat formation. The quality of the pulp and subsequently, the quality of the paper or board required, determines the pulping process used.

In chemical pulping, cellulose fibers are extracted from wood by the chemical dissolution of lignin which binds the fibers together. The kraft, or sulfate pulping process involves the cooking or digestion of wood chips at high temperature and pressure in a white liquor, a water based solution of sodium hydroxide (NaOH) and sodium sulfide (Na_2S). The name sulfate comes from the makeup chemical, sodium sulfate, that is used as the source of the sulfide ion. Sodium sulfate used in the kraft pulping process as a source of sulfide ions, is produced from either a natural sodium sulfate deposit, or a sodium sulfate solution available as a byproduct of various manufacturing processes. Sodium Hydroxide (and chlorine) are produced from the electrolysis of salt, usually in diaphragm cells. Salt is mined from underground deposits by pumping water into the deposit and forcing the brine to the surface.

The cooking process takes place in a vessel called a digester, which can be either batch or continuous in design. From the digesters, the pulp is sent to the brown stock washers (pulp washers) where the black liquor (spent cooking liquor) is washed from the pulp with hot water. The spent wash water from this process is called weak black liquor, and is sent to the black liquor recovery system. The black liquor recovery process is designed to a) remove the water from the weak black liquor via evaporator systems, b) combust the residual organic materials (now called strong black liquor) in a recovery furnace, and c) convert the sodium sulfate in the strong black liquor to sodium sulfide.

The kraft white liquor system is designed to convert the inorganic smelt from the bottom of the recovery furnace into reusable white liquor for kraft pulping. The smelt materials go through a series of dissolving, clarifying, washing, combustion, and recovery steps for either reuse in the process or disposal. One final overflow mixture is the white liquor and is used again in the pulping process.

The pulp proceeds on to screening and cleaning, bleaching and paper production.

Bleaching and Refining Pulp from the kraft process is brown because of the presence of lignin and other deeply colored wood constituents and pulping chemicals. Lignin removal during the bleaching process enhances both the brightness and strength of pulps.

Kraft pulps are generally bleached in three or more stages, starting with an acidic chlorine stage (chlorine reacts with and solubilizes lignin and other colored bodies), followed by an alkaline extraction stage using a solution of sodium hydroxide (sodium hydroxide extracts reacted lignin and other colored bodies form pulp), and followed still by one or more subsequent stages using chlorine dioxide (pulp brightener), sodium or calcium hypochlorite (pulp brightener), and additional caustic extraction stages.

The bleaching and extraction reactions take place in bleaching/extraction retention towers where the pulp and bleaching chemicals are held in contact to allow the bleaching reaction to take place. At the completion of each bleach stage the pulp is washed, usually on vacuum drum filters, to remove the products of the bleaching reaction and spent chemicals. A final mechanical refining step, through cutting and maceration, converts "raw" fiber into a form suitable for papermaking.

Chlorine and caustic are generally purchased as a liquid; and chlorine is vaporized at the mill before introduction into the chlorine tower. Chlorine dioxide is manufactured at the mill from sodium chlorate, either sulfuric or hydrochloric acid, and either sulfur dioxide, methanol or sodium chloride, by one of a number of different processes.

Sheet Forming & Drying Forming is the actual conversion of pulp into sheets of paper. The formation of paper and paperboard occurs in three steps: first, a web of fiber is formed from a fiber/water suspension on a paper machine wire. Often, additives such as sizing (for final product water resistance), clay (for opacity and brightness), and starch (for strength) have been added to this fiber/water suspension. Second, water is pressed out of the web, and last, the remaining water is driven off by heat. While there are numerous types of paper machines used today, the two most common designs are the fourdrinier and cylinder paper machines. The fourdrinier machine can be used to manufacture a variety of paper grades and lightweight boards.

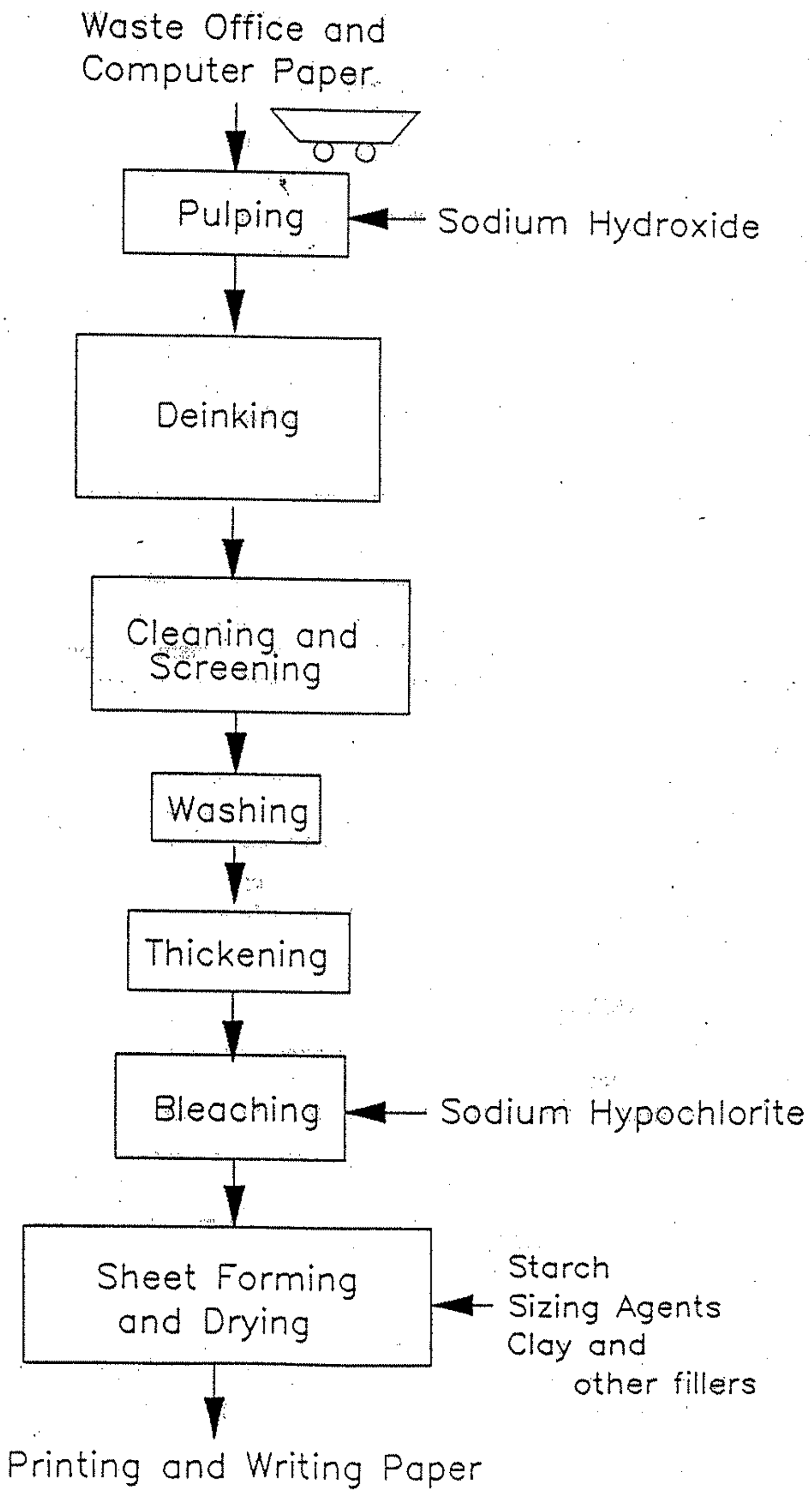
The fourdrinier machine consists of a moving, endless plastic or bronze screen, supported by a table, which carries the sheet through forming, pressing and then drying stages. The stock, containing only about 0.5% fiber and filler (the balance being water) is pumped into a headbox, which distributes the stock across the width of the paper machine, and then flows out onto the screen. Suction devices below the screen pull the water, and some solid material (particularly smaller fibers and fillers) through the wire and into a collection system. This mixture is called "whitewater", the components of which are often recycled within the process.

The fiber web, atop the screen, is picked up by a moving felt which transfers the web into the press section. At the press section, further dewatering takes place as the web and felt pass between a series of paired press rolls, pushed together, much like an old-fashioned clothing wringer. When the sheet leaves the press section and enters the dryer section, it contains approximately 65% water. The dryer section consists of a long progression of steam-heated drying cans, or cylinders, which transfer heat to the sheet and drive off most, but not all of the remaining moisture. When the paper or board is reeled up at the end of the machine, it usually contains about 6% water.

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN PRINTING/WRITING PAPER PRODUCTION

PROCESS **Material Output** Process/Transportation Energy	Units	Units /ton office paper	MMBtu Equivalents/ton office paper
KRAFT PULPING [1]			
Pulp (bone dry)	**pounds**	**1994**	
Fuels:			
Gasoline	gallons	2	0.26
Diesel	gallons	2	0.21
Oil	gallons	10	1.50
Steam	pounds	6729	9.42
Electricity	kWh	78	0.82
Transportation-Diesel [2]	gallons	7	1.02
CHLORINE PRODUCTION [3]			
Chlorine	**pounds**	70	
Fuels:			
Steam	pounds	32	0.05
Electricity	kWh	62	0.66
Transportation-Diesel [4]	gallons	0.003	0.0004
CAUSTIC PRODUCTION [5]			
Caustic	**pounds**	115	
Fuels:			
Steam	pounds	516	0.72
Electricity	kWh	84	0.89
Transportation-Diesel [6]	gallons	0.004	0.0006
KRAFT PULP BLEACHING [7]			
Bleached Pulp (bone dry)	**pounds**	**1884**	
Fuels:			
Steam	pounds	2355	3.30
Electricity	kWh	135	1.41
PRINTING/WRITING PAPER PRODUCTION [8]			
Office Paper	**pounds**	**2000**	
Fuels:			
Steam	pounds	5357	7.50
Electricity	kWh	172	1.80
FINAL MANUFACTURING ELECTRICITY [9]			0.00
Subtotal - Process Energy			**28.53**
Subtotal - Transportation Energy			**1.02**
Total Energy Requirements			**29.55**

RECYCLED PRINTING AND WRITING PAPER PRODUCTION



Recycled Printing and Writing Paper Production

Once waste printing and writing paper is received at the paper mill, it must be repulped before it can be used in the papermaking process. The wastepaper pulping process involves several steps, including Pulping, Deinking, Cleaning & Screening, Washing, Thickening, Bleaching, and finally Sheet Forming & Drying.

Pulping Wastepaper is repulped through mixing with heated water in a hydropulper (a device similar in operation to a household blender) which separates the paper fibers, creating a pulp. Contaminants float to the surface and are removed at this stage using a variety of collection and removal devices. The slurry is pumped out of the pulper, through extraction plates (filtering device).

Deinking The wastepaper pulp is deinked by cooking it for 1 to 2 hours in an alkaline solution. Cooking is done at atmospheric pressure and at temperatures ranging from 120-212 degrees Fahrenheit depending upon the groundwood content of the pulp.

Cleaning & Screening and Washing Deinked pulp usually proceeds to a centrifugal cleaning system. Centrifugal cleaning removes contaminants, such as glass and gravel, which have a higher specific gravity than wood fiber. The clean slurry passes out of the top of the centrifugal cleaner, usually to a series of vibrating or high-pressure screens where light-weight contaminants and any other non-fibrous materials are removed. Plastic contaminants are removed at this point. Some mills employ a washing stage to remove inks, clays and chemicals. The pulp is now ready to be used in the paper or paperboard manufacturing process.

Bleaching Pulp from recycled printing and writing paper usually has to bleached to increase the brightness of the final recycled paper product. Mills that deink and bleach secondary fiber usually use sodium hypochlorite as the bleaching chemical. The bleaching reactions usually take place in bleaching retention towers where the pulp and bleaching chemicals are held in contact to allow the bleaching reaction to take place, but sometimes also occurs in the pulpers themselves.

Sheet Forming & Drying Forming is the actual conversion of pulp into sheets of paper. The formation of paper and paperboard occurs in three steps: first, a web of fiber is formed from a fiber/water suspension on a paper machine wire. Often, additives such as sizing (for final product water resistance), clay (for opacity and brightness), and starch (for strength) have been added to this fiber/water suspension. Second, water is pressed out of the web, and last, the remaining water is driven off by heat. While there are numerous types of paper machines used today, the two most common designs are the fourdrinier and cylinder paper machines. The fourdrinier machine can be used to manufacture a variety of paper grades and lightweight boards.

The fourdrinier machine consists of a moving, endless plastic or bronze screen, supported by a table, which carries the sheet through forming, pressing and then drying stages. The stock, containing only about 0.5% fiber and filler (the balance being water) is pumped into a headbox, which distributes the stock across the width of the paper machine, and then flows out onto the screen. Suction devices below the screen pull the water, and some solid material (particularly smaller fibers and fillers) through the wire and into a collection system. This mixture is called "whitewater", the components of which are often recycled within the process.

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TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED PRINTING/WRITING PAPER PRODUCTION

PROCESS Material Output Process/Transportation Energy	Units	Units/ton office paper	MMBtu Equivalents/ ton office paper
MRF PROCESSING [See Above]			
Waste Copy and Computer Paper	**pounds**	**2283**	
Fuels:			
Electricity			0.25
Diesel			0.04
Transportation - Diesel			0.07
WASTEPAPER PULPING [1]			
Pulp	**pounds**	**1911**	
Fuels:			
Electricity	kWh	398	4.18
Transportation - Diesel [2]	gallons	5	0.72
DEINKING [3]			
Pulp (bone dry)	**pounds**	**1896**	
Fuels:			
Steam	pounds	411	0.58
Electricity	kWh	128	1.34
CLEANING, SCREENING, AND WASHING [4]			
Fuels:			
Steam	pounds	429	0.60
Electricity	kWh	61	0.64
BLEACHING [5]			
Stock (bone dry)	**pounds**	**1859**	
Fuels:			
Steam	pounds	214	0.30
Electricity	kWh	33	0.35
FORMING, PRESSING, DRYING, CALENDERING, AND WINDING [6]			
Office Paper	**pounds**	**2000**	
Fuels:			
Steam	pounds	6143	8.60
Electricity	kWh	67	0.70
FINAL MANUFACTURING ELECTRICITY [7]			0.00
Subtotal - Process Energy			**17.58**
Subtotal - Transportation Energy			**0.79**
Total Energy Requirements			**18.37**

Footnotes:

[1] The energy and material requirements for the production of one ton of kraft pulp are shown in an appendix. The quantity of unbleached pulp required was based upon the quantity of bleached pulp required per ton of virgin printing and writing paper produced, and an assumption that the bleaching process has a 94.48% yield. The quantity of bone dry pulp required per ton of virgin printing and writing paper produced was taken from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, Noyes Data Corporation, 1977, page 14, given the further assumption of 30 pounds of fillers added per ton of paper.

[2] NYSERDA assumed that, on average, roundwood, forest, and manufacturing residues used in pulp production are transported 100 miles to the pulp mill, and they are transported by truck. See the discussion of NYSERDA's transportation methodology for more detail.

[3] The energy use per ton of chlorine was calculated from Batelle Columbus Laboratories, *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, prepared by the US Department of the Interior, Bureau of Mines, June 27, 1975, page 37. The initial steps in chlorine and caustic soda preparation are the same; page 37 reports that after the brine purification, heating and electrolysis steps, 46.54% of the intermediate product is chlorine. Therefore, 46.54% of the energy associated with these steps, plus the energy associated with chlorine cooling and drying, chlorine compressing, and chlorine liquefying, were allocated to chlorine. The quantity of chlorine required per ton of bone dry pulp was taken from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, page 75.

[4] NYSERDA assumed that, on average, chlorine is transported 100 miles to the pulp mill, and is transported by rail. See the discussion of NYSERDA's transportation methodology for more detail.

[5] The energy use per ton of caustic was calculated from Batelle Columbus Laboratories, *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, prepared by the US Department of the Interior, Bureau of Mines, June 27, 1975, page 37. The initial steps in chlorine and caustic soda preparation are the same; page 37 reports that after the brine purification, heating and electrolysis steps, 52.13% of the intermediate product is caustic. Therefore, 52.13% of the energy associated with these steps, plus the energy associated with caustic soda evaporation and separation by centrifuging was allocated to caustic. The quantity of caustic required per ton of bone dry pulp was taken from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, page 76.

[6] NYSERDA assumed that, on average, caustic is transported 100 miles to the pulp mill, and is transported by rail. See the discussion of NYSERDA's transportation methodology for more detail.

[7] The energy requirements for kraft pulp bleaching were taken from a personal communication between Allen White, Tellus Institute and R.T. Campbell, International Paper, March 1992. The quantity of bone dry pulp required per ton of printing and writing paper produced was taken from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, Noyes Data Corporation, 1977, page 14, given the further assumption of 30 pounds of fillers were added per ton of paper.

[8] The energy requirements for forming, drying, calendering and winding were taken from Energetics, Inc., *The U.S. Pulp and Paper Industry: An Energy Perspective*, prepared for Pacific Northwest Laboratories, April 1988. The energy use for forming, calendering and winding was calculated from pages 2.49 for forming and 2.51 for pressing. In the meeting of October 27, 1994, among Tellus, Franklin Associates, ICF, and EPA, Tellus and Franklin Associates' estimates of process energy for virgin printing and writing paper

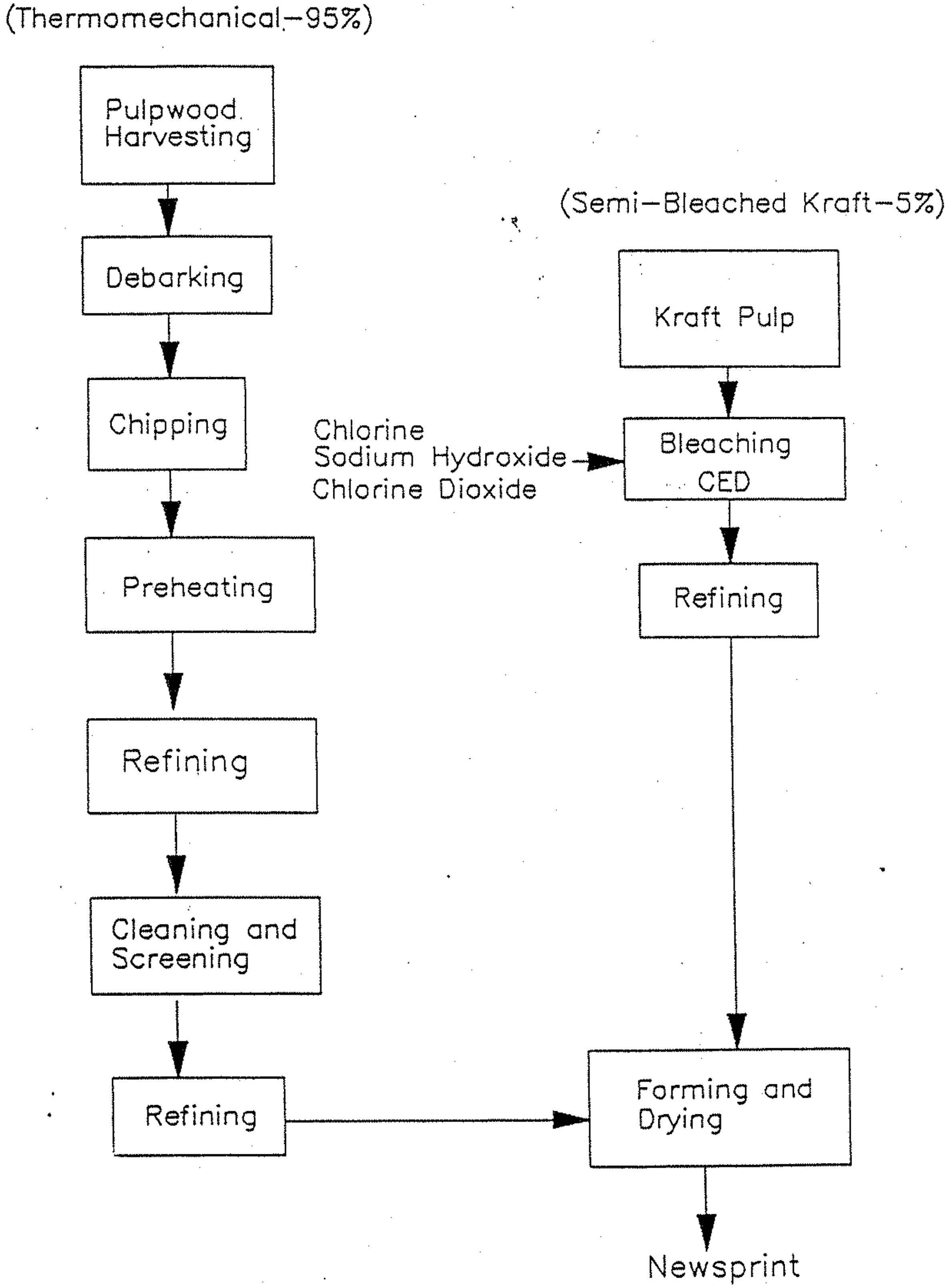
manufacturing differed by significantly more than 10%; Tellus' estimate was lower than Franklin Associates'. NYSERDA used the Energetics range of 5-20 MMBtu/ton for drying paper on page 2.53, and assumed that drying printing and writing paper would require 7.4 MMBtu/ton. In order to approach a consensus figure, Tellus reviewed its data sources, attempting to resolve the discrepancy.

We decided to use a different source within the Energetics report for the drying energy. Table 4.4 (page 4.10) shows energy consumption, by papermaking step, at three levels of energy intensity - "current practice", "state-of-the-art", and "advanced." Since the report used data from 1980-1985, we assumed that "state-of-the-art" energy consumption best approximated papermaking energy use in 1995. The energy consumption per ton of printing and writing paper in a state-of-the-art process is 9.30 MMBtu/ton. Subtracting the energy for forming, pressing, and winding leaves 7.50 MMBtu/ton, which we report as the drying energy.

[9] NYSERDA included final manufacturing energy for printing and writing paper. The listing for final manufacturing electricity, therefore, is zero.

Newspaper

VIRGIN NEWSPRINT PRODUCTION



Virgin Newsprint Production

Virgin newsprint can be produced using two different process sequences. Both sequences begin with the following steps: Pulpwood Harvesting; Debarking; and Chipping. The process sequences diverge at the next step - Pulping. Either Thermomechanical Pulping or Kraft Pulping of the wood chips is possible. Thermomechanical Pulping consists of Preheating, Refining, and Cleaning & Screening steps, followed by a final Refining step. Kraft Pulping, on the other hand, consists of pulping via sulfate chemicals, and is followed by a chemical Bleaching Step and then Refining. At this point the two processes converge again; the final manufacturing step for either process is Forming & Drying for use in the final product. We modeled virgin newsprint production using 95% thermomechanical pulp and 5% kraft pulp.

<u>Pulpwood Harvesting</u> Typically trees are severed from the stump by one person using a chain saw. The trees are then skidded, or dragged, by a tractor to a truck road. At the roadside they are cut into bolts (i.e. transportable sized logs) and loaded onto a truck with either a crane, hydraulic loader or a fork-lift attachment on a tractor. The wood is commonly trucked directly to a mill.

<u>Debarking</u> When the wood arrives at the mill it is usually stored for days or months in a woodyard, and then loaded onto a mechanized conveyor system or water flume for transport to the debarker. Mechanical conveyance, the more common transport mode, requires washing of the logs before debarking to reduce equipment wear.

Debarking is generally done by one of three methods, dry debarking by friction, wet debarking by friction, or hydraulic debarking. The process used depends on the size of the logs handled. Since most pulpwood used today is small in diameter, most debarking is done in dry drum barkers. A dry drum barker consists of a slotted drum with internal staves that remove the bark from the pulpwood as the drum rotates. The bark sifts out of the slots and the debarked logs travel out the end of the drum and fall onto a conveyor belt.

<u>Chipping</u> Debarked logs or sawmill wastes are cut into chips by means of a rotating flywheel face with bars which act as cutting blades. The chips are then screened, and the screened out fines are sent to a boiler for combustion.

<u>Pulping</u> Wood consists of hollow cellulosic fibers and other cells cemented together by lignin and hemicelluloses into a rigid and strong material. Pulping separates the wood into its cell components; paper and paperboard are formed when these cells are reunited in a mat formation. The quality of the pulp and subsequently, the quality of the paper or board required, determines the pulping process used.

<u>Thermomechanical Pulping (Preheating, Refining, Cleaning & Screening, Refining)</u> Mechanical pulping involves separating wood fibers by mechanical means, and the resulting low grade pulp is used for products such as newspaper, where permanence is not important. Thermomechanical pulping is done by preheating the wood chips with steam, followed by fiberizing of the chips with a specially designed (double-disc) refiner. The steam preheating

softens the chips, which minimizes damage to the wood fibers during refining, and minimizes the energy necessary for refining. Subsequent cleaning of the pulp removes residue such as sand and dirt, while knots and other oversized materials are removed by screening via a perforated screen. A final mechanical refining step, through cutting and maceration, converts "raw" fiber into a form suitable for papermaking.

Kraft Pulping, CED Bleaching, and Refining In chemical pulping, cellulose fibers are extracted from wood by the chemical dissolution of lignin which binds the fibers together. The kraft, or sulfate pulping process involves the cooking or digestion of wood chips at high temperature and pressure in a white liquor, a water based solution of sodium hydroxide (NaOH) and sodium sulfide (Na_2S). The name sulfate comes from the makeup chemical, sodium sulfate, that is used as the source of the sulfide ion. Sodium sulfate used in the kraft pulping process as a source of sulfide ions, is produced from either a natural sodium sulfate deposit, or a sodium sulfate solution available as a byproduct of various manufacturing processes. Sodium Hydroxide (and chlorine) are produced from the electrolysis of salt, usually in diaphragm cells. Salt is mined from underground deposits by pumping water into the deposit and forcing the brine to the surface.

The cooking process takes place in a vessel called a digester, which can be either batch or continuous in design. From the digesters, the pulp is sent to the brown stock washers (pulp washers) where the black liquor (spent cooking liquor) is washed from the pulp with hot water. The spent wash water from this process is called weak black liquor, and is sent to the black liquor recovery system. The black liquor recovery process is designed to a) remove the water from the weak black liquor via evaporator systems, b) combust the residual organic materials (now called strong black liquor) in a recovery furnace, and c) convert the sodium sulfate in the strong black liquor to sodium sulfide.

The kraft white liquor system is designed to convert the inorganic smelt from the bottom of the recovery furnace into reusable white liquor for kraft pulping. The smelt materials go through a series of dissolving, clarifying, washing, combustion, and recovery steps for either reuse in the process or disposal. One final overflow mixture is the white liquor and is used again in the pulping process.

The pulp proceeds on to screening and cleaning, bleaching (if bleaching is desired), and paper and/or board production. Pulp from the kraft process is brown because of the presence of lignin and other deeply colored wood constituents and pulping chemicals. Lignin removal during the bleaching process enhances both the brightness and strength of pulps.

Kraft pulps are generally bleached in three or more stages, starting with an acidic chlorine stage (chlorine reacts with and solubilizes lignin and other colored bodies), followed by an alkaline extraction stage using a solution of sodium hydroxide (sodium hydroxide extracts reacted lignin and other colored bodies form pulp), and followed still by one or more subsequent stages using chlorine dioxide (pulp brightener), sodium or calcium hypochlorite (pulp brightener), and additional caustic extraction stages. NYSERDA modeled the Chlorine - Extraction - Chlorine Dioxide (CED) bleaching sequence.

The bleaching and extraction reactions take place in bleaching/extraction retention towers where the pulp and bleaching chemicals are held in contact to allow the bleaching reaction to take place. At the completion of each bleach stage the pulp is washed, usually on vacuum drum filters, to remove the products of the bleaching reaction and spent chemicals. A final mechanical refining step, through cutting and maceration, converts "raw" fiber into a form suitable for papermaking.

Chlorine and caustic are generally purchased as a liquid; and chlorine is vaporized at the mill before introduction into the chlorine tower. Chlorine dioxide is manufactured at the mill from sodium chlorate, either sulfuric or hydrochloric acid, and either sulfur dioxide, methanol or sodium chloride, by one of a number of different processes.

Forming & Drying Forming is the actual conversion of pulp into sheets of paper. The formation of paper and paperboard occurs in three steps: first, a web of fiber is formed from a fiber/water suspension on a paper machine wire. Often, additives such as sizing (for final product water resistance), clay (for opacity and brightness), and starch (for strength) have been added to this fiber/water suspension. Second, water is pressed out of the web, and last, the remaining water is driven off by heat. While there are numerous types of paper machines used today, the two most common designs are the fourdrinier and cylinder paper machines. The fourdrinier machine can be used to manufacture a variety of paper grades and lightweight boards.

The fourdrinier machine consists of a moving, endless plastic or bronze screen, supported by a table, which carries the sheet through forming, pressing and then drying stages. The stock, containing only about 0.5% fiber and filler (the balance being water) is pumped into a headbox, which distributes the stock across the width of the paper machine, and then flows out onto the screen. Suction devices below the screen pull the water, and some solid material (particularly smaller fibers and fillers) through the wire and into a collection system. This mixture is called "whitewater", the components of which are often recycled within the process.

The fiber web, atop the screen, is picked up by a moving felt which transfers the web into the press section. At the press section, further dewatering takes place as the web and felt pass between a series of paired press rolls, pushed together, much like an old-fashioned clothing wringer. When the sheet leaves the press section and enters the dryer section, it contains approximately 65% water. The dryer section consists of a long progression of steam-heated drying cans, or cylinders, which transfer heat to the sheet and drive off most, but not all of the remaining moisture. When the paper or board is reeled up at the end of the machine, it usually contains about 6% water.

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN NEWSPRINT PRODUCTION

PROCESS Material Output Process/Transportation Energy	Units	Units /ton newsprint	MMBtu Equivalents/ton newsprint
KRAFT PULPING [1]			
Pulp (bone dry)	**pounds**	**103**	
Fuels:			
Gasoline	gallons	0.11	0.01
Diesel	gallons	0.08	0.01
Oil	gallons	1	0.08
Steam	pounds	346	0.48
Electricity	kWh	4	0.04
Transportation-Diesel [2]	gallons	0.38	0.05
KRAFT PULP BLEACHING [3]			
Bleached Pulp (bone dry)	**pounds**	**97**	
Fuels:			
Steam	pounds	121	0.17
Electricity	kWh	7	0.07
TMP PRODUCTION [4]			
TMP (bone dry)	**pounds**	**1841**	
Fuels:			
Gasoline	gallons	1	0.11
Diesel	gallons	1	0.09
Steam	pounds	904	1.27
Electricity	kWh	1717	18.03
Transportation-Diesel [5]	gallons	3.19	0.44
NEWSPRINT PRODUCTION [6]			
Newsprint	**pounds**	**2000**	
Fuels:			
Steam	pounds	4000	5.60
Electricity	kWh	175	1.83
FINAL MANUFACTURING ELECTRICITY [7]			3.22
Subtotal - Process Energy			**31.03**
Subtotal - Transportation Energy			**0.49**
Total Energy Requirements			**31.52**

Footnotes:

[1] The energy and material requirements for the production of one ton of kraft pulp are shown in an appendix. The quantity of unbleached pulp required was based upon the quantity of bleached pulp required per ton of virgin newsprint produced, and an assumption that the bleaching process has a 94.47% yield. The quantity of bleached pulp required was based on three assumptions: that 96.9 pounds of bone dry pulp are required per 100 pounds of finished newsprint, which is taken from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, Noyes Data Corporation, 1977, page 13, that 5% of the bone dry pulp used in newsprint production is kraft pulp, and that 96.9 pounds of bone dry pulp are required per 100 pounds of finished newsprint.

[2] NYSERDA assumed that, on average, roundwood, forest, and manufacturing residues used in pulp production are transported 100 miles to the pulp mill, and they are transported by truck. See the discussion of NYSERDA's transportation methodology for more detail.

[3] The energy requirements for the bleaching of one ton of bone dry pulp were taken from a personal communication between Allen White, Tellus Institute and R.T. Campbell, International Paper, March 1992. The quantity of bleached pulp required was based on the assumption that 5% of the bone dry pulp used in newsprint production is kraft pulp, and that 96.9 pounds of bone dry pulp are required per 100 pounds of finished newsprint. The quantity of chlorine required per ton of bone dry pulp was taken from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, page 75.

[4] The energy requirements for the production of one ton of thermomechanical pulp were taken from several sources. The energy requirements for pulpwood harvesting were calculated from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, page 18. The energy requirements for wood conveyance, debarking, cleaning and screening were taken from Oak Ridge National Laboratory, *Energy Use and Distribution in the Pulp, Paper and Boardmaking Industries*, August 1977, page 23. The energy requirements for preheating and refining were taken from Energetics, Inc., *The U.S. Pulp and Paper Industry: An Energy Perspective*, prepared for Pacific Northwest Laboratory, April 1988, page 2.31. The quantity of thermomechanical pulp required was based on the assumption that 95% of the bone dry pulp used in newsprint production is thermomechanical pulp, and that 96.9 pounds of bone dry pulp are required per 100 pounds of finished newsprint.

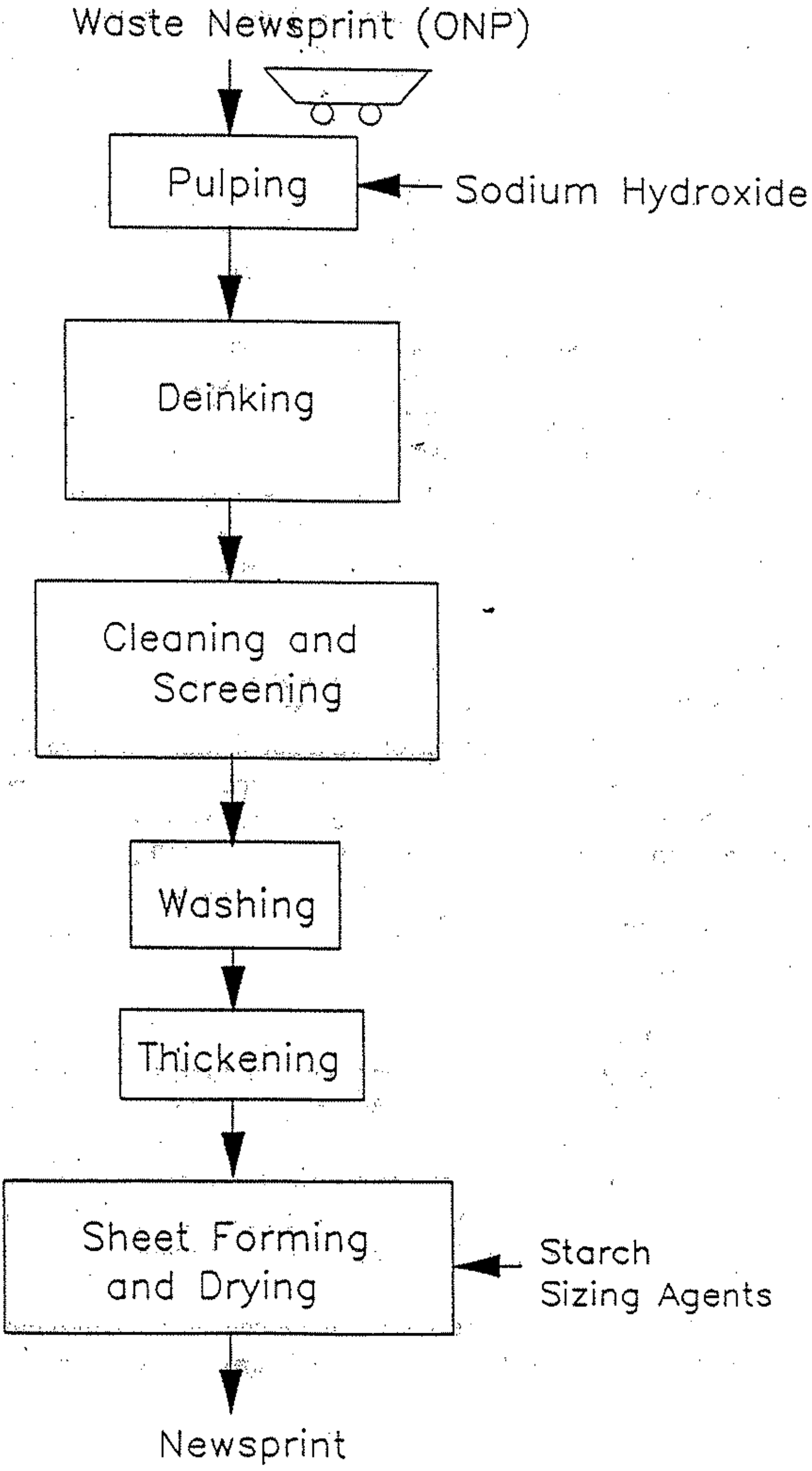
[5] NYSERDA assumed that, on average, roundwood, forest, and manufacturing residues used in pulp production are transported 100 miles to the pulp mill, and they are transported by truck. See the discussion of NYSERDA 's transportation methodology for more detail.

[6] The energy requirements for furnish refining, additives mixing, final cleaning, and temperature adjustment were taken from Oak Ridge National Laboratory, *Energy Use and Distribution in the Pulp, Paper and Boardmaking Industries*, pages 42-45. The energy requirements for forming, drying, calendering and winding were taken from Energetics, Inc., *The U.S. Pulp and Paper Industry: An Energy Perspective*. The energy use for forming, calendering and winding was calculated from pages 2.49 for forming and 2.51 for pressing. Energetics presents a range of 5-20 MMBtu/ton for drying paper on page 2.53; NYSERDA assumed that drying newsprint would require 5 MMBtu/ton.

[7] The energy requirements for the final manufacturing of newspapers were estimated from the U.S. Census Bureau, Census of Manufacturers MC87-1-27A, "Newspapers, Periodicals, Books and Miscellaneous Publishing." Table 3A (page 27A-12) shows that 3.357 million kilowatt hours (35.25 million MMBtu) were used by SIC code 2711 in the manufacture of newspapers. Table 7 (page 27A-27) shows that 10.945 million

tons of newspapers were produced. Dividing yields an estimate of 3.22 (35.25/10.945) MMBtu per ton of newspapers produced. This estimate was not superseded by Franklin Associates data in the final report.

RECYCLED NEWSPRINT PRODUCTION



Recycled Newsprint Production

Once waste newsprint (ONP) is received at the paper mill, it must be repulped before it can be used in the papermaking process. The wastepaper pulping process involves several steps, including Pulping, Deinking, Cleaning & Screening, Washing, Thickening, and finally Sheet Forming & Drying.

Pulping Wastepaper is repulped through mixing with heated water in a hydropulper (a device similar in operation to a household blender) which separates the paper fibers, creating a pulp. Contaminants float to the surface and are removed at this stage using a variety of collection and removal devices. The slurry is pumped out of the pulper, through extraction plates (filtering device).

Deinking The wastepaper pulp is deinked by cooking it for 1 to 2 hours in an alkaline solution. Cooking is done at atmospheric pressure and at temperatures ranging from 120-212 degrees Fahrenheit depending upon the groundwood content of the pulp.

Cleaning & Screening and Washing Deinked pulp usually proceeds to a centrifugal cleaning system. Centrifugal cleaning removes contaminants, such as glass and gravel, which have a higher specific gravity than wood fiber. The clean slurry passes out of the top of the centrifugal cleaner, usually to a series of vibrating or high-pressure screens where light-weight contaminants and any other non-fibrous materials are removed. Plastic contaminants are removed at this point. Some mills employ a washing stage to remove inks, clays and chemicals. The pulp is now ready to be used in the paper or paperboard manufacturing process.

Sheet Forming & Drying Forming is the actual conversion of pulp into sheets of paper. The formation of paper and paperboard occurs in three steps: first, a web of fiber is formed from a fiber/water suspension on a paper machine wire. Often, additives such as sizing (for final product water resistance), clay (for opacity and brightness), and starch (for strength) have been added to this fiber/water suspension. Second, water is pressed out of the web, and last, the remaining water is driven off by heat. While there are numerous types of paper machines used today, the two most common designs are the fourdrinier and cylinder paper machines. The fourdrinier machine can be used to manufacture a variety of paper grades and lightweight boards.

The fourdrinier machine consists of a moving, endless plastic or bronze screen, supported by a table, which carries the sheet through forming, pressing and then drying stages. The stock, containing only about 0.5% fiber and filler (the balance being water) is pumped into a headbox, which distributes the stock across the width of the paper machine, and then flows out onto the screen. Suction devices below the screen pull the water, and some solid material (particularly smaller fibers and fillers) through the wire and into a collection system. This mixture is called "whitewater", the components of which are often recycled within the process.

The fiber web, atop the screen, is picked up by a moving felt which transfers the web into the press section. At the press section, further dewatering takes place as the web and felt pass between a series of paired press rolls, pushed together, much like an old-fashioned clothing wringer. When the sheet leaves the press section and enters the dryer section, it contains approximately 65% water. The dryer section consists of a long progression of steam-heated drying cans, or cylinders, which transfer heat to the sheet and drive off most, but not all of the remaining moisture. When the paper or board is reeled up at the end of the machine, it usually contains about 6% water.

TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED NEWSPRINT PRODUCTION

PROCESS **Material Output** Process Energy	Units	Units/ton newsprint	MMBtu Equivalents/ ton newsprint
MRF PROCESSING [See Above]			
Old Newsprint	**pounds**	**2333**	
Fuels:			
Electricity			0.25
Diesel			0.04
Transportation - Diesel			0.07
WASTEPAPER PULPING [1]			
Pulp	**pounds**	**1954**	
Fuels:			
Electricity	kWh	397	4.17
Transportation - Diesel [2]	gallons	12	1.73
DEINKING [3]			
Stock (bone dry)	**pounds**	**1938**	
Fuels:			
Steam	pounds	414	0.58
Electricity	kWh	129	1.35
CLEANING, SCREENING, AND WASHING [4]			
Steam	pounds	429	0.60
Electricity	kWh	62	0.65
FORMING, PRESSING, DRYING, CALENDERING, AND WINDING [5]			
Newsprint	**pounds**	**2000**	
Steam	pounds	3465	4.83
Electricity	kWh	67	0.70
FINAL MANUFACTURING ELECTRICITY [6]			3.22
Subtotal - Process Energy			**16.39**
Subtotal - Transportation Energy			**1.80**
Total Energy Requirements			**18.19**

Footnotes:

[1] The energy requirements for wastepaper pulping were estimated from Energetics, Inc., *The U.S. Pulp and Paper Industry: An Energy Perspective*, prepared for the Pacific Northwest Laboratory, April 1988, page 2.33. The source presented a range of 4-5.8 MMBtu per ton of pulp; NYSERDA assumed that 4.5 MMBtu are required per ton. The quantity of old newsprint required per ton of pulp was based on the assumption of 7.5% losses during the pulping step. In addition, the material requirements accounted for the fact that the average moisture content of ONP is 10%, as stated in Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, Noyes Data Corporation, 1977, page 62.

[2] NYSERDA assumed that, on average, old newspapers used in recycled pulp production are transported 750 miles to the pulp mill, and they are transported by truck. See the discussion of NYSERDA's transportation methodology for more detail.

[3] The energy requirements were estimated from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, page 62. The quantity of pulp required per ton of recycled newsprint produced was taken from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, page 62.

[4] The energy requirements for furnish refining, additives mixing, final cleaning, and temperature adjustment were taken from Oak Ridge National Laboratory, *Energy Use and Distribution in the Pulp, Paper and Boardmaking Industries*, pages 42-45.

[5] The energy requirements for forming, drying, calendering and winding were taken from Energetics, Inc., *The U.S. Pulp and Paper Industry: An Energy Perspective*. The energy requirements for forming, calendering and winding were calculated from pages 2.49 for forming and 2.51 for pressing. In the meeting of October 27, 1994, among Tellus, Franklin Associates, ICF, and EPA, Tellus and Franklin Associates' estimates of process energy for recycled newsprint manufacturing differed by significantly more than 10%; Tellus' estimate was significantly higher than Franklin Associates'. NYSERDA used the Energetics range of 5-20 MMBtu/ton for drying paper on page 2.53, and assumed that drying newsprint would require 7.5 MMBtu/ton. In order to approach a consensus figure, Tellus reviewed its data sources, attempting to resolve the discrepancy.

We decided to use a different source within the Energetics report for the drying energy. Table 4.4 (page 4.10) shows energy consumption, by papermaking step, at three levels of energy intensity - "current practice", "state-of-the-art", and "advanced." Since the report used data from 1980-1985, we assumed that "state-of-the-art" energy consumption best approximated papermaking energy use in 1995. The energy consumption per ton newsprint in a state-of-the-art process is 5.53 MMBtu/ton. Subtracting the energy for forming, pressing, and winding leaves 4.83 MMBtu/ton, which we report as the drying energy.

[6] The energy requirements for the final manufacturing of newspapers were estimated from the U.S. Census Bureau, Census of Manufacturers MC87-1-27A, "Newspapers, Periodicals, Books and Miscellaneous Publishing." Table 3A (page 27A-12) shows that 3.357 million kilowatt hours (35.25 million MMBtu) were used by SIC code 2711 in the manufacture of newspapers. Table 7 (page 27A-27) shows that 10.945 million tons of newspapers were produced. Dividing yields an estimate of 3.22 (35.25/10.945) MMBtu per ton of newspapers produced. This estimate was not superseded by Franklin Associates data in the final report.

Aluminum Cans

Virgin Molten Aluminum Production

The necessary raw materials and manufacturing process for virgin molten aluminum production is shown in the following flowsheet. The three major processes are: Bauxite Mining and Processing; Alumina Production via The Bayer Process; and Molten Aluminum Production via The Hall Heroult Process.

Bauxite Mining and Processing

Aluminum, the most abundant metal in the earth's crust, has a strong tendency to combine with other elements and thus never occurs in metallic form. Therefore, aluminum is produced by the electrolytic reduction of aluminum oxide, Al_2O_3. This oxide is found in aluminum bearing ores, the most important of which is bauxite, which contains approximately 40-60% Al_2O_3 and is currently the only ore with commercial value. As the number of bauxite mines in the U.S. have decreased over the years, the North American aluminum industry has become dependent upon foreign raw material sources. Thus, the ore is purified on site to reduce transportation costs.

Most bauxite is located near the earth's surface and is mined by the open-pit method. The overburden is removed and then draglines strip the bauxite deposit which is then transported to processing plants. Overburden is replaced and the mining site is restored. Dust is controlled by wetting of mine roads with water spray. The ore is next crushed, washed, and screened at a processing plant to eliminate clay minerals and dirt. The ore is then kiln-dried in a rotary kiln. The majority of the energy needed for mining and processing is consumed by this step.

Alumina Production via The Bayer Process

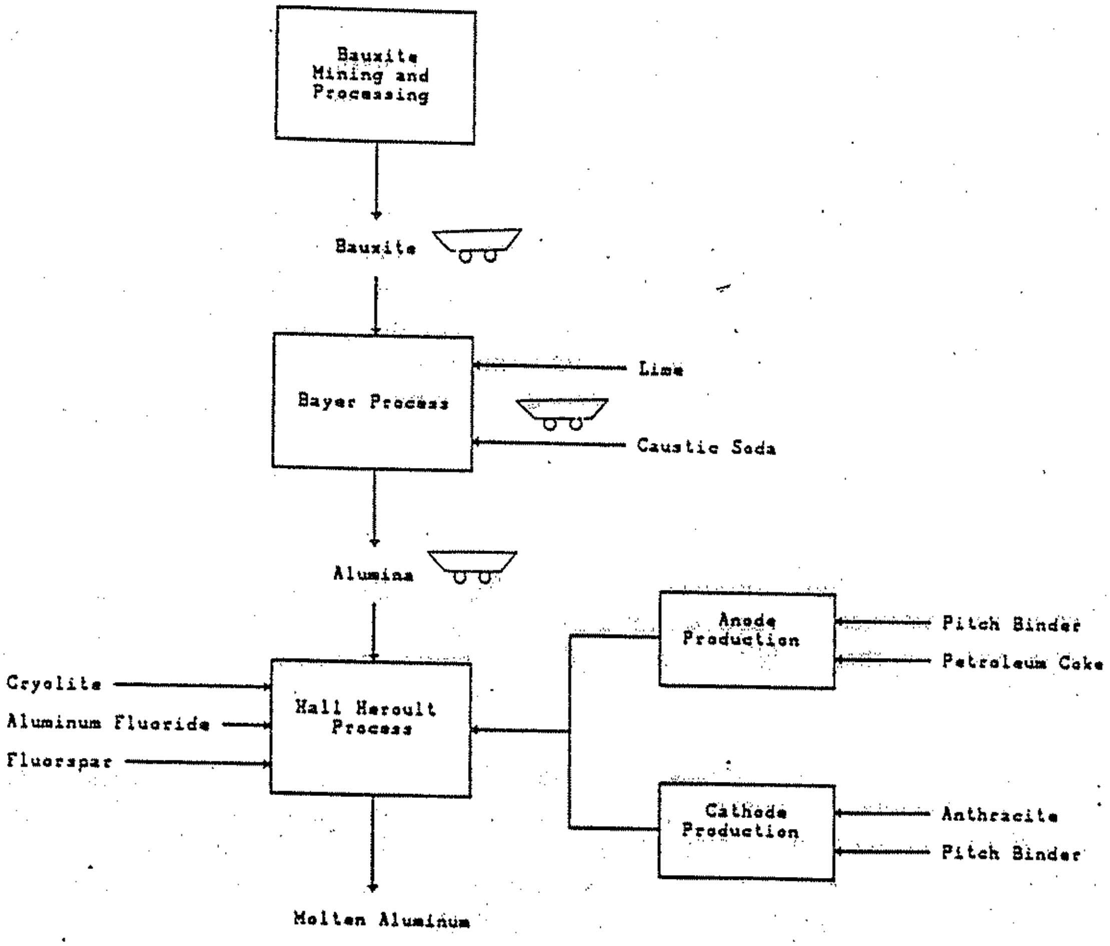
Virtually all commercially produced alumina from bauxite is obtained by the Bayer process. Two major additives are required for alumina production; lime and caustic soda. The production processes for these additives are discussed below, followed by a description of alumina production.

Lime Limestone is quarried by the open-pit method. Overburden is removed and must be disposed. The limestone is transported to a crusher where its size is reduced. It is then conveyed to a second crusher and is screened. The product of this step can be used as is or may be processed in cement kilns to convert the limestone to lime. Rotary kilns account for approximately 90% of all lime production in the United States.

Caustic Soda Chlorine and caustic soda (sodium hydroxide) are simultaneously produced from the electrolysis of salt. Two types of electrolysis cells are used to produce chlorine and caustic soda from brine - the mercury cell and diaphragm cell. Approximately 80% of the U.S. chlor-alkali industry uses the diaphragm cell, the focus of the following description.

Salt is mined from underground deposits by pumping water into the deposit and forcing

VIRGIN MOLTEN ALUMINUM PRODUCTION



dehydrogenation of oil products such as naphtha. Coking involves severe thermal cracking of a stream of refinery residual products. This is then followed by calcining (heating at high temperatures to drive off volatile matter) which causes the release of hydrocarbons.

The Hall Heroult Process. Purified alumina is dissolved in a molten bath of a fluoride electrolyte which contains cryolite (sodium aluminum fluoride, Na_3AlF_6), fluorspar (CaF_2), and aluminum fluoride (AlF_3). Cryolite serves as both an electrolyte and solvent for alumina; at high temperatures cryolite can dissolve 15-20% of the alumina. Fluorspar lowers the melting point of the mix and aluminum fluoride increases the cell efficiency.

During the reduction reaction, a high-amperage, low-voltage direct current passes through the cryolite-alumina bath, reducing the alumina to aluminum metal and oxygen. The oxygen migrates to the carbon anode, where it reacts with carbon, sulfur, and other impurities to form CO_2, CO, and SO_2. Molten aluminum pools at the bottom cathode and is removed from the pots by "tapping", a process in which the aluminum is sucked up with a ladle or crucible. The molten aluminum is then transferred to the cast house where alloying materials such as iron, silicon, magnesium, and manganese can be added. The aluminum is cast as ingots, which are shipped to users. These ingots will be remelted for use.

the brine to the surface. The brine is heated and treated with soda ash and caustic soda to remove impurities. Next, the brine enters the electrolytic cell where a direct current decomposes the salt to chlorine, sodium hydroxide, and hydrogen. The hydrogen is compressed, cooled and dried and then either used on site or sold. The chlorine is collected, cooled and dried; following purification it is compressed and liquefied. The dilute caustic soda is evaporated to produce a solution containing 50% caustic soda by weight. The electrolysis step yields 2000 pounds of chlorine, 2240 pounds of dilute caustic soda, and 57 pounds of hydrogen.

The Bayer Process The Bayer process recovers pure alumina from bauxite ore by removing impurities. First the bauxite ore, mixed with lime, is ground and then mixed with caustic soda (NaOH or sodium hydroxide). This solution is pumped into large pressure tanks called digesters. Pressure and heat (steam) are applied to the mixture so that the available alumina in the bauxite is dissolved in the caustic soda, forming sodium aluminate ($NaAlO_2$). This solution of sodium aluminate and solids, called green liquor, then goes through a series of tanks and filter presses where it undergoes clarification and filtration. During these processes, suspended solids are removed and starch is added as a flocculent to accelerate sedimentation and separation of wastes from the liquor stream. The wastes include dissolved silica and insoluble residues, known as red mud, containing iron oxide, silicon dioxide, and titanium dioxide. The red mud is discharged to settling ponds where the insoluble residues settle out. The remaining liquid, which contains phenols and has a high pH, can be recycled and reused, or discharged.

Some alumina is lost when it combines with silica and is disposed of with the red mud. In order to recover the alumina, limestone and soda ash (Na_2CO_3) is heated with the red mud to produce a $NaAlO_2$ solution. This recovery process produces a silicate waste called brown mud.

The next step involves crystallization and precipitation of aluminum trihydrate from the sodium aluminate. The filtered green liquor is cooled and then seeded with aluminum hydrate, $Al(OH)_2$, which provides seed crystals to enhance crystallization, with aluminum trihydrate, $Al_2O_3 \cdot 3H_2O$, formed. Aluminum trihydrate is then filtered, washed, and the water is driven off (known as calcination) at high temperatures yielding pure alumina, Al_2O_3. The spent liquor solution (green liquor minus alumina), depleted of Al_2O_3, goes through an evaporation process where NaOH is recovered and sent back to the digestion process to be reused.

Molten Aluminum Production via The Hall Heroult Process

Molten aluminum production involves the electrolytic reduction (a chemical change produced by an electrical current) of alumina into aluminum and oxygen. A reduction plant consists of a series of long rows of electrolytic cells ("prebaked" cells in the U.S.) made of steel. Each cell is lined with carbon which acts as a cathode and a consumable anode is made of petroleum coke and pitch. Anode and cathode production are thus ancillary processes. The major input for anode production is petroleum coke. Its production is described below.

Petroleum Coke Petroleum coke is produced at refineries by the complete

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN MOLTEN ALUMINUM PRODUCTION [1]

PROCESS **Material Output** Process/Transportation Energy	Units	Units/ton molten aluminum	MMBtu Equivalents/ton molten aluminum
BAUXITE MINING & PROCESSING [2]			
Bauxite	**pounds**	**8970**	
Fuels:			
Oil	gallons	2	0.32 ✓
Natural Gas	cubic feet	233	0.24 ✓
Other			0.03 ✓
Electricity - Purchased	kWh	56	0.59 ✓
Transportation-Diesel [3]	gallons	13	1.85 ✓
CAUSTIC SODA PRODUCTION [4]			
Caustic Soda	**pounds**	**246**	
Fuels:			
Electricity - Purchased	kWh	208	2.19
Steam	pounds	1274	1.78
Transportation-Diesel [5]	gallons	0.07	0.01
BAYER PROCESS [6]			
Alumina	**pounds**	**3900**	
Fuels:			
Oil	gallons	14	2.09
Natural Gas	cubic feet	21948	22.63
Coal	tons	0.11	2.64
Other			0.02
Electricity - Purchased	kWh	74	0.77
Electricity - On-Site	kWh	352	3.69
Transportation-Diesel [7]	gallons	19	2.59
ANODE PRODUCTION [8]			
Anodes	**pounds**	**900**	
Fuels:			
Natural Gas	cubic feet	1527	1.57
HALL HEROULT PROCESS [9]			
Molten Aluminum	**pounds**	**2000**	
Fuels:			
Oil	gallons	0.95	0.14
Natural Gas	cubic feet	2291	2.36
Other			0.03
Electricity - Purchased	kWh	10297	108.11
Electricity - On-Site	kWh	2018	21.19
Transportation-Diesel [10]	gallons	0.10	0.01
FINAL MANUFACTURING ELECTRICITY [11]			11.68
Subtotal - Process Energy			**182.10**
Subtotal - Transportation Energy			**4.46**
Total Energy Requirements			**186.56**

Footnotes:

[1] NYSERDA estimated that the total energy required to produce one ton of virgin aluminum is 152.05 MMBtu, of which 147.59 MMBtu is process energy and 4.46 MMBtu is transportation energy. In the meeting of October 27, 1994, among Tellus, Franklin Associates, ICF, and EPA, Tellus and Franklin Associates' estimates of process energy for aluminum manufacturing differed by significantly more than 10%; Tellus' estimate was lower than Franklin Associates'. In order to approach a consensus figure, Tellus reviewed its data sources, attempting to resolve the discrepancy. In our revised technical memorandum of November 9, 1994, we cited a personal communication between Allen White, Tellus Institute and James Plumb, The Aluminum Association, April 4, 1992. From that communication we calculated that the process energy required to produce virgin aluminum is 170.42 MMBtu per ton. We were unable to reconcile the energy required for each of the individual aluminum manufacturing steps, however. We therefore multiplied each process energy listing from NYSERDA by a conversion factor of 1.155 (170.42/147.59).

[2] The total energy required to mine one ton of bauxite was taken from The Aluminum Association, "Energy Content in Aluminum Cans: Historical Performance and Future Potential," June 29, 1984, page 9, line marked "Bauxite - Mining," column marked "1983 Unit Energy (Btu/lb)." The energy breakdown by fuel type was calculated from The Aluminum Association, "Energy Conservation and the Aluminum Industry," December 1984, page 4, table entitled "Sources and Uses of Energy - 1972 Base Year Vs. Full Year 1983," column marked "Bauxite '83."

[3] NYSERDA transportation energy requirements were calculated from Patricia A. Plunkert and Errol D. Sehnke, "Bauxite, Alumina and Aluminum," in *Bauxite, Alumina and Aluminum Minerals Yearbook - 1989*, published by US Department of the Interior, Bureau of Mines, 1991. See the discussion of NYSERDA's transportation methodology for more detail.

[4] The energy and materials requirements for the production of one ton of caustic soda were taken from Batelle Columbus Laboratories, *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, page 37.

[5] NYSERDA assumed that, on average, caustic soda is produced 100 miles from the aluminum-producing facility, and that all soda is transported by rail. See the discussion of NYSERDA's transportation methodology for more detail.

[6] The total energy required to produce one ton of alumina in the Beyer process was taken from The Aluminum Association, "Energy Content in Aluminum Cans: Historical Performance and Future Potential," page 9, line marked "Alumina - Processing," column marked "1983 Unit Energy (Btu/lb)." The energy breakdown by fuel type was calculated from The Aluminum Association, "Energy Conservation and the Aluminum Industry," December 1984, page 4, table entitled "Sources and Uses of Energy - 1972 Base Year Vs. Full Year 1983," column marked "Alumina '83."

[7] NYSERDA transportation energy requirements were calculated from Patricia A. Plunkert and Errol D. Sehnke, "Bauxite, Alumina and Aluminum," in *Bauxite, Alumina and Aluminum Minerals Yearbook - 1989*, published by US Department of the Interior, Bureau of Mines, 1991. See the discussion of NYSERDA's transportation methodology for more detail.

[8] The energy required to produce one ton of anodes and the quantity of anodes required per ton of virgin aluminum, were taken from a personal communication between Allen White, Tellus Institute and James

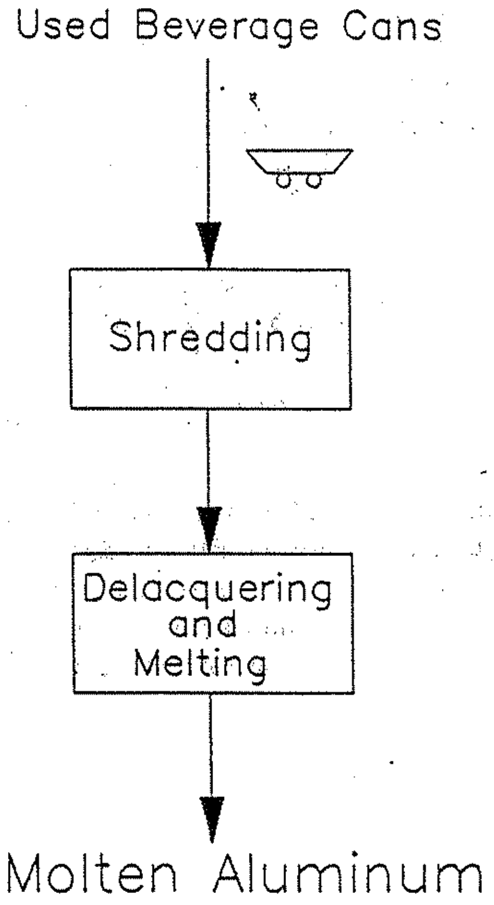
Plumb, The Aluminum Association, April 4, 1992. Note that this step does not include the inherent energy in the anodes, just the process energy.

[9] The total energy required to produce one ton of molten aluminum was taken from The Aluminum Association, "Energy Content in Aluminum Cans: Historical Performance and Future Potential," page 9, line marked "Molten Metal Production," column marked "1983 Unit Energy (Btu/lb)." The energy breakdown by fuel type was calculated from The Aluminum Association, "Energy Conservation and the Aluminum Industry," December 1984, page 4, table entitled "Sources and Uses of Energy - 1972 Base Year Vs. Full Year 1983," column marked "Alumina '83."

[10] NYSERDA transportation energy requirements denote the energy required for the transportation of cathodes, and were taken from a personal communication between Karen Shapiro, Tellus Institute and Mark Hauser, Alcoa, September 20, 1991. See the discussion of NYSERDA's transportation methodology for more detail.

[11] The energy requirements for the final manufacturing of aluminum cans were estimated from the U.S. Census Bureau, Census of Manufacturers MC87-1-34A, "Metal Cans, Cutlery, Handtools and General Hardware." Table 3A (page 34A-11) shows that 2.286 million kilowatt hours (24 million MMBtu) were used by SIC code 3411 in the manufacture of cans. Table 7 (page 34A-22) shows that 1.09 million tons of aluminum were used to make cans; there was no corresponding data available for steel. We calculated from table 6A-1 (page 34A-16) that the value of aluminum can shipments was 52.82% of the value of total can shipments. We assumed that the electricity used in aluminum canmaking was proportional to the value of the cans and thereby calculated that 12.68 million MMBtu (52.82% * 24 million MMBtu) were used to make aluminum cans. Dividing the total energy use by the total aluminum used to make cans yields an estimate of 11.68 (12.68/1.09) MMBtu per ton of aluminum cans produced. We used this information as a proxy for steel can manufacture as well. This estimate was superseded by Franklin Associates data in the final report.

RECYCLED MOLTEN ALUMINUM PRODUCTION



Recycled Molten Aluminum Production

Aluminum can recycling is a closed-loop process -- used beverage cans (known as UBCs) can be recycled back into new aluminum sheet for cans. After UBCs are collected, they are sent to recycling operators, where they are baled and sold, primarily to can sheet manufacturers.

The recovered aluminum must first be processed before it can be used. It can be magnetically screened to remove steel and pneumatically processed to remove paper and other contaminants. The can scrap is shredded into small chips and remelted, usually in reverberatory furnaces. Alloying elements and primary aluminum are added as needed to provide the proper alloy and specifications for the final end-use product. The aluminum is then made into ingots, rolled into can sheet, and then sold to canmakers.

TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED MOLTEN ALUMINUM PRODCTION

PROCESS **Material Output** Process/Transportation Energy	Units	Units /ton molten aluminum	MMBtu Equivalents/ton molten aluminum
MRF PROCESSING [See Above]			
Used Beverage Containers	**pounds**	**2222**	
Fuels:			
Electricity			0.25
Diesel			0.04
Transportation - Diesel			0.07
SHREDDING [1]			
Molten Aluminum	**pounds**	**2000**	
Fuels:			
Electricity - Purchased	kWh	171	1.80
Transportation-Diesel [2]	gallons	5	0.69
DELAQUERING AND MELTING [3]			
Fuels:			
Natural Gas	cubic feet	6324	6.52
FINAL MANUFACTURING ELECTRICITY [4]			11.68
Subtotal - Process Energy			**20.29**
Subtotal - Transportation Energy			**0.76**
Total Energy Requirements			**21.05**

Footnotes:

[1] The energy use for shredding enough aluminum scrap to make one ton of recycled aluminum was based on Arthur D. Little, *Aluminum Industry Scoping Study*, prepared for the Center for Metals Production, August 1986, page A-20.

[2] NYSERDA transportation energy requirements denote the transportation of recycled aluminum beverage containers to a secondary aluminum processor. NYSERDA assumed an average haul of 250 miles. All transportation was assumed to be by truck. See the discussion of NYSERDA's transportation methodology for more detail.

[3] The energy use for delacquering and melting enough aluminum scrap to make one ton of recycled aluminum was based on Arthur D. Little, *Aluminum Industry Scoping Study*, prepared for the Center for Metals Production, August 1986, page A-20.

[4] The energy requirements for the final manufacturing of aluminum cans were estimated from the U.S. Census Bureau, Census of Manufacturers MC87-1-34A, "Metal Cans, Cutlery, Handtools and General Hardware." Table 3A (page 34A-11) shows that 2.286 million kilowatt hours (24 million MMBtu) were used by SIC code 3411 in the manufacture of cans. Table 7 (page 34A-22) shows that 1.09 million tons of aluminum were used to make cans; there was no corresponding data available for steel. We calculated from table 6A-1 (page 34A-16) that the value of aluminum can shipments was 52.82% of the value of total can shipments. We assumed that the electricity used in aluminum canmaking was proportional to the value of the cans and thereby calculated that 12.68 million MMBtu (52.82% * 24 million MMBtu) were used to make aluminum cans. Dividing the total energy use by the total aluminum used to make cans yields an estimate of 11.68 (12.68/1.09) MMBtu per ton of aluminum cans produced. We used this information as a proxy for steel can manufacture as well. This estimate was superseded by Franklin Associates data in the final report.

Steel Cans

Footnotes:

[1] The energy requirements for wastepaper pulping were estimated from Energetics, Inc., *The U.S. Pulp and Paper Industry: An Energy Perspective*, prepared for the Pacific Northwest Laboratory, April 1988, page 2.33. The source presented a range of 4-5.8 MMBtu per ton of pulp; NYSERDA assumed 4.5 MMBtu/ton. The quantity of old waste copy and computer paper required per ton of pulp was based on the assumption of 7.5% losses during the pulping step. In addition, the material requirements account for the fact that the average moisture content of waste paper is 10%, assuming that the moisture content of waste paper is the same as the moisture content of ONP, which was taken from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, Noyes Data Corporation, 1977, page 62.

[2] NYSERDA assumed that, on average, old waste copy and computer paper used in recycled pulp production is transported 250 miles to the pulp mill, and is transported by truck. See the discussion of NYSERDA's transportation methodology for more detail.

[3] The energy requirements were estimated from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, page 62. The quantity of pulp required per ton of recycled printing and writing paper produced was taken from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, page 62; NYSERDA made the further assumption that the yield of newsprint deinking is equal to the yield of waste copy and computer paper deinking.

[4] The energy requirements for furnish refining, additives mixing, final cleaning, and temperature adjustment were taken from Oak Ridge National Laboratory, *Energy Use and Distribution in the Pulp, Paper and Boardmaking Industries*, pages 42-45.

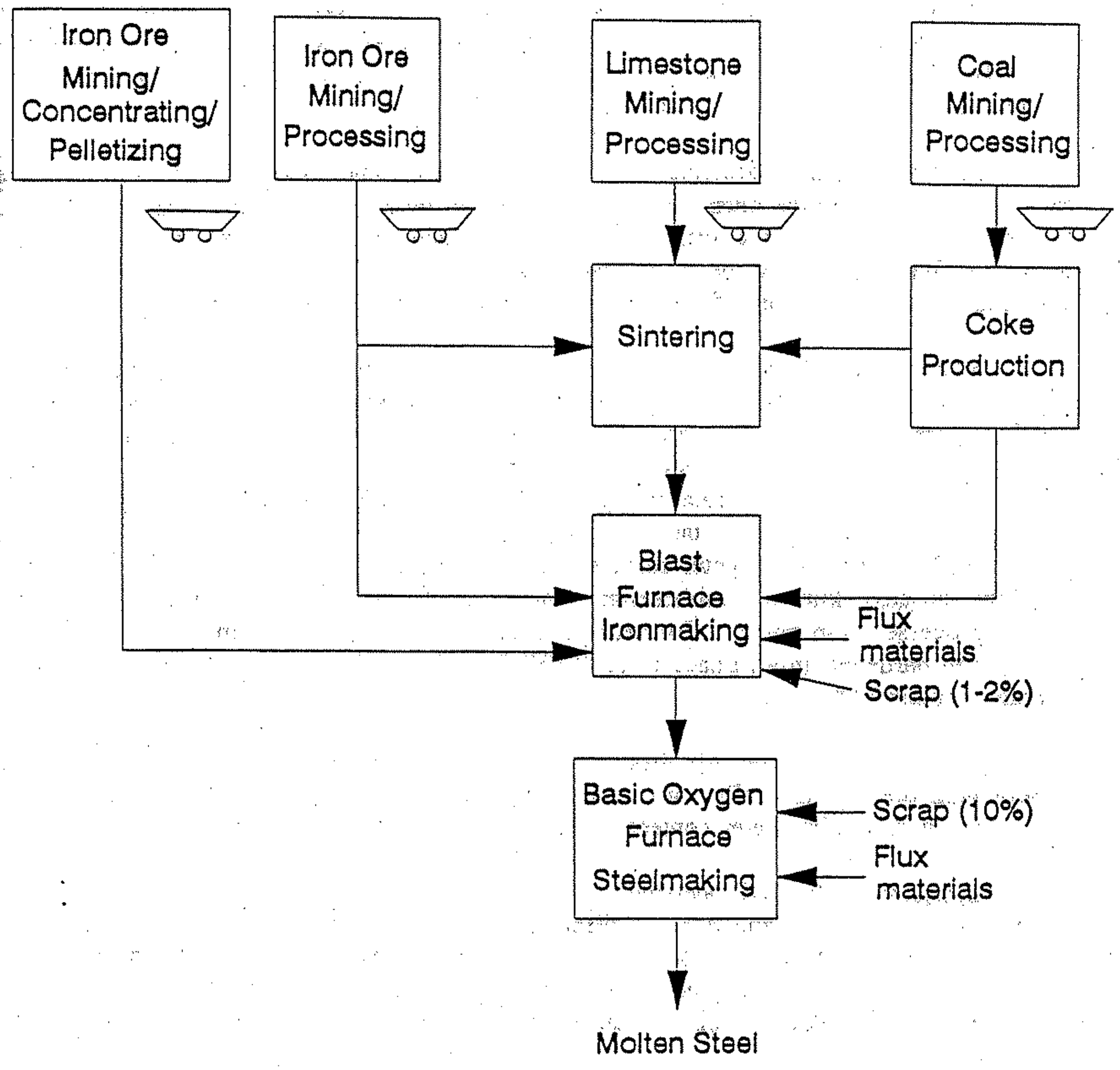
[5] The 2% loss rate during bleaching was taken from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention.*

[6] The energy requirements for forming, drying, calendering and winding were taken from Energetics, Inc., *The U.S. Pulp and Paper Industry: An Energy Perspective*. The energy use for forming, calendering and winding was calculated from pages 2.49 for forming and 2.51 for pressing. In the meeting of October 27, 1994, among Tellus, Franklin Associates, ICF, and EPA, Tellus and Franklin Associates' estimates of process energy for recycled printing and writing paper manufacturing differed by significantly more than 10%; Tellus' estimate was lower than Franklin Associates'. NYSERDA used the Energetics range of 5-20 MMBtu/ton for drying paper on page 2.53, and assumed that drying printing and writing paper would require 7.5 MMBtu/ton. In order to approach a consensus figure, Tellus reviewed its data sources, attempting to resolve the discrepancy.

We decided to use a different source within the Energetics report for the drying energy. Table 4.4 (page 4.10) shows energy consumption, by papermaking step, at three levels of energy intensity - "current practice", "state-of-the-art", and "advanced." Since the report used data from 1980-1985, we assumed that "state-of-the-art" energy consumption best approximated papermaking energy use in 1995. The energy consumption per ton newsprint in a state-of-the-art process is 9.30 MMBtu/ton. Subtracting the energy for forming, pressing, and winding leaves 8.60 MMBtu/ton, which we report as the drying energy.

[7] NYSERDA included final manufacturing energy for printing and writing paper. The listing for final manufacturing electricity, therefore, is zero.

MOLTEN STEEL PRODUCTION - BASIC OXYGEN FURNACE (10% POST-CONSUMER CONTENT)



Molten Steel Production
Basic Oxygen Furnace (10% Post-Consumer Content)

Steel is made from a combination of iron and small quantities of carbon. In addition to iron and carbon, several alloying elements can be used, including tin. Coal is typically used as a source of energy; limestone and lime are used as in steel making as fluxing agents, substances that remove impurities from the molten iron or steel. The production of molten steel involves several processes, including the Mining and Processing of Iron Ore, Limestone, and Coal; Coke Production; Sintering; Blast Furnace Ironmaking; and Basic Oxygen Furnace Steelmaking.

Three different furnace types have been used in recent years in the production of steel -- basic oxygen furnace (BOF), and electric arc furnace (EAF), and open hearth furnace (OH). NYSERDA modeled virgin steel production using the BOF, as it is the major process for manufacture of steel suitable for steel cans.

Iron Ore Mining/Processing Most iron ore that is mined is located near the surface and can thus be mined by the open-pit method. Open-pit mining entails removing earth and rock overburden covering the ore, drilling blasting holes and using explosives to break up the ore body, and finally removing the ore deposits. Overburden is removed and must be disposed of. The iron content of the ore affects the ratio of rock and iron ore to usable iron pellets.

After the ore is mined, it is generally processed onsite to reduce impurities. This process, known as beneficiation, can be as simple as washing and screening the ore, but is usually more complex. The ore generally undergoes crushing and grinding. Grinding generally includes three or four stages of dry crushing followed by wet grinding. A magnetic separator is used to concentrate the ore if the ore contains iron-containing particles. To separate non-magnetic ores, flotation cells are used in which the heavier iron-bearing particles sink to the bottom and the lighter particles remain suspended in the liquid. The ore that results from this process, known as concentrate, can be used directly in steel production or can be further processed into pellets. Concentrate is pelletized by adding a binder such as bentonite and is then hardened in a furnace at 1290-1500° C. The pellets produced during this step on average contain 64% iron.

Tailings are the residue from the beneficiation process. The ratio of tailings to beneficiated ore will naturally vary with the grade of ore. Tailings are generally transported as a slurry with a 45% water content and disposed of in ponds.

Limestone Mining/Processing Limestone is quarried by the open-pit method. Overburden is removed and must be disposed of. The limestone is transported to a crusher where its size is reduced. It is then conveyed to a second crusher and is screened. The product of this step can be used as is or may be processed in cement kilns to convert the limestone to lime. Rotary kilns account for approximately 90% of all lime production in the United States.

Coal Mining/Processing Coal is mined by two processes - surface mining and underground mining. For surface mining, the overburden is drilled, blasted, and removed to expose the coal. The coal is broken up and hauled to a preparation plant where it is cleaned. Underground mining on the other hand is generally accomplished with a single piece of machinery such as a continuous miner which cuts, drills, and mines. The coal is then hauled to the surface and taken to the preparation plant.

Coal supplied for coke production is cleaned after mining to lower its ash and sulfur content. The type of cleaning process used depends upon the coal quality, and may include any of the following: screens, separation baths, separation cyclones, classifiers, froth flotation, dewatering centrifuges, and thermal driers.

Coke Production Most of the coal used by the steel industry is for the production of coke, with bituminous coal used to make coke. Coke is the residue left after the destructive distillation of coal. Coal is converted to coke in the by-product coke oven plant, so named as the useful by-products of coking are recovered and used at the facility or sold. The by-product coke oven plant consists of three processes: coal preparation, coking in a coke battery, and by-product chemical processing. In the coal preparation area various metallurgical grades of coal are crushed and blended. The coal is then stored above the coke battery until needed.

The coke produced is used in the blast furnace where it serves both as a fuel and an oxygen-reducing agent. To convert coal to coke, the coal is heated in the coke battery which consists of a series of ovens which are 40 feet long, 20 feet high, and 18 inches wide. A coke battery can consist of as many as 100 of these ovens. The coal is charged into each oven by a car which operates on rails on top of the coke battery. The slot ovens alternate with spaces heated by the burning of coke gases. These gases heat the coal in the absence of air for 18 hours at 2000° F. Pyrolysis (heat-induced change without burning) drives off the volatile fraction of the coal, leaving behind a solid material which has a high carbon content. This solidified material is coke. The coke is removed from the oven and carried to the quench tower where it is sprayed with water.

During the coking operation approximately one quarter of the weight of coal is liberated as gases and vapors. Over 2000 different chemicals can be found in these gases including carbon monoxide, carbon dioxide, hydrogen sulfide, sulfur dioxide, ammonia, various aromatic hydrocarbons and polynuclear aromatic hydrocarbons. These gases produced during the coking operation are collected and delivered to a by-product plant where useful chemicals are recovered. The cleaned gas is returned to the coke oven battery for use in the slot ovens or used in other parts of the steel plant.

Sintering Sintering is a form of recycling; the process uses iron ore fines that are otherwise too small to be charged to the blast furnace, fine coke known as coke breeze, limestone, mill scale and recovered blast furnace flue dust and converts these into an agglomerated product, sinter, which can then be charged to a blast furnace. Thus the sinter plant is located near the blast furnace. The raw materials are placed on a travelling grate and ignited by a bank of burners. While travelling on the grate, the mixture burns and fuses. Combustion air is drawn down through the strand of sinter material, into a common duct, which leads to an air cleaning device. The sinter is crushed and screened and the undersized material is returned to the sintering process. After cooling, the sinter is crushed and screened a second time and the undersized material is again returned to the beginning of the process. Cooling requires either open air, water sprays, or mechanical fans.

Blast Furnace Ironmaking Pig iron is produced in the blast furnace from iron ore, limestone, and coke. The processed iron ore is charged into the top of the blast furnace, a large cylindrical tower lined with refractory brick, along with the coke and lime. After the furnace is initially charged with materials, it can continually operate for a number of years. As these materials travel down the furnace, their temperature increases due to the burning coke gases. In the top part of the furnace oxygen is removed from the ore by the coke gases. Lower down in the furnace, lime reacts with the coke and ore impurities forming slag. The highest temperatures, 3000° F, are found near the furnace bottom where the molten iron, known as pig iron, forms a pool.

Periodically the molten iron and slag are removed. A taphole is drilled into a clay-filled notch at the base of the furnace. The molten iron, which consists of 93% iron and 7% other elements, flows into runners that lead to transport ladles. Slag is channeled to separate runners that carries the material to a slag pit or slag pots which then are transported to a slag pit. The taphole is then plugged with clay.

Raw materials include several forms of iron-bearing materials including iron ore, pellets, and sinter; mill scale, limestone, scrap, and oxygen. Blast furnaces and various steel furnaces are lined with special brick refractories such as silica brick and fireclays. Due to the high temperatures that the refractories are subjected to, they must regularly be replaced.

Basic Oxygen Furnace (BOF) Steelmaking In this process, hot metal (pig iron) is converted to steel. The basic oxygen furnace (BOF) utilizes a process that produces steel from molten blast-furnace metal and scrap metal. Oxygen is used to oxidize carbon and silicon impurities. The BOF is a large steel shell lined with refractory materials that has a capacity up to 400 tons. To charge, the furnace is tilted and steel scrap is added through an opening at the top. Molten iron from the blast furnace is then added. When the furnace has been returned to its upright position, a water-cooled oxygen lance is lowered into the furnace about 6 feet above the metal surface and oxygen is supplied to oxidize impurities and provide heat. After an initial heating period, lime and fluorspar are added through a chute to form a slag layer with the impurities. As the reactions are exothermic (i.e., heat is given off), no external heat is provided. This full furnace cycle requires 25 to 45 minutes. Molten steel is removed; at this stage alloy metals can be added. The molten steel is then poured into ingot molds or to a continuous strand casting machine. The BOF is only used in integrated steel works since a supply of hot metal is needed.

TOTAL MATERIAL AND ENERGY INPUTS: MOLTEN STEEL PRODUCTION -- BOF (10% POST-CONSUMER CONTENT)

PROCESS **Material Output** Process/Transportation Energy *Coproducts*	Units	Units/ton molten steel	MMBtu Equivalents/ton molten steel
IRON ORE MINING			
Iron Ore Raw/Sinter Feed [1]	**pounds**	**421**	
Fuels:			
Diesel	gallons	0.03	0.005
Gasoline	gallons	0.002	0.0003
Natural Gas	cubic feet	0.03	0.0000
Electricity - Purchased	kWh	5.26	0.06
Transportation-Diesel [2]	gallons	0.53	0.07
IRON ORE MINING & BENEFICIATION [3]			
Iron Ore Concentrate	**pounds**	**2550**	
Fuels:			
Diesel	gallons	0.80	0.11
Gasoline	gallons	0.05	0.006
Electricity - Purchased	kWh	135	1.42
Transportation-Diesel [4]	gallons	3.20	0.44
IRON ORE PELLET PRODUCTION [5]			
Pellets		**2570**	
Fuels:			
Oil	gallons	2	0.29
Natural Gas	cubic feet	353	0.36
Electricity - Purchased	kWh	6	0.07
LIMESTONE MINING & PROCESSING [6]			
Limestone	**pounds**	**776**	
Fuels:			
Diesel	gallons	0.06	0.008
Natural Gas	cubic feet	5	0.005
Other			0.007
Electricity - Purchased	kWh	1	0.01
Transportation-Diesel [7]	gallons	0.12	0.02
LIME PRODUCTION [8]			
Lime	**pounds**	**114**	
Fuels:			
Natural Gas	cubic feet	134	0.14
Coal	tons	0.01	0.13
Electricity - Purchased	kWh	2	0.02
Transportation-Diesel [9]	gallons	0.03	0.00
COAL MINING [10]			
Coal	**pounds**	**1533**	
Fuels:			
Other			0.28
Transportation-Diesel [11]	gallons	1.06	0.15
COKE PRODUCTION [12]			
Coke	**pounds**	**1057**	
Fuels:			
Other			1.84
Electricity - Purchased	kWh	17	0.18
Steam	pounds	529	0.53
Coproducts			-2.12

TOTAL MATERIAL AND ENERGY INPUTS: MOLTEN STEEL PRODUCTION -- BOF (10% POST-CONSUMER CONTENT)

PROCESS **Material Output** Process/Transportation Energy *Coproducts*	Units	Units/ton molten steel	MMBtu Equivalents/ton molten steel
IRON ORE SINTER PRODUCTION [13]			
Sinter	**pounds**	**518**	
Fuels:			
Natural Gas	cubic feet	39	0.04
Coke Breeze	tons	0.02	0.61
Electricity - Purchased	kWh	8	0.08
PIG IRON PRODUCTION [14]			
Pig Iron (Hot Metal)	**pounds**	**2079**	
Fuels:			
Oil	gallons	3	0.47
Natural Gas	cubic feet	1090	1.12
Coke	tons	0.65	13.74
Other			1.69
Electricity - Purchased	kWh	43	0.45
Steam	pounds	1247	1.25
STEEL PRODUCTION [15]			
Molten Steel	**pounds**	**2000**	
Fuels:			
Natural Gas	cubic feet	272	0.28
Other			0.08
Electricity - Purchased	kWh	30	0.32
Transportation-Diesel [16]	gallons	0.52	0.07
FINAL MANUFACTURING ELECTRICITY [17]			11.68
Subtotal - Process Energy			**35.16**
Subtotal - Transportation Energy			**0.75**
Total Energy Requirements			**35.91**

communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992.

[9] NYSERDA transportation energy requirements were calculated from M. Michael Miller, "Lime," *1988 Nonfuel Minerals Yearbook Volume 1: Metals and Minerals*, published by US Department of the Interior, Bureau of Mines, 1990. See the discussion of NYSERDA's transportation methodology for more detail.

[10] The energy requirements for the mining of one ton of coal for steel production were taken from *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, page A-2, line marked "Mining of coal." The source also specifies that 2900 pounds of coal are required per ton of coke; coke is used in the production of pig iron. The quantity of coke required per ton of iron produced was taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992.

[11] NYSERDA transportation energy requirements were calculated from US Department of Energy, Energy Information Administration, *Quarterly Coal Report: April-June 1991*, November 1991, National Coal Association, *Coal Data: 1990 Edition*, 1990, and American Iron and Steel Institute, *1990 Annual Statistical Report*, 1991. See the discussion of NYSERDA's transportation methodology for more detail.

[12] The energy requirements for the production of one ton of coke were taken from *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, page A-2. The quantity of coke required per ton of iron produced was taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992. The coproducts per ton of steel produced are 6.9 gallons of tar, 1.9 gallons of light oil, and 74 pounds of coke breeze; coproduct information was taken from *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, page A-2.

[13] The energy and materials requirements per ton of iron ore sinter produced were taken from *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, June 27, 1975, page A-5. The quantity of sinter required per ton of steel produced was taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992.

[14] The energy and materials requirements per ton of iron ore produced, and the quantity of pig iron required per ton of steel produced, were taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992.

[15] The energy and materials requirements per ton of steel produced were taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992.

[16] NYSERDA transportation energy requirements denote the transportation of recycled scrap to a basic oxygen furnace. NYSERDA assumed an average haul of 250 miles. All transportation is assumed to be by truck. See the discussion of NYSERDA's transportation methodology for more detail.

[17] The energy requirements for the final manufacturing of steel cans were estimated from the U.S. Census Bureau, Census of Manufacturers MC87-1-34A, "Metal Cans, Cutlery, Handtools and General Hardware." This estimate is equivalent to the estimate of final manufacturing energy for aluminum cans, as we could not obtain enough information to make a separate estimate for steel cans. Table 3A (page 34A-11) shows that 2.286 million kilowatt hours (24 million MMBtu) were used by SIC code 3411 in the manufacture of cans. Table 7 (page 34A-22) shows that 1.09 million tons of aluminum were used to make cans; there was no

Footnotes:

[1] Iron ore raw/sinter feed includes iron ore used directly as fines, and in sinter production. The energy used per ton of iron ore raw/sinter feed mined was taken from Batelle Columbus Laboratories, *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing*, prepared by the US Department of the Interior, Bureau of Mines, June 27, 1975, page A-3. The quantity of iron per ton of sinter produced was taken from F.T. Sparrow, *Energy and Materials Flows in the Iron and Steel Industry*, published by Argonne National Laboratory, June 1983, page 50. The quantity of iron ore and sinter required per ton of steel was taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992.

[2] NYSERDA transportation energy requirements were calculated from Peter H. Kuck and Cheryl M. Cvetic, "Iron Ore,"*Iron Ore Minerals Yearbook - 1989, Volume 1: Metals and Minerals*, published by the US Department of the Interior, Bureau of Mines, 1991. See the discussion of NYSERDA's transportation methodology for more detail.

[3] Iron ore concentrate is iron that is used in pellet production. The energy used per ton of iron ore mining and beneficiation was taken from Batelle Columbus Laboratories, *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, page A-4. The quantity of iron ore concentrate required per ton of steel was taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992.

[4] NYSERDA transportation energy requirements were calculated from Peter H. Kuck and Cheryl M. Cvetic, "Iron Ore,"*Iron Ore Minerals Yearbook - 1989, Volume 1: Metals and Minerals*, published by the US Department of the Interior, Bureau of Mines, 1991. See the discussion of NYSERDA's transportation methodology for more detail.

[5] The energy required for iron pellet production was taken from Batelle Columbus Laboratories, *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, page A-4. The quantity of iron pellets required per ton of steel was taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992.

[6] Limestone mining and processing includes the limestone required for iron sinter production, pig iron production, molten steel production, and lime production. The energy required per ton of limestone produced was taken from Batelle Columbus Laboratories, *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, page A-7. The quantity of limestone required for pig iron production, molten steel production, and lime production was taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992. The quantity of limestone required for sinter production was calculated from F.T. Sparrow, *Energy and Materials Flows in the Iron and Steel Industry*, published by Argonne National Laboratory, June 1983, page 50.

[7] NYSERDA transportation energy requirements were calculated from Valentin V. Tepordei, "Crushed Stone," in *1988 Nonfuel Minerals Yearbook Volume 1: Metals and Minerals*, published by US Department of the Interior, Bureau of Mines, 1990. See the discussion of NYSERDA's transportation methodology for more detail.

[8] The energy required per ton of lime produced from limestone was calculated from Batelle Columbus Laboratories, *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, June 27 1975, page A-8. The quantity of lime required per ton of steel produced is taken from a personal

Molten Steel Production
Electric Arc Furnace (100% Post-Consumer Content)

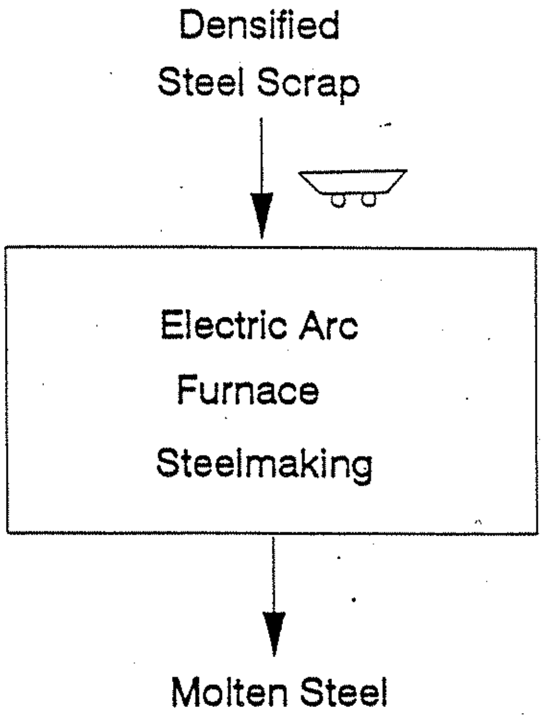
Post-consumer steel food and beverage, and bimetal cans, are 100% recyclable and can be recycled back into packaging cans. Steel cans are often collected as part of the municipal recycling efforts. In addition, magnetic separation systems can be used, allowing relatively easy extraction from the waste stream. NYSERDA did not include detinning in the model of EAF molten steel production, as the tin present in steel scrap is less than 2.5% of the total weight of the scrap.

Electric arc furnaces (EAFs) are capable of using 100% can scrap. NYSERDA modeled EAF molten steel production assuming some addition of iron scrap to the furnace. This assumption was based upon a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992. However, the use of nearly 100% steel scrap does not provide the properties required for the production of steel which can be milled to the thinness of can sheet. EAFs instead can use steel can scrap to produce other steel products such as reinforcing bar for construction, rod, nails, or wire.

TOTAL MATERIAL AND ENERGY INPUTS: MOLTEN STEEL PRODUCTION -- EAF (100% POST-CONSUMER CONTENT)

PROCESS **Material Output** Process/Transportation Energy	Units	Units/ton molten steel	MMBtu Equivalents/ton molten steel
MRF PROCESSING [See Above]			
Used Steel Cans	**pounds**	**1986**	
Fuels:			
Electricity			0.25
Diesel			0.04
Transportation - Diesel			0.07
LIMESTONE MINING & PROCESSING [1]			
Limestone	**pounds**	**135**	
Fuels:			
Diesel	gallons	0.01	0.0014
Natural Gas	cubic feet	0.83	0.0009
Other			0.0012
Electricity - Purchased	kWh	0.25	0.0026
LIME PRODUCTION [2]			
Lime	**pounds**	**72**	
Fuels:			
Natural Gas	cubic feet	85	0.09
Coal	tons	0.003	0.08
Electricity - Purchased	kWh	1	0.01
Transportation-Diesel [3]	gallons	0.02	0.003
SCRAP PROCESSING [4]			
Merchant Steel Scrap	**pounds**	**1986**	
Transportation-Diesel [5]	gallons	4	0.62
STEEL PRODUCTION (additional inputs) [6]			
Molten Steel	**pounds**	**2000**	
Fuels:			
Natural Gas	cubic feet	100	0.10
Electricity - Purchased	kWh	393	4.13
FINAL MANUFACTURING ELECTRICITY [7]			11.68
Subtotal - Process Energy			**16.39**
Subtotal - Transportation Energy			**0.69**
Total Energy Requirements			**17.08**

MOLTEN STEEL PRODUCTION - ELECTRIC ARC FURNACE (100% POST-CONSUMER CONTENT)



corresponding data available for steel. We calculated from table 6A-1 (page 34A-16) that the value of aluminum can shipments was 52.82% of the value of total can shipments. We assumed that the electricity used in aluminum canmaking was proportional to the value of the cans and thereby calculated that 12.68 million MMBtu (52.82% * 24 million MMBtu) were used to make aluminum cans. Dividing the total energy use by the total aluminum used to make cans yields an estimate of 11.68 (12.68/1.09) MMBtu per ton of aluminum cans produced. This estimate was not superseded by Franklin Associates data in the final report.

Footnotes:

[1] The energy requirements for the production of one ton of limestone were taken from Batelle Columbus Laboratories, *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, June 27 1975, page A-7. The quantity of limestone required per ton of recycled steel produced was calculated by multiplying the conversion factor for tons of limestone required per ton of lime produced on page A-7 by the quantity of lime required per ton of recycled steel produced. The quantity of lime required per ton of recycled steel produced was taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992. This communication is based upon 1989 IISI data.

[2] The energy requirements for the production of one ton of lime was taken from Batelle Columbus Laboratories, *Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing: Phase 4*, June 27, 1975, page A-7. The quantity of lime required per ton of recycled steel produced was taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992.

[3] NYSERDA transportation energy requirements were calculated from M. Michael Miller, "Lime," in *1988 Nonfuel Minerals Yearbook Volume 1: Metals and Minerals*, published by US Department of the Interior, Bureau of Mines, 1990. See the discussion of NYSERDA's transportation methodology for more detail.

[4] The personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992 showed 236 pounds of home scrap (factory scrap metal) and 1750 pounds of merchant scrap (recycled steel scrap purchased on the market) required per ton of recycled molten steel produced. In order to model a 100% post-consumer recycled system, NYSERDA made the assumption that all scrap was merchant scrap.

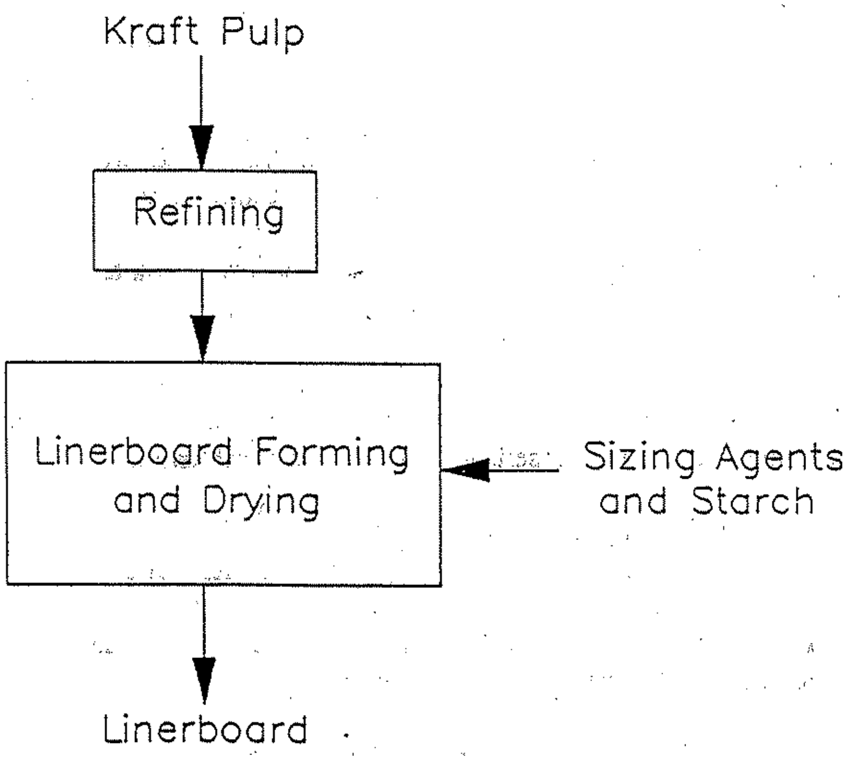
[5] NYSERDA transportation energy requirements denote the transportation of recycled scrap to an EAF furnace. NYSERDA assumed an average haul of 250 miles. All transportation is assumed to be by truck. See the discussion of NYSERDA's transportation methodology for more detail.

[6] The material and energy requirements for one ton of steel produced in an EAF were taken from a personal communication between Allen White, Tellus Institute and Gregory Crawford, Steel Can Recycling Institute, April 13, 1992.

[7] The energy requirements for the final manufacturing of steel cans were estimated from the U.S. Census Bureau, Census of Manufacturers MC87-1-34A, "Metal Cans, Cutlery, Handtools and General Hardware." This estimate is equivalent to the estimate of final manufacturing energy for aluminum cans, as we could not obtain enough information to make a separate estimate for steel cans. Table 3A (page 34A-11) shows that 2.286 million kilowatt hours (24 million MMBtu) were used by SIC code 3411 in the manufacture of cans. Table 7 (page 34A-22) shows that 1.09 million tons of aluminum were used to make cans; there was no corresponding data available for steel. We calculated from table 6A-1 (page 34A-16) that the value of aluminum can shipments was 52.82% of the value of total can shipments. We assumed that the electricity used in aluminum canmaking was proportional to the value of the cans and thereby calculated that 12.68 million MMBtu (52.82% * 24 million MMBtu) were used to make aluminum cans. Dividing the total energy use by the total aluminum used to make cans yields an estimate of 11.68 (12.68/1.09) MMBtu per ton of aluminum cans produced. This estimate was not superseded by Franklin Associates data in the final report.

Corrugated Boxes

VIRGIN LINERBOARD PRODUCTION



Virgin Linerboard Production

Virgin linerboard is produced using the following processes: Pulpwood Harvesting; Debarking; Chipping; Kraft Pulping; Refining; and Linerboard Forming & Drying.

Pulpwood Harvesting Typically trees are severed from the stump by one person using a chain saw. The trees are then skidded, or dragged, by a tractor to a truck road. At the roadside they are cut into bolts (i.e. transportable sized logs) and loaded onto a truck with either a crane, hydraulic loader or a fork-lift attachment on a tractor. The wood is commonly trucked directly to a mill.

Debarking When the wood arrives at the mill it is usually stored for days or months in a woodyard, and then loaded onto a mechanized conveyor system or water flume for transport to the debarker. Mechanical conveyance, the more common transport mode, requires washing of the logs before debarking to reduce equipment wear.

Debarking is generally done by one of three methods, dry debarking by friction, wet debarking by friction, or hydraulic debarking. The process used depends on the size of the logs handled. Since most pulpwood used today is small in diameter, most debarking is done in dry drum barkers. A dry drum barker consists of a slotted drum with internal staves that remove the bark from the pulpwood as the drum rotates. The bark sifts out of the slots and the debarked logs travel out the end of the drum and fall onto a conveyor belt.

Chipping Debarked logs or sawmill wastes are cut into chips by means of a rotating flywheel face with bars which act as cutting blades. The chips are then screened, and the screened out fines are sent to a boiler for combustion.

Kraft Pulping Wood consists of hollow cellulose fibers and other cells cemented together by lignin and hemicelluloses into a rigid and strong material. Pulping separates the wood into its cell components; paper and paperboard are formed when these cells are reunited in a mat formation. The quality of the pulp and subsequently, the quality of the paper or board required, determines the pulping process used.

In chemical pulping, cellulose fibers are extracted from wood by the chemical dissolution of lignin which binds the fibers together. The kraft, or sulfate pulping process involves the cooking or digestion of wood chips at high temperature and pressure in a white liquor, a water based solution of sodium hydroxide (NaOH) and sodium sulfide (Na_2S). The name sulfate comes from the makeup chemical, sodium sulfate, that is used as the source of the sulfide ion. Sodium sulfate used in the kraft pulping process as a source of sulfide ions, is produced from either a natural sodium sulfate deposit, or a sodium sulfate solution available as a byproduct of various manufacturing processes. Sodium Hydroxide (and chlorine) are produced from the electrolysis of salt, usually in diaphragm cells. Salt is mined from underground deposits by pumping water into the deposit and forcing the brine to the surface.

The cooking process takes place in a vessel called a digester, which can be either batch or continuous in design. From the digesters, the pulp is sent to the brown stock washers (pulp washers) where the black liquor (spent cooking liquor) is washed from the pulp with hot water. The spent wash water from this process is called weak black liquor, and is sent to the black liquor recovery system. The black liquor recovery process is designed to a) remove the water from the weak black liquor via evaporator systems, b) combust the residual organic materials (now called strong black liquor) in a recovery furnace, and c) convert the sodium sulfate in the strong black liquor to sodium sulfide.

The kraft white liquor system is designed to convert the inorganic smelt from the bottom of the recovery furnace into reusable white liquor for kraft pulping. The smelt materials go through a series of dissolving, clarifying, washing, combustion, and recovery steps for either reuse in the process or disposal. One final overflow mixture is the white liquor and is used again in the pulping process.

<u>Refining</u> A final mechanical refining step, through cutting and maceration, converts "raw" fiber into a form suitable for papermaking.

<u>Linerboard Forming & Drying</u> Forming is the actual conversion of pulp into linerboard. The formation of paper and paperboard occurs in three steps: first, a web of fiber is formed from a fiber/water suspension on a paper machine wire. Often, additives such as sizing (for final product water resistance), clay (for opacity and brightness), and starch (for strength) have been added to this fiber/water suspension. Second, water is pressed out of the web, and last, the remaining water is driven off by heat. While there are numerous types of paper machines used today, the two most common designs are the fourdrinier and cylinder paper machines. The fourdrinier machine can be used to manufacture a variety of paper grades and lightweight boards.

The fourdrinier machine consists of a moving, endless plastic or bronze screen, supported by a table, which carries the sheet through forming, pressing and then drying stages. The stock, containing only about 0.5% fiber and filler (the balance being water) is pumped into a headbox, which distributes the stock across the width of the paper machine, and then flows out onto the screen. Suction devices below the screen pull the water, and some solid material (particularly smaller fibers and fillers) through the wire and into a collection system. This mixture is called "whitewater", the components of which are often recycled within the process.

The fiber web, atop the screen, is picked up by a moving felt which transfers the web into the press section. At the press section, further dewatering takes place as the web and felt pass between a series of paired press rolls, pushed together, much like an old-fashioned clothing wringer. When the sheet leaves the press section and enters the dryer section, it contains approximately 65% water. The dryer section consists of a long progression of steam-heated drying cans, or cylinders, which transfer heat to the sheet and drive off most, but not all of the remaining moisture. When the paper or board is reeled up at the end of the machine, it usually contains about 6% water.

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN CORRUGATED BOXBOARD PRODUCTION [1]

PROCESS Material Output Process/Transportation Energy	Units	Units/ton corrugated	MMBtu Equivalents/ ton corrugated
KRAFT PULPING [2]			
Pulp (bone dry)	**pounds**	**1783**	
Fuels:			
Gasoline	gallons	2	0.23
Diesel	gallons	1	0.19
Oil	gallons	9	1.34
Steam	pounds	6017	8.42
Electricity	kWh	69	0.73
Transportation-Diesel [3]	gallons	7	0.91
FURNISH REFINING, ADDITIVES MIXING, FINAL CLEANING, AND TEMP. ADJUSTMENT [4]			
Stock (bone dry)	**pounds**	**1818**	
Fuels:			
Steam	pounds	429	0.30
Electricity	kWh	64	0.34
FORMING, DRYING, CALENDERING, COATING AND WINDING (FOURDRINIER MACHINE) [5]			
Corrugated Boxboard	**pounds**	**2000**	
Fuels:			
Steam	pounds	8429	11.80
Electricity	kWh	584	1.29
FINAL MANUFACTURING ELECTRICITY [6]			1.03
Subtotal - Process Energy			**25.67**
Subtotal - Transportation Energy			**0.91**
Total Energy Requirements			**26.58**

Footnotes:

[1] NYSERDA did not include virgin corrugated boxboard; we used the average of the report's virgin linerboard and virgin unbleached coated folding boxboard results as a proxy.

[2] The energy and material requirements for the production of one ton of kraft pulp are shown in an appendix. The quantity of unbleached pulp required was assumed to be 1783 pounds of pulp per ton of material for both linerboard and folding boxboard.

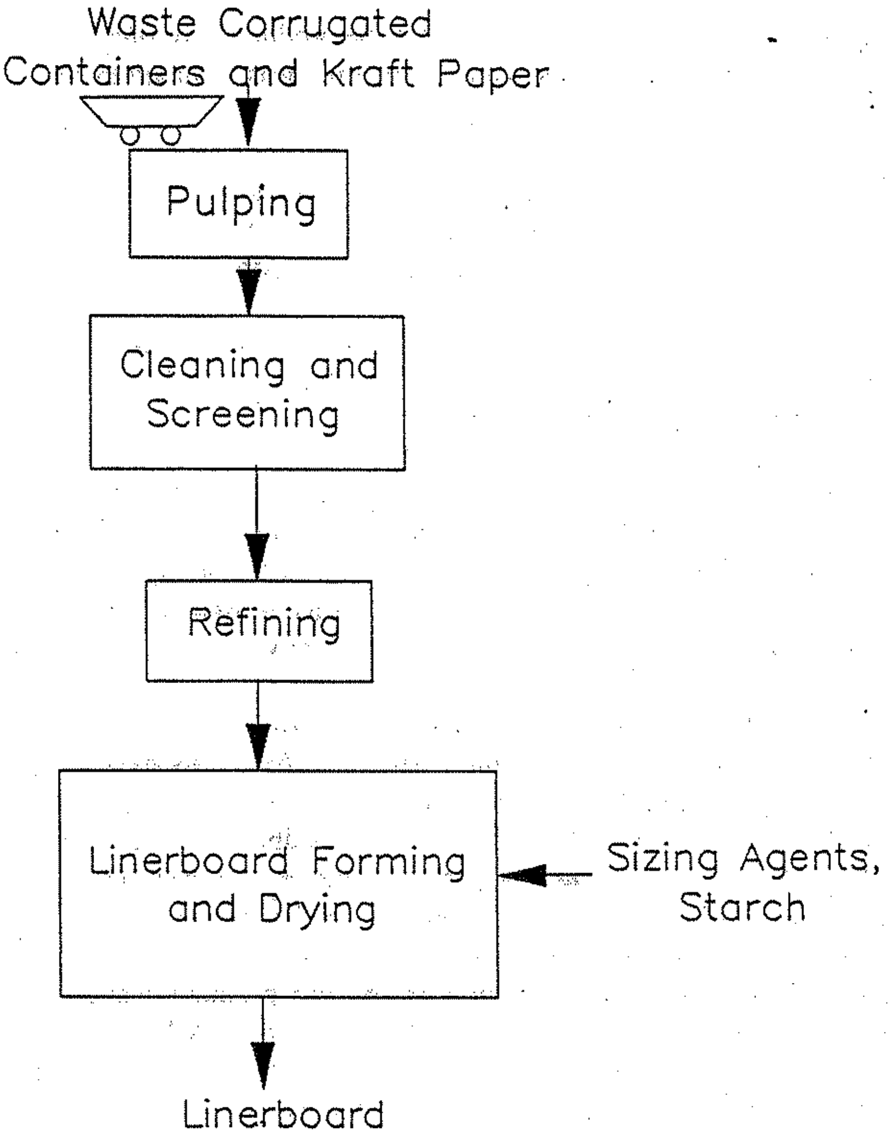
[3] NYSERDA assumed that, on average, roundwood, forest, and manufacturing residues used in pulp production are transported 100 miles to the pulp mill, and they are transported by truck. See the discussion of NYSERDA's transportation methodology for more detail.

[4] The energy requirements for furnish refining, additives mixing, final cleaning, and temperature adjustment were taken from Oak Ridge National Laboratory, *Energy Use and Distribution in the Pulp, Paper and Boardmaking Industries*, pages 42-45.

[5] The energy requirements for forming, drying, calendering and winding were taken from Energetics, Inc., *The U.S. Pulp and Paper Industry: An Energy Perspective*. The energy for forming, calendering and winding were calculated from pages 2.49 for forming and 2.51 for pressing. Energetics presents a range of 5-20 MMBtu/ton for drying paper on page 2.53; NYSERDA assumed that drying linerboard would require 11 MMBtu/ton and drying unbleached coated folding boxboard would require 12.60 MMBtu/ton.

[6] The energy requirements for the final manufacturing of corrugated boxes were estimated from the U.S. Census Bureau, Census of Manufacturers MC87-1-26B, "Paperboard Containers and Boxes." Table 3A (page 26B-12) shows that 2.535 million kilowatt hours (26.62 million MMBtu) were used by SIC code 2653 in the manufacture of paperboard containers and cardboard boxes. Table 7 (page 26B-16) shows that 5.8 million tons of food and beverage paperboard containers were produced, with a value of 3.49 billion dollars, and the total value of all paperboard containers and boxes produced was 15.6 billion dollars. There was no estimate of total tonnage; we made the assumption that value was directly proportional to tonnage and thereby estimated total paperboard container and box production at 25.91 million tons. Dividing total energy by total tonnage yields an estimate of 1.03 (26.62/25.91) MMBtu per ton of paperboard boxes produced, and we assumed that this estimate could be applied to corrugated box manufacture as well. This estimate was not superseded by Franklin Associates data in the final report.

RECYCLED LINERBOARD PRODUCTION



Recycled Linerboard Production

Recycled linerboard is made with pulp from a combination of materials such as waste corrugated containers and kraft paper. Once the waste materials are received at the paper mill, they must be repulped before they can be used in the papermaking process. The process involves several steps, including Pulping, Cleaning & Screening, Refining, and Linerboard Forming & Drying.

Pulping Wastepaper is repulped through mixing with heated water in a hydropulper (a device similar in operation to a household blender) which separates the paper fibers, creating a pulp. Contaminants float to the surface and are removed at this stage using a variety of collection and removal devices. The slurry is pumped out of the pulper, through extraction plates (filtering device).

Cleaning & Screening The pulp usually proceeds to a centrifugal cleaning system. Centrifugal cleaning removes contaminants, such as glass and gravel, which have a higher specific gravity than wood fiber. The clean slurry passes out of the top of the centrifugal cleaner, usually to a series of vibrating or high-pressure screens where light-weight contaminants and any other non-fibrous materials are removed. Plastic contaminants are removed at this point. Some mills employ a washing stage to remove inks, clays and chemicals. The pulp is now ready to be used in the paper or paperboard manufacturing process.

Refining A final mechanical refining step, through cutting and maceration, converts "raw" fiber into a form suitable for papermaking.

Linerboard Forming & Drying Forming is the actual conversion of pulp into linerboard. The formation of paper and paperboard occurs in three steps: first, a web of fiber is formed from a fiber/water suspension on a paper machine wire. Often, additives such as sizing (for final product water resistance), clay (for opacity and brightness), and starch (for strength) have been added to this fiber/water suspension. Second, water is pressed out of the web, and last, the remaining water is driven off by heat. While there are numerous types of paper machines used today, the two most common designs are the fourdrinier and cylinder paper machines. Linerboard is primarily manufactured on a fourdrinier machine.

The fourdrinier machine consists of a moving, endless plastic or bronze screen, supported by a table, which carries the sheet through forming, pressing and then drying stages. The stock, containing only about 0.5% fiber and filler (the balance being water) is pumped into a headbox, which distributes the stock across the width of the paper machine, and then flows out onto the screen. Suction devices below the screen pull the water, and some solid material (particularly smaller fibers and fillers) through the wire and into a collection system. This mixture is called "whitewater", the components of which are often recycled within the process.

The fiber web, atop the screen, is picked up by a moving felt which transfers the web into the press section. At the press section, further dewatering takes place as the web and felt pass between a series of paired press rolls, pushed together, much like an old-fashioned clothing wringer. When the sheet leaves the press section and enters the dryer section, it contains approximately 65% water. The dryer section consists of a long progression of steam-heated drying cans, or cylinders, which transfer heat to the sheet and drive off most, but not all of the remaining moisture. When the paper or board is reeled up at the end of the machine, it usually contains about 6% water.

TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED CORRUGATED BOXBOARD PRODUCTION [1]

PROCESS **Material Output** Process/Transportation Energy	Units	Units/ton corrugated	MMBtu Equivalents/ ton corrugated
MRF PROCESSING [See Above]			
Used Corrugated Boxes	**pounds**	**2054**	
Fuels:			
Electricity			0.25
Diesel			0.04
Transportation - Diesel			0.07
WASTEPAPER PULPING [2]			
Pulp (bone dry)	**pounds**	**1780**	
Fuels:			
Electricity	kWh	397	4.17
Transportation - Diesel [3]	gallons	8	1.04
FURNISH REFINING, ADDITIVES MIXING, FINAL CLEANING, AND TEMP. ADJUSTMENT [4]			
Stock (bone dry)	**pounds**	**1937**	
Fuels:			
Steam	pounds	429	0.60
Electricity	kWh	57	0.60
FORMING, PRESSING, DRYING, CALENDERING, WINDING, AND COATING [5]			
Corrugated Boxboard	**pounds**	**2000**	
Fuels:			
Steam	pounds	10072	14.10
Electricity	kWh	187	1.96
FINAL MANUFACTURING ELECTRICITY [6]			1.03
Subtotal - Process Energy			22.74
Subtotal - Transportation Energy			1.12
Total Energy Requirements			23.86

Footnotes:

[1] NYSERDA did not include recycled corrugated boxboard; we used the average of the report's recycled linerboard and recycled unbleached coated folding boxboard results as a proxy.

[2] The energy requirements for wastepaper pulping were estimated from Energetics, Inc., *The U.S. Pulp and Paper Industry: An Energy Perspective*, prepared for the Pacific Northwest Laboratory, April 1988, page 2.33. The source presented a range of 4-5.8 MMBtu per ton of pulp; NYSERDA assumed 4.5 MMBtu per ton of pulp. The quantity of mixed waste paper required per ton of pulp was based on the assumption of 11.25% losses during the pulping step - 7.5% for folding boxboard and 15% for linerboard. The linerboard assumption was based upon an engineering estimate for a planned linerboard mill, cited in "Solid Waste Report," April 20, 1992. In addition, the material requirements account for the fact that the average moisture content of waste paper is 10%, which was based on Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, Noyes Data Corporation, 1977, page 62.

[3] NYSERDA assumed that, on average, old waste paper used in recycled pulp production is transported 375 miles to the pulp mill (500 for linerboard and 250 for folding boxboard), and is transported by truck. See the discussion of NYSERDA's transportation methodology for more detail.

[4] The energy requirements for furnish refining, additives mixing, final cleaning, and temperature adjustment were taken from Oak Ridge National Laboratory, *Energy Use and Distribution in the Pulp, Paper and Boardmaking Industries*, pages 42-45.

[5] The energy requirements for forming, drying, calendering and winding recycled linerboard were taken from Energetics, Inc., *The U.S. Pulp and Paper Industry: An Energy Perspective*. The energy use for forming, calendering and winding was calculated from pages 2.49 for forming and 2.51 for pressing. Energetics presents a range of 5-20 MMBtu/ton for drying paper on page 2.53; NYSERDA assumed that drying recycled linerboard would require 11.60 MMBtu/ton.

Energy requirements for forming, drying, calendering and winding recycled unbleached coated folding boxboard were taken from Arthur D. Little, *Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Volume V. Pulp and Paper Industry Report*, prepared for U.S. Department of Commerce, Industrial Environmental Research Laboratory, December 1976. The quantity of stock required to make one ton of folding boxboard was taken from Marshall Sittig, *Pulp and Paper Manufacture: Energy Conservation and Pollution Prevention*, page 15.

[6] The energy requirements for the final manufacturing of corrugated boxes were estimated from the U.S. Census Bureau, Census of Manufacturers MC87-1-26B, "Paperboard Containers and Boxes." Table 3A (page 26B-12) shows that 2.535 million kilowatt hours (26.62 million MMBtu) were used by SIC code 2653 in the manufacture of paperboard containers and cardboard boxes. Table 7 (page 26B-16) shows that 5.8 million tons of food and beverage paperboard containers were produced, with a value of 3.49 billion dollars, and the total value of all paperboard containers and boxes produced was 15.6 billion dollars. There was no estimate of total tonnage; we made the assumption that value was directly proportional to tonnage and thereby estimated total paperboard container and box production at 25.91 million tons. Dividing total energy by total tonnage yields an estimate of 1.03 (26.62/25.91) MMBtu per ton of paperboard boxes produced, and we assumed that this estimate could be applied to corrugated box manufacture as well. This estimate was not superseded by Franklin Associates data in the final report.