Lecture #9

Environmentally Responsible Design and Manufacturing

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Jan. 30, 2004

"National Material Metrics for Industrial Ecology," Wernick & Ausubel

all values in Mmt per year (1Mt = 1Gg)

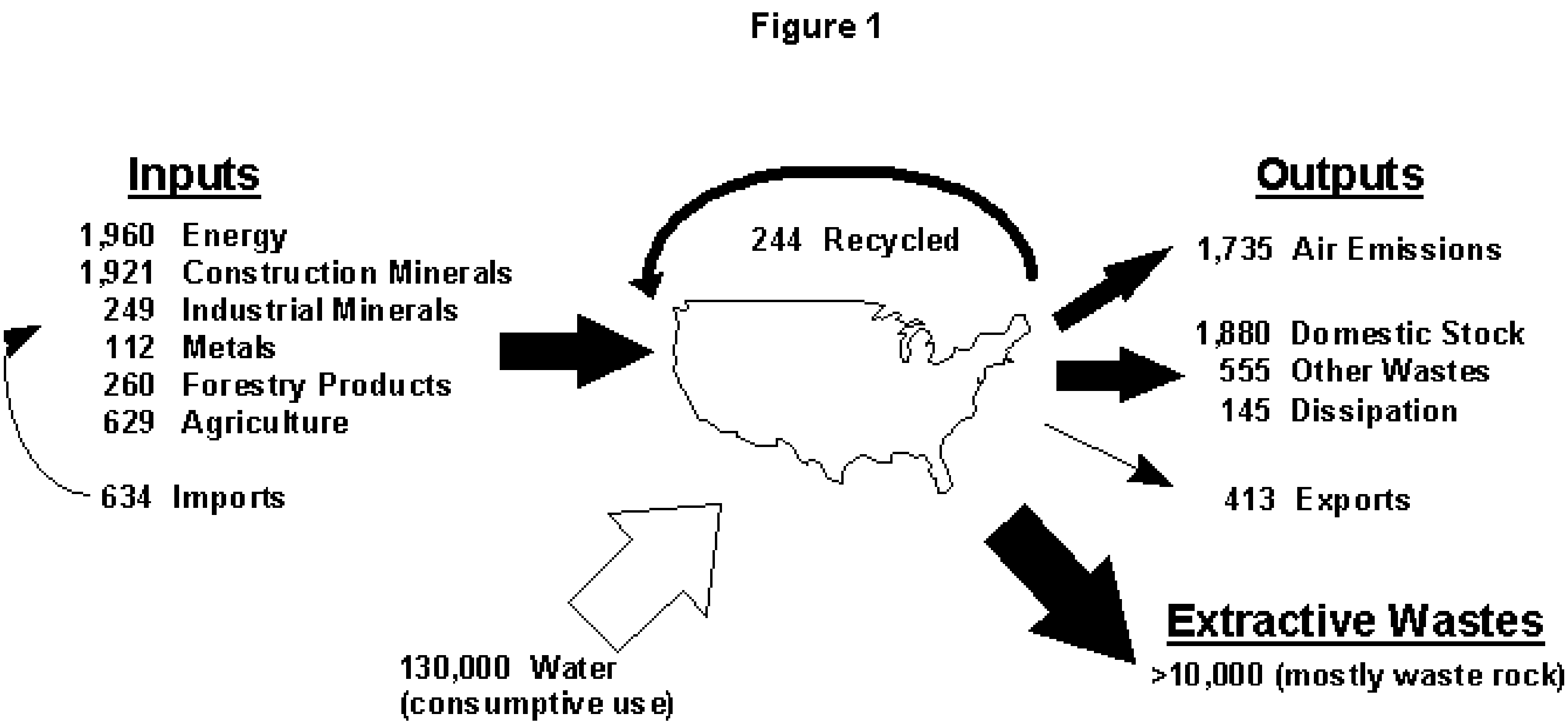
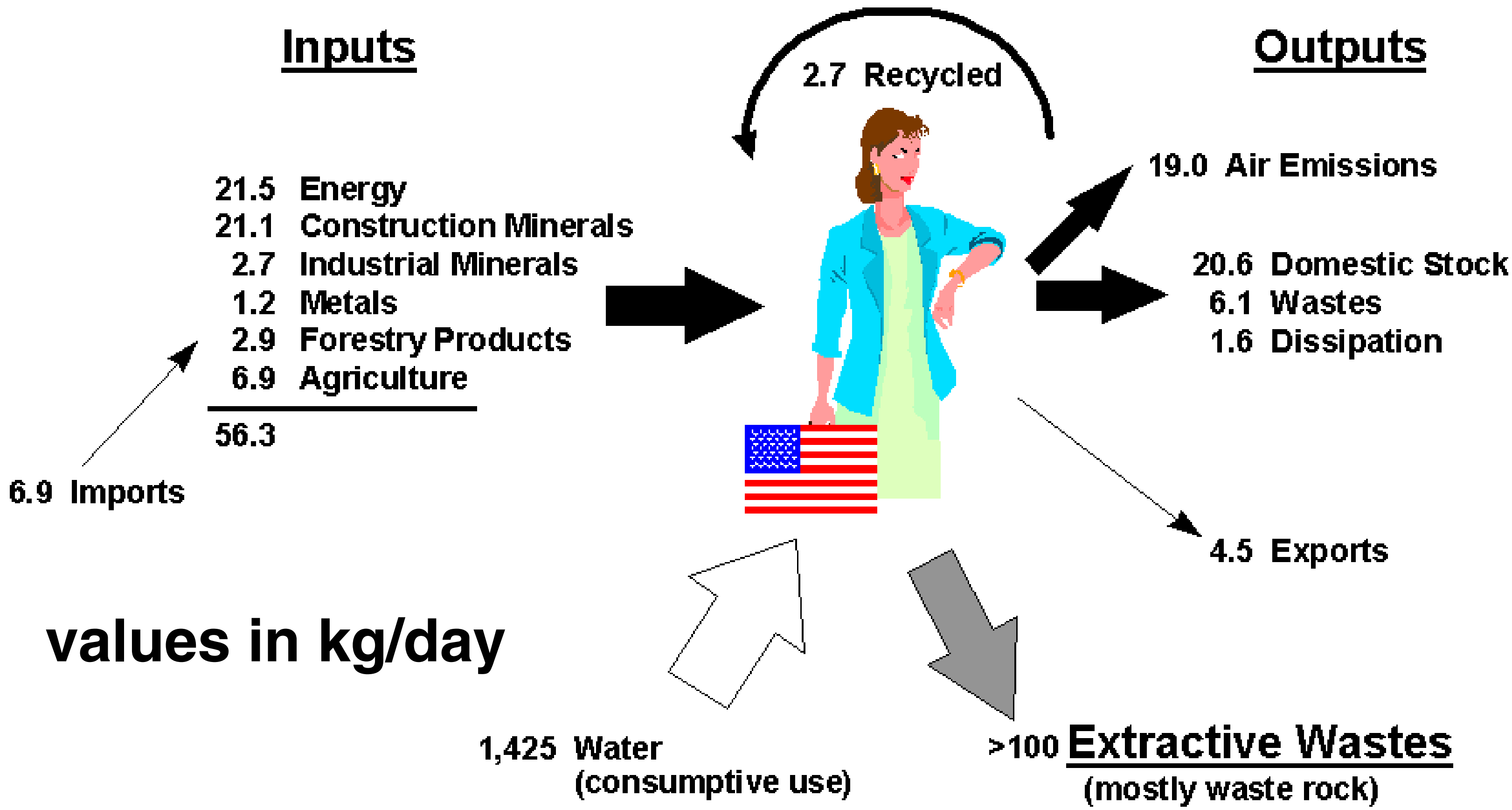


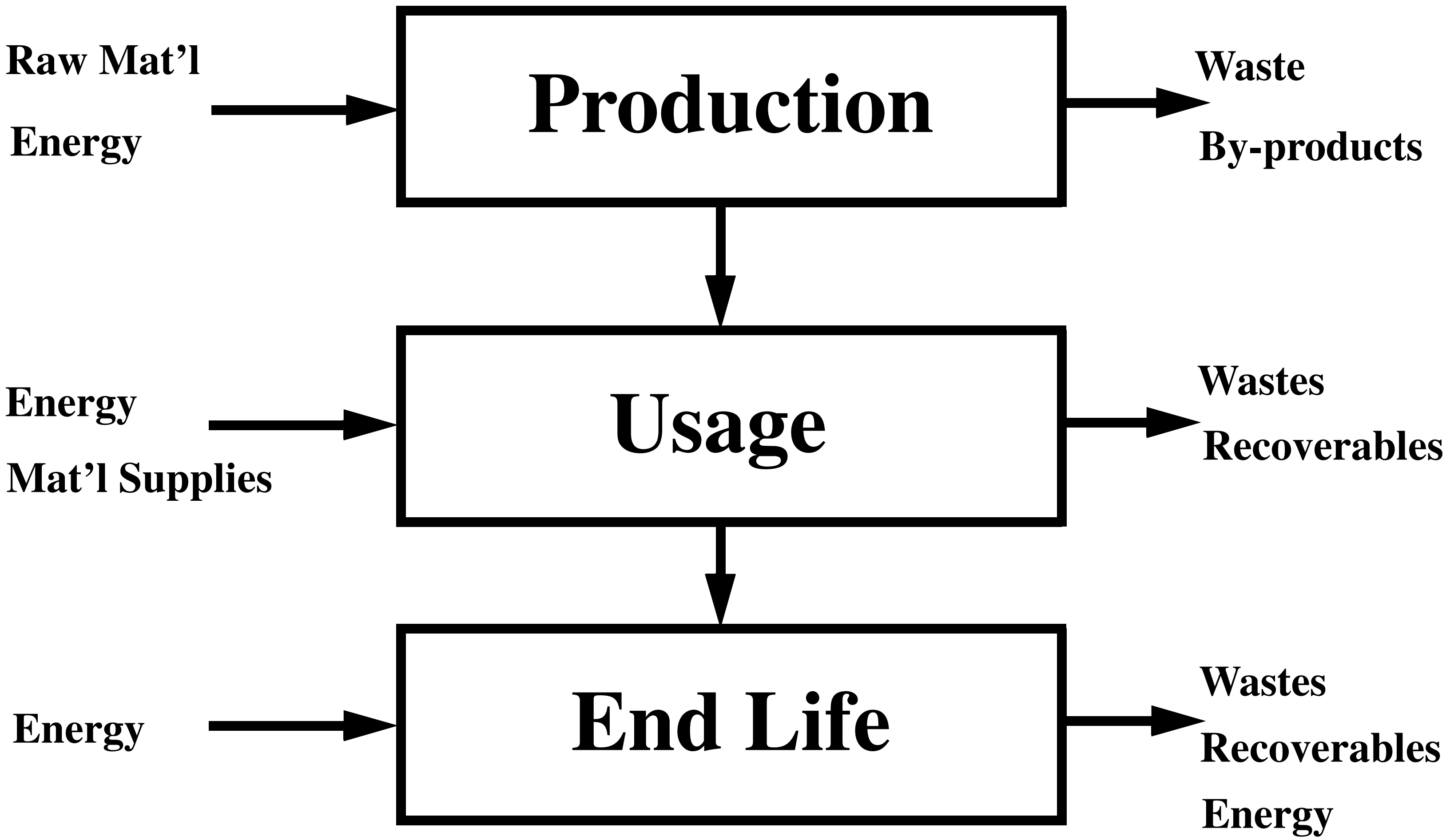
Figure 2


Inputs
Outputs
2.7 Recycled
21.5 Energy
21.1 Construction Minerals
2.7 Industrial Minerals
1.2 Metals
2.9 Forestry Products
6.9 Agriculture
56.3
6.9 Imports
19.0 Air Emissions
20.6 Domestic Stock
6.1 Wastes
1.6 Dissipation
4.5 Exports
values in kg/day
1,425 Water
(consumptive use)
>100 Extractive Wastes
(mostly waste rock)

Material Reserves

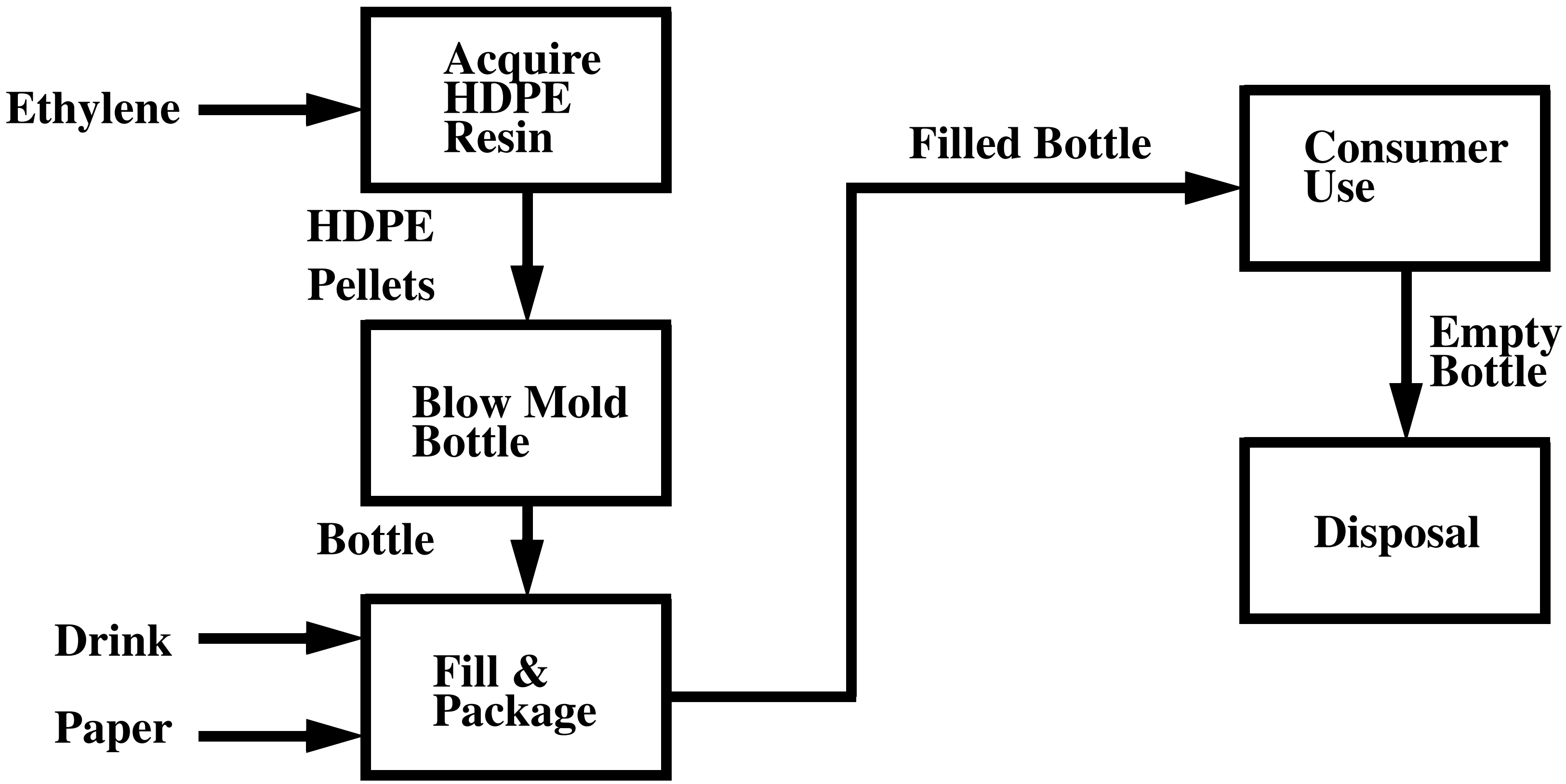
Material	Range of Reserves at Current Price Levels	
Aluminum	3,247.7 - 4,726.4	Tg
Copper	335.7 - 459.9	Tg
Gold	31.1 - 57.5	Gg
Iron	87,724.8 - 186,880.1	Tg
Lead	87.1 - 130.6	Tg
Nickel	41.9 - 90.3	Tg
Tin	4.2 - 9.4	Tg
Titanium	143.3 - 296.6	Tg
Zinc	118.8 - 235.9	Tg

More on Flow Charts



Flow Charts (continued)

On the flowsheet indicate the inputs and the outputs on the arrows. Plastic Drink Bottle.



More on Flow Charts

Once flowsheet is prepared, determine the data needed and where to get it (quality of the data?)

- **number of bottles**
- **makeup of caps**
- **makeup of labels**
- **packing boxes**
- **foils**
- **post use of plastic**
- **energy usage**

More on Materials (courtesy of Prof. Rundman)
** also see the "materials.pdf" document **

Material flow Diagram: Disposal in Landfill

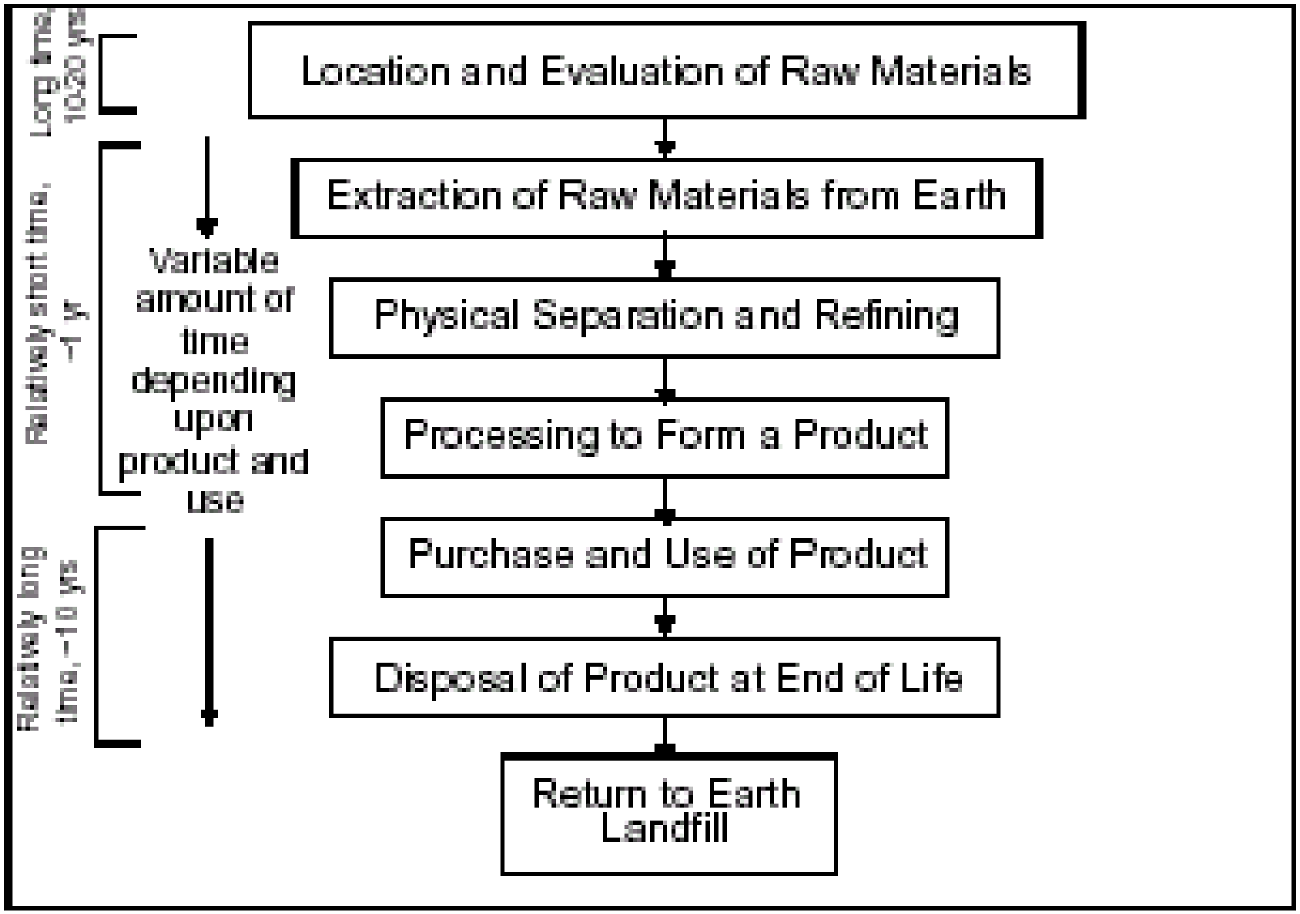


Figure 5-2
Material Flow Diagram: Recycle, Reuse, or Remanufacturing

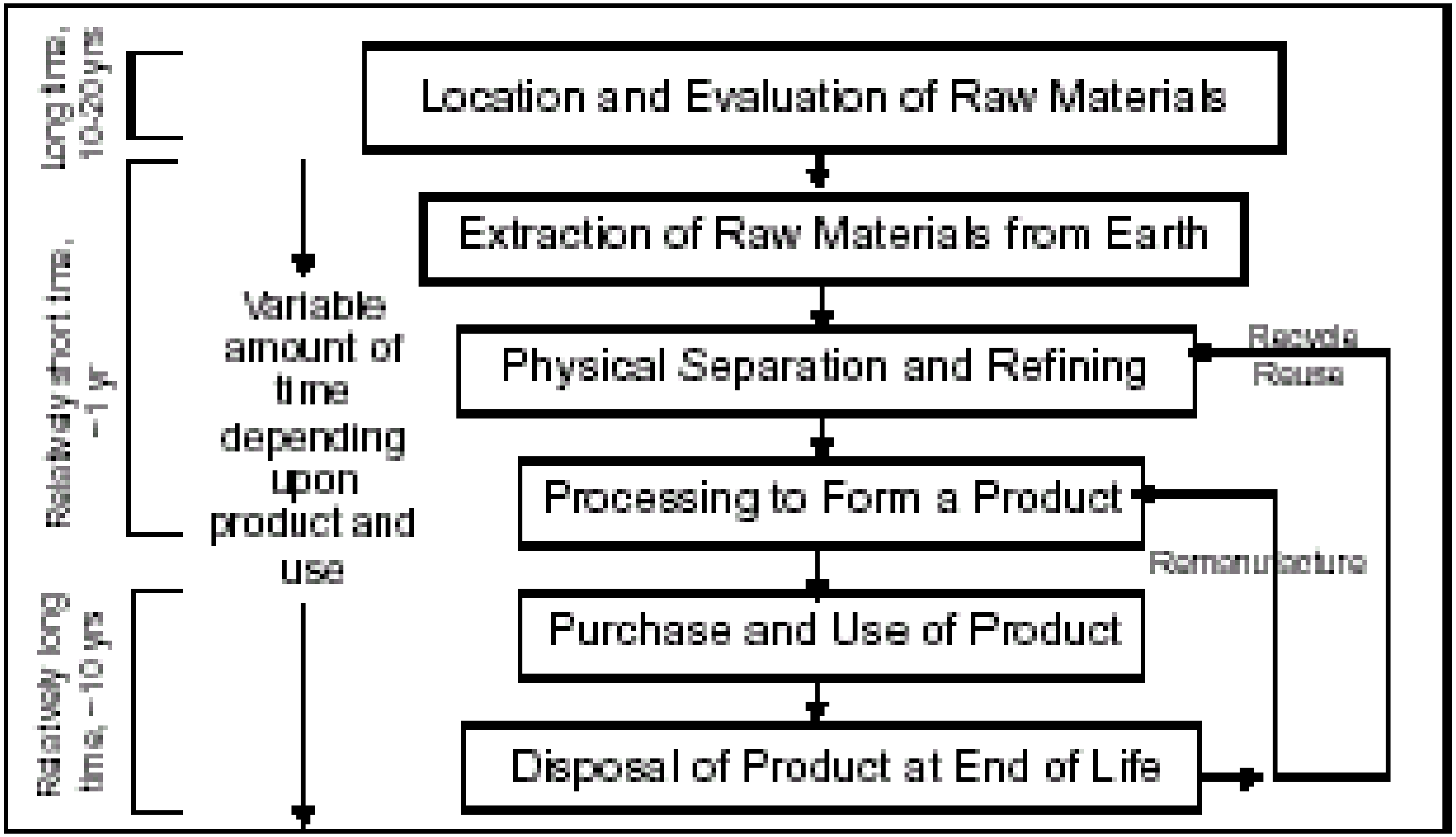


Table 7-2: World and U.S. Production Statistics of Primary Metals and Castings (in millions of metric tons)

Primary Metals*			Castings**		
Metal	World	U.S.	Metal	World	U.S.
Steel (97)	792.8	128.5	Cast Iron and Steel	59.6	11.7
Aluminum (96)	20.7	3.6	Aluminum base	6.37	1.64
Copper (97)	10.8	1.7	Copper base	1.03	0.31
Zinc (97)	7.7	0.45	Zinc base	0.81	0.37
Magnesium (96)	0.34	0.13	Magnesium base	0.05	0.03
Percent Ferrous	95.2	95.6		88	83

*Data from *Metal Statistics* 1998, for the years 1996 & 1997, American Metal Market
**Data from *Modern Casting*, Dec. 1997, American Foundrymen's Society.

Steel Production

- Mining
- Beneficiation -- Concentrating
- Pelletizing
- Reduction (in a Blast Furnace) -- remove oxygen
- Decarburizing (in Basic Oxygen Furnace) -- remove carbon

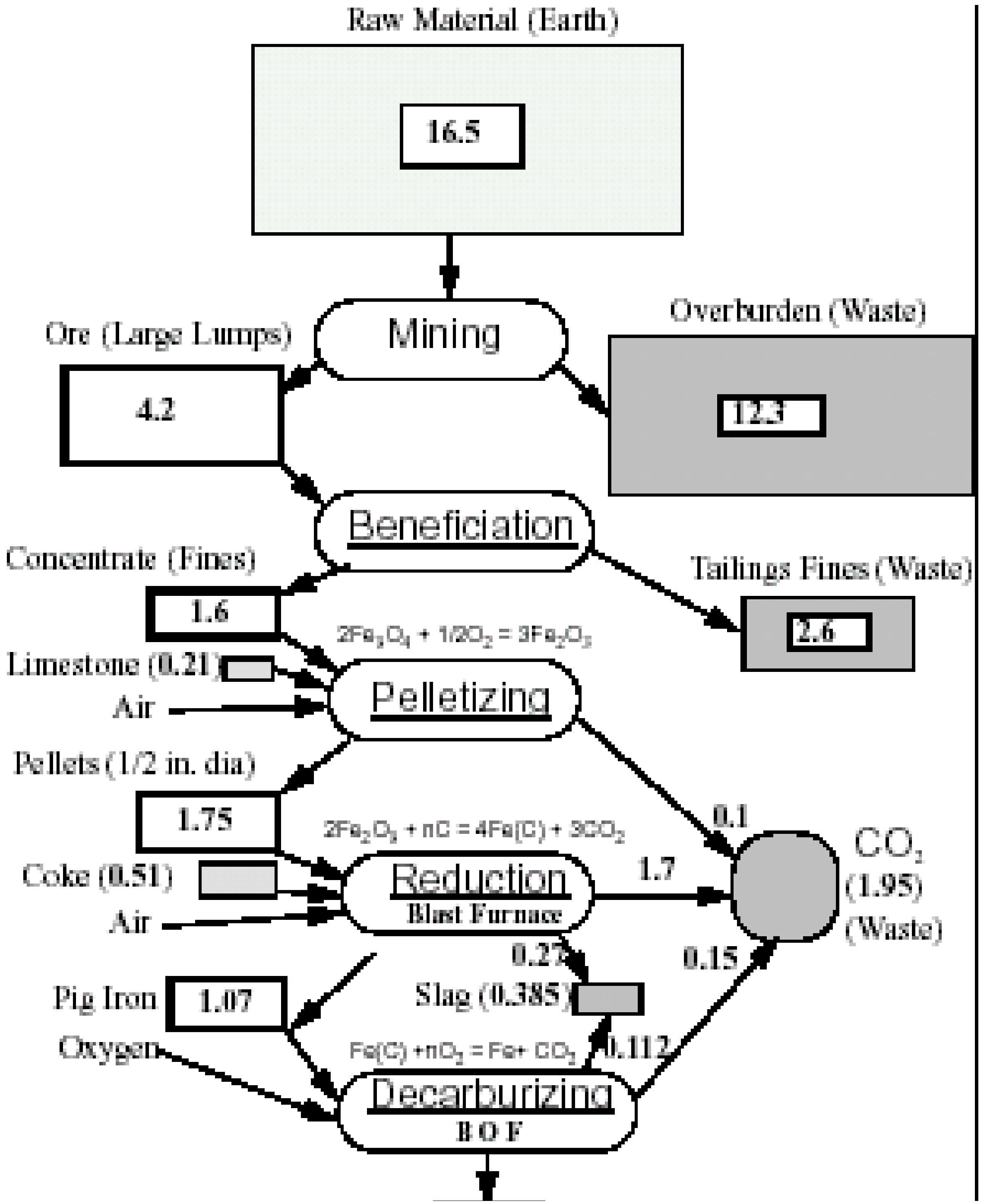
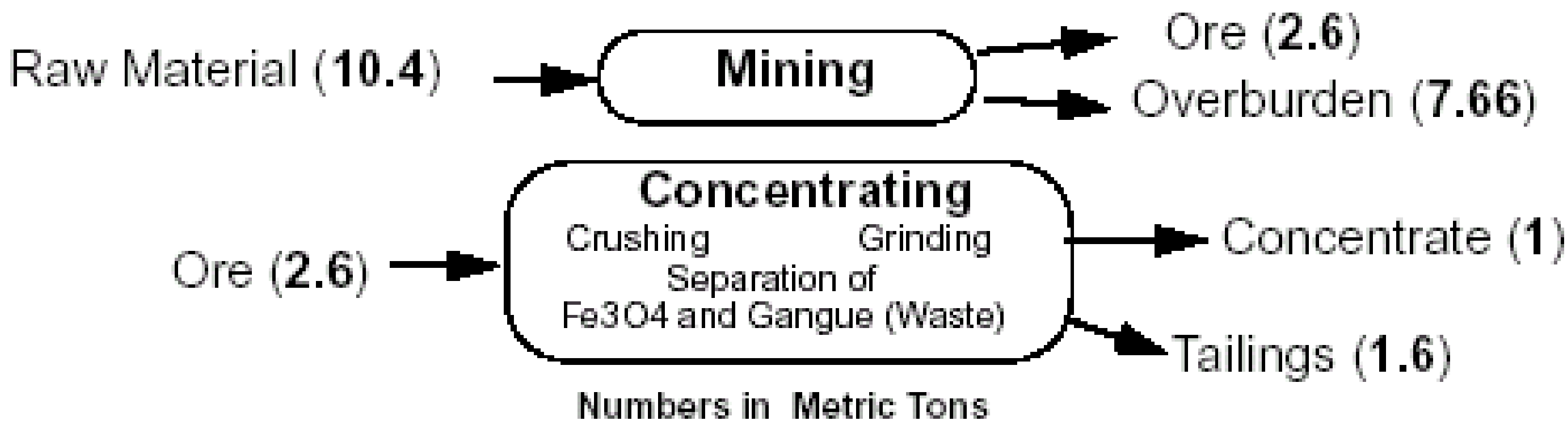

Raw Material (Earth)
16.5
Mining
Ore (Large Lumps)
4.2
Overburden (Waste)
12.3
Beneficiation
Concentrate (Fines)
1.6
Tailings Fines (Waste)
2.6
$2Fe_3O_4 + 1/2O_2 = 3Fe_2O_3$
Limestone (0.21)
Air
Pelletizing
Pellets (1/2 in. dia)
1.75
$2Fe_2O_3 + nC = 4Fe(C) + 3CO_2$
0.1
Coke (0.51)
Air
Reduction
Blast Furnace
1.7
CO_2
(1.95)
(Waste)
0.27
0.15
Pig Iron
1.07
Slag (0.385)
Oxygen
$Fe(C) + nO_2 = Fe + CO_2$
0.112
Decarburizing
BOF

Figure 5-6 Simplified Mining and Beneficiation Mass Balances



Material In [Composition, Wt%]

Ore into concentrator [38.7 Fe_3O_4, 7.15 Fe_2O_3, 54.15 SiO_2]

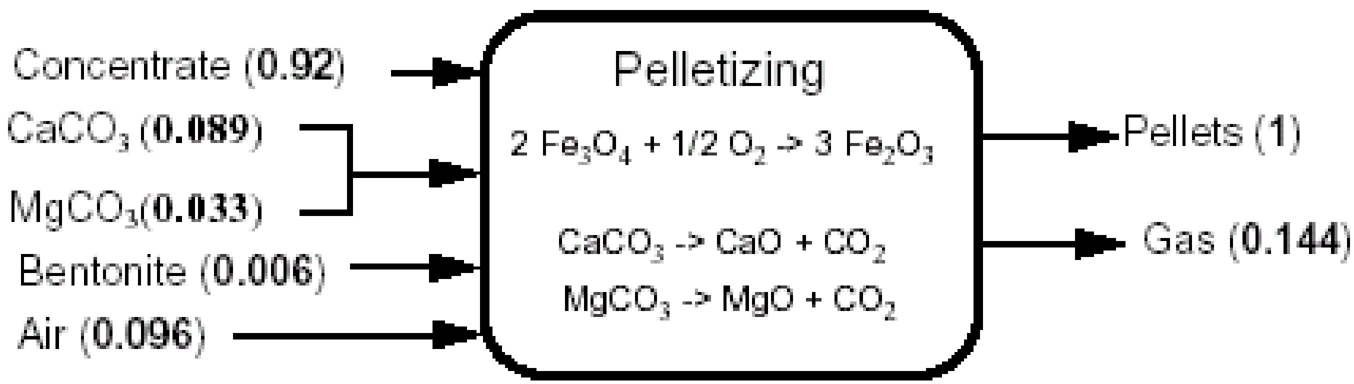
Material Out [Composition, Wt%]

Concentrated Ore [91.16 Fe_3O_4, 8.84 SiO_2]

Tailings [6.0 Fe_3O_4, 11.6 Fe_2O_3, 82.4 SiO_2]

Figure 5- 7 Simplified Pelletizing Materials Balance

Requirements for Fluxed Pellets
(Numbers in metric tons)



Materials In [Composition, Wt %]

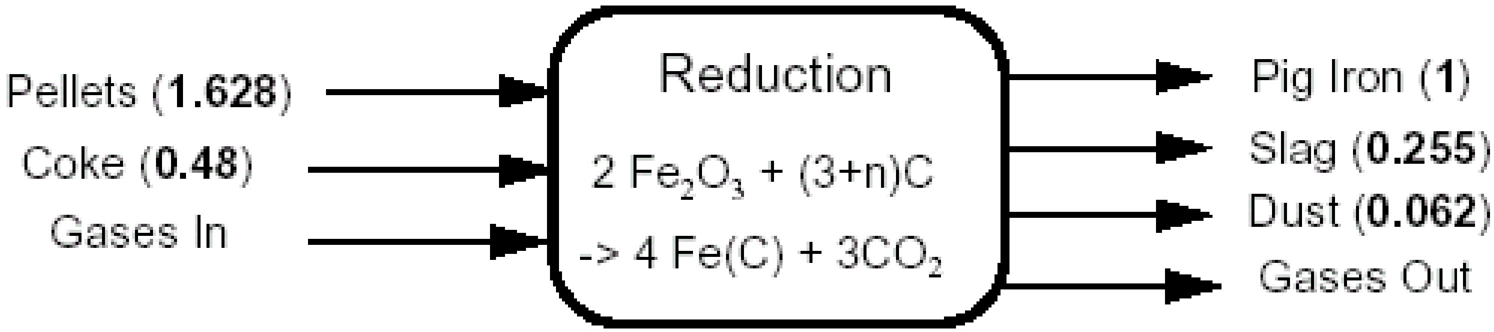
Iron Ore Concentrate [91.2 Fe_2O_3, 8.8SiO_2]
Flux [72 $CaCO_3$, 28 $MgCO_3$]
Air [23.3 O_2, 76.7 N_2]
Bentonite [$(OH)_4Al_4Si_8O_{20}$]

Materials Out [Composition, Wt %]

Pellets [87.3 Fe_2O_3, 5.8 SiO_2, 5CaO, 1.6 MgO, 0.3 Al_2O_3]
Gas [CO_2, N_2]

Figure 5- 8 Simplified Blast Furnace Materials Balance

Production of One Metric Ton of Pig Iron



Materials In [Composition, Wt %]

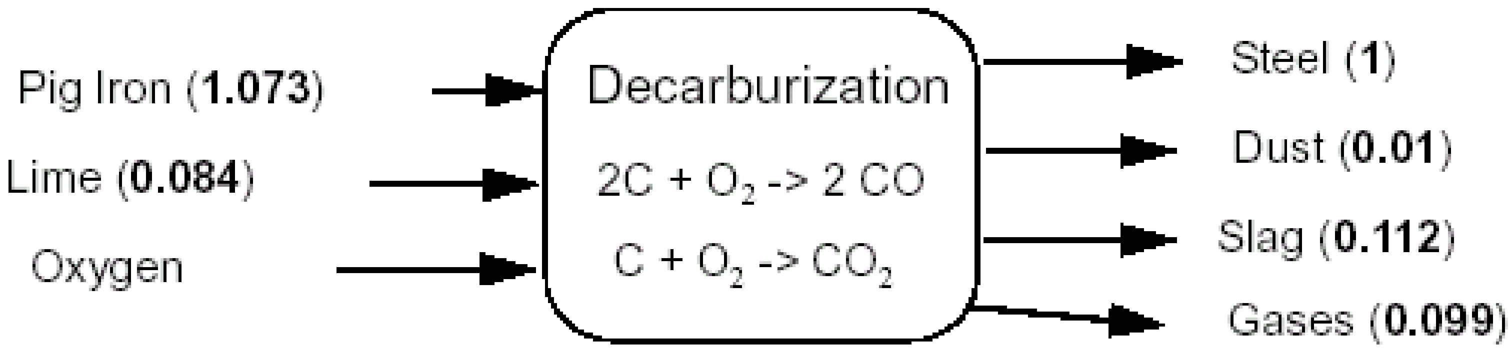
Pellets [87.3 Fe_2O_3, 5.8 SiO_2, 5 Cao, 1.6 MgO, 0.3 Al_2O_3]
Coke [90 C, 6 SiO_2, 3.5 Al_2O_3, 0.5 CaO]
Gases In [O_2, H_2, CH_4, C_2H_6, CO, CO_2]

Materials Out [Composition, Wt %]

Pig Iron [95 Fe, 4.2 C, 0.8 Si]
Slag [48.3 SiO_2, 33 CaO, 8.4 Al_2O_3, 10.3 MgO]
Dust [Fe_2O_3]
Gases Out [H_2O, CO, CO_2]

Figure 5- 9 Simplified (B O F) Materials Balance

Production of One Metric Ton of Steel



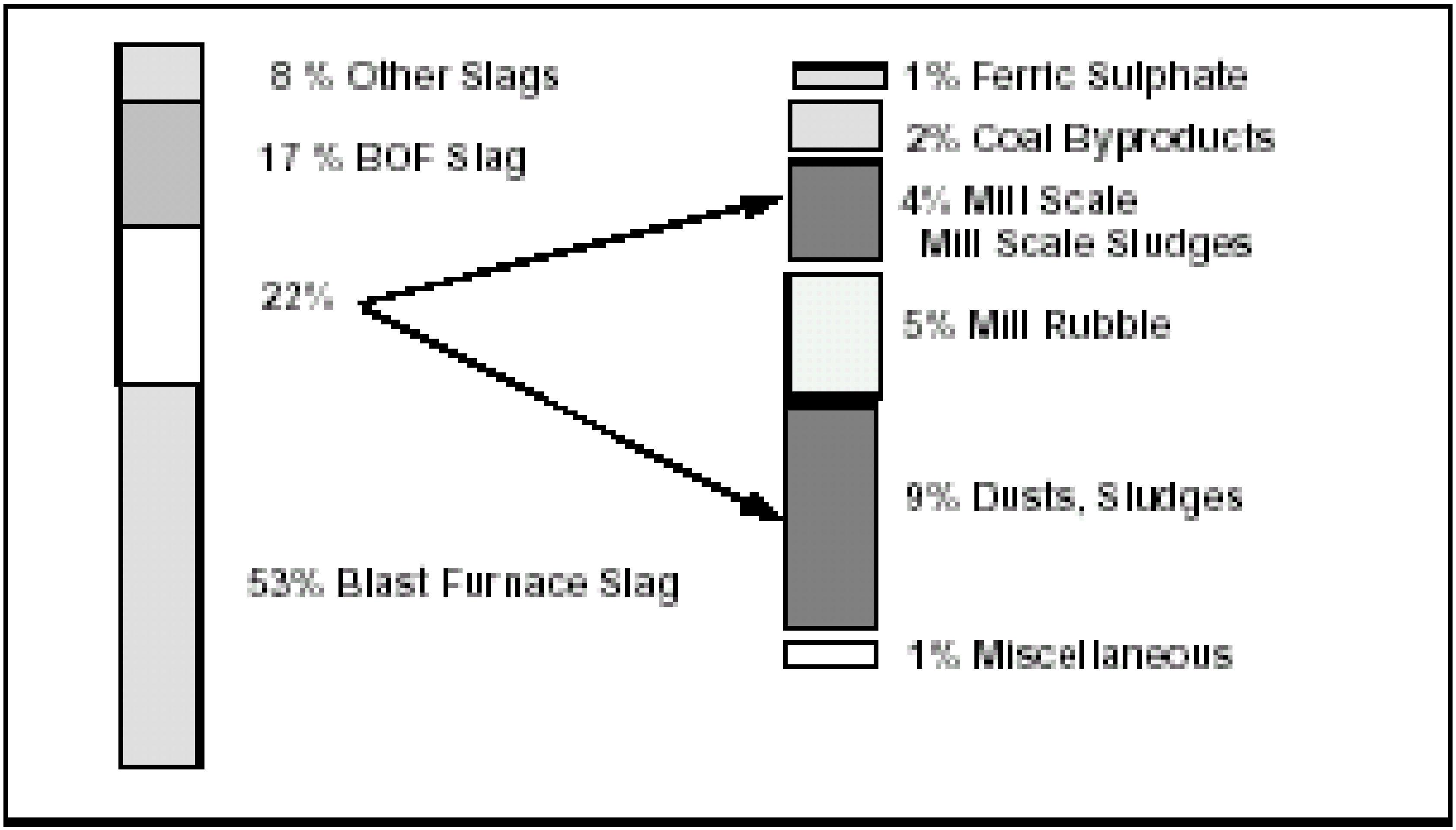
Material In [Composition, Wt %]

Pig Iron [95 Fe, 4.2 C, 0.8 Si]
Lime [100CaO]
Oxygen [100O_2]

Material Out [Composition, Wt %]

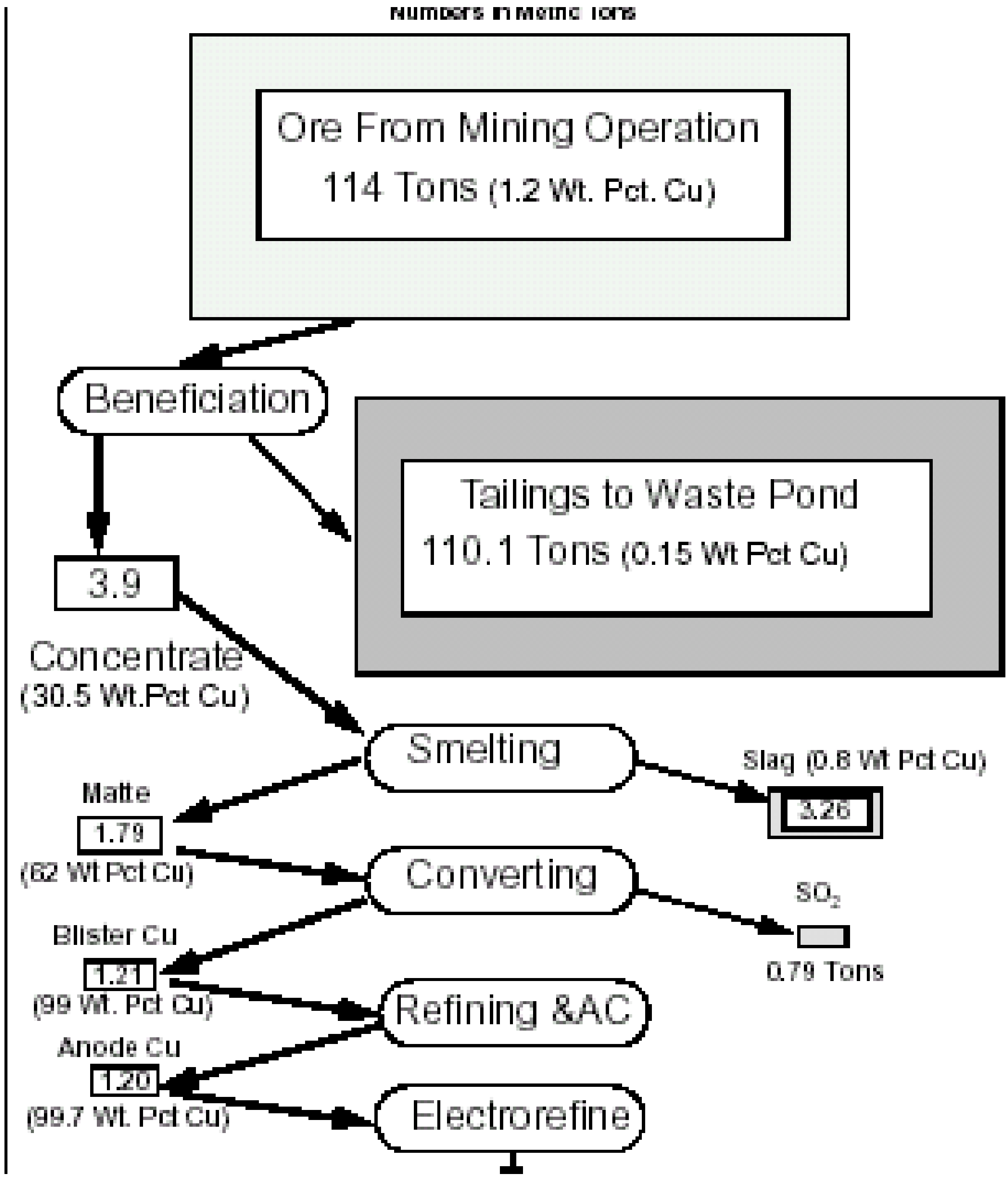
Steel [99.3 Fe, 0.4 C, 0.3 Si]
Slag [25 Fe_2O_3, 75 CaO]
Dust [100Fe_2O_3]
Gases [90 CO, 10 CO_2]

Breakdown of the Waste Materials by Location in Steel Production

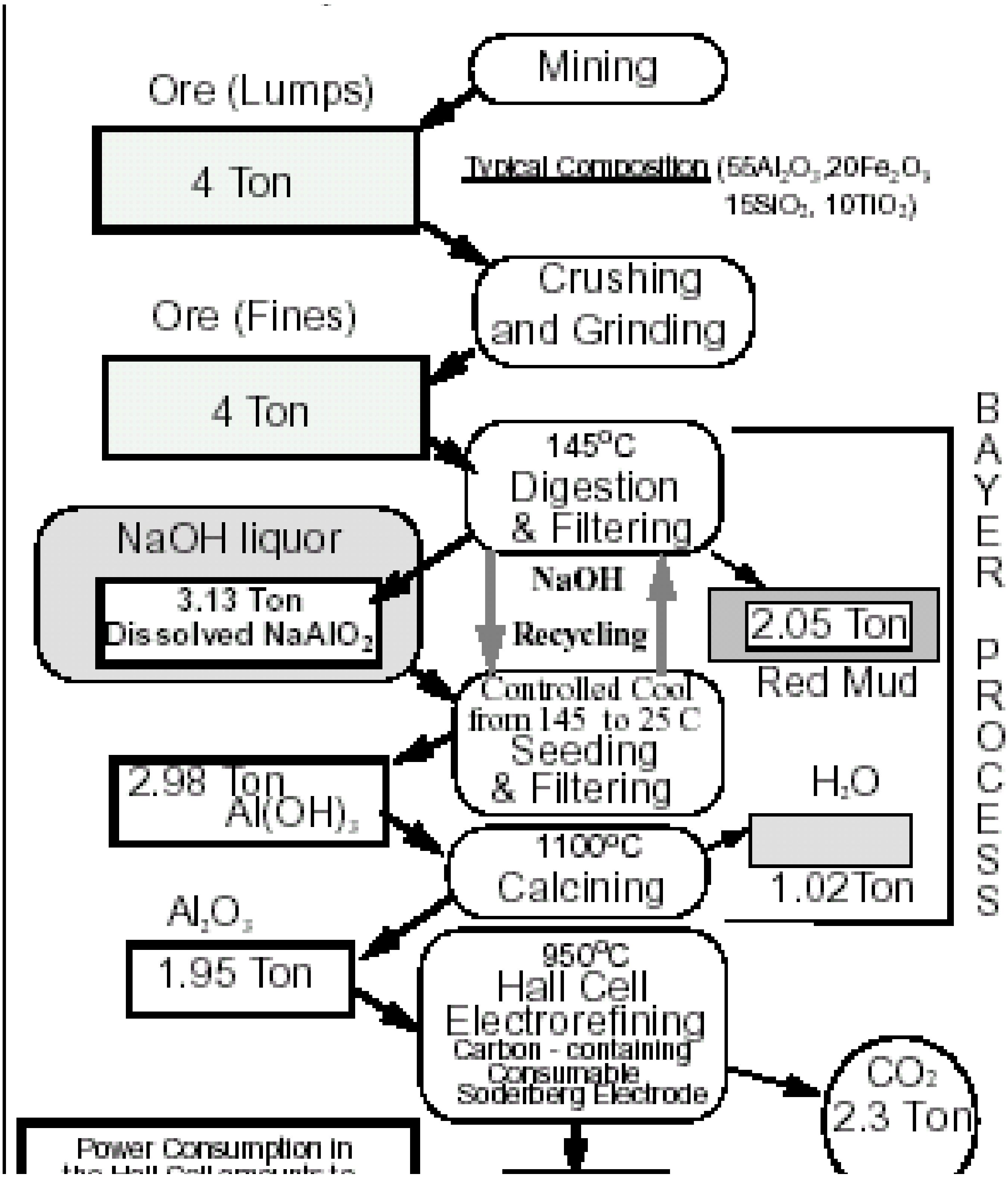


Copper Production

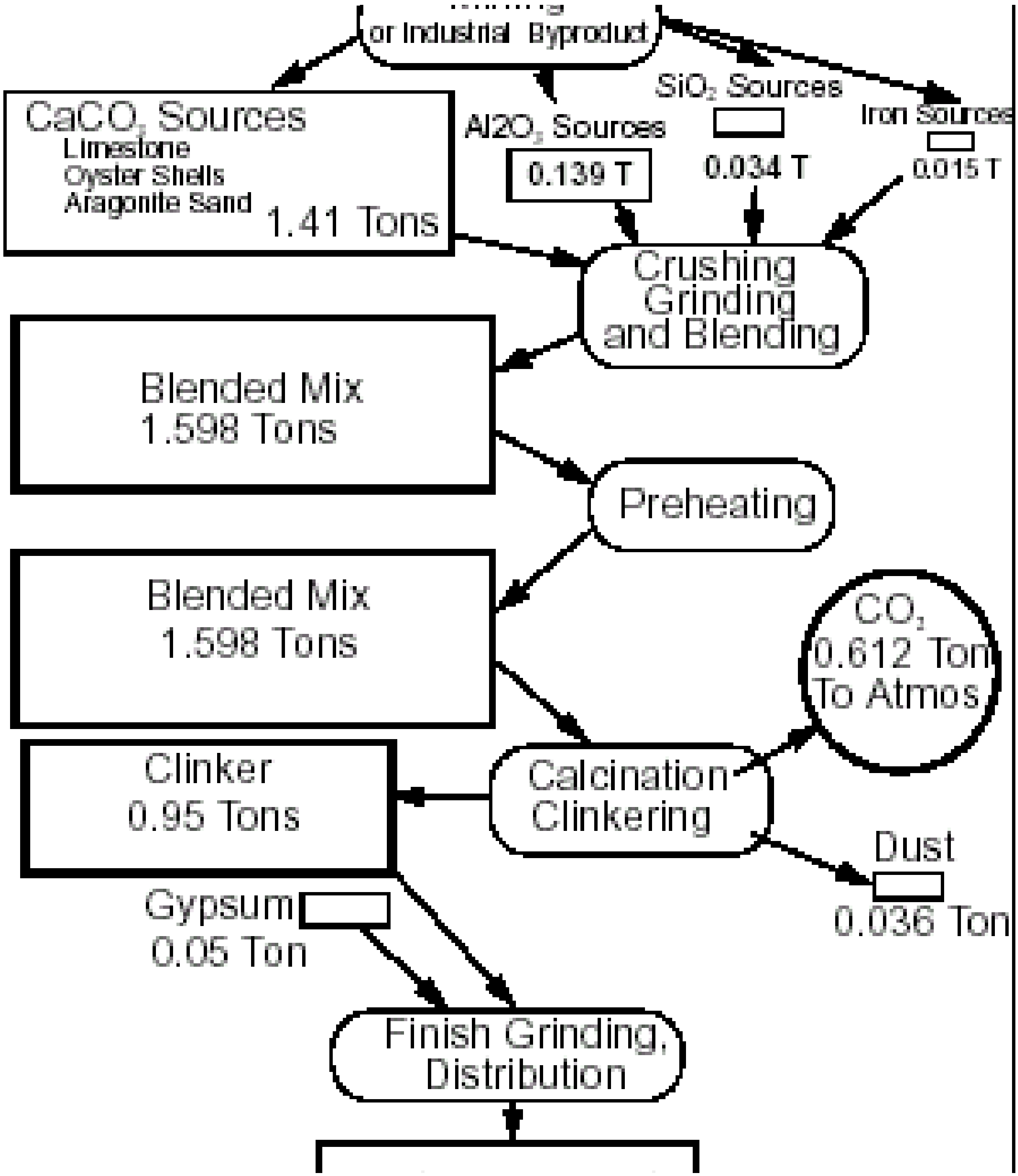
1. Mining - Removal of Ore in Seams (1.2 wt Pct Cu) Leaving Waste Rock Underground
2. Beneficiation - Production of Concentrate containing 30.5 wt. pct Copper. Discard Waste Rock in Tailings Pond
3. Smelting - Production of Matte (62.5 wt pct Copper) in a coal-fired reverberatory furnace. Discard Slag to Dump and SO2 Gas into the Atmosphere
4. Converting - Production of Blister Copper (99 wt. pct Copper) with release of SO2 gas to Atmosphere and Slag Recycled to the Reverberatory Smelting Furnace
5. Fire Refining - Deoxidizing the Blister Copper to Produce Anode Copper (99.7 wt. Pct Copper)
6. Anode Casting and Electro-refining - Produce Anode Shape, Electro-refine to Produce 99.997 Wt. Pct Copper. Send Slimes to Recover Precious Metals (Ag, Au, Pt, etc.)



Numbers in Metric Tons
Ore From Mining Operation
114 Tons (1.2 Wt. Pct. Cu)
Beneficiation
Tailings to Waste Pond
110.1 Tons (0.15 Wt Pct Cu)
3.9
Concentrate
(30.5 Wt.Pct Cu)
Smelting
Slag (0.8 Wt Pct Cu)
3.26
Matte
1.79
(62 Wt Pct Cu)
Converting
SO2
0.79 Tons
Blister Cu
1.21
(99 Wt. Pct Cu)
Refining &AC
Anode Cu
1.20
(99.7 Wt. Pct Cu)
Electrorefine

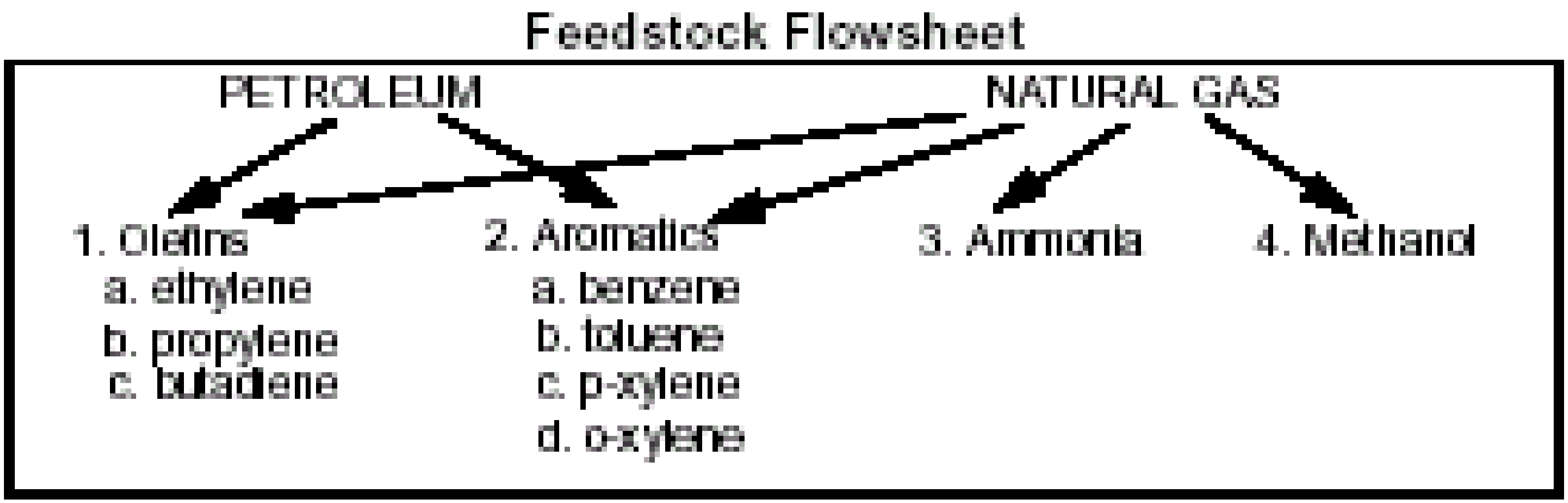


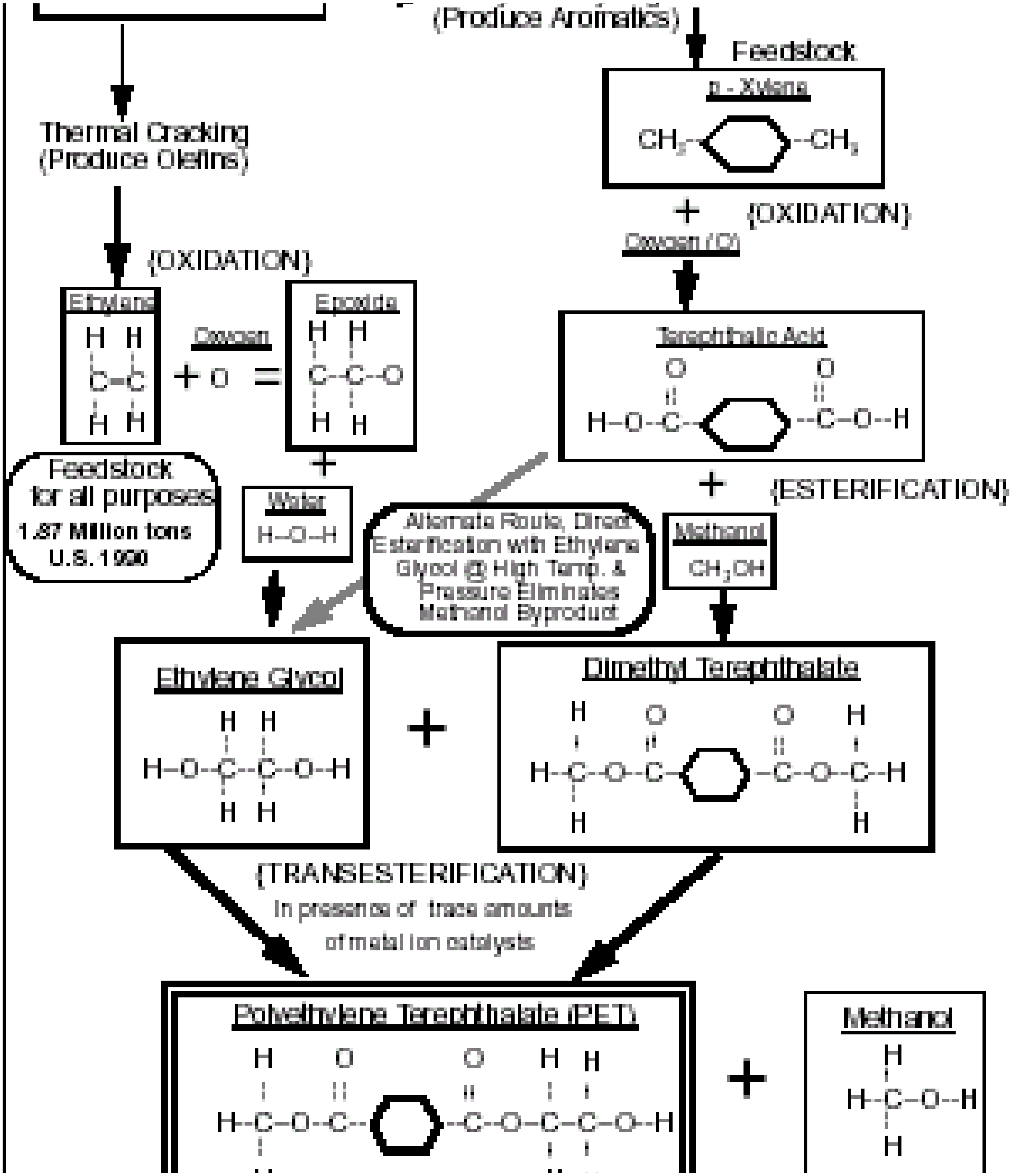
Mining
Ore (Lumps)
4 Ton
Typical Composition (55Al2O3,20Fe2O3 15SiO2, 10TiO2)
Crushing and Grinding
Ore (Fines)
4 Ton
145°C Digestion & Filtering
NaOH liquor
3.13 Ton Dissolved NaAlO2
NaOH Recycling
2.05 Ton
Red Mud
Controlled Cool from 145 to 25 C Seeding & Filtering
2.98 Ton Al(OH)3
H2O
1100°C Calcining
1.02Ton
BAYER PROCESS
Al2O3
1.95 Ton
950°C Hall Cell Electrorefining Carbon - containing Consumable Soderberg Electrode
CO2 2.3 Ton
Power Consumption in



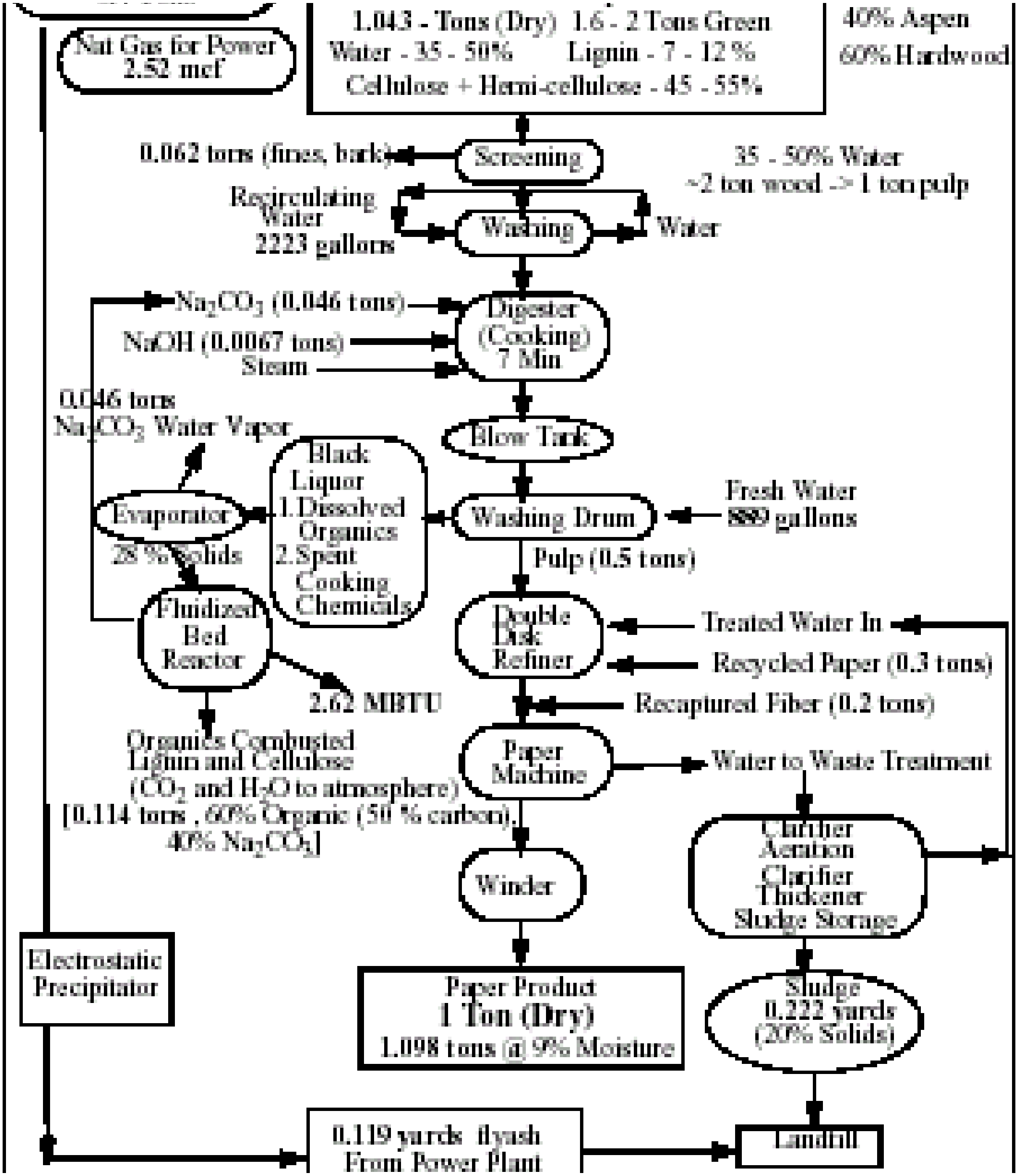
or Industrial Byproduct
$CaCO_3$ Sources
Limestone
Oyster Shells
Aragonite Sand
1.41 Tons
$Al2O_3$ Sources
0.139 T
SiO_2 Sources
0.034 T
Iron Sources
0.015 T
Crushing Grinding and Blending
Blended Mix 1.598 Tons
Preheating
Blended Mix 1.598 Tons
CO_2 0.612 Ton To Atmos
Clinker 0.95 Tons
Calcination Clinkering
Dust
0.036 Ton
Gypsum
0.05 Ton
Finish Grinding, Distribution

Production of Plastics





(Produce Aromatics)
Feedstock
p - Xylene
Thermal Cracking
(Produce Olefins)
{OXIDATION}
Oxygen (O)
{OXIDATION}
Ethylene
Oxygen
Epoxide
Terephthalic Acid
Feedstock for all purposes
1.87 Million tons
U.S. 1990
Water
{ESTERIFICATION}
Alternate Route, Direct Esterification with Ethylene Glycol @ High Temp. & Pressure Eliminates Methanol Byproduct
Methanol
Ethylene Glycol
Dimethyl Terephthalate
{TRANSESTERIFICATION}
In presence of trace amounts of metal ion catalysts
Polyethylene Terephthalate (PET)
Methanol


1.043 - Tons (Dry) 1.6 - 2 Tons Green
Water - 35 - 50% Lignin - 7 - 12 %
Cellulose + Hemi-cellulose - 45 - 55%
40% Aspen
60% Hardwood
Nat Gas for Power
2.52 mcf
0.062 tons (fines, bark)
Screening
35 - 50% Water
~2 ton wood -> 1 ton pulp
Recirculating
Water
2223 gallons
Washing
Water
Na_2CO_3 (0.046 tons)
NaOH (0.0067 tons)
Steam
Digester
(Cooking)
7 Min
0.046 tons
Na_2CO_3 Water Vapor
Blow Tank
Black
Liquor
1.Dissolved
Organics
2.Spent
Cooking
Chemicals
Evaporator
28 % Solids
Washing Drum
Fresh Water
889 gallons
Pulp (0.5 tons)
Fluidized
Bed
Reactor
Double
Disk
Refiner
Treated Water In
Recycled Paper (0.3 tons)
2.62 MBTU
Recaptured Fiber (0.2 tons)
Organics Combusted
Lignin and Cellulose
(CO_2 and H_2O to atmosphere)
[0.114 tons , 60% Organic (50 % carbon),
40% Na_2CO_3]
Paper
Machine
Water to Waste Treatment
Clarifier
Aeration
Clarifier
Thickener
Sludge Storage
Winder
Electrostatic
Precipitator
Paper Product
1 Ton (Dry)
1.098 tons @ 9% Moisture
Sludge
0.222 yards
(20% Solids)
0.119 yards flyash
From Power Plant
Landfill