BACKGROUND DOCUMENT A

Background Data
Submitted by Franklin Associates, Ltd.

A LIFE CYCLE INVENTORY OF PROCESS AND TRANSPORTATION ENERGY FOR EIGHT DIFFERENT MATERIALS

INTRODUCTION

This appendix presents the aggregated process and transportation energy used to manufacture eight different types of materials from virgin raw materials and recycled postconsumer materials. The eight different materials studied are: newspapers, aluminum cans, office paper, steel cans, corrugated boxes, low density polyethylene (LDPE), high density polyethylene (HDPE), and polyethylene terephthalate (PET).

Although they are not complete life cycle inventories, the energy profiles for each virgin material are based on life cycle inventory (LCI) practices. The process energy and transportation energy for most steps in the life cycle of the materials are included. The life cycle of each virgin material begins with the acquisition of raw materials, such as the harvesting of trees for making newsprint or the production of crude oil for making plastic. The energy profiles for the virgin materials include raw materials acquisition through manufacture of the material or product specified.

For most of the recycled materials, the energy profiles represent a system which begins with the collection and transportation of postconsumer materials and finishes with reprocessing into the recycled material or product specified. In two cases, office paper recycled into tissue paper and corrugated recycled into folding boxes, the energy profiles represent "open-loop" recycling. Open-loop recycling is discussed later in this appendix.

The following sections of this appendix present: 1) the data tables and flow diagrams illustrating the systems evaluated; 2) a discussion of the overall boundary conditions for the systems studied; 3) a discussion of the processes evaluated for each system, and 4) an overview of the data sources.

FLOW DIAGRAMS AND DATA TABLES

A flow diagram and data table(s) are presented for the production of each material both from virgin and from recycled inputs. Each flow diagram shows the process steps that are included in the boundaries of the analysis. The data in the associated table(s) show the aggregated energy to produce one ton of the material specified. The boundaries of the analysis include manufacturing into the final product; for aluminum and plastic resins, fabrication is shown separately. Where fabrication is included in the boundaries, fabrication data may be presented in a separate table from material production (e.g., aluminum), or a single table may contain data encompassing material production and fabrication (e.g., corrugated containers).

Table 1a

DATA FOR THE PRODUCTION OF ONE TON OF AVERAGE* NEWSPRINT

Energy Usage			Thousand Btu
Process Energy			
Electricity	1,781	kwh	19,541
Natural gas **	9,999	cu ft	11,347
LPG	0.16	gal	17.1
Coal	31.9	lb	362
Distillate oil**	0.098	gal	27.9
Residual oil	0.99	gal	166
Gasoline	0.0028	gal	0.39
Diesel	1.78	gal	278
Wood	2,218	thousand Btu	2,218
Total Process			33,956
Transportation Energy			
Combination truck	236	ton-miles	
Diesel	2.78	gal	433
Single unit truck	87	ton-miles	
Diesel	1.66	gal	273
Rail	101	ton-miles	
Diesel	0.31	gal	48.6
Barge	2.33	ton-miles	
Diesel	0.0047	gal	0.73
Residual oil	0.0014	gal	0.23
Ocean freighter	51.4	ton-miles	
Diesel	0.0051	gal	0.80
Residual	0.051	gal	8.63
Pipeline-natural gas	0.50	ton-miles	
Natural gas	1.15	cu ft	1.29
Pipeline-petroleum products	3.18	ton-miles	
Electricity	0.070	kwh	0.77
Total Transportation			767

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* The "average" data presented here represent the average recycled content and recycling level of 39%

** Includes energy of material resource

Source: Franklin Associates, Ltd.

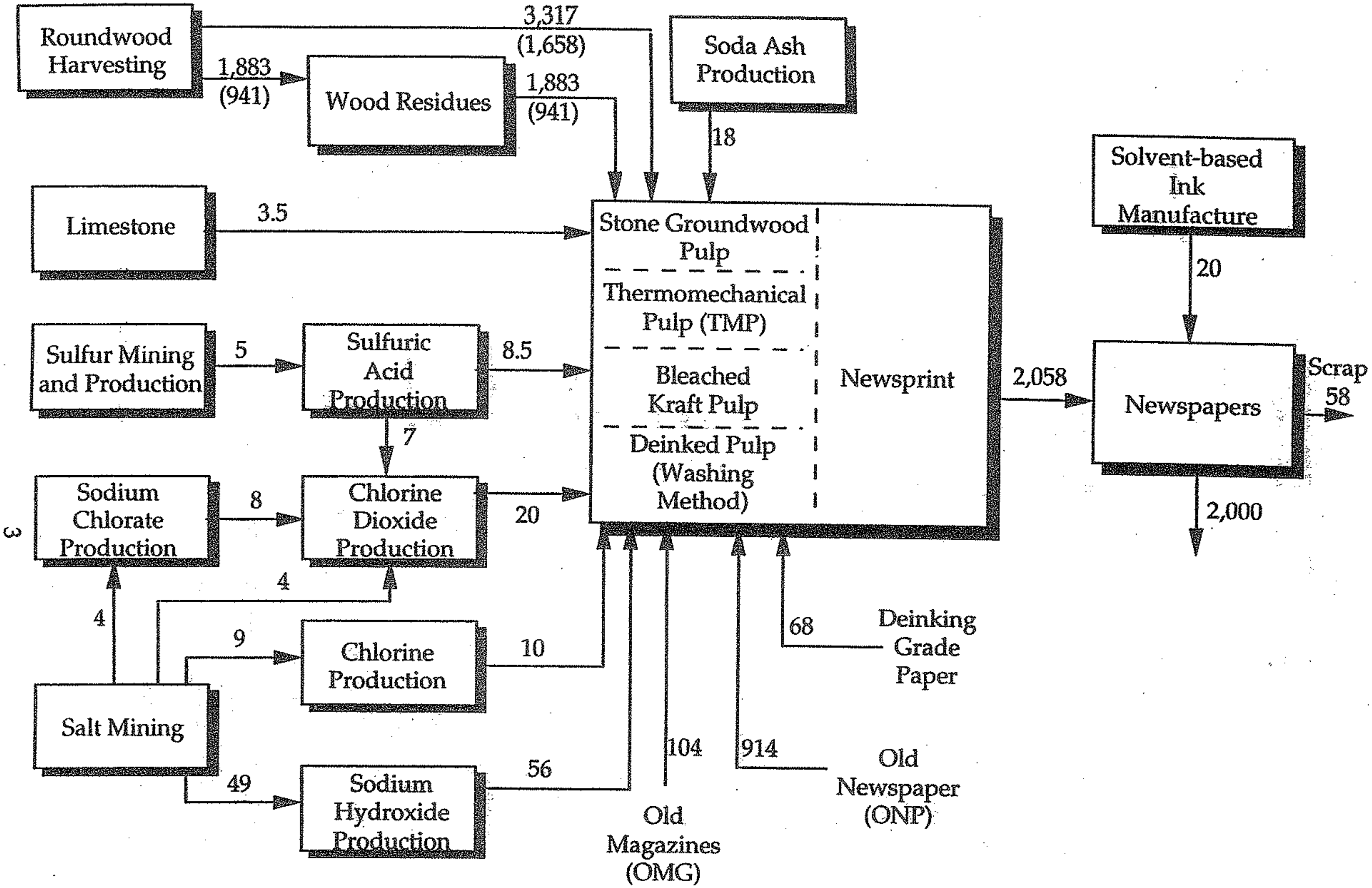

Figure 1a. Flow diagram for the U.S. production composite of one ton recycled and virgin fiber newsprint/newspaper. Numbers represent actual weight of materials in pounds. Numbers in parenthesis represent bone dry weight.

Table 1b

DATA FOR THE PRODUCTION OF ONE TON OF NEWSPRINT FROM RECYCLED NEWSPRINT

Energy Usage			Thousand Btu
Process Energy			
Electricity	1,251	kwh	13,723
Natural gas *	7,888	cu ft	8,978
LPG	0.41	gal	43.5
Coal	19.3	lb	219
Distillate oil*	0.093	gal	27.0
Residual oil	0.068	gal	11.4
Gasoline	0.0025	gal	0.35
Total Process			23,005
Transportation Energy			
Combination truck	10.7	ton-miles	
Diesel	0.13	gal	19.6
Single unit truck	222	ton-miles	
Diesel	4.24	gal	700
Rail	46.0	ton-miles	
Diesel	0.14	gal	22.2
Barge	0.86	ton-miles	
Diesel	0.0017	gal	0.27
Residual oil	5.2E-04	gal	0.087
Ocean freighter	48.6	ton-miles	
Diesel	0.0049	gal	0.76
Residual	0.049	gal	8.16
Pipeline-natural gas	0.43	ton-miles	
Natural gas	0.99	cu ft	1.11
Pipeline-petroleum products	2.99	ton-miles	
Electricity	0.066	kwh	0.72
Total Transportation			752

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* Includes energy of material resource

Source: Franklin Associates, Ltd.

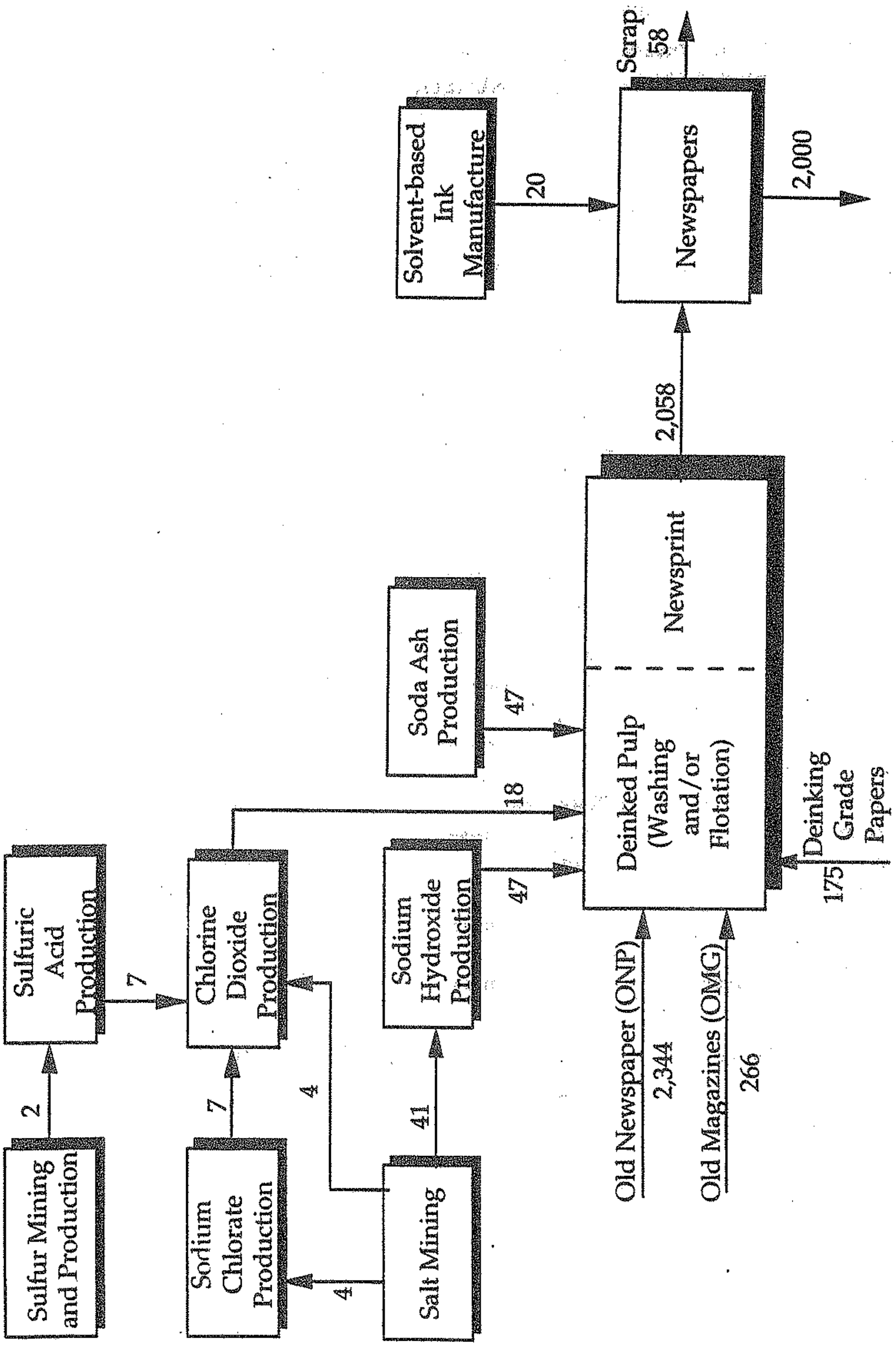

Figure 1b. Flow diagram for the production of one ton of 100% recycled fiber newsprint/newspaper. Numbers represent weight of materials in pounds.

Table 2a

DATA FOR THE PRODUCTION OF ONE TON OF ALUMINUM INGOT FROM VIRGIN MATERIAL

Energy Usage			Thousand Btu
Process Energy			
Coal (for coke)	251	lb	3,009
Petroleum (for coke)	706	lb	13,668
Electricity	16,545	kwh*	177,227 *
Natural gas	10,889	cu ft	12,576
LPG	0.17	gal	20
Coal	46.1	lb	565
Distillate oil	3.18	gal	523
Residual oil	10.4	gal	1831
Gasoline	0.074	gal	11
Diesel	2.99	gal	491
Total Process			209,922
Transportation Energy			
Combination truck	27	ton-miles	
Diesel	0.32	gal	53
Rail	1,438	ton-miles	
Diesel	4.46	gal	733
Barge	26	ton-miles	
Diesel	0.052	gal	9
Residual oil	0.016	gal	3
Ocean freighter	20,254	ton-miles	
Diesel	2.03	gal	333
Residual	20.3	gal	3,553
Pipeline-petroleum products	99	ton-miles	
Electricity	2.18	kwh	23
Total Transportation			4,706

Source: Franklin Associates, Ltd.

* The electricity values have been revised to reflect smelting energy as reported in Alcoa's 1993 Annual Report. The Btu value for electricity is based on the U.S. national average grid.

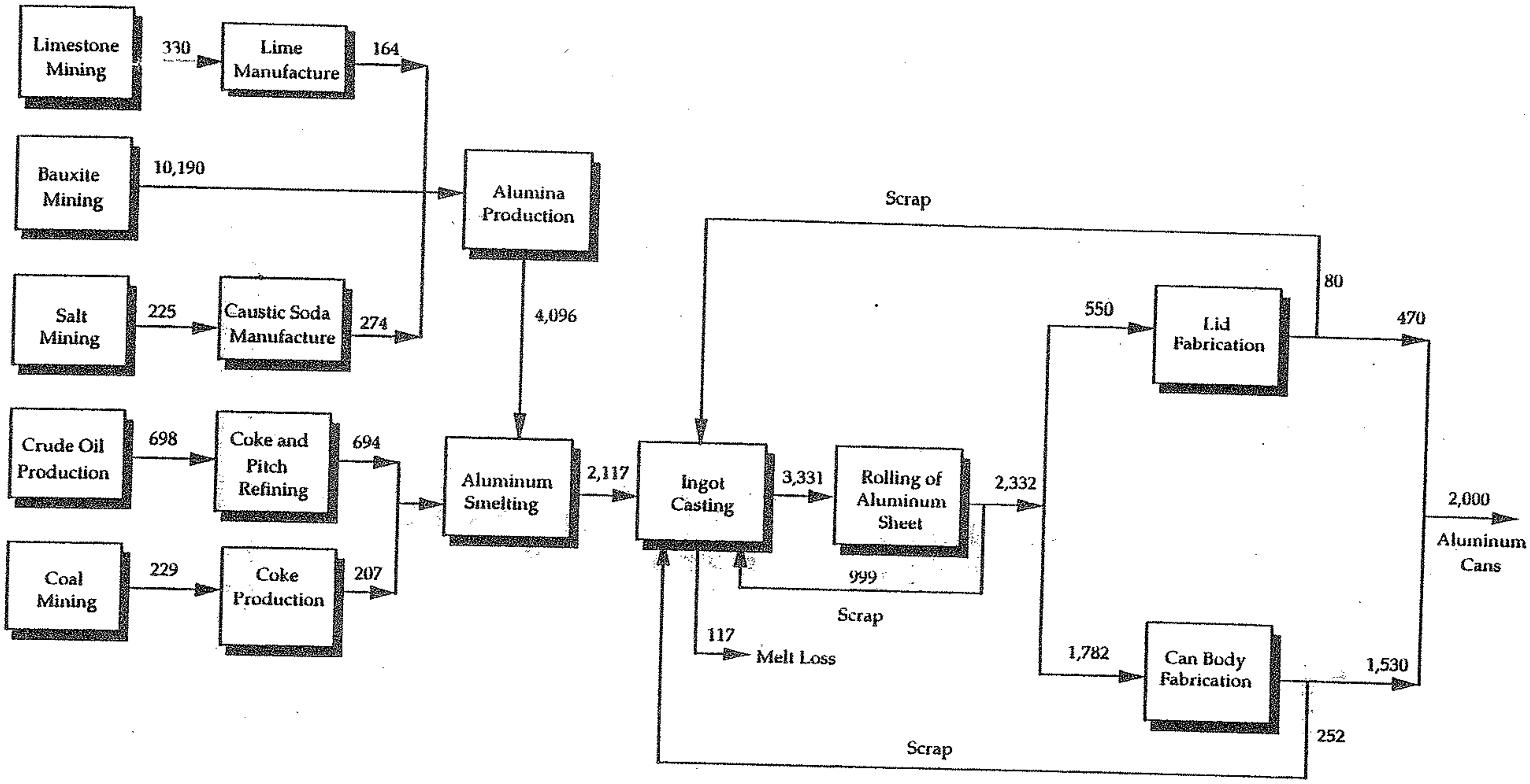

Figure 2a. Flow diagram for the manufacture of one ton of virgin aluminum beverage cans. Numbers represent pounds of material.

Table 2b

DATA FOR THE PRODUCTION OF ONE TON OF ALUMINUM INGOT FROM 100 PERCENT RECYCLED MATERIAL

(includes recovery, reprocessing, and ingot casting)

Energy Usage			**Thousand Btu**
Process Energy			
Electricity*	223	kwh	2,392
Natural gas	3,550	cu ft	4,100
Residual oil	1.38	gal	242
Total Process			6,734
Transportation Energy			
Combination truck	43	ton-miles	
Diesel	0.51	gal	83
Rail	1,070	ton-miles	
Diesel	3.32	gal	545
Total Transportation			628

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* The Btu value for electricity is based on the U.S. national average grid.

Source: Franklin Associates, Ltd.

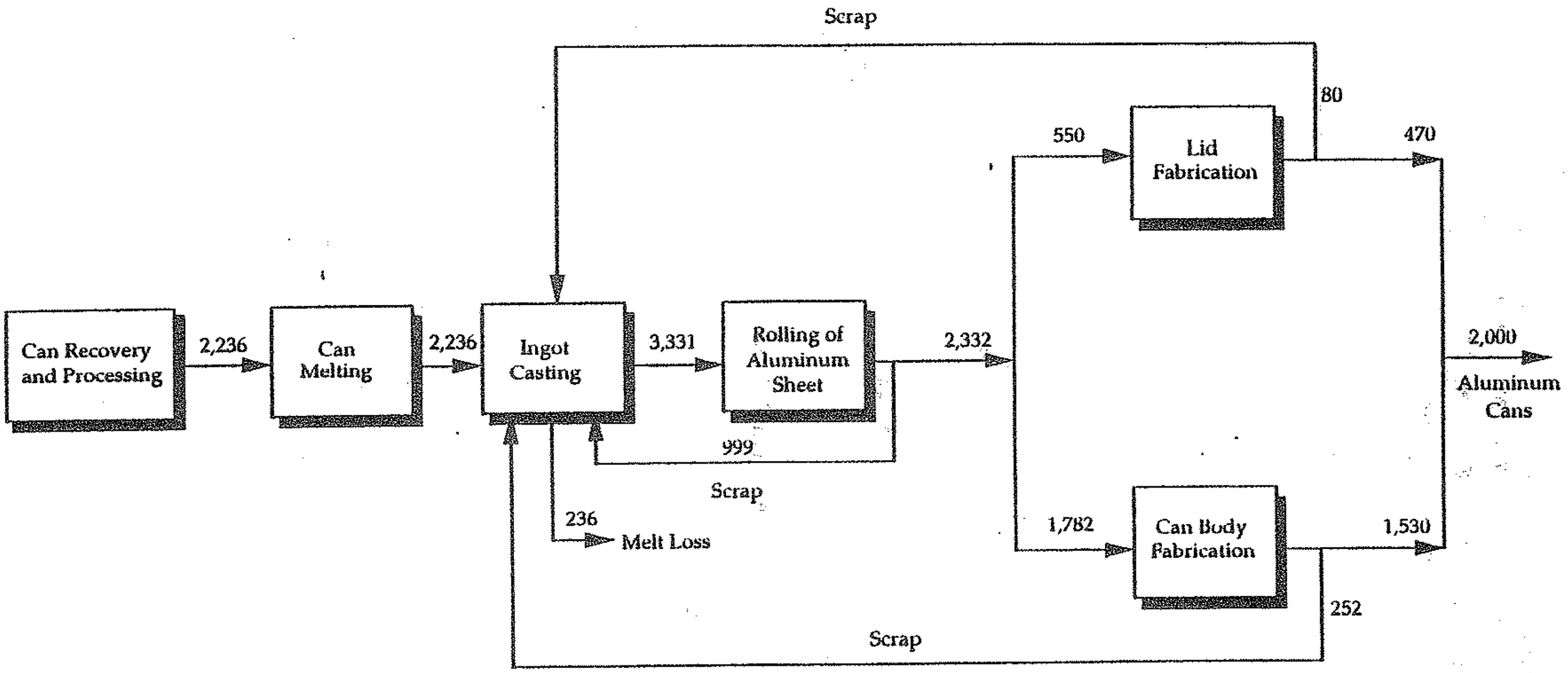

Figure 2b. Flow diagram for the manufacture of one ton of aluminum beverage cans from recycled cans. Numbers represent pounds of material.

Table 2c

DATA FOR THE FABRICATION OF ONE TON OF ALUMINUM CANS FROM INGOT*

(includes sheet rolling and can production)

			Thousand Btu
Raw Materials			
Aluminum Ingot	2,000	lb	
Energy Usage			
Process Energy			
Electricity**	1,282	kwh	13,735
Natural gas	16,339	cu ft	18,871
Residual oil	5.75	gal	1,008
Total Process			33,614
Transportation Energy			
Combination truck	73	ton-miles	
Diesel	0.86	gal	141
Rail	1,728	ton-miles	
Diesel	5.36	gal	881
Total Transportation			1,022

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* These data are identical for fabrication from virgin ingot or recycled ingot.

** The Btu value for electricity is based on the U.S. national average grid.

Source: Franklin Associates, Ltd.

Table 3a

DATA FOR THE PRODUCTION OF ONE TON OF OFFICE PAPER FROM VIRGIN MATERIALS

Energy Usage			Thousand Btu
Process Energy			
Electricity	1,266	kwh	13,561
Natural gas	4,301	cu ft	4,967
Coal	437	lb	5,361
Distillate oil	0.019	gal	3.07
Residual oil	13.6	gal	2,377
Gasoline	7.22	gal	1,089
Wood	27,438	thousand Btu	27,438
Total Process			54,796
Transportation Energy			
Combination truck	691	ton-miles	
Diesel	8.15	gal	1,340
Rail	2,153	ton-miles	
Diesel	6.68	gal	1,097
Barge	14.1	ton-miles	
Diesel	0.028	gal	4.64
Residual oil	0.0085	gal	1.48
Ocean freighter	52.0	ton-miles	
Diesel	0.0052	gal	0.85
Residual	0.052	gal	9.12
Pipeline-natural gas	1.02	ton-miles	
Natural gas	2.34	cu ft	2.70
Pipeline-petroleum products	3.10	ton-miles	
Electricity	0.068	kwh	0.73
Total Transportation			2,457

Source: Franklin Associates, Ltd.

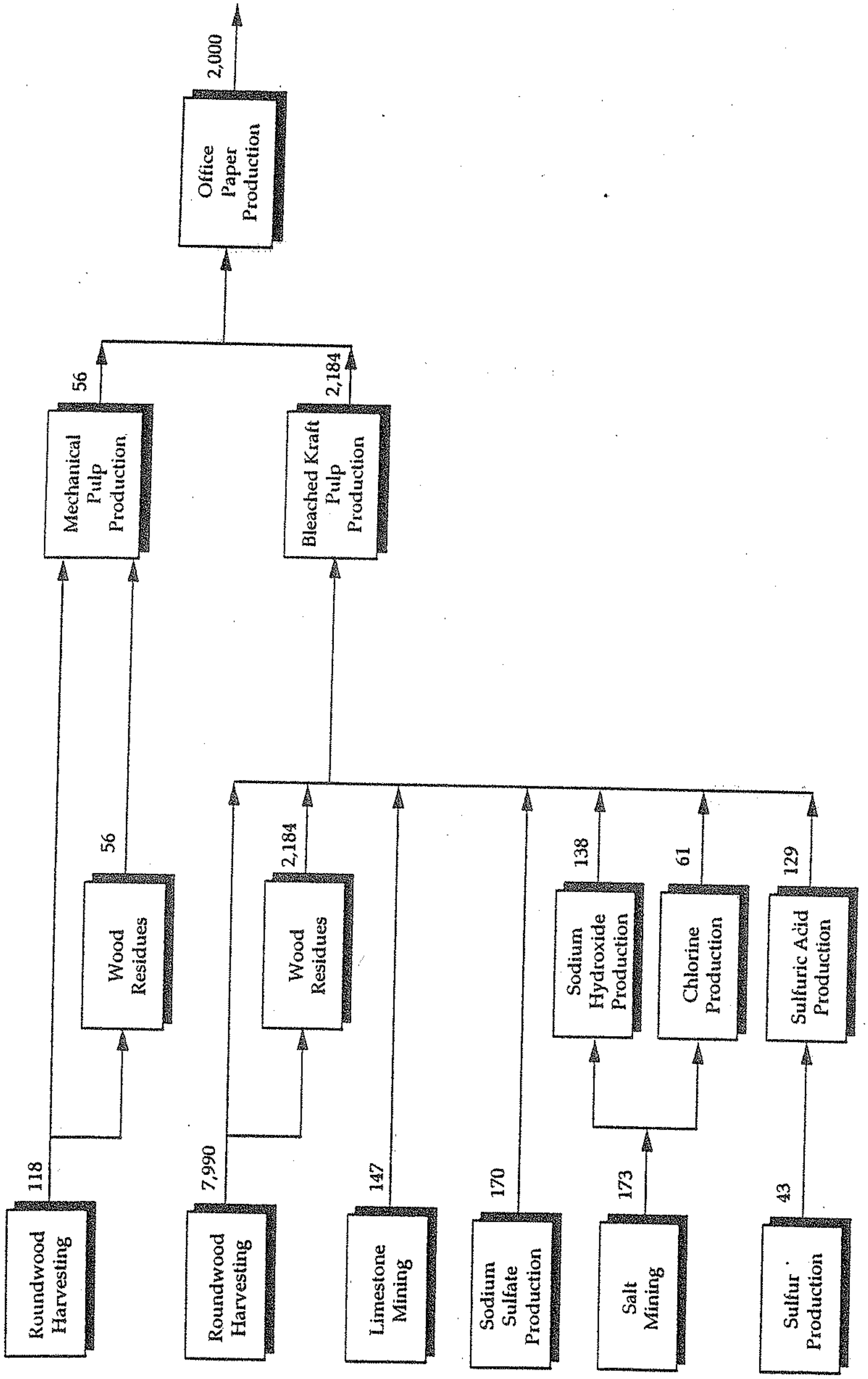

Figure 3a. Flow diagram for the production of one ton of virgin office paper. Numbers represent pounds of material.

Table 3b

DATA FOR THE PRODUCTION OF ONE TON OF OFFICE PAPER FROM RECYCLED OFFICE PAPER

(includes collection and recycled paper production)

Energy Usage			**Thousand Btu**
Process Energy			
Electricity	1,201	kwh	12,870
Natural gas	5,456	cu ft	6,301
Distillate oil	23.0	gal	3,781
Residual oil	20.0	gal	3,508
Total Process			26,461
Transportation Energy			
Combination truck	661	ton-miles	
Diesel	7.80	gal	1,283
Single unit truck	65	ton-miles	
Diesel	1.25	gal	205
Rail	240	ton-miles	
Diesel	0.74	gal	122
Total Transportation			1,610

Source: Franklin Associates, Ltd.

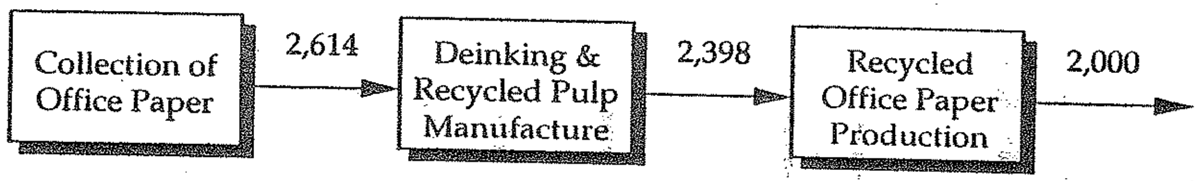

Figure 3b. Flow diagram for the production of one ton of recycled office paper. Numbers represent pounds of material.

Table 3c

DATA FOR THE PRODUCTION OF ONE TON OF VIRGIN TISSUE PAPER

Energy Usage			Thousand Btu
Process Energy			
Electricity	919	kwh	9,847
Natural gas	4,255	cu ft	4,915
Coal	508	lb	6,224
Distillate oil	10.6	gal	1,745
Residual oil	39.2	gal	6,872
Gasoline	7.89	gal	1,191
Wood	21,296	thousand Btu	21,296
Total Process			52,091
Transportation Energy			
Combination truck	328	ton-miles	
Diesel	3.87	gal	636
Rail	777	ton-miles	
Diesel	2.41	gal	396
Barge	27.7	ton-miles	
Diesel	0.055	gal	9
Residual oil	0.0166	gal	3
Ocean freighter	41.6	ton-miles	
Diesel	0.0042	gal	0.7
Residual	0.042	gal	7
Pipeline-natural gas	0.81	ton-miles	
Natural gas	1.87	cu ft	2
Pipeline-petroleum products	2.48	ton-miles	
Electricity	0.055	kwh	0.6
Total Transportation			1,055

Source: Franklin Associates, Ltd.

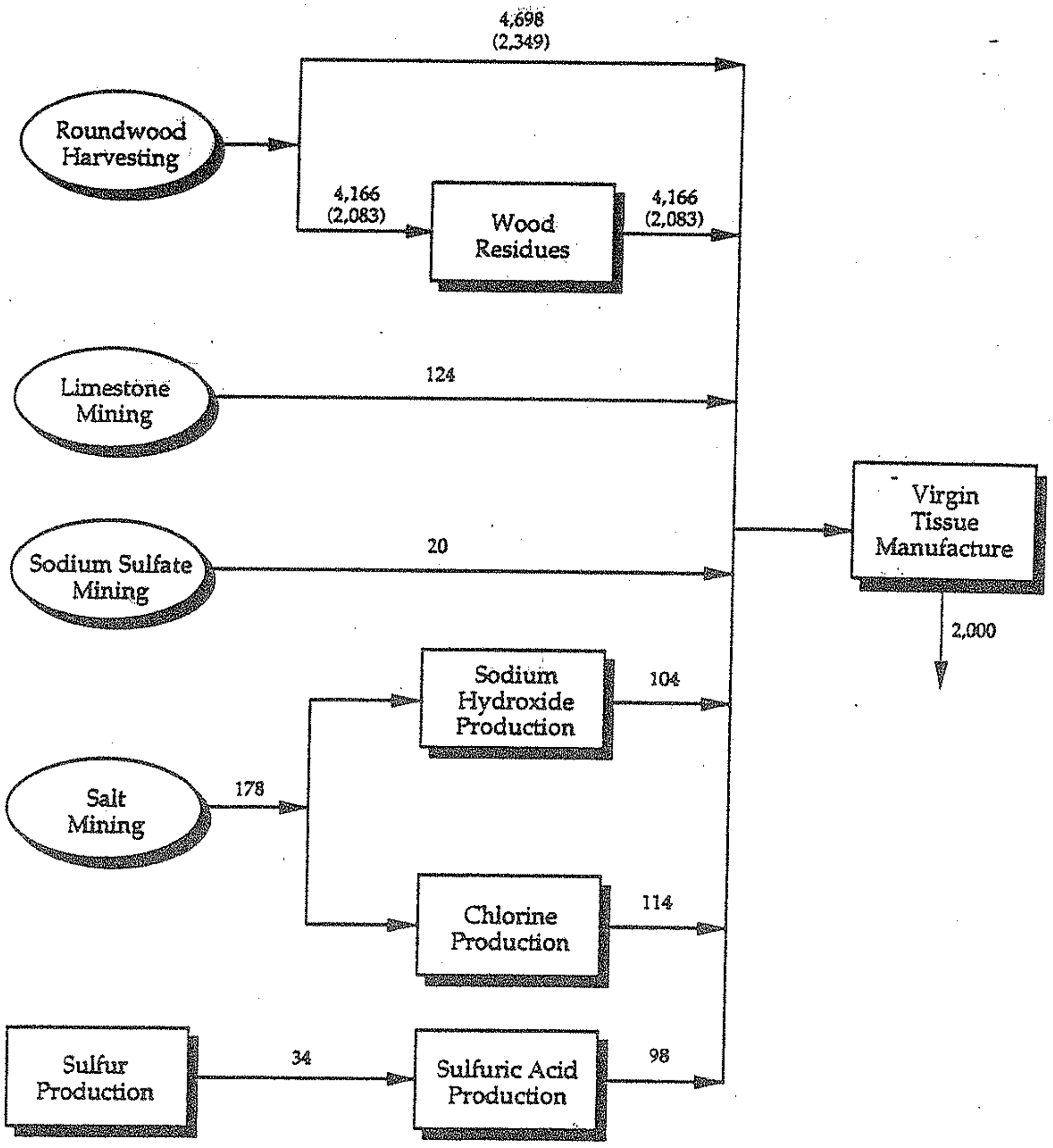

Figure 3c. Flow diagram for the production of one ton of virgin tissue paper. Numbers represent the weight of materials in pounds. (Values in parentheses represent dry fiber base.)

Table 3d

DATA FOR THE PRODUCTION OF ONE TON OF TISSUE PAPER FROM RECYCLED OFFICE PAPER
(includes collection and recycled tissue production)

Energy Usage			Thousand Btu
Process Energy			
Electricity	1,201	kwh	12,870
Natural gas	5,456	cu ft	6,301
Distillate oil	23.5	gal	3,781
Residual oil	20	gal	3,508
Total Process			26,461
Transportation Energy			
Combination truck	661	ton-miles	
Diesel	7.80	gal	1,283
Single unit truck	65	ton-miles	
Diesel	1.25	gal	205
Rail	240	ton-miles	
Diesel	0.74	gal	122
Total Transportation			1,610

Source: Franklin Associates, Ltd.

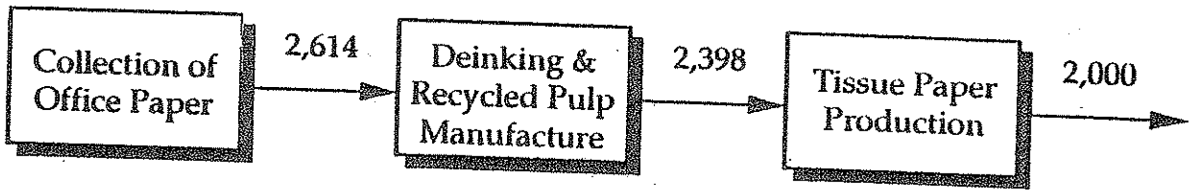

Figure 3d. Flow diagram for the production of one ton of tissue paper from office paper.
Numbers represent pounds of material.

Table 4a

DATA FOR THE PRODUCTION OF ONE TON OF STEEL INGOT FROM VIRGIN MATERIALS *

Energy Usage			Thousand Btu
Process Energy			
Coal (for coke)	1,080	lb	12,929
Electricity	316	kwh	3,387
Natural gas	2,443	cu ft	2,822
Coal	5.44	lb	67
Distillate oil	7.43	gal	1221
Residual oil	0.49	gal	85
Gasoline	0.34	gal	51
Total Process			20,562
Transportation Energy			
Combination truck	368	ton-miles	
Diesel	4.3	gal	713
Rail	1,352	ton-miles	
Diesel	4.19	gal	689
Barge	587	ton-miles	
Diesel	1.17	gal	193
Residual oil	0.35	gal	62
Total Transportation			1,657

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* The basic oxygen furnace uses approximately 20 percent recycled scrap in the production of "virgin" steel.

Source: Franklin Associates, Ltd.

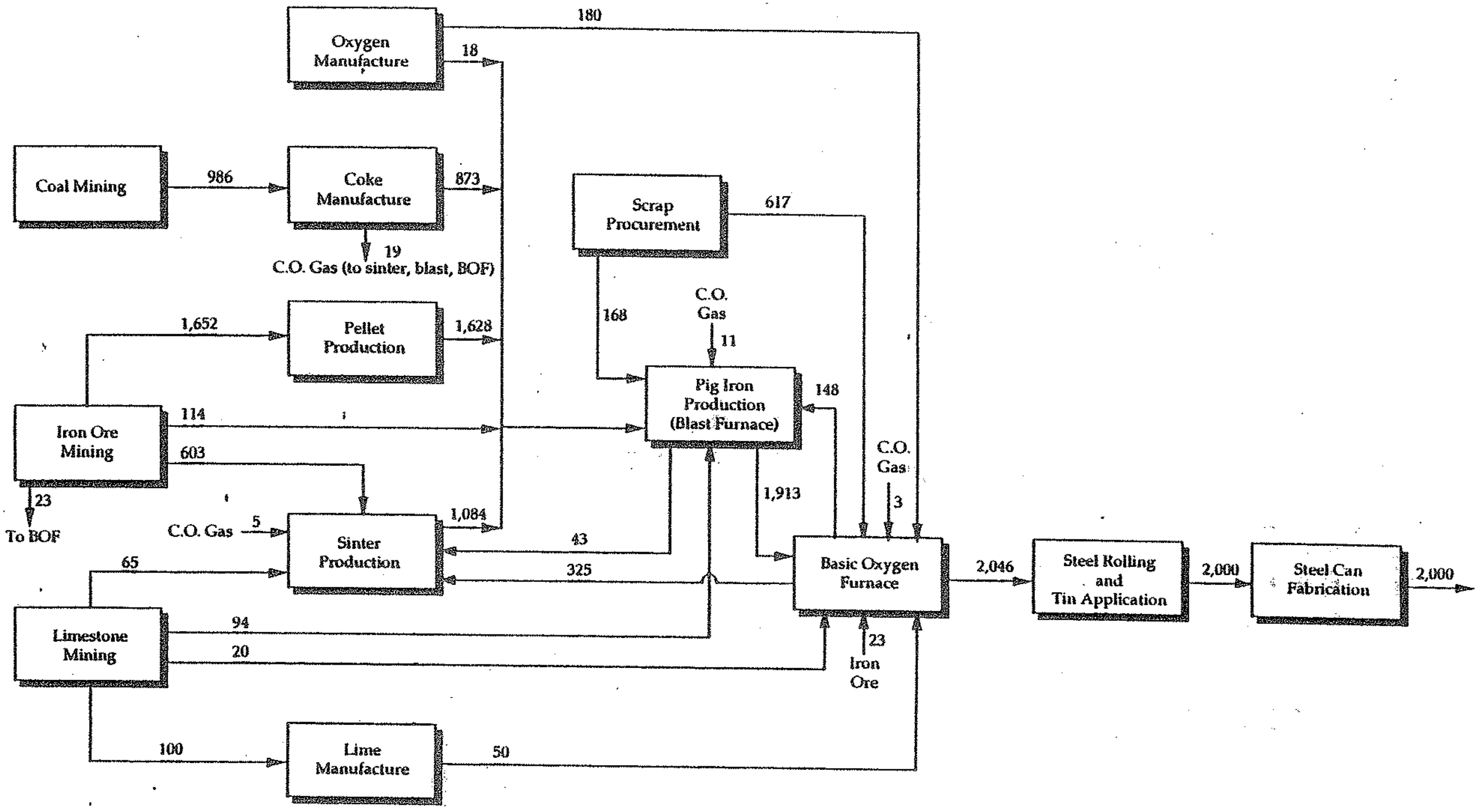

Figure 4a. Flow diagram for the manufacture of one ton of tin-coated steel cans from virgin materials. Numbers represent pounds of material.

Table 4b

DATA FOR THE PRODUCTION OF ONE TON OF STEEL INGOT FROM 100% RECYCLED STEEL CANS

(includes steel can collection, baling, and electric arc furnace)

Energy Usage			**Thousand Btu**
Process Energy			
Electricity	492	kwh	5,267
Natural gas	83	cu ft	96
LPG	0.16	gal	19
Coal	6.09	lb	75
Distillate oil	0.048	gal	8
Residual oil	0.017	gal	3
Gasoline	0.0055	gal	1
Total Process			5,468
Transportation Energy			
Combination truck	7	ton-miles	
Diesel	0.088	gal	15
Single unit truck	382	ton-miles	
Diesel	7.29	gal	1198
Rail	12	ton-miles	
Diesel	0.038	gal	6
Barge	3	ton-miles	
Diesel	0.0051	gal	1
Residual oil	0.0015	gal	0.3
Total Transportation			1,220

Source: Franklin Associates, Ltd.

Table 4c

DATA FOR THE PRODUCTION OF ONE TON OF TIN PLATED STEEL CANS FROM STEEL INGOT*

(includes sheet rolling through can production)

			Thousand Btu
Raw Materials			
Steel Ingot	2,046	lb	
Energy Usage			
Process Energy			
Electricity	347	kwh	3,715
Natural gas	2,139	cu ft	2,470
Total Process			6,185
Transportation Energy			
Combination truck	1,434	ton-miles	
Diesel	16.921	gal	2,782
Total Transportation			2,782

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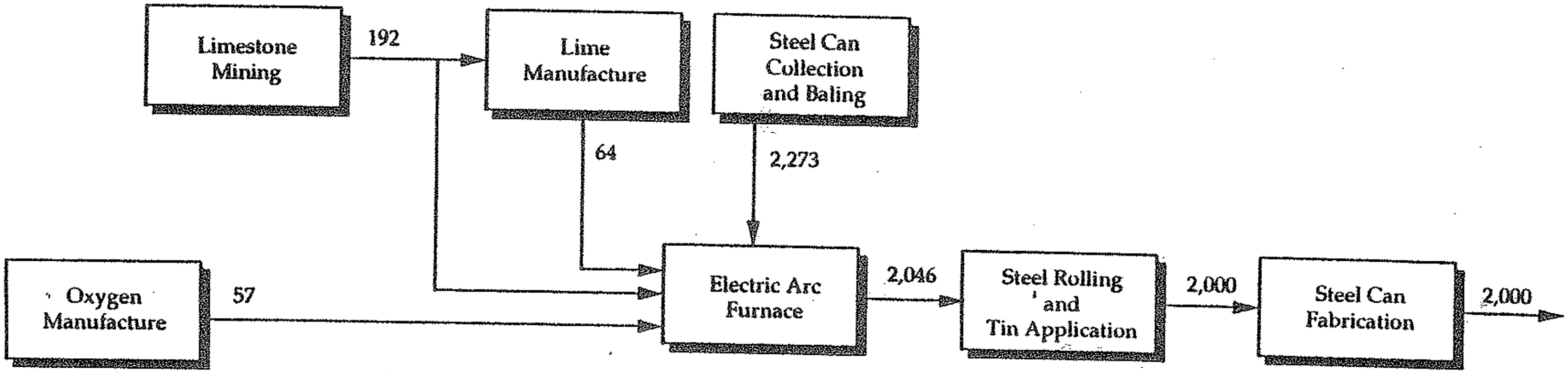
* These data are identical for fabrication from virgin ingot or recycled ingot. The data in the table include an estimate of 46 pounds of steel ingot loss.

Source: Franklin Associates, Ltd.



Electric Arc Process

Figure 4b. Flow diagram for the manufacture of recycled tin-coated steel cans. Numbers represent pounds of material.

Table 5a

DATA FOR THE PRODUCTION OF ONE TON OF VIRGIN* CORRUGATED BOXES

Energy Usage			Thousand Btu
Combustion Process Energy			
Electricity	549	kwh	6,023
Natural gas	3,379	cu ft	3,792
LPG	0.0034	gal	0.36
Coal	250	lb	2,838
Distillate oil	0.020	gal	3.12
Residual oil	2.73	gal	458
Gasoline	0.0020	gal	0.28
Diesel	2.18	gal	339
Wood	15,172	thousand Btu	15,172
Total Combustion Process			28,625
Combustion Transportation Energy			
Combination truck	588	ton-miles	
Diesel	6.94	gal	1,080
Rail	674	ton-miles	
Diesel	2.09	gal	325
Barge	13.5	ton-miles	
Diesel	0.027	gal	4.21
Residual oil	0.0081	gal	1.36
Ocean freighter	6.18	ton-miles	
Diesel	6.2E-04	gal	0.096
Residual	0.0062	gal	1.04
Pipeline-natural gas	0.12	ton-miles	
Natural gas	0.28	cu ft	0.31
Pipeline-petroleum products	0.37	ton-miles	
Electricity	0.0081	kwh	0.089
Total Combustion Transportation			1,412

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* Corrugated boxes are always manufactured with some recycled content. The "virgin" data presented here represent the minimum possible recycled content and recycling level of 9.8%

Source: Franklin Associates, Ltd.

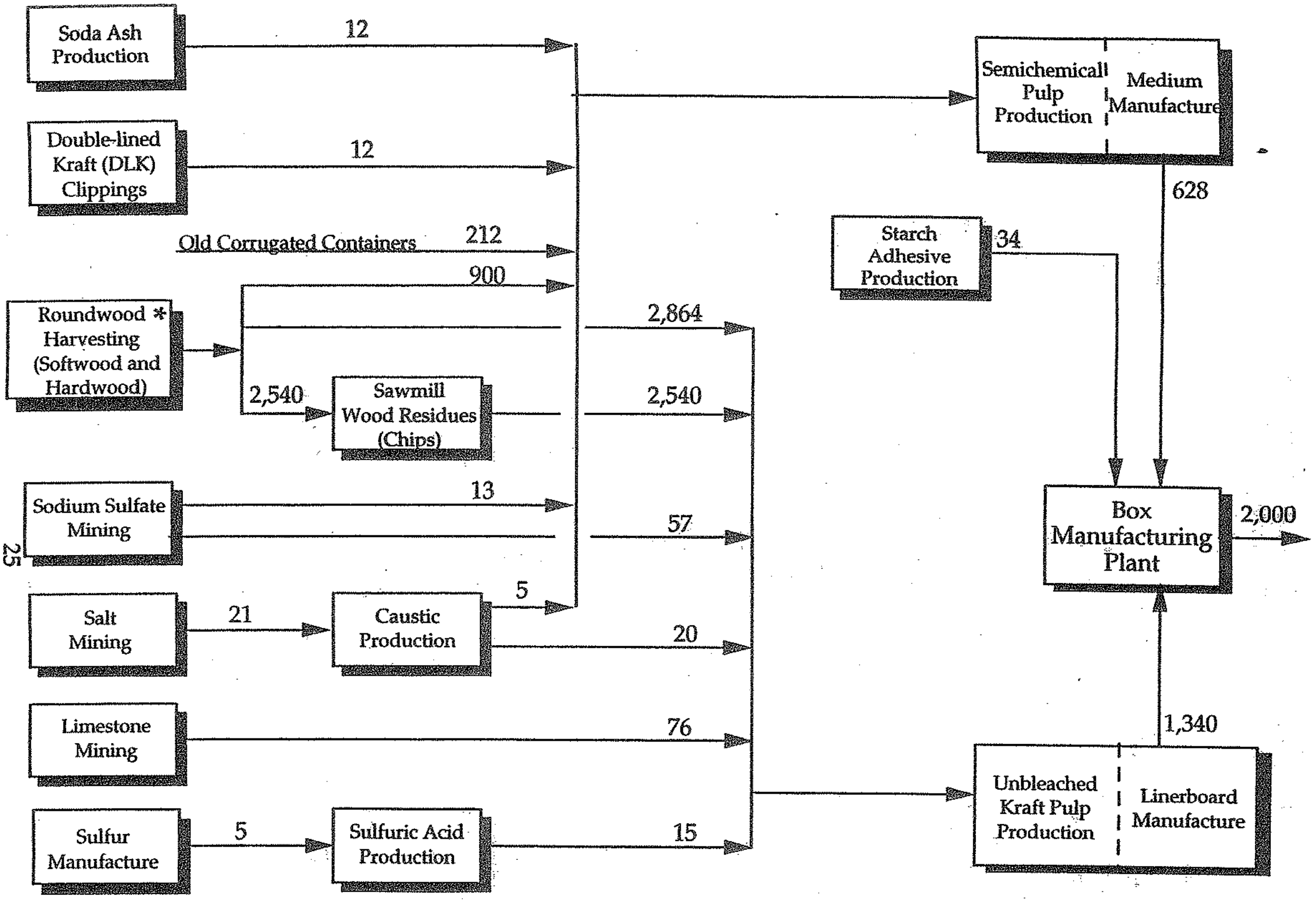

Figure 5a. Flow diagram for the production of one ton of "virgin" corrugated containers.

*Managed and/or unmanaged forest

Note: Corrugated boxes are usually manufactured with some recycled content. The virgin system presented here represent a minimum recycled content of 10 percent.

Table 5b

DATA FOR THE PRODUCTION OF ONE TON OF CORRUGATED BOXES FROM RECYCLED CORRUGATED

(includes corrugated collection, recycled paperboard production, adhesive production, and box fabrication)

Energy Usage			Thousand Btu
Process Energy			
Electricity	651	kwh	7,145
Natural gas	3,270	cu ft	3,668
LPG	0.20	gal	21.5
Coal	422	lb	4,797
Distillate oil	0.013	gal	2.08
Residual oil	1.23	gal	206
Gasoline	1.3E-05	gal	0.0019
Diesel	0.68	gal	106
Total Process			15,946
Transportation Energy			
Combination truck	507	ton-miles	
Diesel	5.99	gal	931
Rail	617	ton-miles	
Diesel	1.91	gal	298
Barge	12.1	ton-miles	
Diesel	0.024	gal	3.77
Residual oil	0.0073	gal	1.22
Total Transportation			1,234

Source: Franklin Associates, Ltd.

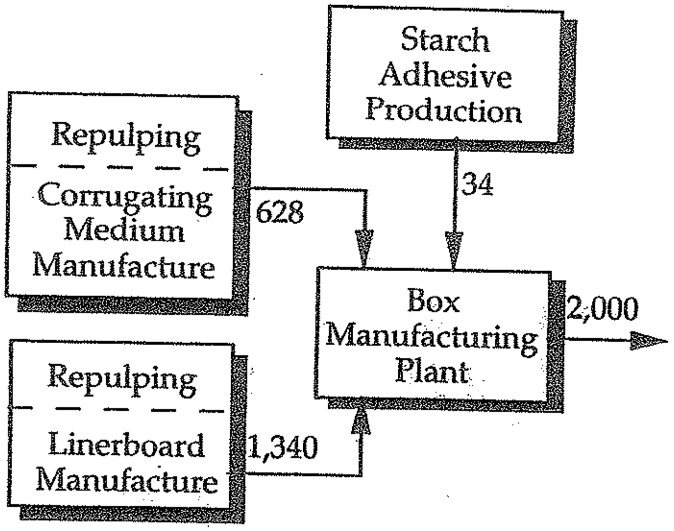

Figure 5b. Flow diagram for the production of one ton of 100% closed-loop recycled corrugated boxes.

Table 5c

DATA FOR THE PRODUCTION OF ONE TON OF VIRGIN FOLDING CARTONS

Energy Usage			Thousand Btu
Process Energy			
Electricity	682	kwh	7,310
Natural gas	4,694	cu ft	5,422
Coal	337	lb	4,128
Distillate oil	3.51	gal	577
Residual oil	13.44	gal	2,358
Gasoline	7.42	gal	1,119
Wood	19,203	thousand Btu	19,203
Total Process			40,117
Transportation Energy			
Combination truck	326	ton-miles	
Diesel	3.85	gal	633
Rail	719	ton-miles	
Diesel	2.23	gal	366
Barge	19.21	ton-miles	
Diesel	0.038	gal	6
Residual oil	0.0115	gal	2
Ocean freighter	20.3	ton-miles	
Diesel	0.0020	gal	0.3
Residual	0.020	gal	4
Pipeline-natural gas	0.40	ton-miles	
Natural gas	0.91	cu ft	1.1
Pipeline-petroleum products	1.21	ton-miles	
Electricity	0.027	kwh	0.3
Total Transportation			1,013

Source: Franklin Associates, Ltd.

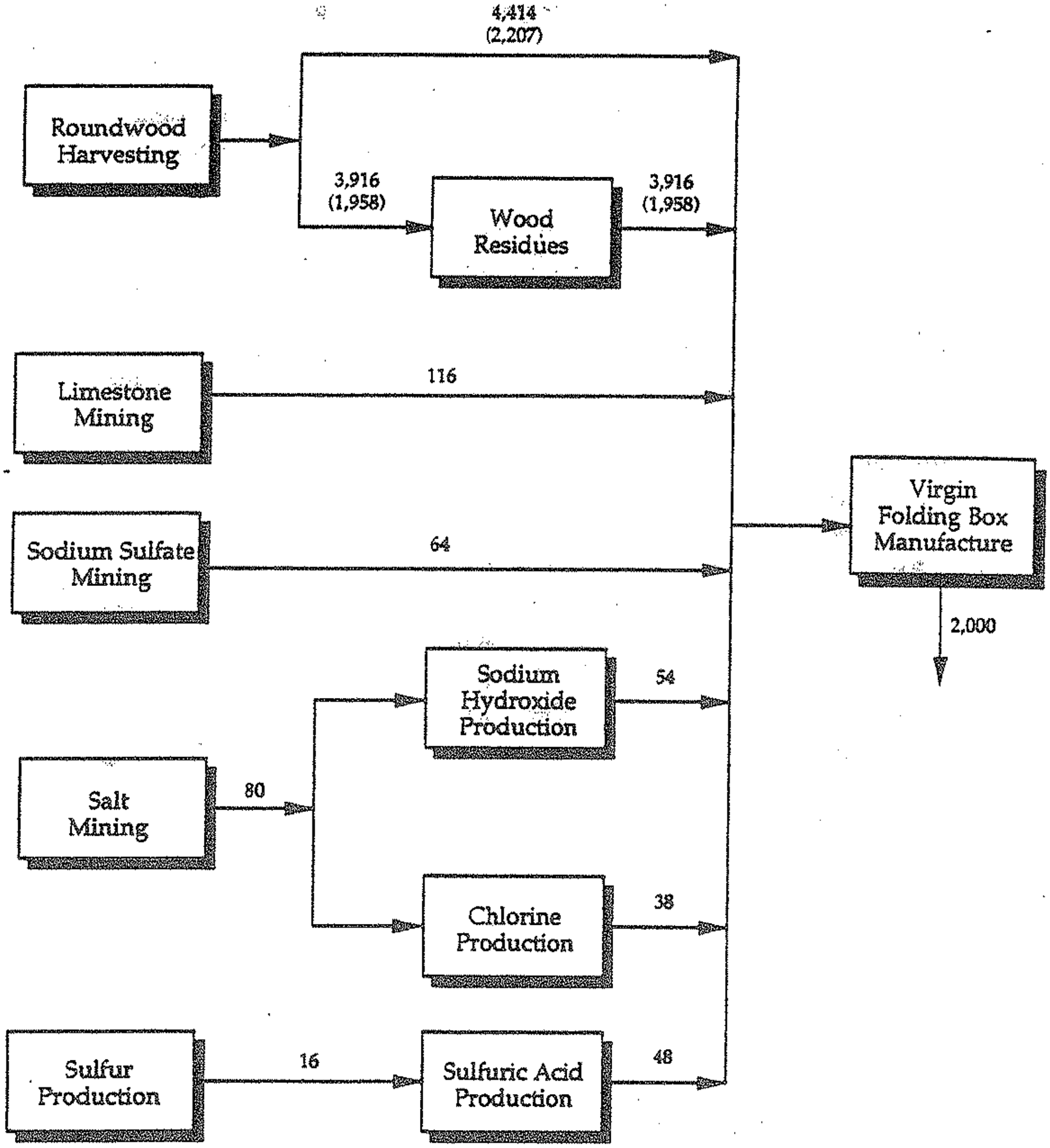

Figure 5c. Flow diagram for the production of one ton of folding boxes made from bleached and unbleached paperboard. Numbers represent the weight of materials in pounds. (Values in parentheses represent dry fiber base.)

Table 5d

DATA FOR THE PRODUCTION OF ONE TON OF FOLDING BOXES FROM RECYCLED CORRUGATED

(includes corrugated collection and recycled paperboard production)

Energy Usage			Thousand Btu
Process Energy			
Electricity	639	kwh	6,846
Natural gas	6,235	cu ft	7,201
Coal	346	lb	4,242
Residual oil	3.47	gal	609.3
Total Process			18,898
Transportation Energy			
Combination truck	500	ton-miles	
Diesel	5.90	gal	970
Rail	610	ton-miles	
Diesel	1.89	gal	311
Barge	12	ton-miles	
Diesel	0.024	gal	4
Residual oil	0.007	gal	1
Total Transportation			1,286

Source: Franklin Associates, Ltd.

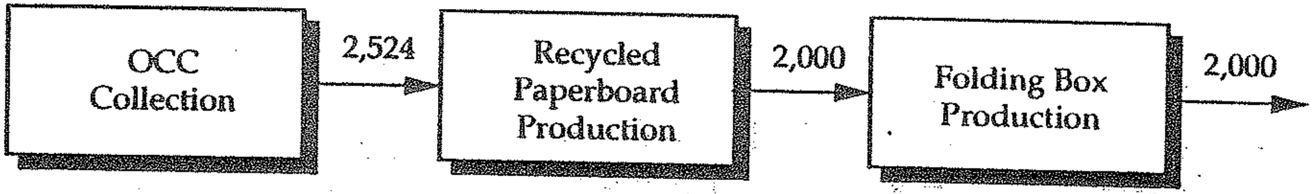

Figure 5d. Flow diagram for the production of one ton of folding boxes from recycled corrugated boxes. Numbers represent pounds of material.

~20% loss.

524lb

Table 6a

DATA FOR THE PRODUCTION OF ONE TON OF VIRGIN LDPE RESIN

Energy Usage			Thousand Btu
Process Energy			
Electricity	1,198	kwh	12,829
Natural gas	15,661	cu ft	18,088
LPG	0.086	gal	10.4
Distillate oil	0.44	gal	71.6
Residual oil	1.26	gal	220
Gasoline	0.19	gal	29.4
Total Process			31,249
Transportation Energy			
Combination truck	26.4	ton-miles	
Diesel	0.31	gal	51.3
Rail	1,064	ton-miles	
Diesel	3.30	gal	542
Barge	35.6	ton-miles	
Diesel	0.071	gal	11.7
Residual oil	0.021	gal	3.75
Ocean freighter	1,244	ton-miles	
Diesel	0.12	gal	20.5
Residual	1.24	gal	218
Pipeline-natural gas	107	ton-miles	
Natural gas	245	cu ft	283
Pipeline-petroleum products	74.2	ton-miles	
Electricity	1.63	kwh	17.5
Total Transportation			1,148

Source: Franklin Associates, Ltd.

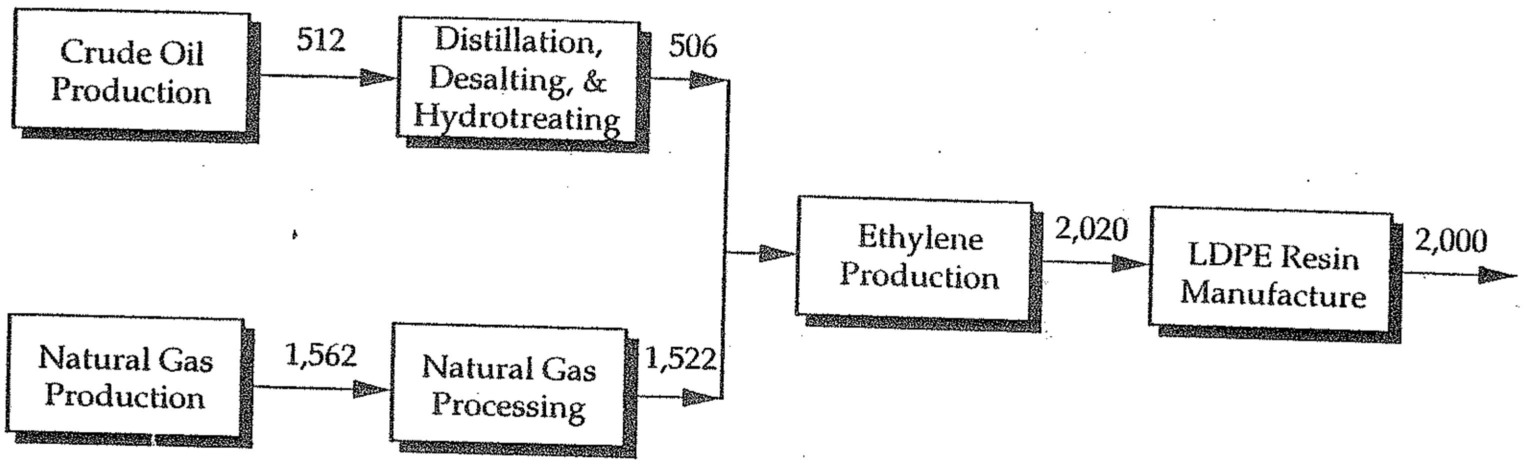

Figure 6a. Flow diagram for the production of one ton of virgin low-density polyethylene (LDPE) resin. Numbers represent pounds of material.

Table 6b

DATA FOR THE PRODUCTION OF ONE TON OF RECYCLED LDPE RESIN

(includes collection and reprocessing to pellets)

Energy Usage			Thousand Btu
Process Energy			
Electricity	464	kwh	4,975
LPG	0.22	gal	26.7
Total Process			5,002
Transportation Energy			
Combination truck	284	ton-miles	
Diesel	3.35	gal	551
Single unit truck	378	ton-miles	
Diesel	7.23	gal	1,188
Total Transportation			1,739

Source: Franklin Associates, Ltd.

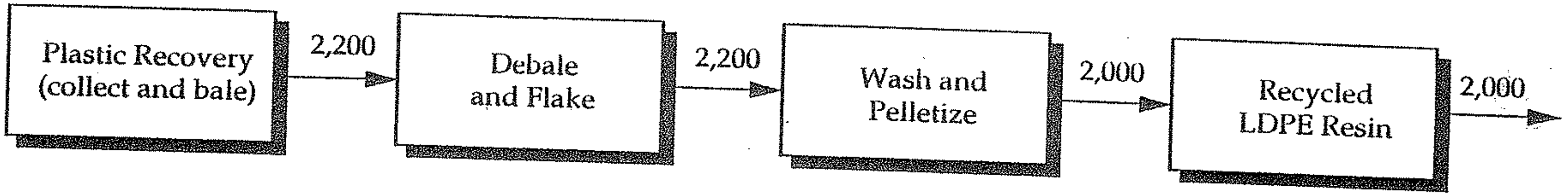

Figure 6b. Flow diagram for the production of one ton of recycled low-density polyethylene (LDPE) resin. Numbers represent pounds of material.

Table 6c

DATA FOR THE FABRICATION OF ONE TON OF BLOW MOLDED LDPE PRODUCTS

Energy Usage			Thousand Btu
Process Energy			
Electricity	600	kwh	6,427
Total Process			6,427

Source: Franklin Associates, Ltd.

Table 7a

DATA FOR THE PRODUCTION OF ONE TON OF VIRGIN HDPE RESIN

Energy Usage			Thousand Btu
Process Energy			
Electricity	617	kwh	6,609
Natural gas	15,011	cu ft	17,337
LPG	0.086	gal	10.4
Distillate oil	0.44	gal	71.6
Residual oil	1.26	gal	220
Gasoline	0.19	gal	29.4
Total Process			24,278
Transportation Energy			
Combination truck	26.4	ton-miles	
Diesel	0.31	gal	51.3
Rail	1,064	ton-miles	
Diesel	3.30	gal	542
Barge	35.6	ton-miles	
Diesel	0.071	gal	11.7
Residual oil	0.021	gal	3.75
Ocean freighter	1,244	ton-miles	
Diesel	0.12	gal	20.5
Residual	1.24	gal	218
Pipeline-natural gas	107	ton-miles	
Natural gas	245	cu ft	283
Pipeline-petroleum products	74.2	ton-miles	
Electricity	1.63	kwh	17.5
Total Transportation			1,148

Source: Franklin Associates, Ltd.

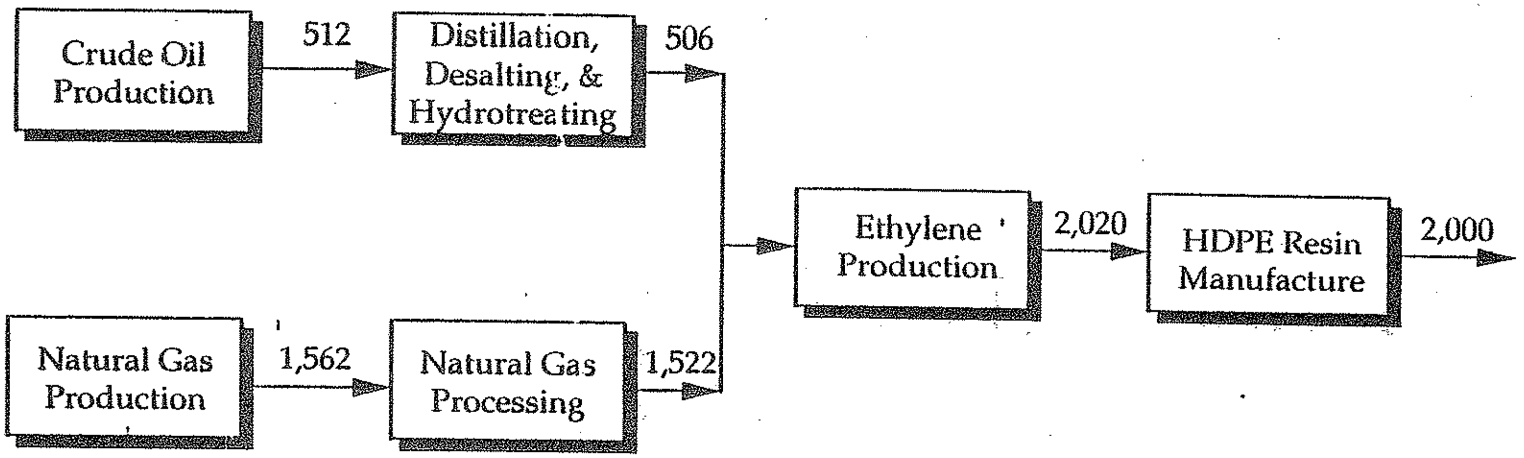

Figure 7a. Flow diagram for the production of one ton of virgin high-density polyethylene (HDPE) resin. Numbers represent pounds of material.

Table 7b

DATA FOR THE PRODUCTION OF ONE TON OF RECYCLED HDPE RESIN

(includes collection and reprocessing to pellets)

Energy Usage			Thousand Btu
Process Energy			
Electricity	581	kwh	6,224
LPG	0.22	gal	26.7
Total Process			6,250
Transportation Energy			
Combination truck	284	ton-miles	
Diesel	3.35	gal	551
Single unit truck	378	ton-miles	
Diesel	7.23	gal	1,188
Total Transportation			1,739

Source: Franklin Associates, Ltd.

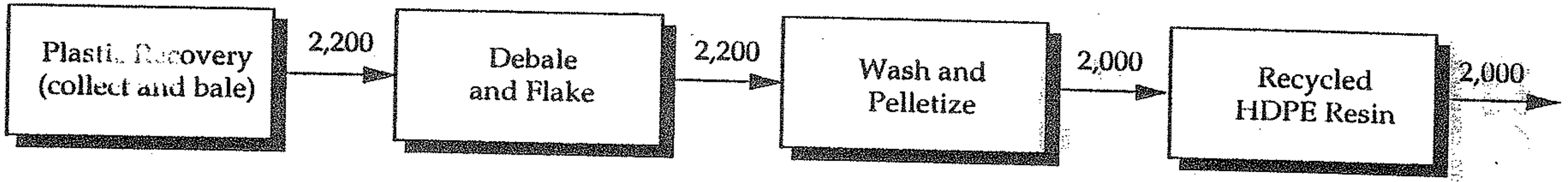

Figure 7b. Flow diagram for the production of one ton of recycled high-density polyethylene (HDPE) resin. Numbers represent pounds of material.

Table 7c

DATA FOR THE FABRICATION OF ONE TON OF BLOW MOLDED HDPE PRODUCTS

Energy Usage			Thousand Btu
Process Energy			
Electricity	600	kwh	6,427
Total Process			6,427

Source: Franklin Associates, Ltd.

Table 8a

DATA FOR THE PRODUCTION OF ONE TON OF VIRGIN PET RESIN

Energy Usage			Thousand Btu
Process Energy			
Electricity	936	kwh	10,021
Natural gas	9,037	cu ft	10,438
LPG	0.21	gal	25.2
Coal	253	lb	3,102
Distillate oil	18.1	gal	2,968
Residual oil	44.8	gal	7,860
Gasoline	0.16	gal	24.0
Total Process			34,439
Transportation Energy			
Combination truck	913	ton-miles	
Diesel	10.8	gal	1,771
Rail	1,473	ton-miles	
Diesel	4.57	gal	751
Barge	108	ton-miles	
Diesel	0.22	gal	35.4
Residual oil	0.065	gal	11.3
Ocean freighter	3,039	ton-miles	
Diesel	0.30	gal	50.0
Residual	3.04	gal	533
Pipeline-natural gas	29.8	ton-miles	
Natural gas	68.6	cu ft	79.2
Pipeline-petroleum products	181	ton-miles	
Electricity	3.99	kwh	42.8
Total Transportation			3,274

Source: Franklin Associates, Ltd.

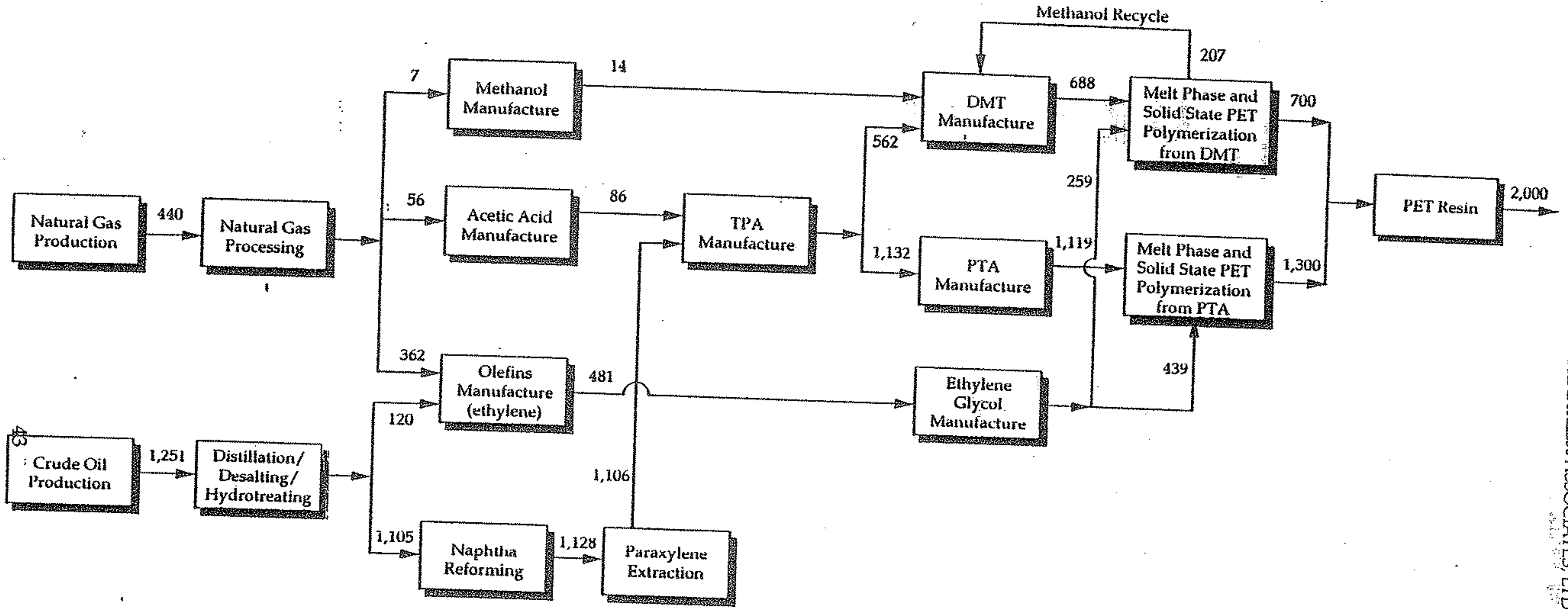

Figure 8a. Flow diagram for the manufacture of one ton of virgin polyethylene terephthalate (PET) resin. Numbers represent pounds of material.

Table 8b

DATA FOR THE PRODUCTION OF ONE TON OF RECYCLED PET RESIN
(includes collection and reprocessing to pellets)

Energy Usage			Thousand Btu
Process Energy			
Electricity	539	kwh	5,769
LPG	0.22	gal	26.7
Total Process			5,796
Transportation Energy			
Combination truck	284	ton-miles	
Diesel	3.35	gal	551
Single unit truck	378	ton-miles	
Diesel	7.23	gal	1,188
Total Transportation			1,739

Source: Franklin Associates, Ltd.

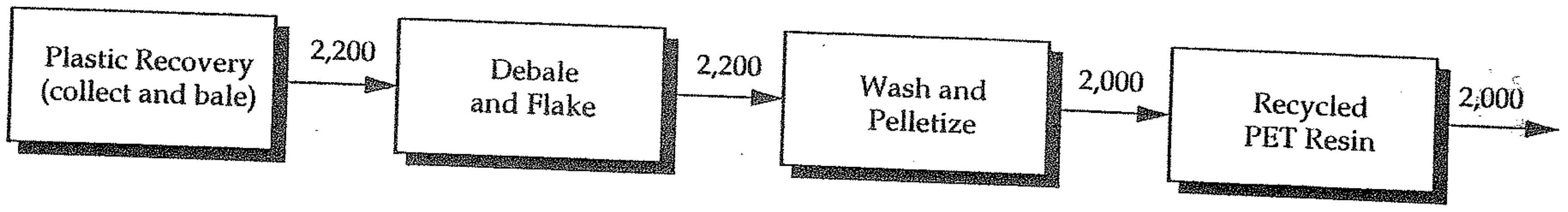

Figure 8b. Flow diagram for the production of one ton of recycled polyethylene terephthalate (PET) resin. Numbers represent pounds of material.

Table 8c

DATA FOR THE FABRICATION OF ONE TON OF BLOW MOLDED PET PRODUCTS

Energy Usage			Thousand Btu
Process Energy			
Electricity	1500	kwh	16,068
Total Process			16,068

Source: Franklin Associates, Ltd.

BOUNDARY CONDITIONS

Each materials flow diagram shows the process steps that are included within the system boundaries for each material analyzed. The data in the associated table(s) show the aggregated energy to produce one ton of the material specified, including the energy needed for each process step shown in the flow diagram.

If marketable coproducts or byproducts are produced in any process step in the system, adjustments have been made in the materials balance and energy requirements to reflect only the portion of each that is attributable to the product being considered. This is done based on the mass of each coproduct.

The first column in each data table shows the units of each fuel that are consumed in the process and transportation steps in the life cycle of the material. In the second column, these fuel units are converted to Btu values. The conversion factors account for not only the energy content of the fuels but also the energy required to extract, transport, and process the fuels. The energy to extract, transport, and process fuels into a usable form is labeled **precombustion energy**.

For electricity, precombustion energy calculations include adjustments for the average efficiency of conversion of fuel to electricity, and for transmission losses in power lines. Therefore, the kilowatt-hour (kwh) value shown on the tables is the aggregated amount of electricity used by the system. The Btu value shown in the second column accounts for the average mix of fuels used by utilities to produce electricity in the United States, in 1990. The energy value for the average mix of fuels used to produce electricity in the United States in 1992 varies from the 1990 value by only 1 percent.

The data tables for each material system report energy data in the categories of **process energy** and **transportation energy**. Process energy is energy consumed in the various processes used to manufacture the material or product. Transportation energy describes the energy to transport the materials and components to the site of the next processing step. The Btu values shown for each fuel include precombustion and combustion energy.

Transportation energy is calculated by using the distance of transport (miles), mode of transport (truck, rail, barge, ship), and Franklin Associates (FAL) transportation database. The distance and mode of transportation are usually provided by specific companies or facilities from which materials are shipped. The FAL transportation database has been developed by FAL staff. It expresses fuel usage per ton-mile of goods transported by specific modes of transportation.

Franklin Associates assigns an **energy of material resource** to fossil fuels (i.e., petroleum, natural gas, or coal—materials that are normally used as fuels) when they are used as raw materials. The energy of material resource is the fuel energy equivalent of the material, i.e., the amount of energy that would be obtained through combustion of the designated quantity of fossil fuel material. In this analysis, this energy is included in process energy *if the material is consumed in the process, thus creating carbon dioxide emissions*. If the fuel material becomes part of the product, the energy of material resource is *not* included. For example, the process energy for plastic resins does *not* include the energy content of natural gas and petroleum that are used as raw materials for plastic resins, because they become part of the plastic. On the other hand, the process energy for aluminum *does* include the energy content of natural gas and petroleum that are raw materials for coke (a raw material for smelting), because the coke is consumed in the production of aluminum.

Geographic Scope

With the exception of overseas transportation of crude oil, bauxite, and alumina to the United States, all energy data are for the United States.

Electricity

In general, detailed data do not exist on the fuels used to generate the electricity consumed by each industry. Electricity production and distribution systems in the United States are interlinked. Users of electricity, in general, cannot specify the fuels used to produce their share of the electric power grid. Therefore, the national average fuel consumption by electrical utilities is used for this study.

Electricity generated on-site at a manufacturing facility is not shown as electricity. Instead, the fuels used at the facility to produce self-generated electricity are represented in the process data.

Recycling

Some materials in this analysis can be recycled only a limited number of times, while others may be recycled over and over again into the same or similar products. In traditional life cycle studies, limited recycling is referred to as "open-loop" recycling, while repeated (theoretically infinite) recycling is called "closed-loop" recycling. The type of recycling depends not only on infrastructure, but to a large extent on the nature of the material. For example, paper fibers degrade with each reprocessing, while aluminum can be remelted over and over.

None the less, in this study, each of the recycled materials systems is modeled as if it were a closed-loop system. That is, the recycled product systems all begin with the collection of postconsumer materials and end with the manufacture of a recycled product (or in some cases, two different recycled products), as shown in the flow diagrams. This was done specifically for this project because of the emphasis on the evaluation of incremental differences in the carbon dioxide emissions due to recycling.

Components Not Included

Capital Equipment. The energy associated with the manufacture of capital equipment is not included in the energy profiles. This includes equipment to manufacture buildings, motor vehicles, and industrial machinery. The energy associated with such capital equipment generally, for a ton of materials, becomes negligible when averaged over the millions of pounds of product which the capital equipment manufactures.

Space Conditioning. The fuels and power consumed to heat, cool, and light manufacturing establishments are omitted from the calculations. For most industries, space conditioning energy is quite low compared to process energy. Energy consumed for space conditioning is usually less than one percent of the total energy consumption for the manufacturing process.

Support Personnel Requirements. The energy associated with research and development, sales, and administrative personnel or related activities have not been included in this analysis.

Miscellaneous Materials and Additives. Selected materials such as catalysts, pigments, or other additives which total less than one percent of the net process inputs are not included in the assessment.

BOUNDARY CONDITIONS SUMMARY

The following table summarizes the boundary conditions for each material analyzed for this study. The table consists of four sections. The first section lists the name of the material analyzed. The second section indicates whether or not the fabrication of a final product is included in the analysis. The third section indicates whether open-loop or closed-loop recycling is analyzed. The fourth section notes any special boundary conditions. For example, average "virgin" newsprint and corrugated box components contain some recycled content. This use of recycled material is part of the energy profile for these materials. For steel cans, steel scrap is used as a raw material in the manufacture of "virgin" steel.

BOUNDARY CONDITIONS FOR EACH MATERIAL

Material	Fabrication Included	Other Special Boundary Conditions
Newspaper	yes	approximately 12% recycled newspaper content in average ("virgin") newspaper
Aluminum cans	yes	
Office paper	yes	
Tissue paper from office paper	yes	
Steel cans	yes	approximately 20% scrap content in "virgin" steel; fabrication loss is assumed to be approximately 5%
Corrugated	yes	approximately 8% recycled content in "virgin" corrugated
Folding boxes from corrugated	yes	
LDPE	yes	
HDPE	yes	
PET	yes	

PROCESS DESCRIPTIONS

NEWSPRINT PRODUCTION

It is assumed that an average of 12 percent recycled pulp from recovered newspapers is continuously recycled into newsprint (Reference N-1). The majority of the newsprint pulp is made from virgin pulp. The virgin pulp used for newsprint is primarily made from mechanical pulp and small quantities of chemical pulp. Mechanical pulp represents approximately 70 percent of the virgin fiber, with chemical pulp making up the other 30 percent (Reference N-2).

The following steps in the production of newsprint are discussed in the section below:

- Roundwood harvesting
- Wood residues production
- Salt mining
- Caustic soda and chlorine production
- Sodium chlorate production
- Limestone mining
- Sulfur production
- Bleached chemical pulp manufacture
- Mechanical pulp manufacture
- Recovered paper collection
- Deinked recovered pulp manufacture
- Newsprint production
- Ink manufacture

Roundwood Harvesting

The technique of harvesting trees has become a highly mechanized process. Typically, trees are harvested by using a feller buncher to fell the wood. The wood is pulled to the roadside, where branches are removed and the wood is cut to manageable lengths for loading on trucks and delivery to the mill. After the wood is cleared from the forest, a variety of site preparations are used. On some sites debris is manually removed from the forest before replanting, while other sites are left to grow back naturally. Finally, some harvested sites are burned to remove any remaining debris before replanting. Emissions do result from clearing the site by burning, but this practice occurs infrequently compared to the mass of trees harvested. It is assumed that these emissions are negligible for this study.

Trees harvested specifically for wood pulp production account for approximately 53 percent of the wood delivered to the paper mill. The remainder comes from wood residues (sawdust and chips) generated by lumber production or other wood processing operations.

Wood Residues Production

Wood residues used in the production of paper are either mill residues generated by lumber mills or other wood processing operations, or forest residues.

Mill residues are estimated to make up about 90 percent of the wood residue used by paper mills. Typically the wood that a sawmill receives will already be delimbed and cut to manageable lengths. The roundwood is sorted by diameter and then sent to a debarker. After debarking, the logs are conveyed through a series of cutting and planing operations. Roughly 75 to 80 weight percent of the tree as received is converted to lumber, with the remaining 20 to 25 percent becoming wood chips and fines. The chips are sold to pulp mills, and the fines are either burned as an energy source at a paper mill or burned for waste disposal.

The remaining 10 percent of wood residue used by paper mills are assumed to be forest residue. Forest residues are small diameter trees, limbs and cuttings which are turned into chips in the forest. In general, wood residues are generated on site or quite close to the mills.

Salt Mining

For the most part, salt-based chlorine and caustic facilities use captive salt from another process or use salt recovered from underground deposits in the form of brine. In solution mining, an injection well is drilled and pressurized fresh water is introduced to the bedded salt (Reference N-3). The brine is then pumped to the surface for treatment. Salt mines are widely distributed throughout the United States.

Caustic Soda and Chlorine Production

Caustic soda (sodium hydroxide) and chlorine are produced from salt by an electrolytic process. The aqueous sodium chloride solution is electrolyzed to produce caustic soda, chlorine, and hydrogen gas. For this analysis, resource requirement and environmental emission coproduct credit is allocated on a weight basis to each of the materials produced in the cell. The reason for giving coproduct credit on a weight basis is that it is not possible, using the electrolytic cell, to get chlorine from salt without also producing sodium hydroxide and hydrogen, both of which have commercial value as useful coproducts. Likewise, sodium hydroxide cannot be obtained without producing the valuable coproducts of chlorine and hydrogen. Furthermore, it is not possible to control the cell to increase or decrease the amount of chlorine or caustic soda resulting from a given input of salt. This is determined by the stoichiometry of the reaction. The electrolytic cell is perceived as a "black box" with an input of salt and electricity, and an output of chlorine, sodium hydroxide, and hydrogen.

The electrolysis of sodium chloride is performed by one of two processes: the mercury cathode cell process, or the diaphragm cell process. About 83 percent of electrolyzed chlorine and caustic soda production comes from the diaphragm process, with the remainder coming from the mercury cell process (Reference N-4).

The diaphragm cell uses graphite anodes and steel cathodes. Brine solution is passed through the anode compartment of the cell, where the salt is decomposed into chlorine gas and sodium ions. The gas is removed through a pipe at the top of the cell. The sodium ions pass through a cation-selective diaphragm. The depleted brine is either resaturated with salt or concentrated by evaporation and recycled to the cell. The sodium ions transferred across the diaphragm react at the cathode to produce hydrogen and sodium hydroxide. Diffusion of the cathode products back into the brine solution is prevented by the diaphragm.

The mercury cathode cell process is described by:

$$NaCl + xHg \rightarrow 1/2\ Cl_2 + Na(Hg)x \quad \text{and}$$
$$Na(Hg)x + H_2O \rightarrow NaOH + 1/2\ H_2 + xHg$$

Chlorine gas collects at graphite anodes. The chlorine gas from the anode compartment is cooled and dried in a sulfuric acid scrubber. The gas is then cooled further to a liquid for shipment, generally by rail and barge. Metallic sodium reacts with the mercury cathode to produce an amalgam, which is sent to another compartment of the cell and reacted with water to produce hydrogen and high purity sodium hydroxide. Mercury loss is a disadvantage of the mercury cathode cell process. Some of the routes by which mercury can escape are in the hydrogen gas stream, in cell room ventilation air and washing water, through purging of the brine loop and disposal of brine sludges, and through end box fumes.

Sodium Chlorate Production

Sodium chlorate is used to produce chlorine dioxide at the pulp mill site. The chlorine dioxide is used for bleaching. Sodium chlorate is produced from electrolysis of salt brine similar to the production of caustic and chlorine, except that the chlorine and caustic are not separated, but are instead allowed to mix (Reference N-5). Hypochlorite forms first, followed by the formation of sodium chlorate. It is assumed that the energy and emissions for the manufacture of sodium chlorate are the same as those for chlorine (Reference N-6).

Limestone Mining

Limestone is quarried primarily from open pits. The most economical method of recovering the stone has been through blasting, followed by mechanical crushing and screening (References N-7 and N-8).

Sulfur Production

Sulfur exists in nature as elemental sulfur and is also found in ores such as pyrite (FeS_2). Sulfur is also recovered from hydrogen sulfide (H_2S), a component of petroleum and natural gas. The Frasch process accounts for approximately 34 percent of U.S. sulfur production, while the Claus process accounts for approximately 66 percent. Descriptions of these two processes follow.

Frasch Process. Sulfur is obtained from sulfur-bearing porous limestone primarily by the Frasch process. In this process, a set of three concentric pipes are inserted into a well drilled into an underground sulfur dome. Injecting superheated water into the well raises the temperature of the sulfur-bearing rock above the melting point of sulfur. The molten sulfur is then forced to the surface by compressed air injected into the well. As all Frasch mines in the U.S. are near waterways, the sulfur is shipped by insulated barge or boat, or allowed to solidify and shipped as a solid.

Claus Process. Approximately 59 percent of the sulfur produced via Claus recovery is obtained from hydrogen sulfide recovered from petroleum refining, and the remaining 41 percent is recovered from natural gas sweetening (Reference N-8).

Hydrogen sulfide is recovered from natural gas or refinery gases by absorption in a solvent or by regenerative chemical absorption (Reference N-9). Hydrogen sulfide concentrations in the gas from the absorption unit vary. For this analysis, an industry average H_2S gas concentration of 85 percent is used (References N-1 and N-10). This concentrated hydrogen sulfide stream is treated by the Claus process to recover the sulfur. The Claus process is based upon the reaction of hydrogen sulfide with sulfur dioxide according to the exothermic reaction (Reference N-9):

$$2H_2S + SO_2 \leftrightarrow 3S + 2H_2O \qquad \text{(Reaction 1)}$$

Sulfur dioxide for the reaction is prepared by oxidation of hydrogen sulfide with air or oxygen in a furnace using either the partial combustion process (once-through process) or the split-stream process. The partial combustion method is used when the H_2S concentration is greater than 50 percent and the hydrocarbon concentration is less than 2 percent. The split stream process is used when there is an H_2S concentration of 20 to 50 percent and a hydrocarbon concentration of less than 5 percent.

In the partial combustion method, the hydrogen sulfide-rich gas stream is burned with a fuel gas in an oxygen-limited environment to oxidize one-third of the H_2S to SO_2 according to the reaction (Reference N-11):

$$2H_2S + 2O_2 \rightarrow SO_2 + S + 2H_2O \qquad \text{(Reaction 2)}$$

Sulfur is removed from the burner and the H_2S/SO_2 mixture moves to the catalytic converter chambers.

In the split stream process, one-third of the hydrogen sulfide is split off and completely oxidized to SO_2 according to the reaction:

$$H_2S + 1.5\,O_2 \rightarrow SO_2 + H_2O \qquad \text{(Reaction 3)}$$

The remaining two-thirds of the H_2S is mixed with the combustion product and enters the catalytic converter chambers.

The H_2S and SO_2 mixture from either process is passed through one or more catalyst beds and is converted to sulfur, which is removed by condensers between each bed (Reference N-9). For this analysis, an H_2S concentration of 85 percent has been assumed; therefore, it is also assumed that the partial combustion process is used.

Although efficiencies of 96 to 99 percent sulfur recovery have been demonstrated for the Claus process, recovery is usually not over 95 percent and is limited by thermodynamic considerations (References N-9 and N-11). For this analysis, a sulfur recovery efficiency of 93 percent is assumed.

The energy generated from burning hydrogen sulfide to produce SO_2 is usually recovered and used directly to reheat the process stream in secondary and tertiary condensers, or recovered as steam for use in other processes (Reference N-11). Heat released from cooling the exothermic reaction to form sulfur is also recovered. The theoretical potential energy recoverable from the process is calculated from the overall sulfur production reaction:

$$H_2S + 0.5\,O_2 \rightarrow S + H_2O \qquad \text{(Reaction 4)}$$

The standard heats of formation, $\Delta H_{f\,298}$, for the species in Reactions 4 are (Reference N-11):

$$\Delta H_{f\,298}\,(O_2\,(g)) = 0 \text{ kcal mole}^{-1}$$
$$\Delta H_{f\,298}\,(S\,(s)) = 0 \text{ kcal mole}^{-1}$$
$$\Delta H_{f\,298}\,(H_2S\,(g)) = -4.93 \text{ kcal mole}^{-1}$$

$$\Delta H_{f\,298}\,(H_2O\,(g)) = -57.8 \text{ kcal mole}^{-1}$$

The standard heat of formation for Reaction 4 is therefore:

$$\Delta H_{f\,298} = [0 + -57.8 \text{ kcal/mol } H_2O] - [-4.96 \text{ kcal/mol } H_2S + 0]$$
$$\Delta H_{f\,298} = -52.87 \text{ kcal/mole}$$

For this analysis, a sulfur recovery rate of 93 percent has been assumed; therefore 1,073 pounds of H_2S are required to recover 1,000 pounds of sulfur. This equates to 14,315 moles of hydrogen sulfide. According to the above formation energy calculation, processing this amount of hydrogen sulfide could theoretically release 7.57×10^5 kcal, or 3.0 million Btu.

Industry sources report steam recovery from the sulfur recovery process of approximately 2,000 lb of steam per 1,000 lb of recovered sulfur. Assuming the heat value of 250 psia steam to be 1,200 Btu/lb (Reference N-12), this equates to 2.40 million Btu per 1,000 lb of recovered sulfur. The difference of 0.6 million Btu between the heat generated by the process and the heat recovered to produce steam is a loss of heat from the system. The fuel value of H_2S is not included in the total energy for the system because H_2S is not used as a commercial fuel. The system is also not given an energy credit for any steam exported from the system.

The energy requirements for crude oil production and refining processes that produce hydrogen sulfide-containing refinery gases and for sour natural gas production, processing, and sweetening processes that produce concentrated hydrogen sulfide gas are included with those for sulfur recovery.

Bleached Chemical Pulp Manufacture

Many different pulping methods are used to produce chemical pulps. Kraft, sulfite, and semichemical are the most common (Reference N-2). The data developed for producing chemical pulp is a weighted average from the previous processes and the chemi-thermomechanical pulp process which is also used in newsprint production. The following is a general discussion of a chemical pulp process.

Wood chips are delivered to the mill and washed and screened. To soften and increase brightness, the chips are impregnated with sodium sulfite. The sodium sulfite is produced from the reaction between the sulfur and the caustic soda. The sulfite also aids in separation of the fibers. After sulfonation, the fiber bundles are further separated by a series of refining operations (mechanically breaking down the fiber bundles). The refining operation consists of forcing the chips under great pressure between the surfaces of two metal disks, one stationary and one that rotates, that are separated by a very small gap.

The combined pressure and friction cause any remaining fiber bundles to be separated. After two to three refining operations, the consistency of the wood fiber has been converted from chips to pulp. After the refining operation, several stages of screening, cleaning, and filtering are needed to separate undesirable particles from the pulp. The pulp is then placed in storage tanks to await bleaching.

Chlorine dioxide, generated from sodium chlorate, is used to bleach the pulp along with chlorine and possibly other bleaching chemicals. After bleaching, the pulp is mechanically dewatered by the use of both filters and roll presses. In an integrated mill, the pulp is transferred to the paper or paperboard manufacturing section of the mill. If market pulp is being manufactured, the pulp is dried and baled. The final pulp drying operation involves passing the dewatered pulp through a series of columns that circulate hot air over the pulp. The pulp reaches a final consistency of approximately 80 percent solids.

Mechanical Pulp Manufacture

Mechanical pulp, which is commonly either groundwood pulp or refiner mechanical pulp, is the major pulp source used for manufacturing newsprint (Reference N-2). Data on refiner mechanical pulp production, which employs a disc refiner to break down wood chips, are not available. The data for mechanical pulp represents only the stone groundwood process. The groundwood process produces pulp by pressing blocks of wood against an abrasive rotating stone surface. Very little, if any, chemicals are used in this process (Reference N-2).

Recovered Paper Collection

Collection of waste paper, whether from an industrial or consumer setting, involves separation of the various grades of waste paper, baling the discards for ease of shipment, and delivery to a repulping operation.

Deinked Recovered Pulp Manufacture

The following discussion describes the production of deinked market pulp from recovered fiber sources, either industrial scrap or postconsumer. For many paper products, repulped wastepaper can be used as a raw material substitute for wood pulp.

The most common method of preparing recovered paper for reuse begins with repulping the fiber sources. During the repulping step, large sized contaminants are separated from the fiber. Immediately following pulping, smaller sized contaminants are screened for removal prior to deinking. If inks are present, a portion of the inks are washed from the fiber during the screening process and may result in sufficient deinking for some applications, such as for combination paperboard. This process also removes some coatings and fillers from the recovered paper.

When higher brightness is needed in the final product, a washing and/or flotation process involving chemical digestion "cooking" is required to further remove inks, fillers and coatings. This intensive digestion process often results in a significant weight loss of fiber in terms of both cellulosic fines and ash. These losses end up as deinking sludge. Chemicals, such as detergent, are used in the deinking process.

The deinked pulp is then dried or partially dried and prepared for delivery to a paper mill. The deinked and partially dried pulp, referred to as deinked wet lap, has an average moisture content of 50 percent.

Newsprint Production

As discussed at the beginning of this section, newsprint is made primarily from mechanical pulp. The fiber products are brought into the stock storage chest where they are mixed with water and combined with other pulps to form a suspension which is ready to be made into paper. Small amounts of caustic soda and bleaching chemicals may be used but are assumed to be negligible for making newsprint from pulp in this study (References N-2 and N-6).

From stock prep, the furnish is fed into the headbox. With the use of pressure, the headbox deposits the furnish in a regulated fashion onto a wire mesh. From the headbox, the wire mesh moves over a series of vacuum boxes where the sheet is mechanically dewatered.

Next, the furnish sheet is transferred from the plastic wire to a synthetic fabric. This felt conveys the sheet to a pressure roll with an internal vacuum box designed to remove additional water. This same pressure roll also transfers the web to the dryer. This operation is the final drying operation for the sheet.

Once the fiber has passed through the dryer, it has entered the "dry end" of the papermaking operation. From the dryer, the paper is passed through calender rolls to soften and smooth the paper, and wound onto a large, bulk size reel (now referred to as a parent roll). As the fiber passes through the papermaking process, scrap or broke that is created is fed directly into the holding chest underneath the machine to be repulped and sent back to the headbox. This internally recycled scrap is referred to as machine broke.

The rolls of newsprint are sold to newspaper publishers who convert the paper into newspaper. The converting operation is assumed to be small compared to the production of pulp and paper and is not considered in this study.

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ALUMINUM CAN PRODUCTION

The following sections describe the steps for the manufacture of primary aluminum from raw materials extracted from the earth and from recycled containers. The process of producing molten aluminum from recycled containers is much simpler than from virgin materials.

The following steps in the production of aluminum cans are discussed in the sections below:

- Lime production
- Bauxite mining
- Alumina production
- Crude oil production
- Petroleum coke production
- Coal mining
- Metallurgical coke production
- Aluminum smelting
- Ingot casting
- Aluminum can recover and process
- Used container melting and ingot casting
- Aluminum sheet rolling
- Can fabrication
- Lid fabrication

The following steps are discussed in the Newsprint section and are not repeated here:

- Limestone mining
- Salt mining
- Caustic soda production

Lime Production

Lime is produced by calcining limestone. Limestone (calcium carbonate) is heated in a kiln to a high temperature to drive off any water present in the limestone. The carbonate is decomposed by the evolution of carbon dioxide. The product that remains is lime (calcium oxide) (References A-1 and A-2).

Bauxite Mining

Aluminum is the most widely distributed metal in the earth's crust, with only the nonmetallic elements oxygen and silicon surpassing it in abundance. However, bauxite ore is at the present time the only commercially exploited source of aluminum. Although other types of earth, including ordinary clay, contain aluminum, economics favor the use of bauxite.

Bauxite is formed by the action of rain and erosion on materials containing aluminum oxide (alumina). The heavy rainfall and warm temperatures of the tropics provide the most nearly ideal conditions for this process, and most of the world's bauxite is mined in these regions. Australia is the leading producer of bauxite, followed by Guinea, which is second, and Jamaica, which is third (References A-3). Although a number of other countries also produce and export bauxite to the United States, more than 90 percent of the total is supplied by these three countries. Therefore, for this analysis, only these three countries are considered as the suppliers of bauxite to the United States.

Alumina Production

Before it can be used in the manufacture of metallic aluminum, bauxite ore must be refined to nearly pure aluminum oxide, usually called alumina. The method used to accomplish this is called the Bayer process, which is used almost exclusively. Bauxite is crushed and dissolved in digesters using strong caustic soda and lime solution. The undissolved residue, known as red mud, is filtered out. Sodium aluminate remains in solution, where it is hydrolyzed and precipitated as aluminum hydroxide, which is then calcined to alumina, generally in a rotary kiln.

Crude Oil Production

Oil is produced by drilling into porous rock structures generally located several thousand feet underground. Once an oil deposit is located, numerous holes are drilled and lined with steel casing. Some oil is brought to the surface by natural pressure in the rock structure, although most oil requires some energy to drive pumps which lift oil to the surface. Once oil is on the surface, it is stored in tanks to await transportation to a refinery. In some cases, it is immediately transferred to a pipeline which transports the oil to a larger terminal.

There are two primary sources of waste from crude oil production. The first source is the "oil field brine," or water which is extracted with the oil. The brine goes through a separator at or near the well head in order to remove the oil from the water. These separators are very efficient and leave minimal oil in the water.

According to the American Petroleum Institute (API) it is estimated that 21 billion barrels of brine water were produced from crude oil production in 1985. This quantity of water equates to a ratio of 5.4 barrels of water per barrel of oil. The majority of this water (90 percent) is injected into separate wells specifically designed to accept production-related waters. Some drilling operations discharge brine water directly into tidal areas or large bodies of fresh water. The waterborne waste from crude oil production represents the amount of waste present in the 10 percent of brine water discharged into bodies of fresh water.

It is assumed that roughly 25 percent of all natural gas is produced from wells in combination with oil. Therefore, a portion of the waterborne waste is attributed to natural gas production.

The second source of waste is the gas produced from oil wells. While most of this is recovered for sale, some is not. Atmospheric emissions from crude oil production are primarily hydrocarbons. They are attributed to the natural gas produced from combination wells and relate to line or transmission losses and unflared venting.

The transportation data assume a mix of foreign and domestically produced crude oil. According to the **Petroleum Supply Annual, June 1994**, 49 percent of the crude oil used in the United States is imported.

Petroleum Coke Production

Petroleum coke is utilized in the manufacture of carbon electrodes, which are used in the electrolytic reduction of alumina to aluminum.
Coking is an extreme form of thermal cracking which uses high temperatures and a long residence time to break down heavy crude residues to get lighter liquids (Reference A-4). Coking takes place in a series of ovens in the absence of oxygen. After a typical coking time of 12 to 20 hours, most of the volatile matter is driven from the crude residue and the coke is formed. The desired products of the coking process are actually the volatile products. The petroleum coke itself is considered a byproduct. The coke is collected in a coke drum, while the lighter products go overhead as vapors.

The energy requirements and environmental emissions for crude oil desalting and atmospheric and vacuum distillation to produce heavy crude residues are included in those for production of petroleum coke.

Coal Mining

Coal may be obtained by surface mining of outcrops or seams that are near the earth's surface or by underground mining of deposits. In strip mining, the overburden is removed from shallow seams, the deposit is broken up, and the coal is loaded for transport. Generally, the overburden is eventually returned to the mine and is not considered as a solid waste in this analysis.

After the coal is mined, it goes through various preparation processes before it is used. These processes vary depending on the quality of the coal and the use for which it is intended. Coal preparation usually involves some type of size reduction and partial removal of ash-forming materials.

Metallurgical Coke Production

The two proven processes for manufacturing metallurgical coke are known as the beehive process and the byproduct process (Reference A-5). The primary method for manufacturing coke is the byproduct method, which accounts for more than 98 percent of U.S. coke production (Reference A-6). For this analysis, it is assumed that all metallurgical coke is produced in the byproduct oven.

In the byproduct method, air is excluded from the coking chambers, and the necessary heat for distillation is supplied from external combustion of some of the gas recovered from the coking process (Reference A-5). Coking 1,000 pounds of coal in the byproduct oven is assumed to produce the following: coke, 774 lb; tar, 37 lb; water, 32 lb; benzene, 11 lb; and coke oven gas, 147 lb (Reference A-7). Coproduct credit is given on a weight basis to all of the byproducts from the oven, except water. It is assumed that about 40 percent of the coke oven gas (59 pounds) is used as a fuel for underfiring the coke oven (Reference A-5). Therefore, coproduct credit is given for the remaining 88 lb of coke oven gas. The energy content of the coke oven gas is accounted for in the energy of material resource for the coal used as a feedstock for the coke oven. While it is recognized that the gas is actually used as a fuel in the coke oven, the methodology used in this study accounts for the energy derived from materials used as feedstocks on the basis of the energy content of the material that is extracted from the ground to produce the raw material.

Aluminum Smelting

Smelting is the reduction of refined alumina to metallic aluminum by the electrolytic separation of aluminum from its oxide. The process is carried out in a long series of electrolytic cells carrying direct current. The alumina is dissolved in a molten bath of cryolite (an electrolyte) and aluminum fluoride (which increases the conductivity of the electrolyte). These chemicals are assumed to be recovered with little or no loss. Carbon anodes carry the current to the solution, and on to the next cell. The anodes are consumed during the reaction at a rate of approximately 500 pounds of material per 1,000 pounds of aluminum produced. The principal products of the reaction are carbon dioxide, which is evolved as a gas, and elemental aluminum, which settles to the bottom of the cell and is periodically drained off.

Ingot Casting

Molten aluminum is discharged from a smelter into the holding and ingot casting facility. In this step, molten metal is typically combined with high quality scrap and then cast into aluminum ingots (References A-8 and A-9).

Electricity for ingot casting is assumed to be produced by the same fuel mix used for aluminum smelting because smelting and ingot casting usually occur in the same facility.

A melt loss of 35 pounds per 1,000 pounds of primary aluminum produced is assumed for this study. The loss occurs when dross is skimmed off the molten aluminum.

Aluminum Can Recovery and Processing

Widespread aluminum can recovery is observed through voluntary collection centers, curbside collection programs and mandatory beverage container deposit laws. The high scrap value and easily identified container are two reasons for the high recovery rate experienced with aluminum cans. In the 1980s, collection centers could be commonly found in shopping centers and other retail store locations. At the present time, the recovery of cans creates little environmental disruption and requires energy only to the extent that fuel is required to transport cans to the collection center.

Once the cans are collected, they must be densified in some fashion and shipped. At present, cans are commonly flattened or shredded at recycling centers. The processed scrap is usually blown into tractor-trailer vehicles for shipment to an aluminum recycling plant. The scrap can also be densified in balers at the recycling center, a MRF, or in special units which produce smaller bales called briquettes.

Used Container Melting and Ingot Casting

Once containers are recovered in a reasonably pure form and prepared for melting, they can be placed in a secondary furnace. The data for melting, holding, and casting to produce ingots are assumed to be relevant to both the virgin and recycled aluminum systems. This is partially due to the fact that containers are frequently remelted at virgin smelter sites, and significant quantities of in-house scrap are melted in the virgin system. A melt loss of 71 pounds per 1,000 pounds of secondary aluminum produced is assumed for this study.

Aluminum Sheet Rolling

Ingots which are cast from recycled and/or virgin molten metal are further processed into intermediate products. For example, they are heated, then rolled to produce can stock. The term rolling is quite descriptive for the operation occurring in this step. Care is taken to collect trim and other internally generated scrap so it can be remelted.

The energy model for aluminum cans accounts for the large amounts of scrap that are rolled, collected, melted, and recycled back into the sheet rolling process.

Aluminum Can and Lid Fabrication

Aluminum coil is transported to can fabrication plants located throughout the U. S. Typically, these plants are located within a few miles of large breweries or near concentrations of beverage filling plants. The aluminum can is fabricated in a process where a circular blank is first stamped from the stock sheet and formed into a cup. The cup is then drawn, ironed and shaped into the can body. Various coatings and decorations are added.

Aluminum lids are usually fabricated at the same plant as the cans. However, it is not unusual for there to be dedicated lid plants. The lids and tabs are stamped separately from aluminum sheet and joined after shaping. The lids are coated and sometimes decorated. Also, the lids are formed from a different alloy than is used for can bodies.

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OFFICE PAPER

The following steps in the production of office paper are discussed in the sections below:

- Bleached virgin kraft pulp production
- Paper production
- Tissue production

The tissue data used is an approximation using bleached kraft paper data. The following steps are discussed in the Newsprint section and are not repeated here:

- Roundwood harvesting
- Wood residues production
- Salt mining
- Caustic soda and chlorine production
- Sodium chlorate production
- Limestone mining
- Sulfur production
- Mechanical pulp manufacture
- Recovered paper collection
- Deinked pulp manufacture

Bleached Virgin Kraft Pulp Production

Kraft pulp is the most widely used type of wood pulp in the United States today, accounting for 70 percent of the total wood pulp produced. It is used in either an unbleached or bleached form. The data in this study are for bleached pulp.

The kraft pulping process is based on chemical digestion of wood which has been previously debarked and chipped. The digester is a closed container which holds the wood chips and digestion liquors. The liquor is mainly an aqueous solution of chemicals including sodium sulfide and sodium hydroxide. In order for digestion to take place, heat and pressure are applied to the mixture of wood and liquor. The digestion process delignifies the wood and removes other chemical components from the wood, leaving only the wood fiber.

One of the features of the kraft process is that the used digestion liquor, called black liquor, is burned. Because the liquor contains a high percentage of flammable wood components, it burns readily. The remaining digestion chemicals, called green liquor, are removed and reacted with lime. The resulting white liquor is returned to the digester.

Combustion of black liquor and the bark and "fines" removed from logs entering the mill often provides sufficient energy to operate a pulp mill. Thus, there are minimal fossil fuel requirements for the pulp-making process. Some additional energy from fossil fuel sources is used in the paper-forming steps that immediately follow pulp making. The black liquor that is burned in the recovery furnace is treated as fuel for the process. A few mills may acquire additional wood wastes to convert to energy in their boilers.

The bleaching process can be accomplished with a variety of chemicals. Chlorine dioxide, generated on-site from sodium chlorate, is commonly used. Salt cake (sodium sulfate), which is generated as a byproduct of chlorine dioxide manufacture, is introduced into the recovery boiler. Additional salt cake is not required because enough is generated from the chlorine dioxide manufacture (Reference O-1).

After the wood pulp is "blown" from the digester by the steam used in the process, it is washed free of the chemicals, screened and refined for entry into the paper-forming section of the mill.

Paper Production

The fiber is pumped to the paper machine as a very dilute suspension in water. To form the paperboard, the fiber suspension drains onto a finely woven plastic or wire mesh belt which allows the water to drain through and retains the fiber. Approximately 98 percent of the excess water is removed from draining and pressing the fiber web between hard machine rolls. Paper (wood) fibers have a natural affinity for themselves and coupled with the mechanical interweaving and chemical additives, the web becomes a structure. The final excess water is evaporated by passing the web of paperboard over a number of steam-heated drums. The paper is wound onto rolls as it comes off of the end of the drying section. If the paper is coated, this step may take place before the roll is produced.

Tissue Production

Tissue is a lightweight grade of paper produced in the same way as the kraft pulp and paper discussed previously. Principal products are toilet tissue, towels and facial tissue. A high percentage of the "commercial" market products are made of recycled fiber, whereas the "retail" (consumer) products are made largely of virgin fiber.

OFFICE PAPER REFERENCES

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TIN-COATED STEEL CAN PRODUCTION AND RECYCLING OF STEEL CANS INTO STEEL INGOT

The following steps in the production of tin-coated steel cans are discussed in the sections below:

- Iron ore mining
- Oxygen manufacture
- Agglomerates manufacture
- External scrap procurement
- Pig iron production
- Basic oxygen process furnace (BOF)
- Tin-coated steel sheet manufacture
- Steel can production

A large portion of recycled steel ingots are produced using an electric arc furnace. This process is described for the recycling of steel cans into steel ingot.

- Electric arc furnace (EAF)

Limestone mining was discussed in the Newspaper section. The following steps are discussed in the Aluminum can section and are not repeated here:

- Coal mining
- Metallurgical coke production
- Lime production

Iron Ore Mining

The basic raw material for steel manufacture is iron ore. This material is usually found in flat-lying or gently sloping beds not more than 20 feet thick. Open pit mining accounts for 90 percent of the iron ore extracted at present, with the remainder being recovered from deep vertical shaft mines. Overburden and waste rock from mining are eventually returned to the mine and are not considered solid waste in this analysis.

Because of the stringent specifications placed on iron ore used in blast furnaces, it is necessary to beneficiate the ore. Beneficiation consists of crushing and grinding, screening, magnetic separation and other concentrating techniques. During beneficiation, a large quantity of tailings are produced. Tailings are liquid sludges from the concentration operations. These tailing are generally pumped back to the mine site and deposited in settling ponds. The water is often recovered for reuse in the beneficiation facility and the solids are returned to the earth. Unlike overburden from mining operations, tailing solids are considered solid waste because they result from ore processing operations and are unlike the natural materials found at the mine sites. For this analysis, it is assumed that about 2,181 kilograms of ore tailings are produced per 1,000 kilograms of refined ore (Reference S-1).

Oxygen Manufacture

The iron and steel industry consumes more oxygen than all other industries combined, using well over one-half of all oxygen produced in this country. Oxygen is used in a variety of iron- and steel-making operations ranging from scrap preparation to basic oxygen process steel furnaces.

Oxygen is manufactured by cryogenic separation of air. This technique is essentially one of liquefying air, then collecting the oxygen by fractional distillation. The oxygen is produced in the form of a liquid which boils at 300 degrees Fahrenheit below zero at normal atmospheric pressure, so it must be kept under stringent conditions of temperature and pressure for handling. Most oxygen plants are located quite close to their point of consumption to minimize transportation difficulties. For this analysis, it is assumed that oxygen is produced on-site at the steel production facility.

Agglomerates Manufacture

Approximately 96 percent of iron ore charged into a blast furnace enters not as raw ore, but as agglomerates. These agglomerates are most commonly in the form of pellets and sinter.

Pellets are made from fine concentrates of iron ore mixed with a binder (usually bentonite). After formation, the pellets are rolled, then heated to remove moisture. This process is usually carried out at the mine site.

Sinter is generally made at the iron or steel mill, and consists of iron ore fines, coke dust, mill scale, flue dust, etc., gathered from the steel-making process. These materials are heated on a grate to form sinter.

External Scrap Procurement

The recycling of metallic scrap back into iron and steel furnaces has long been an economically viable means of utilizing ferrous waste materials. About one-half of the metallic input to steel furnaces is in the form of scrap. Much of the scrap recovered is generated within the mills themselves (and is referred to as "home" scrap or "run-around" scrap) and the impacts associated with their recovery are included with normal iron and steel mill operations. However, substantial quantities of scrap are transported to iron and steel mills from external sources (including other mills at different sites).

Electric furnaces are based on 100% scrap feedstock. Small capacity steel mills, called minimills, utilizing electric furnaces have recorded a marked increase in number during recent years.

Obsolete ferrous scrap originates from several sources, but railroad and automotive wreckers account for the bulk of total recovery. Other important sources include building demolition, shredded appliances, farms, metal products manufacturing, shipbreaking, and oil field and refinery scrap.

In general, most obsolete scrap undergoes similar processing prior to consumption in an electric furnace. It is usually manually or semi-manually handled to remove valuables (e.g., tin-plating, copper wire, chrome, etc.) and some contaminants (e.g., chemical impurities, organic materials). Subsequent processing includes flattening, shredding, magnetic separation, and all necessary transportation steps including transport from the flattener to the shredder, transport of waste from shredder to landfill, and the transport of steel scrap from the shredder to the furnace.

Pig Iron Production

Iron-bearing material, coke, and fluxes are charged into a blast furnace, where the iron ore is reduced to pig iron. A blast of heated air, and, in most instances, a gaseous, liquid or powdered fuel are introduced into the furnace through openings at the bottom of the furnace shaft. The heated air burns the injected fuel and most of the coke charged in from the top to produce the heat required by the process and to provide reducing gas (carbon monoxide) that removes oxygen from the iron ore. The reduced iron melts and runs down to the bottom of the hearth. The flux combines with the impurities in the ore to produce a slag which also melts and accumulates on top of the liquid iron in the hearth (Reference S-1).

The energy obtained from the combustion of both coke and coke oven gas in the blast furnace are accounted for as the energy of material resource of the coal used to produce the coke. While it is recognized that most of the energy content in the coke and coke oven gas is liberated in the blast furnace, the methodology used in this study accounts for the energy derived from materials used as feedstocks on the basis of the energy content of the material that is extracted from the earth to produce the raw material.

The following assumptions were made while analyzing available data for the production of pig iron from a blast furnace:

- The iron-bearing agglomerate burden for the blast furnace is assumed to be input as 60 percent iron ore pellets and 40 percent sinter (Reference S-1).

- Coproduct credit is given on a weight basis for coke breeze (very fine particles of coke) and flue dust recovered during operation of the blast furnace. Both of the materials are raw materials for sinter production. Therefore, the outputs from the blast furnace include the requirements of coke breeze and flue dust to sinter production.

- Coke oven gas is used as a fuel at a rate of 5.63 pounds of gas per 1,000 pounds of pig iron.

- Blast furnace gas produced in the process is assumed to be used to heat air injected back into the furnace.

- About 214 pounds of blast furnace slag are produced for every 1,000 pounds of pig iron. Approximately 75 percent of the blast furnace slag produced in the United States is used in aggregate applications such as fill, road bases and the coarse aggregate components of asphalt and concrete (Reference S-2). This slag is not considered to be solid waste; however, no coproduct credit is given for the material. The remaining 25 percent of the slag is stockpiled (Reference S-2). This slag (approximately 54 lb) is considered solid waste in this analysis.

Basic Oxygen Furnace (BOF)

Since the mid 1970s, the basic oxygen process has seen widespread use in steel making. In the oxygen steelmaking process, high-purity oxygen is blown under pressure through, onto or over a bath containing hot metal, steel scrap and fluxes to produce steel (Reference S-1).

The BOF offers the advantage of using both virgin pig iron and scrap or recycled steel as feedstock. Hot metal composition and temperature are the most important variables that determine the percentage of scrap that can be charged to a heat. Typically, most pneumatic furnaces (of which the BOF is an outgrowth) consume 20 to 35 percent of the total metallic charge as cold scrap (Reference S-1). On average, about 28.5 percent of the total metallic material charged to BOFs in the United States is cold scrap (Reference S-3).

The primary sources of heat for oxygen steelmaking processes are from the hot metal charged to the furnace and from the oxidation of carbon, silicon, manganese, phosphorus, iron and other elements contained in the hot metal charge (Reference S-1). Minimal quantities of natural gas and coke oven gas are used to supply supplemental heat to the furnace and to preheat ladles and casters.

The following assumptions were made in analyzing available data for the production of raw steel from the basic oxygen furnace:

- Coke oven gas is used as a fuel at a rate of 1.23 pounds of gas per 1,000 pounds of raw steel.
- Energy requirements and environmental emissions for heating and operating ladles and casters are included with those for the BOF.
- Coproduct credit is given on a weight basis for the slag produced in the BOF. This material is used as an input to sinter production and directly into the blast furnace for its iron content. Because the coproduct credit is given on a weight basis, the output from the BOF is increased to account for the input of BOF slag into sinter production and the blast furnace.

Tin-coated Steel Sheet Manufacture

After the raw steel leaves the BOF, it proceeds through a series of milling processes before emerging as tin-coated steel strip. A vacuum degassing process refines the steel from the furnace before it enters the casting step. Continuous casting is used almost exclusively to produce slabs for flat rolled products from raw steel produced in the basic oxygen process (Reference S-3). The continuously cast slabs pass through the hot rolling mill and then the cold rolling mill to produce sheet. The surface of the steel is cleaned by an acid treatment (using hydrochloric acid) called pickling. Finally, the steel strip is coated with a very thin layer of tin. The tin provides a barrier to corrosion at a relatively low cost. For this analysis, it is assumed that about 3 pounds of tin are applied per 1,000 pounds of steel sheet. The resource requirements and environmental emissions for producing this small amount of tin are assumed to be negligible.

Available data for steel milling operations indicated the use of coke oven gas to supply energy for reheating the steel during hot milling. For this analysis, this heat is assumed to be supplied by natural gas instead of coke oven gas.

Steel Can Production

For this study, a three-piece welded can is analyzed. The can is produced by first stamping a body blank that is lacquered and decorated prior to can making. It is then formed with a narrow overlap, welded and flanged. A protective strip of lacquer is applied over the side seam after joining (Reference S-1). The can ends are stamped and one end is applied to the can and crimped in place at the site of production. The other end for the can is applied at the canning plant.

The trim scrap and "skeletons" that result from stamping the can body and ends are collected and sent back to the tinplate manufacturer for recycling. Coproduct credit is given on a weight basis for this material.

Electric Arc Furnace (EAF)

While a blast furnace and BOF are used to produce raw steel from virgin materials and limited amounts of scrap, and electric furnace is used for making raw steel from process and recycled scrap. The electric furnace is capable of accepting a charge of nearly 100 percent scrap (Reference S-4). For the purposes of this analysis, it was assumed that the charge to the electric furnace is virtually all scrap with small amounts of iron ore, limestone, and lime added. No agglomerates are assumed to be included in the charge, although they are often included in the input to electric furnaces.

Scrap metal and various additives are charged into an electric furnace through its top. These materials are melted by the conversion of electric energy to heat. Current is brought into the furnace through large carbon electrodes, and the energy is converted to heat in the furnace.

STEEL REFERENCES

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CORRUGATED BOX

Corrugated paperboard is produced by gluing a fluted corrugating medium between two linerboards. Often the corrugating medium contains recycled fiber from industrial or postconsumer sources. The construction of a corrugated box is typically 67.9 percent linerboard and 32.1 percent corrugating medium by weight (Reference C-1).

Based on national statistics for linerboard production, this analysis assumes the linerboard contains 85 percent unbleached virgin kraft paper and 15 percent recycled paperboard (Reference C-2).

Based on national statistics for corrugating medium production, corrugated boxes are made using 26 percent recycled medium and 74 percent semichemical paperboard (Reference C-2). Semichemical medium is made from approximately 69 percent virgin semichemical pulp and 31 percent recycled content, of which 67 percent comes from old corrugated containers (OCC) (References C-2 and C-3).

The following steps in the production of corrugated boxes are discussed in the sections below:

- Sodium sulfate mining and processing
- Sulfuric acid production
- Unbleached virgin kraft paper production
- Old corrugated container (OCC) collection
- Recycled medium and linerboard production
- Semichemical paper production
- Soda ash production
- Starch adhesives
- Corrugated container manufacture
- Folding box manufacture

The folding box data is an approximation using bleached and unbleached kraft paperboard. The following steps are discussed in the Newsprint section and are not repeated here:

- Roundwood harvesting
- Wood residues
- Limestone mining
- Salt mining
- Caustic soda production
- Sulfur production

Sodium Sulfate Mining and Processing

Sodium sulfate is consumed in the Kraft pulping process. The upper levels of Searles Lake in California, the Great Salt Lake in Utah, and the brines of west Texas all contain sodium sulfate. Typically sodium sulfate crystals are removed from cooled brine. The crystals are then dissolved again and precipitated to achieve the desired purity.

Sulfuric Acid Production

Sulfur is burned with air to produce sulfur dioxide and heat. The heat is used to generate steam that is usually used in adjacent processing plants and to supply energy to the sulfuric acid plant. The energy import (as the calorific value) of sulfur and the energy export of steam cancel in the energy balance for this process. Thus, it is assumed here that there are no net fuel requirements. The sulfur dioxide gas is converted to sulfur trioxide and combined with dilute sulfuric acid to form the concentrated product.

Unbleached Virgin Kraft Paper Production

Kraft pulp is the most widely used type of wood pulp in the United States today, accounting for 70 percent of the total wood pulp produced. It is used in either an unbleached or bleached form. The following description is for the production of unbleached kraft paper. The production of bleached kraft paper was covered previously.

Unbleached kraft paperboard is manufactured using the same processes as bleached kraft paper, except without the bleaching steps.

Recycled Medium and Linerboard Production

The manufacture of recycled medium and linerboard for corrugated boxes uses old corrugated containers (OCC) and box cuttings as raw materials.

Semichemical Paper Production

Most of the increase in semichemical pulp production in the past 40 years has been made using non-sulfur semichemical processes, not only because of tightened environmental regulations, but also because of realization of higher yields and simpler recovery systems. There are three major pulping processes used to manufacture semichemical pulps in integrated as well as stand-alone semichemical pulp mills:

- The Neutral Sulfite (NSSC) process uses sodium carbonate and sulfur or, in some cases, purchased sodium sulfite byproduct from a nearby chemical operation as the cooking chemical. This process is the most widely used of all semichemical processes (Reference C-1).

- The Green Liquor process uses green liquor from the kraft recovery process as the cooking chemical.

- The Non-sulfur process uses a combination of sodium carbonate, sodium hydroxide and traces of other proprietary chemicals to enhance the properties of the pulp.

Many semichemical operations integrated with kraft mills use green liquor from the kraft recovery process as the cooking chemical. This allows integration of the semichemical cooking chemical preparation and recovery into the kraft recovery cycle. The quality of semichemical pulp is superior when produced by the neutral sulfite process, but it produces less pulp per pound of wood. The pulp yields from wood in the semichemical pulping processes range from 75 to 88 percent.

Mills use secondary fiber in the preparation of corrugating medium. Most mills producing corrugating medium use a significant amount of recovered fiber (usually OCC) in their product since it requires less chemicals and energy to produce and improves the performance characteristics of the semichemical pulp. Secondary fiber in the form of old corrugated cartons and kraft clippings used in the production of corrugating medium with semichemical pulp is as high as 70 percent (Reference C-3). The recycled fiber content must be below 50 percent for the product to be classified as semichemical medium, but this is not a technical requirement.

Semichemical pulp and paper mills purchase more energy in the form of fuel and/or electrical energy than full chemical pulp mills. Only a relatively small part of the steam and electrical power required to operate the pulp mill is generated by burning recovered chemicals. In contrast, kraft pulp mills burn black liquor as well as bark, wood and wastes.

Soda Ash (Sodium Carbonate) Production

Most soda ash (sodium carbonate) used in the U.S. is natural soda ash obtained from a mineral called trona and from naturally occurring alkaline brines. Almost all of the soda ash is mined from the Green River basin in Wyoming and Searles Lake in California. Underground trona mining is similar to coal mining. The most common methods are the room and pillar method and the long wall method. In both of these processes the material is undercut, drilled, blasted, crushed and then transported to the surface. Solution mining is presently being developed as a more efficient technique. In the refining process, the predominant energy use is in the calcining of bicarbonate to produce carbonate.

Soda ash can be synthesized by the Solvay process. The Solvay process uses salt, coke and limestone, with ammonia as a catalyst. All synthetic soda ash is manufactured in New York State. Synthetic soda ash is more expensive to produce than natural soda ash, and it also has high concentrations of calcium chloride and sodium chloride in the process effluent. U. S. production provides nearly all of the soda ash required by U.S. manufacturers.

Starch Adhesives

Most of the adhesives used to construct corrugated cartons are starch based. Starch adhesives are low-cost powders that form irreversible gels in hot water. They are made predominantly from unmodified cornstarch derived from hybrid yellow dent corn, but can also be made from starch derived from potatoes, rice, wheat or other vegetable products (References C-4 and C-5).

Whole grain corn is composed of approximately 72 percent starch (Reference C-6). A single fertilizer applied to corn often contains nitrogen, phosphorus and potassium, nutrients critical for growth. Pesticide emissions are difficult to quantify since there are many pesticides used, each varying in application rate and degradability. Anywhere from 0.1 percent to 5 or 10 percent of the pesticide applied may be found in water runoff. The cultivation of corn is almost entirely mechanized, with little hand labor being required. Mechanical field harvesters pick the corn and remove the grain from the cobs. Thus, a relatively clean grain is hauled from the field, leaving the leaves, stalks, and cobs to be plowed back into the ground. Nutrients in agricultural runoff vary depending on planting practices, soil erosion, control practices, rainfall, and soil type. The two most problematic nutrients lost from crop lands are nitrogen and phosphorus, since increased concentrations lead to eutrophication.

Cornstarch is produced from corn by wet milling. The corn is soaked in steeping tanks containing a solution of 0.3 percent sulfur dioxide in water to soften the kernel and dissolve inorganic components. This steep liquor is later concentrated for sale as a co-product. The softened corn is lightly milled to free the germ from the kernel. The germ is then processed for oil removal. The remaining corn fraction, mostly starch, protein, and hulls, is then heavily milled. The starch is washed from the hulls, and the resulting starch slurry is separated from the protein fraction, refined, washed, and dried.

Starch is added to caustic soda and water in a primary mixer and then cooked to form a tacky, viscous paste. This paste is transferred to a secondary mixer containing additional starch and borax. The borax reacts with the caustic soda in the paste starch to form metaborate. During the gluing operations of corrugated production, the raw starch from the secondary mixer becomes gelled and contributes to the bond (Reference C-4).

A cradle-to-grave analysis of starch adhesives, includes the following steps: fertilizer production, corn production, sulfur mining, corn starch production, salt mining, sodium hydroxide production, borax production, and starch adhesive manufacture.

Corrugated Container Manufacture

The data for producing corrugated boxes include manufacture of corrugated board by combining a top and bottom linerboard with the fluted corrugating medium, as well as scoring and cutting the board to form the box. The box is then usually shipped flat to the point where a product is placed in it.

Folding Box Manufacture

Folding boxes are made of paperboard produced in the same way as the kraft pulp and paperboard discussed previously. Common calipers for paperboard used to produce folding boxes are 18 point and 21 point.

CORRUGATED REFERENCES

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C-4 **Tappi Journal.** July, 1991.

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LOW-DENSITY POLYETHYLENE RESIN

The following steps in the production of LDPE resin are discussed in the sections below:

- Distillation, desalting, and hydrotreating
- Natural gas production
- Natural gas processing
- Ethylene manufacture
- Low-density polyethylene (LDPE) resin production
- Postconsumer plastics collection and baling
- Postconsumer plastics processing (recycling)
- Blow molding polyethylene products

Crude oil production was discussed in the Aluminum can section.

Distillation, Desalting, and Hydrotreating

In a petroleum refinery, a complex combination of processes serve to separate and physically and chemically transform the mixture of hydrocarbons found in crude oil into a number of products. Modern refineries are able to vary the different processing steps through which a charge of crude oil passes in order to maximize the output of higher value products. This variation of processing steps can change according to the make-up of the crude oil as well as the economic value of the products. Because of this variation, it is necessary to make certain assumptions about the refinery steps to which crude oil is subjected in order to produce petrochemical feedstocks.

For this analysis, it is assumed that the crude oil used to produce feedstocks for olefins production goes through the following refinery operations: desalting, atmospheric and vacuum distillation, and hydrotreating. Due to a lack of facility-specific data, literature sources were used to estimate the energy requirements for these refining steps. A number of literature references were used, most of which showed similar energy inputs (References L-1 through L-5).

Crude oil desalting is the water-washing of crude oil to remove water-soluble minerals and entrained solids (Reference L-6). For this analysis it is assumed that all of the crude oil that enters a refinery passes through the desalting step (References L-4 and L-6).

Crude oil distillation separates the desalted crude oil into fractions with differing boiling ranges. Atmospheric distillation is used to separate the fractions with a boiling point less than 650° Fahrenheit (References L-4 through L-6). At temperatures greater than 650° Fahrenheit thermal cracking of the hydrocarbons starts. Fuel gas or still gas that is liberated from the crude oil during distillation is further processed into liquefied petroleum gas or natural gas, depending on the carbon chain length. This gas is sold or used in the refinery to generate heat. About 52 percent of the non-electrical energy used in a refinery for direct heating or steam production comes from fuel gas (Reference L-7). Coproduct credit is given on a mass basis for the gas fractions not used for energy in the refinery. Fuel gas or still gas used as an energy source in refining is assumed to have the same composition as natural gas and is shown as process energy. It is not included as raw material.

The residue from the atmospheric distillation unit passes to a vacuum distillation unit where separation of the various fractions can be accomplished at lower temperatures than would be required at atmospheric pressure. The residue, or bottoms, of the vacuum distillation unit is a valuable coproduct that is further processed to make usable products. Coproduct credit is given on a weight basis for this residue. It is assumed that all of the crude oil used to produce olefins feedstock passes through atmospheric distillation, while only 46 percent of the initial crude oil charge passes through vacuum distillation (References L-1, L-2, and L-6).

Hydrotreating is a catalytic hydrogenation process that reduces the concentration of sulfur, nitrogen, oxygen, metals, and other contaminants in a hydrocarbon feed. These contaminants can poison or foul catalysts used in catalytic crackers and contribute to air emissions if the hydrocarbon is used as a fuel. It is assumed that all of the feedstock for olefin cracking passes through hydrotreatment. Sulfur and metals removed from crude oil are separated and sold as coproducts (References L-1 and L-4). Coproduct credit is given for these materials on a mass basis.

Energy requirements for petroleum refineries are usually listed in literature sources as Btu of fuel, pounds of steam, and electricity per 42-gallon barrel of crude oil processed. For this analysis, a conversion of 3.385 barrels/1,000 pounds of crude oil was used. Steam inputs were converted to Btu requirements using a conversion of 1,200 Btu per pound. Btu inputs for steam were added to the Btu inputs listed as fuels, and the total was converted to quantities of fuels using the combustion energy values listed in Appendix A and the following refinery fuel mix: residual oil and residues (coke), 22 percent; purchased natural gas, 24 percent; LPG, 2 percent; and fuel gas or still gas, 52 percent (Reference L-8). Negligible quantities of coal and distillate oil are also used in the "average" refinery. In the listing of process fuels, the still gas produced in the refinery is combined with purchased natural gas.

Raw material inputs are calculated from the average loss due to atmospheric, waterborne, and solid waste emissions per 1,000 pounds of crude oil processed in a one-year period (Reference L-8). The data used for distillation, desalting, and hydrotreating are assumed to be representative of petroleum refineries in 1992.

Natural Gas Production

Natural gas is extracted from deep underground wells, being either co-produced with crude oil or from natural gas reserves. Because of its gaseous nature, natural gas flows quite freely from wells which produce primarily natural gas, but some energy is required to pump natural gas and crude oil mixtures to the surface. Atmospheric emissions from natural gas production are based primarily on line or transmission losses and unflared venting. Waterborne wastes are associated with that natural gas which is produced in combination with oil. These combination wells account for approximately 25 percent of all natural gas production.

Natural Gas Processing

Light straight-chain hydrocarbons are normal products of a gas processing plant. The plants typically use compression, refrigeration, and oil adsorption to extract these products. Heavy hydrocarbons are removed first.
The remaining components are extracted and kept under controlled conditions until transported in high-pressure pipelines, insulated rail cars, or barges.

If the natural gas has a hydrogen sulfide content of greater than 0.25 grain per 100 standard cubic feet, then it is considered "sour." Before it can be used, the gas must undergo removal of the hydrogen sulfide by adsorption in an amine solution, a process known as "sweetening."

The primary pollutants from the natural gas stream are volatile hydrocarbons leaking into the atmosphere. Additional sources of pollutants are natural gas-fired compressor engines. Emissions will also result from the gas sweetening plants if the acid waste gas from the amine process is flared or incinerated. When flaring or incineration is practiced, sulfur dioxide is the major pollutant of concern.

Ethylene Manufacture

The primary process used for manufacturing ethylene and other olefins is the thermal cracking of saturated hydrocarbons such as ethane, propane, naphtha, and other gas oils. Currently the feedstocks in the United States are approximately 75 percent ethane/propane and 25 percent naphtha.

Typical production of ethylene and other coproducts begins when hydrocarbons and steam are fed to the cracking furnace. After being heated to temperatures around 1,000° Celsius, the cracked products are quenched in heat exchangers which produce high pressure steam. Fuel oil is separated from the main gas stream in a multi-stage centrifugal compressor. The main gas stream then undergoes hydrogen sulfide removal and drying. The final step involves fractional distillation of the various reaction products.

When ethane is the principal feedstock, the final production distribution shows approximately 80 percent ethylene and 20 percent other coproducts. For propane and naphtha feeds, ethylene production represents only 45 percent and 35 percent of the total reaction products, respectively. Therefore, with the present feedstock mix (75 percent ethane/propane, 25 percent heavier fuels), ethylene represents about 60 percent of the total reaction products (assuming the light feed represents 68 percent ethane and 32 percent propane, and assuming the heavier feed to be all naphtha). The data for the manufacture of ethylene are based upon this feedstock mixture.

Low-Density Polyethylene (LDPE) Resin Production

Low-density polyethylene (LDPE) is produced by the polymerization of ethylene in high-pressure reactors (above 3,000 psi). The two reactor types used are autoclaves and tubular reactors. Generally, tubular reactors operate at a higher average ethylene conversion than autoclave reactors. The polymerization mechanism is either free-radical, using peroxide initiators, or ionic polymerization, using Ziegler catalyst.

Reactor effluent consists of unreacted ethylene and polymer. The pressure of the effluent mixture is reduced and the ethylene is purified and recycled back to the reactor. The polyethylene is fed to an extruder and pelletized.

Postconsumer Plastics Collection And Baling

For this analysis, postconsumer products are assumed to be collected by curbside collection techniques using single unit diesel trucks. Curbside collection is assumed to use 3.28 gallons of diesel per 1,000 pounds to collect recyclables and transport them to a processing facility (Reference L-9).

Plastics collected by curbside collection techniques are assumed to require no further sorting before baling. Baling is done using a double ram horizontal baler that produces a 30-inch by 44-inch by 46-inch bale (References L-10 and L-11). Bales of postconsumer plastics have an average density of 25 pounds per cubic foot (Reference L-12). The baler uses a 100 horsepower motor and has a throughput of 5 tons per hour (Reference L-12). An LPG fueled front-end loader is used to move the material from the collection truck unloading area to the baler.

Plastics Mechanical Recycling

In the plastics mechanical recycling process, the postconsumer plastic is received at the plant, typically in bales of recyclable plastic containers. The bales are sent through a debaler, and then sorted if they contain mixed plastics. Sorting is usually done by hand. The selected plastics are then sent by conveyor belt to a granulator. The granulated plastic flakes are blown into a washer. They are washed in water of approximately 200 degrees F and then spun dry. The flakes must be completely dry before going into the extruder; therefore, they may be stored to dry for an extended period of time (Reference L-10).

The dried plastic flakes are then sent through an extruder. In the extrusion process, the granules of plastic are placed in a hopper on the extruder which feeds the plastic through a barrel. In this barrel, a screw rotates and drives the plastic to an exit port at the other end. Friction and mechanical work produce enough heat to melt the plastic. From the exit port, the resin is immersed in a water-filled cooling tank. It is air dried and enters the pelletizer, which cuts the rod of dried resin into small pellets (Reference L-7). The final pellets are packed and sent to plastic product manufacturers.

To collect the energy data for plastic mechanical recycling, a survey of 6 different recycling plants from across the United States was performed. As very few of the plants could tell how many kilowatt-hours of electricity they use, a survey of motor sizes for each piece of machinery and their throughput was taken. From the motor sizes, an efficiency for each size motor was found (References L-8 and L-13). The motors were assumed to be a 3-phase, 60 Hz, 1750 RPM, wound-rotor type.

Energy use for recycling the various types of resin were estimated depending on the differences in the specific plastics' recycling process. Differences between specific facility operations may be greater than any differences caused by differences in resin properties.

Blow Molding Polyethylene Products

Three stages are required to blow mold a product. In the first, the resin is melted or plasticized. In the second stage, the parison or preform is formed using extrusion. In the last stage, the mold closes around the parison or preform, pinching off the ends. Then, compressed air expands the plastic against the mold walls and circulating cooling water in the walls cools the plastic. The product is removed from the mold when the plastic is set and excess resin is trimmed off. Blow moldin g is usually done continuously using a number of molds.

LDPE REFERENCES

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L-3 **1989 Industrial Process Heating Energy Analysis**. Gas Research Institute. May, 1991.

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L-10 Personal communication between Franklin Associates, Ltd. and various recycling plants. 1993.

L-11 Handbook Material Recovery Facilities for Municipal Solid Waste, EPA/625/6-91/031. United States Environmental Protection Agency. September, 1991.

L-12 Conversations with Mike Whalen, Global Equipment Company, Spokane Washington. September, 1992.

L-13 **Grainger™ General Catalog**. No. 377. W.W. Grainger, Inc.

HIGH-DENSITY POLYETHYLENE RESIN

The production of HDPE resin is discussed in the section below.

Crude oil production was discussed in the Aluminum can section. The following steps are discussed in the LDPE section and are not repeated here:

- Distillation, desalting, and hydrotreating
- Natural gas production
- Natural gas processing
- Ethylene manufacture
- Postconsumer plastics collection and baling
- Plastics mechanical recycling
- Blow molding polyethylene products

High-Density Polyethylene Production

High-density polyethylene is produced through the polymerization of ethylene. Polyethylene is most commonly manufactured by either a slurry process or a gas phase process. Ethylene and small amounts of co-monomers are continuously fed with a catalyst into a reactor.

In the slurry process, ethylene and co-monomers come into contact with the catalyst, which is suspended in a diluent. Particulates of polyethylene are then formed. After the diluent is removed, the reactor fluff is dried and pelletized (Reference H-1).

In the gas phase process, a transition metal catalyst is introduced into a reactor containing ethylene gas, co-monomer, and a molecular control agent. The ethylene and co-monomer react to produce a polyethylene powder. The ethylene gas is separated from the powder, which is then pelletized (Reference H-1).

HDPE REFERENCES

H-1 **Modern Plastics Encyclopedia.** Volume 68. Number 11. McGraw-Hill. October, 1991.

POLYETHYLENE TEREPHTHALATE (PET) RESIN

The following steps in the production of PET resin are discussed in the sections below:

- Ethylene glycol manufacture
- Mixed xylenes
- Paraxylene extraction
- Methanol manufacture
- Acetic acid manufacture
- Crude terephthalic acid (TPA) manufacture
- Crude TPA purification
    Purified terephthalic acid (PTA) manufacture
    Dimethyl terephthalate (DMT) manufacture
- PET melt phase polymerization
- PET solid phase polymerization
- Blow molding PET products

Crude oil production was discussed in the Aluminum can section. The following steps are discussed in the LDPE section and are not repeated here:

- Distillation, desalting, and hydrotreating
- Natural gas production
- Natural gas processing
- Ethylene manufacture
- Postconsumer plastics collection and baling
- Postconsumer plastic processing (recycling)

Ethylene Glycol Manufacture

In the manufacture of ethylene glycol, the first step is to produce ethylene oxide (EO) from ethylene. Ethylene oxide is manufactured by reacting ethylene feedstock with oxygen in the presence of a silver-based catalyst. The reaction is highly exothermic, producing medium pressure steam as a byproduct. The reactor effluent is mixed with water to effect removal of unreacted gases. The water-rich stream of ethylene oxide is fed to a stripper where the EO is recovered. Ethylene glycol is produced by the hydration (reaction with water) of ethylene oxide.

The waste water from the ethylene oxide plant contains about two percent glycols and is generally routed to the glycols plant for product recovery. Therefore, it is assumed there are zero water pollutants from the ethylene oxide plant.

Mixed Xylenes

The reforming processes are used to convert paraffinic hydrocarbon streams into aromatic compounds such as benzene, toluene, and xylene. Catalytic reforming has virtually replaced thermal reforming operations. Catalytic reforming has many advantages over thermal reforming including the following:

1. Greater production of aromatics
2. More olefin isomerization
3. More selective reforming and fewer end products
4. Operation at a low pressure, hence comparatively lower cost

Catalysts such as platinum, alumina, or silica-alumina and chromium on alumina are used (Reference P-1).

Paraxylene Extraction

To manufacture paraxylene, reformate feedstock rich in xylenes is fractionated to obtain a stream rich in the para-isomer. Further purification is accomplished by heat exchange and refrigeration. The solid paraxylene crystals are separated from the feedstock by centrifugation.

Methanol Manufacture

Methanol is produced from light hydrocarbons using steam reforming and low-pressure synthesis. The feed gas is compressed, preheated, and desulfurized. Then, it is mixed with steam and fed to the catalytic reformer. The synthesis gas from the reformer, containing primarily hydrogen, carbon monoxide, and carbon dioxide, is cooled to remove condensate and reheated to the proper temperature for entry into the process-to-process interchanger. From the interchanger, the feed goes to a multi-bed inter-cooled methanol converter system. Converter effluent is sent to a cooler and catchpot to remove the crude methanol from the gas mixture. Distillation is used to eliminate dissolved gases from the methanol before refining the crude product to obtain the desired grade.

Acetic Acid Manufacture

Several methods are used for producing acetic acid in the U.S. The most common method of production is by liquid phase oxidation of butane or LPG. Outside the U.S., the oxidation of acetaldehyde is the most widely used process. Acetic acid can also be made by reacting carbon monoxide with methanol. Oxidation of butane or LPG is the method examined for this study.

Crude Terephthalic Acid (TPA) Manufacture

Crude terephthalic acid is manufactured primarily by the oxidation of paraxylene in the liquid phase. Liquid paraxylene, acetic acid, and a catalyst, such as manganese or cobalt bromides, are combined as the liquid feed to the oxidizers. The temperature of this exothermic reaction is maintained at about 200° Celsius. The pressure may range from 300 to 400 psi.

Reactor effluents are continuously removed from the reactor and routed to a series of crystallizers, where they are cooled by flashing the liquids. The partially oxidized impurities are more soluble in acetic acid and tend to remain in solution, while crude TPA crystallizes from the liquor.

The slurry from the crystallizers is sent to solid/liquid separators, where crude TPA is recovered in the solids. The liquid portion is distilled and acetic acid, methyl acetate, and water are recovered overhead. Acetic acid is removed from the solution and recycled back to the oxidizer.

Crude TPA Purification

There are two primary methods of crude TPA purification. One is by direct production of fiber grade TPA or purified terephthalic acid (PTA). The other is by conversion of crude TPA to dimethyl terephthalate (DMT). For the basis of this study, it is assumed that 65 percent of crude TPA is purified by production of PTA and 35 percent is purified by conversion to DMT.

Purified Terephthalic Acid (PTA) Manufacture. In the production of fiber grade TPA from crude TPA, the crude acid is dissolved under pressure in water at 225 to 275° C. The solution is hydrogenated in the presence of a catalyst to convert some troublesome intermediates of reaction. The solution is then cooled, causing PTA to crystallize out.

Dimethyl Terephthalate (DMT) Manufacture. Crude TPA is also purified by reaction with methanol to produce DMT at moderate temperature and pressure. No catalyst is required for the reaction. The DMT is brought to fiber grade by crystallization and distillation.

PET Melt Phase Polymerization

PET resin is manufactured by the esterification of PTA with ethylene glycol and loss of water or the trans-esterification of DMT with ethylene glycol and loss of methanol. Both reactions occur at 100 to 150° C in the presence of a catalyst. Bis (2-hydroxyethyl) terephthalate is produced as an intermediate. This intermediate then undergoes polycondensation under vacuum at 10 to 20° C above the melting point of PET (246° C). Ethylene glycol is distilled over, and

PET resin with an I.V. (intrinsic viscosity) of 0.60 to 0.65 is produced. The resulting resin is cooled and pelletized.

PET Solid State Polymerization

The final step in PET resin manufacture is a solid state polymerization process. This step raises the temperature of the solid pellets to just below the melting point in the presence of a driving force to further the polymerization. Solid stating increases the final I.V. to 0.72 to 1.04. It also produces a polymer with low acetaldehyde content.

Blow Molding PET Products

Three stages are required to blow mold a product. In the first, the resin is melted or plasticized. In the second stage, the parison or preform is formed using injection molding. The parison is then cooled to assure good clarity and reheated before the final stage. In the last stage, the mold closes around the parison or preform, pinching off the ends. Then, compressed air expands the plastic against the mold walls and circulating cooling water in the walls cools the plastic. The product is removed from the mold when the plastic is set and excess resin is trimmed off.

PET REFERENCES

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