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ENVIRONMENTAL IMPACTS

OF VIRGIN AND RECYCLED STEEL AND ALUMINUM

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ABSTRACT

This study has analyzed the environmental impacts which result from the production of selected products which use virgin materials and various amounts of recycled ferrous metals and aluminum. Determinations were made of the material, water, and energy requirements of all stages of virgin and waste materials acquisition, transportation and processing, as well as secondary effects such as energy use. Also determined were the outputs at each stage including solid, airborne and waterborne waste that are generated, assuming EPA Air Standards for FY 1975 and Water Standards for FY 1977. The virgin and waste materials systems were analyzed up to the processing point at which materials are comparable. Estimates were also made of the dollar costs to industry to meet 1975 Air Standards and 1977 Water Standards.

Nine systems which produce carbon steel from virgin materials and/or obsolete scrap were examined. The environmental impact analysis for these systems showed that steel production from virgin materials had the highest environmental impacts of these systems. In addition, six systems which produce aluminum from virgin materials or obsolete scrap were examined. The environmental impact analysis for these systems show that aluminum production from virgin materials had the highest environmental impacts of these systems.

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SECTION I

SUMMARY

This study has analyzed the environmental impacts which result from the production of selected products which use virgin materials and various amounts of recycled ferrous metals and aluminum. Determinations were made of the material, water, and energy requirements of all stages of virgin and waste materials acquisition, transportation and processing, as well as secondary effects such as energy use. Also determined were the outputs at each stage including solid, airborne and waterborne waste that are generated, assuming EPA Air Standards for FY 1975 and Water Standards for FY 1977. The virgin and wastes materials systems were analyzed up to the processing point at which materials are comparable. Estimates were also made of the dollar costs to industry to meet 1975 Air Standards and 1977 Water Standards.

Steel

Nine systems which produce carbon steel from virgin materials and/or obsolete scrap were examined in this study. These systems are the following:

F1 Virgin Materials in the Basic Oxygen Furnace
F2 Virgin Materials and Obsolete Scrap from Auto Shredders in the BOF
F3 Virgin Materials and Obsolete Scrap from Auto Balers in the BOF
F4 Virgin Materials and Obsolete Scrap from Municipal Solid Waste in the BOF
F5 Virgin Materials and Obsolete Scrap from Separated Steel Cans in the BOF
F6 Obsolete Scrap from Auto Shredders in the Electric Furnace
F7 Obsolete Scrap from Auto Balers in the Electric Furnace
F8 Obsolete Scrap from Municipal Solid Waste in the Electric Furnace
F9 Obsolete Scrap from Separated Steel Cans in the Electric Furnace

The total environmental impacts for these systems are presented in Table 35. A comparison of the impacts of the systems revealed that System F1 which consumes virgin materials in the B.O.F. has the highest environmental impacts. The impacts from Systems F2, F3, F4, and F5 which consume virgin materials and obsolete scrap in B.O.F. are slightly less than those from System F1. However, Systems F2, F3, F4, and F5 use only a 10% obsolete scrap charge. Therefore, if the impacts from the

resource recovery processes were zero, only a slight change would be expected between System F1 and Systems F2, F3, F4, and F5. It was also determined that there was very little difference in the impacts between Systems F2, F3, F4 and F5.

Systems F6, F7, F8 and F9 which consume obsolete scrap in the electric furnace had the lowest environmental impacts of all the steel systems studied. The greatest changes were seen in raw material consumption, water use, energy consumption and solid wastes. System F6 had the minimum environmental impacts of systems which consume obsolete scrap in the electric furnace while System F9 had the greatest. The impacts of these systems were determined largely by the amount of energy consumed.

Since 1975 Air Standards and 1977 Water Standards were assumed to be met when air and water wastes were reported, the direct costs to the steel industry in meeting these standards were determined for the systems studied. The control costs for System F1 which consumes virgin materials in the B.O.F. are $5.58-6.46 per metric ton of steel. Pollution control costs for Systems F2, F3, F4 and F5 which consume virgin materials and obsolete scrap in the B.O.F. are $4.97-5.79 per metric ton of steel. Systems F6, F7, F8 and F9 which consume obsolete scrap in the electric furnace have the lowest control costs, $2.30 per metric ton of steel.

Aluminum

Six systems which produce wrought and/or cast aluminum from virgin materials or obsolete scrap were examined in this study. These systems are the following:

- A1 Aluminum Production from Virgin Materials
- A2 Wrought Aluminum Production Using Obsolete Scrap from Municipal Solid Waste
- A3 Wrought Aluminum Production Using Obsolete Scrap from Separated Aluminum Cans
- A4 Cast Aluminum Production Using Obsolete Scrap from Municipal Solid Waste
- A5 Cast Aluminum Production Using Obsolete Scrap from Auto Shredders
- A6 Cast Aluminum Production Using Obsolete Scrap from Auto Balers

The total environmental impacts for these systems are presented in Table 51. A comparison of the impacts of these systems revealed that System A1 which consumes virgin materials has the highest environmental impacts. Systems A2 and A3 which produce wrought aluminum products from can scrap have the lowest environmental impacts, with System A3 slightly superior to System A2.

Systems A5 and A6 which produce cast aluminum from auto scrap have environmental impacts which are slightly greater than Systems A2 and A3 but much less than System A1.

System A4 which produces cast aluminum using scrap from municipal solid waste has environmental impacts which are much greater than Systems A2, A3, A5 and A6, but somewhat less than System A1. Compared with System A1, System A4 greatly reduced raw materials consumption, water discharged, energy consumption, solid wastes and air emissions. However, System A4 produces considerable chloride emissions and water pollutants.

Costs to the aluminum industry in meeting 1975 Air Standards and 1977 Water Standards were determined. Pollution control costs for System A1 which produces aluminum from virgin materials are $10.91 to 15.33 per metric ton of aluminum. Systems A2, A3, A4 and A5 which produce aluminum from scrap materials have costs for pollution control which range from $4.98 to 10.10 per metric ton of aluminum. Systems such as A2 and A3 which use a minimum amount of chlorine would be in the low end of the range while System A4 which uses a large amount of chlorine would be in the high end of the range.

General

The assumption that 1975 Air Standards and 1977 Water Standards would be met had a great effect on the results of this study. These standards are presumably set to stop environmental degradation. In most instances, these standards are directly related to the amount of product produced. Therefore, processes which have more environmental impacts than others when uncontrolled have similar impacts when controlled. In this study, the specific effects of processes were less noticeable than the secondary environmental impacts of energy use. All energy used in this study came directly or indirectly from fossil fuels. It was the environmental impacts which result from the extraction, processing, and combustion of these fuels which became dominant factors in this study.

The outstanding exception to this situation was System A4 which produced cast aluminum using scrap from municipal solid waste. This system requires the use of a large amount of chlorine by secondary smelters to remove magnesium. Standards for secondary aluminum smelters are written in terms of the amount of chlorine used, not in terms of the amount of product produced. Therefore, greater chlorine use resulted in more chlorine emissions and water pollutants. These pollutants accounted for a large percentage of the impacts from System A4.

SECTION II

INTRODUCTION

In recent years, the American public has become increasingly aware that it can no longer continue to be a throwaway society. The fact that our natural resources are limited has caused widespread interest in recycling of post consumer solid wastes. Although recycling of solid wastes has been practiced in varying degrees throughout man's history, it is only recently that attempts have been made to make recycling a national policy. However, before recycling can be accepted as a national goal, it must be determined if recycling actually benefits society.

Previous studies have only looked at parts of the total problem. For example, they have only looked at savings in raw materials or the removal of solid wastes from the environment. They have not looked at the total picture. Our basic concept, however, is to use a total systems approach to analyze the environmental impacts of producing selected products utilizing virgin materials and various amounts of recycled ferrous metals and aluminum. Determinations are made of the material, water, and energy requirements of all stages of virgin and waste materials acquisition, transportation, and processing. Also determined are the outputs at each stage including solid, airborne, and waterborne wastes that are generated, assuming EPA Air Standards for FY 1975 and Water Standards for FY 1977. The virgin and waste materials system are analyzed up to the processing point at which materials are comparable.

The environmental impacts are examined for cases in which the selected products are made solely from virgin materials and from various amounts of virgin and waste materials. Consideration is given to air and water pollutants, solid wastes, and the amounts of material, energy, and water consumed. Estimates are made of the dollar costs of controlling the environmental impacts.

The specific products considered in this study are carbon steel manufactured from either virgin and scrap materials in the Basic Oxygen Furnace (BOF) or scrap materials in an Electric Furnace and cast and wrought aluminum manufactured from either virgin materials by primary smelters using the Bayer-Hall Process or from scrap aluminum by secondary smelters.

Carbon steel was chosen for study because it comprises about 90 percent of the total steel produced.[1] Although a large variety of different grade carbon steels with varying amounts of carbon and silicon are produced as basic materials, the overall processes involved in their manufacture are quite similar. Basic steelmaking from scrap and pig iron can be achieved in four types of steel furnaces: (1) Bessemer, (2) Open Hearth, (3) BOF, and (4) Electric Furnace. However, the BOF and electric furnace were selected for study because trends in steel production show sharp rises in production volumes by the BOF and electric furnace, with decreasing production volumes from the Bessemer and Open Hearth Furnaces[2], indicating future steel making will be in BOF and Electric Furnaces.

Wrought and cast aluminum products are both considered in this study because the specifications for the two aluminum types are quite different. Primary smelters produce mainly wrought products with some cast products while secondary aluminum smelters primarily produce cast products. The Bayer-Hall Process is studied for primary aluminum production because it accounted for all the primary aluminum produced in the U. S. in 1973. Secondary aluminum smelters were selected for recycled aluminum production because they account for most of the aluminum produced from scrap materials.[3]

The sources of scrap materials chosen for this study are obsolete steel and aluminum cans and junk autos. They were chosen because of their volume and impact on the environment. In 1971, 71.3 billion steel cans, consuming 6.5 million metric tons of steel were produced in the U. S.[4,5] This figure accounts for about four percent of the municipal solid waste collected. Only four to five percent of these cans were recycled in 1971.[6] From 1961 to 1971, aluminum containers and packaging had an annual growth rate of 15.7 percent. They accounted for 14.6 percent of all aluminum shipments in 1971.[3] Nine billion aluminum cans were produced in 1971 resulting in 410 thousand metric tons of MSW.[3] Recycling centers collected 11.6% of aluminum cans produced in 1971, 16.3% in 1972 and 20% in 1973.[7]

Annual discard of vehicles approached 8 million units in 1968. Based on current trends, the number scrapped annually is expected to climb to 10.4 million units by 1975, 11.6 million by 1980, and 13.2 million by 1985. Autos account for about 85 percent of the total, with trucks and buses accounting for the remaining 15 percent.[2]

Presently, about one-fourth of the recycled steel scrap is from discarded automobiles. However, the availability of scrapped autos exceeds the demand for them. It is estimated that a backlog of some 12-20 million auto hulks exists with an additional 0.9 million being abandoned each year.[8]

SECTION III

STUDY APPROACH AND METHODOLOGY

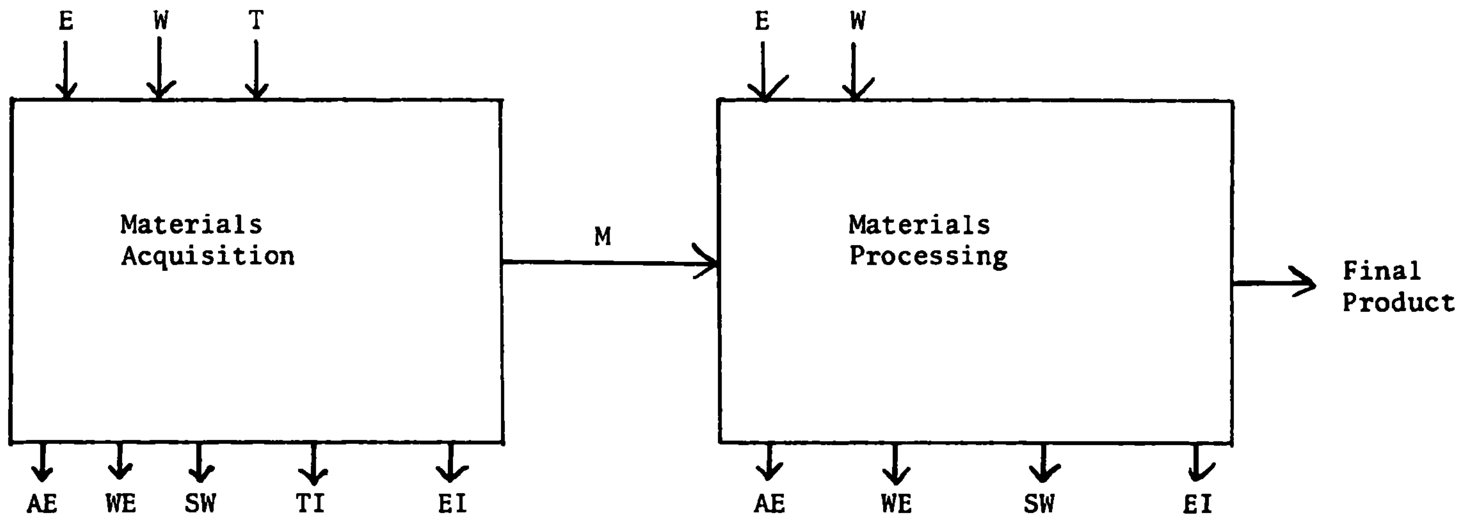
There are two broad classes of environmental impacts which can be discerned and discussed--quantifiable impacts, and those of a more subjective, qualitative nature. The former category includes those impacts which can be measured, such as kilocalories of energy and kilograms of air pollutants for various manufacturing processes. The latter category includes impacts for which hard data do not exist. For example, it is impossible to assign precise numerical measures of aesthetic blight caused by mining activities. For other cases, data may exist; but it might be of poor quality, examples being the relative environmental damage of solid waste disposal of various products, or the relative environmental damage of various air pollutants or of various water pollutants. This study is confined to the determination of the quantitative impacts only. Qualitative aspects, although referred to from time to time in this study, are not part of this analysis.

Basic Approach

Modules

The effort expended in this study went into determining the quantifiable impacts of manufacture. The term "manufacture" is used throughout this report in a general sense--it includes those activities associated with materials from the time they are severed from the earth or recovered from the solid waste stream to the point where the finished product has been produced. Also included are all transportation links in the processing sequence. The manufacturing activities which intervene are designated processes or subprocesses.

The data obtained for each process or subprocess are presented in a module summary. The module summary presents the data for basic materials, water and energy consumptions for both the process and the transportation of the product to the next process. Also shown in the module summary are the on-site air emissions, water effluents and solid wastes for the process as well as the off-site environmental impacts which result from the production of energy consumed in the process and the transportation of the product from that process to the next process. Figure 1 summarizes the data which are presented in each module.



Inputs

E = Energy (in all forms)

M = Materials

W = Water

T = Transportation to Next Process
(includes all modes)

Outputs

AE = Atmospheric Emissions

WE = Water Effluent

SW = Solid Wastes

TI = Transportation Impacts

EI = Energy Impacts

FIGURE 1. SUMMARY OF DATA PRESENTED IN EACH MODULE

The on-site environmental impacts and off-site environmental impacts from energy production and transportation are then totaled and the total environmental impact of the process is presented in terms of six basic impacts:

1. Material Inputs: The amounts and types of virgin raw materials or scrap materials required for each operation were determined in terms of a given product output. Materials not intended to become part of the finished product, such as cooling water and fuels, were excluded from raw materials. The materials used are totaled individually, and no attempt was made to compare the various virgin materials based on availability or scarcity. The most widely acknowledged projections of this type have been made by the Bureau of Mines. However, questions have been raised about the validity of these projections because of the assumptions on which they are based.

2. Energy: The energy used by each operation, including transportation, for a given product output was reported. Process energy used by the actual manufacturing operations was considered. That used for space heating of buildings and other miscellaneous categories was excluded wherever possible. The second-order energy necessary to extract, process and transport fuels are included as well as the heating value of the specific fuels used in a system.

3. Water Discharged: The volume of water discharged to the natural bodies of water per unit of product output from each process is reported. Also reported separately in this category is mine drainage, that is, water which must be pumped from a mine site to continue the operation. This impact category considers water use only, not what is discharged from a process into the water in the form of pollutants. (This factor is covered separately.)

4. Solid Wastes: The volume of solid waste per unit of product output which must be landfilled, or disposed of in some other way, was determined also. Three types were measured: process wastes, post consumer wastes, and overburden from mining. The first type process wastes, includes wastewater treatment sludges, solids resulting from air pollution control, trim and waste materials from manufacturing operations and fuel combustion residues generated by coal combustion. Post consumer solid wastes are junk autos and scrap which are removed from the solid waste stream by the resource recovery modules. Mining overburden is the material removed to expose ore bodies.

5. Atmospheric Emissions: This category includes only those emissions (expressed in kilograms per unit of product output) generally considered to be pollutants. Ten identifiable pollutants were considered

for each operation--particulates, nitrogen oxides, hydrocarbons, sulfur oxides, carbon monoxide, aldehydes, other organics, chlorides, fluorides and ammonia. The amounts reported represent actual discharges into the atmosphere after emission controls meeting 1975 Air Standards have been applied. If no standards presently exist for the operation, a level of control which was judged to be the best practical technology was assumed. All such atmospheric emissions were treated as being of equal weight, and no attempt was made to determine the relative environmental damage of each of these pollutants. However, we do note that there are differences in the relative harm caused by air pollutants. There is not sufficient documentation available to weight them with respect to each other now.

6. Waterborne Wastes: This category includes the water pollutants from each operation expressed in kilograms per unit product output. These are effluents after wastewater treatment meeting 1977 Water Standards have been applied and represent discharges into receiving waters. As with air emissions, if no standards current exist for the process, a level of control which was judged to be the best practical technology was assumed. Fifteen specific pollutants are included--BOD, COD, suspended solids, dissolved solids, oil and grease, fluorides, chlorides, phenol, sulfides, iron, ammonia, cadmium, lead, manganese, and cyanide. Other factors such as turbidity and heat, were not included because there was no acceptable way to quantify them.

Synthesis Methodology

The general approach used to carry out the calculations for the quantitative comparison was straightforward. All processes and subprocesses were first considered to be separate, independent systems and data were reported in the modules. For each system, a standard unit such as 1,000 kilograms of output was used as a basis for calculations. A complete materials balance was first determined. If marketable co-products or by-products were produced, the materials inputs were adjusted to reflect only the input attributable to the output product of interest.

Once the detailed impact information had been determined for 1,000 kilograms or 1 metric ton of output from each module, a master flow chart was established for the manufacture of a product. Using known yield data, the kilograms of output of each module necessary to produce 1,000 kilograms or 1 metric ton of a finished product were determined. Summary tables of impacts for the manufacture of 1,000 kilograms or 1 metric ton of a product were then constructed. Transportation steps or energy inputs were not shown on the master flow charts because they had previously been incorporated in the individual modules.

After the impacts for each system were determined, it was then possible to compare the systems using virgin materials with the systems using recycled materials. Comparisons were made on the basis of 1) materials 2) energy 3) water use 4) air emissions 5) water effluents, and 6) solid wastes.

Environmental Cost Estimates

An assumption basic to this study was that 1975 Air Standards and 1977 Water Standards would be met. Air emissions and water effluents were reported with this premise in mind. However, there is a real dollar cost to industry in meeting these standards. When sufficient data were available, cost estimates for meeting the standards were developed for each module and reported as dollars per metric ton of product. Costs for the total system were developed by weighting the environmental costs for the individual modules by the number of kilograms of output from that module which were required to produce a metric ton of finished product for the system. Although the total costs of controlling the environmental impacts could not be determined for each system, care was taken to see that the cost data were comparable for all systems.

Assumptions

An important part of any study concerns the assumptions that must be made since some assumptions are always necessary to limit a study to reasonable scope. It is important for the reader to know what assumptions have been made in order for him to understand fully the scope and applicability of the study.

In the course of this research, the following assumptions were made:

1. Data Sources: An attempt was made in every case to obtain data which were "typical" and which could be verified in the open literature. Extensive use was made of government agencies and publications, technical associations and open literature sources.

National average data were used where possible. Certain sets of data involved proprietary processes so that information was submitted to us on a confidential basis. However, data in the public domain were used whenever possible.

2. Sources of Raw Materials: Although iron ore and bauxite are both imported to the U. S., all raw materials were considered to originate in the U. S.

3. Secondary Impacts: Secondary impacts resulting from extraction, processing and transporting fuels were considered as well as the primary impacts of the fuels themselves. Secondary impacts resulting from effects such as manufacturing the equipment used in mining and processing are small per unit output, and can be excluded without significant error.

4. Small Amounts of Materials: The impacts associated with materials which aggregate to 5 percent or less by weight of the container were not included. The list of materials which comprise the "less than 5 percent" category was examined to insure that no known "high environmental impact" materials were included. This inspection insures that the values from this assumption do not lead to an error of greater than 5 percent in the final results.

5. Electricity: Electrical energy is considered from the point of view of its impact on the total energy resources of the nation. A national average energy expenditure of 2,977 kilocalories of fossil fuels is required for each kilowatt-hour of electricity made available to the public. Hence, this conversion factor is used rather than the direct use conversion factor of 860 kilocalories per kilowatt-hour. The impacts from mining or extraction of these fuels were included in the analysis.

6. Resource Recovery: When a resource recovery operation processes twenty metric tons of solid waste to recover 1 metric ton of cans, the solid wastes for the operation are: Post consumer solid wastes = 20 metric tons, Processing wastes = 19 metric tons. The net effect is the removal of 1 metric ton of solid waste from the environment.

Limitations

A basic hindrance to a study of this type is that many industrial plants do not keep records in sufficient detail to determine the data in the desired form. For instance, if energy data are needed for a specific subprocess in a plant, that information may not be available. The plant may have data only for several combined processes. In this event, prorations must be made to the particular processes of interest.

Another problem is that many of the resource recovery processes are in the experimental or pilot plant stage, especially aluminum recovery from municipal solid waste. Energy requirements may be known within 50%, but no data exist on air emissions or water effluents. Therefore, it was necessary to use engineering calculations of materials balances for processes in some instances where actual operating data are not available.

SECTION IV

AUXILIARY MODULES

Introduction

Energy and transportation are common inputs for most modules in the steel and aluminum systems. The systems which use recycled materials also require resource recovery modules as sources of steel and aluminum scrap. This section describes these auxiliary processes and their associated environmental impacts. The sources of energy given consideration in this study are coal, petroleum, natural gas and electricity. In addition, the emissions which result from the on-site combustion of fossil fuels are described here. The modes of transportation considered are rail, truck, water and pipeline. The resource recovery modules include municipal solid waste recovery, separated can recovery, detinnning, auto hulk processing and auto scrap processing by shredding or baling and incineration.

Energy

The environmental impacts resulting from the extraction, processing and transportation of coal, petroleum and natural gas are described here as well as the emissions which result from the combustion of these fuels by stationary sources. Finally, the production of electricity and its resulting environmental impacts are discussed.

Coal Mining and Processing

Open pit and underground operations each account for half of the coal mined in the U. S. Since 80% of a coal deposit can be recovered by open pit operations as opposed to 50% by underground methods, open pit mining operations are becoming more prevalent every year. Coal is usually cleaned or processed before use. The primary purpose of a preparation plant is to crush the coal, remove impurities and classify the product into standard size. Approximately 20% of the raw coal processed in a cleaning plant is rejected as refuse.

Acid mine drainage and overburden are the principal impacts resulting from coal mining. However, EPA effluent guidelines for the coal mining industry[12] have set the following schedules for coal processing plants, underground mine drainage and surface mine drainage:

suspended solids	30 mg/l
pH	6.0-9.0
total iron	4.0 mg/l
alkalinity	greater than acidity
toxic materials	none
oil and grease	5.0 mg/l

These figures and the water use figures shown in Table 1 were used to calculate the water effluents shown in the table. The dissolved solids figure in the table is based on an average of 3000 mg/l of dissolved solids in the discharge of a mining operation.[20] The recommended water pollution control procedure is neutralization to a pH of 6.0 to 9.0 accomplished by the use of lime, limestone, oxidation or varied combinations of the three.

It can also be seen from Table 1 that the amount of overburden resulting from coal mining is 8.34 MT/MT of coal. This figure is based on the fact that the average coal production per acre from strip mining is 6,661 metric tons,[14] and the average depth of overburden (specific gravity of 1.5) removed by the operation is 18.3 meters;[15] yielding 16.68 MT of overburden per MT of coal. However, only 50% of coal production is by strip mining and the volume of overburden extracted during underground operations is negligible in comparison with that removed during surface mining. Hence, the average weight of overburden removed per ton of coal extracted is only half that value removed during stripping alone.

Air emissions result primarily from fuels burned on site and dusts from coal cleaning operations which contribute 1.55 kg of dust for each ton of coal mined.

Crude Petroleum Extraction

More than 80 percent of modern wells are drilled by the rotary process. In this process, a bit is turned at the bottom of the hole and drilling mud is pumped through the drill pipe to cool the bit and flush drill cuttings to the surface. After drilling to an intrusion area, the hole is protected by inserting a casing. Upon completion of the well construction, production can begin. Oil wells produce primarily under four mechanisms: gas expansion, gascap drive, water drive, and gravity drainage. Once production is started, the products are transported mainly by pipeline to oil field tank batteries or refinery storage vessels. Preliminary treatment involves separation of hydrocarbons from brine and settleable solids. The hydrocarbons are then processed by a gas plant or refinery.

TABLE 1. ENVIRONMENTAL IMPACT RESULTING FROM COAL MINING AND TRANSPORTATION

Basis: 1 metric ton of coal

	Coal Mining	Transportation	Total	Sources*
WATER DISCHARGED (liters):				9
Process	150			
Mine Drainage	310			
AIR EMISSIONS (grams):				11
Particulates	1689	34	1723	
Sulfur Oxides	148	35	183	
Carbon Monoxide	33	47	80	
Hydrocarbons	8	43	51	
Nitrogen Oxides	54	64	118	
Aldehydes	1.5	3.4	5	
Organics	0.1	3.7	4	
WATER POLLUTANTS (grams):				10, 12
Suspended Solids	14		14	
Dissolved Solids	1380		1380	
Oil and Grease	2		2	
Iron	2		2	
SOLID WASTES (kilograms):				13
Overburden	8340		8340	
Processing Waste	190		190	
ENERGY CONSUMPTION -- (kilocalories)	83,500	50,900	134,400	16
TRANSPORTATION (metric ton kilometers):				
Rail	315			
Water	55			

*For sources, see references beginning on page 111.

The major pollutant sources in oil drilling production operations are lost oils resulting from well blowouts, leaks and spills, and produced brine. Approximately 2 liters of brine containing 100,000 mg/l of dissolved solids are produced with each liter of crude oil.[18] These brines may be disposed of by evaporation or deep well injection. If care is not exercised in selection of the subsurface formation, contamination of ground water can result from deep well injection. However, with proper precaution, deep well injection or evaporation are environmentally adequate for brine disposal and result in no pollutants being released to the environment.

The major emissions associated with crude petroleum extraction are evaporated hydrocarbons from processing losses which amount to 1.4 kg per 1000 liters of crude oil extracted[19] and emissions resulting from the combustion of fuels. Table 2 summarizes the environmental impacts for the extraction of 1000 liters of crude petroluem.

TABLE 2. MODULE SUMMARY SHEET FOR CRUDE PETROLEUM EXTRACTION

Basis: 1000 liters of crude oil shipped

		Source
WATER DISCHARGED (liters):		
Process	610	17
AIR EMISSIONS (grams):		11,19
Particulates	526	
Sulfur Oxides	4543	
Carbon Monoxide	812	
Hydrocarbons	1439	
Nitrogen Oxides	208	
Aldehydes	40	
Organics	0.23	
SOLID WASTES (kilograms):		20
Processing Waste	0.60	
ENERGY CONSUMPTION (kilocalories):	471,100	16,21
TRANSPORTATION (metric ton kilometers)		17
Barge	89.9	
Truck	32.1	
Pipeline	353.1	

Petroleum Refining

An integrated petroleum refinery produces a large number of gasoline, fuel oil and petrochemical products using various alternative processes and feedstocks. It is extremely difficult to specify the quantity of emissions, effluents and solid wastes attributable to the production of specific output products since a number of products may evolve from the same operation and alternative processes and feedstocks are used to produce particular products.

Emissions and effluents from petroleum refineries have been typified in accordance with the complexity of operations performed. The American Petroleum Institute has categorized petroleum refineries in five groups for which profiles of effluents have been described.[22] Their category C refinery performs topping and cracking and also produces petrochemicals. Outputs consisting of gasoline, diesel and residual fuel oil and petroleum coke are inputs to many processes in this study. In this study no distinction is made between the effluents and emissions which result from the different products. They are only given for the refining of 1000 liters of liquid hydrocarbon fuels.

The emissions shown in Table 3 are from a new 100,000-barrel per day capacity refinery with a 3 percent process loss assumed. The possible sources of emissions include the sludge incinerator, catalytic cracker, flare, boiler and process heaters, blowdown systems, process drains, cooling towers, pipe valves and flanges, vessel relief valves, pump and compressor seals and the tank farm.

The major sources of water pollutants from refinery operations are storage tank drainoffs, crude desalting and distillation, and thermal and catalytic cracking. Table 3 contains the summary data on biologically treated effluents from a class C refinery as defined by the API. Also shown in this table are the environmental impacts for the overall system of supplying petroleum fuel which includes the steps of extraction, transportation, and refining.

Natural Gas Production

Natural gas extraction operations may be associated with 1) "dry gas" fields, 2) condensate natural gas liquid extraction, or 3) operations associated with crude petroleum. Dry gas fields produce no liquids and only require processing to remove water, hydrogen, sulfide and carbon dioxide. Water is removed by cooling the gas to the dew point with subsequent removal of the condensed water. Complete dehydration usually requires the use of solid absorbents or hygroscopic

TABLE 3. ENVIRONMENTAL IMPACT RESULTING FROM EXTRACTION, TRANSPORTATION AND REFINING OF 1000 LITERS OF LIQUID HYDROCARBON FUEL

Basis: 1000 liters of liquid petroleum fuels

	Extraction	Transportation	Refining	Total	Source
WATER DISCHARGED (liters):					24
Process	630		7.8	638	
AIR EMISSIONS (grams):					23
Particulates	54.2	37.9	13.2	105	
Sulfur Oxides	467.9	7.3	257.1	732	
Carbon Monoxide	83.6	465.5	214.5	764	
Hydrocarbons	1482.6	112.2	287.1	1882	
Nitrogen Oxides	215.0	462.0	273.7	951	
Aldehydes	41.2	8.1	--	44	
Organics	0.2	3.3	--	4	
WATER POLLUTANTS (grams):					22
Suspended Solids			38	38	
Dissolved Solids			2517	2517	
BOD			99	99	
COD			284	284	
Oil and Grease			42	42	
Phenols			6	6	
Sulfide			6	6	
Ammonia			10	10	
SOLID WASTES (kilograms):					
Processing Wastes	0.62			1	
ENERGY CONSUMPTION (kilocalories)	485,200	75,510	655,690	1,196,400	24
TRANSPORTATION (metric ton-kilometers):					
Barge	893.6				
Truck	33				
Pipeline	364				

liquids. Contact with various alkaline solutions is commonly used to remove hydrogen sulfide and carbon dioxide.

A number of detailed processes may be used in the removal of liquified natural gas. Most involve manipulation of working pressures and temperatures to selectively extract out various fractions, followed by refrigeration to liquify the desired gas.

Table 4 shows the environmental impacts which result from natural gas production. Of prime concern is the large amount of carbon monoxide, hydrocarbons and nitrogen oxides. The hydrocarbon emissions result from process leaks to the atmosphere. The carbon monoxide and nitrogen oxides primarily result from the use of natural gas to run large compressor engines.

TABLE 4. ENVIRONMENTAL IMPACTS RESULTING FROM NATURAL GAS PRODUCTION AND TRANSPORTATION

Basis: 1000 cu meters of natural gas

	Extraction	Transportation	Total	Source
WATER DISCHARGED (liters):				17
Process	2410		2410	
AIR EMISSIONS (grams):				17
Particulates	128	19	147	
Sulfur Oxides	385	15	400	
Carbon Monoxide	8333	178	8,511	
Hydrocarbons	22,596	69	22,665	
Nitrogen Oxides	24,679	237	24,916	
Aldehydes		3.0	3.0	
Organics		4.3	4.3	
ENERGY CONSUMPTION (kilocalories)	390,540	52,520	443,060	16,21
TRANSPORTATION (metric ton-kilometers)				17
Rail	100			
Truck	33			
Barge	33			
Pipeline	166			

Fuel Combustion

Table 5 shows a set of atmospheric emission factors resulting from the combustion of fossil fuels. The emissions for coal combustion are those which result after control by multiple cyclones or an electrostatic precipitator. The emissions for fuel oil and natural gas combustion are those that result from a well-operated source. These factors have been used throughout the study to determine the on-site atmospheric emissions which result from fuel combustion.

TABLE 5. EMISSION FACTORS FROM STATIONARY SOURCES

Pollutant	Coal Industrial Heat (1 metric ton)	Coal Utility Heat (1 metric ton)	Fuel Oil Industrial (1000 liters)	Fuel Oil Utility (1000 liters)	Natural Gas Industrial (1000 m^3)	Natural Gas Utility (1000 m^3)
Particulates	12,000[a]		2,750		290	
Sulfur Oxides	38,000[b]		28,880[c]		10	
Carbon Monoxide	500	500	25	5	6	6
Hydrocarbons	150	150	350	250	640	640
Nitrogen Oxides	9		7,200		3,700	
Aldehydes	3	3	120	120	48	48
Organics					112	64

(a) After control by multiple cyclones or an electrostatic precipitator with an 85% efficiency.

(b) 2% sulfur coal.

(c) 1.5% sulfur fuel oil.

Source: Reference 11.

Electricity Production

Table 6 shows the environmental impacts associated with electricity production from fossil fuel fired plants in the U. S. Column 1 shows the on-site impacts resulting from fuel combustion. Coal, fuel oil, and natural gas are assumed to provide 54.5, 17.0, and 28.5 percent, respectively of the energy requirements.[25] The emissions shown in Column 1 are after 1975 Standards for New Sources[26] are met for particulates, sulfur oxides and nitrogen oxides. The quantities shown for carbon monoxide, hydrocarbons, aldehydes and organics were obtained using the values for power plants in Table 5. The offsite impacts are those which result from the extraction, processing and transportation of the required coal, fuel oil and natural gas. Of particular interest in this column are the impacts resulting from coal usage in the form of solid wastes.

Transmission losses are assumed to be 5%. On site and off site impacts were multiplied by this figure to determine the impact of electricity transmission. Of particular interest is the total energy used (2,977,000 kilocalories) in the production of 1000 kw-hr of electricity which has a fuel equivalent of 860,000 kilocalories. This use represents an overall efficiency of 29% in electricity production.

Transportation

Environmental impacts occur when goods are transported because of the consumption of fossil fuels to provide necessary energy. In this study, the modes of transportation included are rail, truck, pipeline and water. These impacts were calculated by determining the kinds and amounts of fuels used by each mode on a national average basis. Impacts were then calculated for 1,000 metric ton-kilometers.

Rail

The latest complete set of fuel consumption data[27] indicates that diesel fuel accounted for 98 percent of the energy expended by railroads in 1968. We assumed that 100 percent of the energy was supplied by diesel fuel and that 1.42×10^{14} kilocalories of fuel were used. This fuel use resulted in 11.21×10^{11} metric ton-kilometers of transportation. The corresponding fuel consumption was 13.64 liters per 1,000 metric ton-kilometers. This value was combined with information in Table 7 to yield the impacts presented in Table 8.

TABLE 6. ENVIRONMENTAL IMPACTS OF ELECTRICITY PRODUCTION

Basis: 1000 kw-hr = 860,000 kcal

	On-Site	Off-Site	Transmission[a]	Total	Source
WATER DISCHARGED (liters)					
Process		261	13	274	
Mine Drainage		67	3	70	
AIR EMISSIONS (grams)					11,26
Particulates	330	393	36	759	
Sulfur Oxides	3,960	106	203	4,269	
Carbon Monoxide	110	755	43	908	
Hydrocarbons	100	1,972	104	2,176	
Nitrogen Oxides	2,430	2,127	228	4,785	
Aldehydes	10.2	3.3	0.7	14.2	
Organics	0.5	1.4	0.1	2.0	
WATER POLLUTANTS (grams)					
Suspended Solids		4.8	0.2	5	
Dissolved Solids		416	21	437	
BOD		4.5	0.2	5	
COD		13.0	0.7	14	
Oil and Grease		2.4	0.1	3	
Iron		0.5	0.0	0.5	
Phenols		0.3	0.0	0.3	
Sulfide		0.3	0.0	0.3	
Ammonia		0.5	0.0	0.5	
SOLID WASTES (kilograms)					
Overburden		1,818	91	1,909	
Processing Waste	38	42	4	84	
ENERGY CONSUMPTION					25
Coal (kg)	218				
Equivalent kcal	1,482,400				
Oil (ℓ)	45.9				
Equivalent kcal	459,000				
Natural Gas (m^3)	28.5				
Equivalent kcal	772,777				
Total kilocalories	2,714,100	120,800	141,700	2,977,000	

(a) A transmission loss of 5 percent was assumed. On site and off site impacts were multiplied by this figure to determine the impact of electricity transmission.

TABLE 7. EMISSIONS FROM FUEL COMBUSTION BY MOBILE SOURCES

	Gasoline (one liter)	Diesel Locomotive (one liter)	Diesel (one liter)	Fuel Oil Mobil Source (one liter)	Natural Gas Interval Combustion (one m^3)
ATMOSPHERIC EMISSIONS (grams)					
Particulates	1.2	3	1.56	24.0	
Nitrogen Oxide	21.2	9.0	44.4	18.0	76.9
Hydrocarbons	35.4	6.0	4.44	18.0	12.8
Sulfur Oxides	0.7	7.8	3.24	18.0	
Carbon Monoxide	150.4	8.4	27.0	6.0	25.6
Aldehydes	1.4	0.48	0.36	1.3	
Organics	5.3	0.84	0.36	--	
ENERGY (kilocalories)	8,200	9,350	9,350	10,000	9,350

Source: Reference 11

TABLE 8. FUEL CONSUMPTION AND ENVIRONMENTAL IMPACTS RESULTING FROM 1000 METRIC TON-KILOMETERS OF TRANSPORTATION BY EACH MODE

	Rail	Truck	Water	Pipeline
FUELS				
Gasoline - liters		15.9		
Diesel - liters	13.64	28.6	3.64	
Fuel Oil - liters			15.86	
Natural Gas - m^3				13.1
ENERGY kilocalories	128,000	397,000	193,000	122,000
ATMOSPHERIC EMISSIONS (grams)				
Particulates	41	64	386	--
Sulfur Oxides	106	104	40	--
Carbon Monoxide	115	3,164	194	335
Hydrocarbons	82	690	302	168
Nitrogen Oxides	123	1,607	447	1,007
Aldehydes	6.6	32.6	21.6	--
Other Organics	11.5	94.6	1.3	--

Truck

In 1967, a total of 14.95 X 10^9 kilometers were traveled by trucks engaged in intercity highway hauling. This resulted in 1.61 X 10^{11} metric ton-kilometers of transportation.[28] It is estimated that 35 percent of this distance was traveled by gasoline engine trucks while 65 percent was traveled by diesel fueled trucks.[29] National average fuel mileage data are not available, but a reasonable assumption based on actual experience is that this type of truck travel results in fuel consumption rates of about 2.2 kilometers per liter for either type of fuel. Thus, 24.6 X 10^8 liters of gasoline and 4.54 X 10^9 liters of diesel fuel were used in 1967. From this, it was calculated that 15.4 liters of gasoline and 28.5 liters of diesel fuel were consumed per 1,000 metric ton-kilometers.. Using data in Table 7, impacts were calculated and are reported in Table 8.

Water

During 1966, water traffic resulted in 7.3 X 10^{11} metric ton-kilometers of transportation.[30] Fuel consumption was 26.46 X 10^8 liters of diesel fuel and 11.7 X 10^9 gallons of residual.[17] Therefore, 3.64 liters of diesel fuel and 15.86 liters of residual were consumed per 1,000 metric ton kilometers. Again, impacts were calculated and are listed in Table 8.

Pipeline

Sources in the pipeline industry report that, on the average, about 0.85 cubic meters of natural gas fuel are required to transport 159 liters of oil 485 kilometers through a pipeline.[17] This requirement translates to 0.85 cubic meters for 65.7 metric ton-kilometers, or 13 cubic meters of natural gas per 1000 metric ton-kilometer of crude petroleum transportation. This factor, combined with information from Table 7 enabled us to calculate the impacts for 1,000 metric ton-kilometers of pipeline transportation. Pipeline transportation impacts for moving other types of materials of interest in this study were assumed to be approximately the same as for crude oil.

Resource Recovery

The waste materials which are considered for recycling in this study are ferrous and aluminum scrap from junk autos, and steel and aluminum cans. Junk autos first go to the auto hulk processor, where usable parts are stripped from the car and then to an auto scrap processor where usable ferrous and aluminum scrap are produced by shredding or baling and incineration. The cans may be recovered from composite municipal solid waste or they may be collected separately. After recovery, steel cans must go to a detinner before going to a steel furnace. The following section describes the processes necessary to make these materials available for recycling.

Auto Hulk Processing

Auto hulk preparation begins with the collection of individual autos. After collection, the autos are stripped of their radiator, battery, starter, wheels, gas tank, generator and other parts for sale. The stripped auto is then crushed for transportation from dismantler to the scrap processor. Approximately 80 percent of all junk autos first go to an auto wrecker before going to a scrap processor. Table 9 shows the environmental impacts associated with auto hulk processing. The on-site impacts result from fuels consumed for auto crushing. Other activities at the auto wrecker are assumed to be connected with spare auto parts acquisition, which would occur even if the hulks were not sold for scrap. It should be noted that the auto hulk processor removes 1,532 kilograms (weight of an auto) of solid waste from the environment, 1,378 kilograms of which are iron and steel and 23 kilograms of which are aluminum.(31) Any wastes which result from dismantling the auto are assumed to come from the scrap processor.

Auto Scrap Processing

Auto scrap processors use balers, shredders and shears to produce ferrous and aluminum scrap. For urban centers that discard at least 40,000 autos per year, the preferred method is shredding.(33) In this procedure, huge hammer mills shred automobiles stripped of radiator, battery, and motor into fist-size chunks which are passed over a magnetic separator to clean steel from non-magnetic materials. Aluminum can either be hand picked or separated from other metallics by dense media separation.

TABLE 9. SUMMARY SHEET FOR AUTO HULK PROCESSING

Basis: 1 auto hulk

	On-Site	Off-Site	Transportation	Total	Sources
AIR EMISSIONS (grams)					11
Particulates	5		11	16	
Sulfur Oxides	6	3	17	26	
Carbon Monoxide	1000	3	525	1528	
Hydrocarbons	210	7	114	331	
Nitrogen Oxides	120	4	267	391	
Aldehydes	4		5	9	
Organics	2		16	18	
SOLID WASTES (kilograms)					31
Post-consumer wastes	-1532			-1532	
ENERGY CONSUMPTION					32
Liquid Hydrocarbon fuels (ℓ)	3.75				
Equivalent kcal	32,100	4,500			
Total Kilocalories	32,100	4,500	65,900	102,500	
TRANSPORTATION (metric ton kilometers)					2
Truck	166				

For areas that do not discard enough cars to support a shredder, a combination of incineration, hand-tool dismantling and baling or shearing can be used. In the baling operation, the hulk is stripped, either by hand or incineration, and then compressed into a cube.

Table 10 shows the environmental impacts which result from the production of scrap metal by shredding. Published data for air emissions and water effluents does not exist. Shredder manufacturers[37] claim that the installations are equipped with the appropriate dust control equipment and water, when used, is recycled. The on-site emissions shown in Table 10 are from the consumption of liquid hydrocarbon fuels.

Table 11 summarizes the environmental impacts for scrap metal production using a smokeless incinerator and an auto baler. The on-site impacts are emissions from the incinerator which is equipped with an afterburner.[34] The energy consumption of this system is higher than for the shredding system because of the fuels used for incineration. Incineration also results in the release of more atmospheric emissions than shredding but less solid waste. In both systems, the water pollutants result from the use of electricity which is partially produced through the use of coal.

Municipal Solid Waste Recovery

The municipal solid waste recovery system considered in this module is one which produces the outputs shown in Table 12.

TABLE 12. OUTPUTS PER METRIC TON OF WET MUNICIPAL SOLID WASTE PROCESSED

Material	Kilograms
Baled Paper	50
Light Combustibles	670
Ferrous Metals	75
Aluminum	5
Usable Products (Total)	800
Land Fill	200

Source: References 42, 43 and 45.

TABLE 10. SUMMARY SHEET FOR AUTO SCRAP PROCESSING BY A SHREDDER

Basis: 1 metric ton of steel or aluminum scrap

	On-Site	Off-Site	Transportation	Total	Sources
MATERIAL INPUTS					31
Auto Hulk (No.)	0.71			0.71	
WATER DISCHARGED (liters)					
Process Water		9		9	
Mine Drainage		2		2	
AIR EMISSIONS (grams)					11
Particulates	5	25	23	53	
Sulfur Oxides	52	144	51	247	
Carbon Monoxide		31	498	529	
Hydrocarbons		76	128	204	
Nitrogen Oxides	1	162	275	438	
Aldehydes	13		7	20	
Organics			18	18	
WATER POLLUTANTS (grams)					
Dissolved Solids		14		14	
SOLID WASTES (kilograms)					2, 11
Overburden		64		64	
Processing Waste	94	3		97	
ENERGY CONSUMPTION					35
Liquid Hydrocarbon fuels (ℓ)	1.8				
Equivalent kcal	16,900	2,200			
Electricity (kw-hrs)	33.4				
Equivalent kcal	99,400				
Total kcal (thousands)	116.3	2.2	101.1	219.6	
TRANSPORTATION (metric-ton kilometers)					36
Rail	340				
Truck	145				

TABLE 11. SUMMARY SHEET FOR AUTO SCRAP PROCESSING BY HAND STRIPPING AND A SMOKELESS INCINERATOR

Basis: 1 metric ton of steel or aluminum scrap

	On-site	Off-site	Transportation	Total	Source
MATERIAL INPUTS					31
Auto Hulk (NO)	0.71			0.71	
WATER DISCHARGED (liters)					
Process Water		43		43	
Mine Drainage		2		2	
AIR EMISSIONS (grams)					11
Particulates	490	23	23	536	
Sulfur Oxides		124	51	175	
Carbon Monoxide		141	498	639	
Hydrocarbons	8	438	128	564	
Nitrogen Oxides	55		275	330	
Aldehydes	23		7	30	
Organics	131		18	149	
WATER POLLUTANTS (grams)					
Dissolved Solids		32		32	
SOLID WASTES (kilograms)					2,11
Overburden		50		50	
Processing	14	2		16	
ENERGY CONSUMPTION					31
Liquid Hydrocarbon fuels (ℓ)	8.34				
Equivalent kcal	78,000				
Natural Gas (m^3)	13.05				
Equivalent kcal	122,000				
Electricity (kw-hr)	26.4				
Equivalent kcal	78,600				
Total kilocalories (thousands)	278.6	15.8	101.1	395.5	
TRANSPORTATION (metric ton-kilometers)					36
Rail	340				
Truck	145				

This system has the capacity to process 1000 tons per day of MSW from residential and commercial sources. The unit processes in the system consist of handpicking and baling of the paper fraction and shredding the remaining waste. The shredded refuse is air classified to separate the light combustibles, which are compacted and used as fuel. The heavy materials from the air classifier are magnetically separated twice to remove the ferrous materials. This part of the system requires motors with a total of 2800 horsepower, which operate 9 hours per day at 60% of their rated current capacity.[42] The energy requirements of this part of the system are shared equally on a weight basis by the baled paper, light combustible, ferrous metal and aluminum products.

Aluminum is separated from the materials which remain after magnetic separation (20.5% of the original waste stream) by an aluminum magnet which draws 40 kilowatts of electricity for 10 hours.[42] All of this energy is allotted to the aluminum. The material remaining after aluminum separation is then landfilled.

Table 13 shows the environmental impacts which result from the recovery of one metric ton of ferrous scrap. It can be seen from this table that the only on-site impacts are particulate emissions and solid wastes. Approximately 2 kilograms of dust result from the shredding and handling of one metric ton of MSW. However, it is assumed that bag filters with a 90% efficiency will be used to control this dust. The on-site processing waste shown in Table 13 results from the production of 250 kilograms of material which must be land filled for each metric ton of output products. The transportation requirements are assumed to be the same as those for ferrous scrap from auto scrap processors since the distribution of junk autos and municipal solid waste both vary with population.

Table 14 summarizes the environmental impacts which result from the recovery of one metric ton of aluminum scrap. It can be seen from this table that 108.7 kw-hr of electricity are required to recover one metric ton of aluminum scrap as compared to 19.8 kw-hr of electricity required to recover one metric ton of ferrous scrap. This higher electricity consumption is due to the high power requirements of the aluminum magnet and results in greater off-site impacts.

Separated Can Recovery

The can recovery systems considered in this module consist of separate shredding operations to process steel and aluminum cans which have been separated in the home and have been collected separately. The cans are assumed to ride piggyback on the trucks which collect the remaining municipal solid waste.

TABLE 13. MODULE SUMMARY SHEET FOR FERROUS SCRAP RECOVERY FROM MUNICIPAL SOLID WASTE

Basis: 1 metric ton scrap steel

	On Site	Off Site	Transportation	Total	Source
MATERIAL INPUTS (kilograms)					42
Municipal Solid Waste	1250			1250	
AIR EMISSIONS (grams)					44
Particulates	200	15	23	238	
Sulfur Oxides		85	51	136	
Carbon Monoxide		18	498	516	
Hydrocarbons		43	128	171	
Nitrogen Oxides		95	275	370	
Aldehydes			7	7	
Organics			18	18	
SOLID WASTES (kilograms)					42
Overburden		38		38	
Processing	250	2		252	
Post-consumer	-1250			-1250	
ENERGY CONSUMPTION					42
Electricity (kw-hr)	19.8				
Equivalent kilocalories	58,900				
Total kilocalories	58,900		101,100	160,000	
TRANSPORTATION (metric-ton kilometers)					36
Rail	340				
Truck	145				

TABLE 14. MODULE SUMMARY SHEET FOR ALUMINUM SCRAP RECOVERY FROM MUNICIPAL SOLID WASTE

Basis: 1 metric ton of aluminum scrap

	On Site	Off Site	Transportation	Total	Source
MATERIAL INPUTS (kilograms)					42
Municipal Solid Waste	1250			1250	
WATER DISCHARGED (liters)					
Process		30		30	
Mine Drainage		8		8	
AIR EMISSIONS (grams)					44
Particulates	200	83	23	306	
Sulfur Oxides		465	51	516	
Carbon Monoxide		99	498	597	
Hydrocarbons		237	128	365	
Nitrogen Oxides		521	27	796	
Aldehydes		2	7	9	
Organics			18	18	
WATER POLLUTANTS (grams)					
Dissolved Solids		48		48	
SOLID WASTES (kilograms)					42
Overburden		208		208	
Processing	250	9		259	
Post-consumer	-1250			-1250	
ENERGY CONSUMPTION					42
Electricity (kw-hr)	108.7				
Equivalent kilo-calories					
Total kilocalories	324,200		101,100	425,300	
TRANSPORTATION (metric-ton kilometers)					36
Rail	340				
Truck	145				

The unit processes necessary for steel scrap recovery are shredding followed by magnetic separation to remove the ferrous from organic materials which would accompany the cans. The unit processes necessary for aluminum scrap recovery are magnetic separation to remove unwanted steel cans and shredding of the remaining aluminum cans.

Table 15 shows the environmental impacts which result from processing separated aluminum cans. The energy requirements shown were obtained from operating data for Alcoa's can recovery centers.(46) Transportation requirements are assumed to be the same as for ferrous scrap. The only on-site impact is the removal of one metric ton of post-consumer solid waste from the environment.

Table 16 shows the environmental impacts which result from processing separated steel cans. The energy requirement of 34.3 kw-hr of electricity was obtained by dividing the energy requirement for processing aluminum cans by 2.42 which is the ratio of the weight of a steel can to the weight of an aluminum can. Therefore, it was assumed that the energy requirement for processing cans depends on the number of cans which must be processed.

Detinning

The alkaline chemical process is used by nearly all modern large installations for the detinning of tinplate. This process covers the variations possible when a caustic solution containing an oxidizing agent is used to remove both the tin and the underlying iron-tin alloy from the steel. After washing, the steel is virtually free of tin and the solution can be processed in several ways to yield either pig tin or tin chemicals. Nearly all alkaline chemical detinning is done with sodium hydroxide as the caustic and either sodium nitrate, sodium nitrite, or a mixture as the oxidant. The variations possible in pretreatment, number of detinning stages, posttreatment, and recovery are numerous.(39) However, this module is not concerned with tin recovery, and its environmental impacts will not be considered.

Following detinning, scrap is put through as many as four rinses. Rinse waters are advanced and used as solution makeup to conserve chemicals and tin. The detinned scrap is compressed into large bales weighing up to 270 kg or more using hydraulic presses if the scrap is to be sold to steel mills.

TABLE 15. MODULE SUMMARY SHEET FOR ALUMINUM SCRAP RECOVERY FROM ALUMINUM CANS

Basis: 1 metric ton of aluminum scrap

	On site	Off site	Transportation	Total	Source
MATERIAL INPUTS (kilograms)					
Aluminum cans	1000			1000	
WATER DISCHARGE (liters)					
Processing		23		23	
Mine Drainage		6		6	
AIR EMISSIONS (gms)					
Particulates		63	23	86	
Sulfur Oxides		354	51	405	
Carbon Monoxide		75	498	573	
Hydrocarbons		181	128	309	
Nitrogen Oxides		397	275	672	
Aldehydes		1	7	8	
Organics			18	18	
WATER POLLUTANTS (grams)					
Dissolved solids		36		36	
SOLID WASTES (kilograms)					
Overburden		158		158	
Processing		7		7	
Post-consumer	-1000			-1000	
ENERGY CONSUMPTION					46
Electricity (kw-hr)	83				
Equivalent kcal	247,100				
Total kilocalories	247,100		101,100	348,200	
TRANSPORTATION (metric-ton kilometers)					36
Rail	340				
Truck	145				

TABLE 16. MODULE SUMMARY SHEET FOR FERROUS SCRAP RECOVERY FROM STEEL CANS

Basis: 1 metric ton of ferrous scrap

	On Site	Off Site	Transportation	Total	Source
MATERIAL INPUTS (kilograms)					
Steel Cans	1000			1000	
WATER DISCHARGED (liters)					
Process		9		9	
Mine Drainage		2		2	
AIR EMISSIONS (grams)					
Particulates		26	23	49	
Sulfur Oxides		146	51	197	
Carbon Monoxide		31	498	529	
Hydrocarbons		75	128	203	
Nitrogen Oxides		164	275	439	
Aldehydes			7	7	
Organics			18	18	
WATER POLLUTANTS (grams)					
Dissolved Solids		15		15	
SOLID WASTES (kilograms)					
Overburden			65	65	
Process			3	3	
Post-consumer		-1000		-1000	
ENERGY CONSUMPTION					46
Electricity (kw-hr)	34.3				
Equivalent (kcal)	102,100				
Total kilocalories	102,100		101,100	203,000	
TRANSPORTATION (metric-ton kilometers)					36
Rail	340				
Truck	145				

The use of aluminum ends on steel cans presents a problem to detinners The aluminum residual totalling 5 percent by weight reacts violently in the detinning solution and causes considerable loss of caustic values without any suitable recovery. The aluminum consumes an amount of caustic equal to one and one half times its weight and an amount of sodium nitrate equal to twice its weight.[38] With aluminum present, a two stage detinning operation is necessary to keep sodium nitrate consumption to a minimum. From Table 17, it can be seen that 95 kg of sodium hydroxide and 7.6 kg of sodium nitrate are consumed for every metric ton of detinned scrap produced. It can also be seen from this table that the only on-site environmental impact resulting from detinning is 160 kg of solid waste. This waste is $NaAlO_2$ which is an endproduct of the aluminum and caustic reaction.

Other than a small amount of ammonia given off during the reduction of sodium nitrate, there are no process emissions or effluents produced at a modern detinning plant. Spent caustic is a byproduct which is sold for regeneration. The residue which results from delacquering is dewatered and sold to tin smelters for recovery of tin values. Water used for rinsing the detinned steel is recycled within the plant to prevent the loss of chemicals.[38] The on-site air emissions shown in Table 17 result from fuel combustion.

An assumption basic to this module is that when sufficient steel cans are recovered from solid wastes to necessitate detinning because of a potential build up of tin in the steel product, new detinning plants will be built either at the resource recovery center or near the steel plant.[41] Therefore, no additional transportation will be necessary for scrap steel cans on their way to the steel mill. This view is supported by the detinning industry, for there are only 14 detinning plants presently in operation in the U. S. New plants would have to be built if steel cans were to be recovered on a large scale.

TABLE 17. MODULE SUMMARY SHEET FOR DETINNING

Basis: 1 metric ton of tin free scrap

	On Site	Off Site	Total	Source
MATERIAL INPUTS (kilograms)				
Scrap Cans	1060		1060	38
Sodium Hydroxide	95.4		95.4	38
Sodium Nitrate	7.6		7.6	39,40
WATER DISCHARGED (liters)				
Process		21	21	
Mine Drainage		3	3	
AIR EMISSIONS (grams)				11
Particulates	84	26	110	
Sulfur Oxides	400	107	507	
Carbon Monoxide	2	55	57	
Hydrocarbons	5	143	148	
Nitrogen Oxides	84	200	284	
Aldehydes		1	1	
Organics				
WATER POLLUTANTS (grams)				
Dissolved Solids		41	41	
SOLID WASTES (kilograms)				38
Overburden		81	81	
Processing	160	3	163	
ENERGY CONSUMPTION				38
Coal (kg)	4.56			
Equivalent kcal	31,000			
Liquid Petroleum Fuel (ℓ)	9.94			
Equivalent kcal	92,900			
Natural Gas (m^3)	3.32			
Equivalent kcal	31,000			
Electricity (kw-hr)	22.5			
Equivalent kcal	67,000			
Total kilocalories	221,900	14,100	236,000	

SECTION V

STEEL

Steel From Virgin Materials

This section describes the operations necessary to produce steel from virgin materials. Figure 2 shows the arrangement of processes necessary for steel production. Iron ore is reduced to metallic iron in the blast furnace. Limestone and other fluxes are used to form a slag to remove impurities from the iron, while coke acts as a source of fuel and carbon monoxide which reduces the iron ore. Coking operations and the necessary coal input are not shown in the figure because the coking operations are discussed in the blast furnace module and the coal is handled as a fuel input. The molten iron from the blast furnace is refined into steel in the Basic Oxygen Furnace where oxygen chemically unites with the impurities which are burned out.

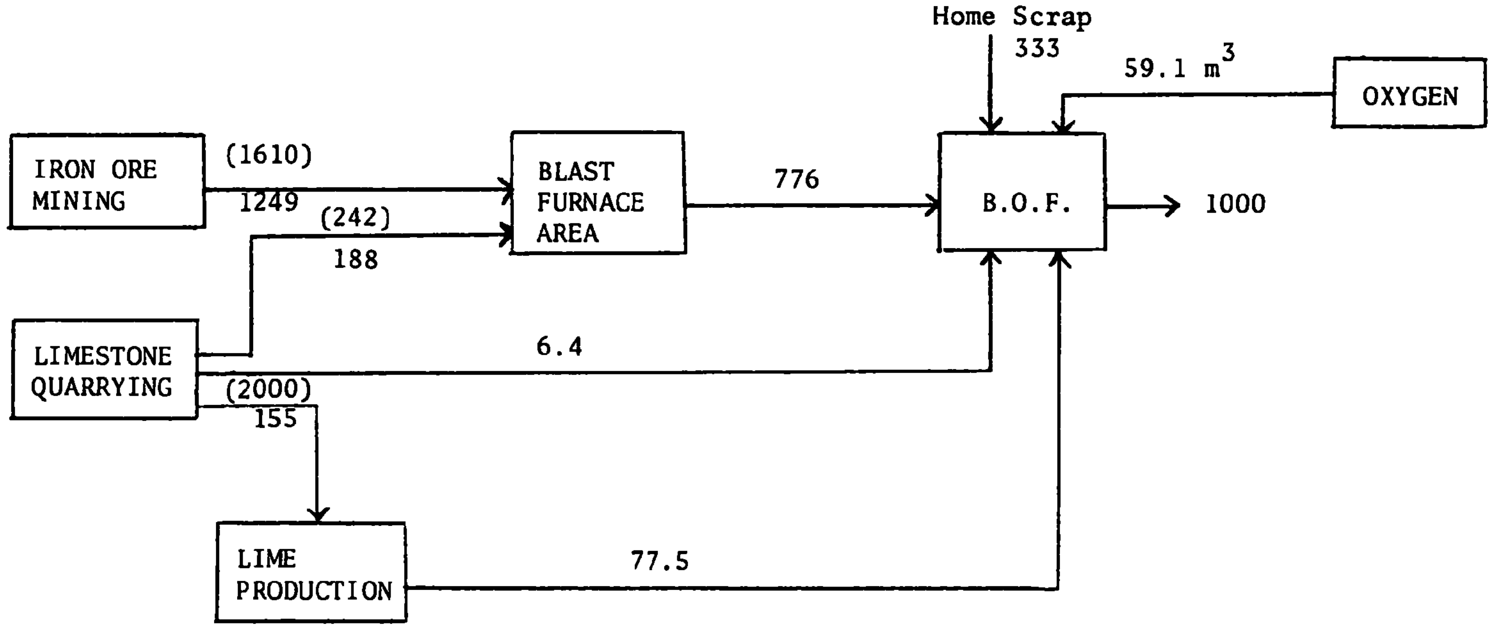
Iron Ore Mining

Iron ore is the basic raw material for steel production. Over 90% of the iron ore is presently extracted by open pit surface mining techniques with the remainder being recovered from deep vertical shaft mines. Production is concentrated in the North Central states with over 60% of the total amount originating in Minnesota.

Iron ore is beneficiated to enhance either its chemical or physical characteristics to make a more desirable feed for the blast furnace. The ore is crushed and screened to reduce crude ore in size to eliminate handling problems and to increase heat transfer. Blending of the ore produces a more uniform product. Concentrating processes, such as washing, jigging, magnetic separation, heavy mineral separation or flotation, remove unwanted sand, clay or rock from crushed or screened ore. Agglomerating processes, such as sintering, follow concentration operations and serve to increase permeability of furnace feed and reduce "fines" which normally would be lost in the flue gases. The agglomeration procedure may take place at either the mine or the steel mill.

The crushing and screening operations and materials handling operations result in the generation of 73% of the onsite particulate emissions.

Figure 2: Steel Production by the Basic Oxygen Furnace Using Virgin Materials
(current mix - 30% Home Scrap; 70% Pig Iron) System F1



Numbers are kilograms of material required to produce one metric ton of steel ingot.
Numbers in parenthesis are kilograms of material required to produce one metric ton of iron or lime.

The remaining emissions result from the combustion of fossil fuels. Table 18 summarizes the environmental impacts of iron ore mining. It can be seen from the table that the dominant environmental effect of mining iron ore is on-site mining wastes. These wastes are quite sizable and amount to 3.6 metric tons per metric ton of marketable ore.

Limestone Quarrying

Limestone is used as a flux in the blast furnace and is processed into lime for use in steel making furnaces. Limestone is typically mined quite close to the ultimate consumer which frequently dictates that the mining operation be near, or even within, heavily populated areas. Hence, their environmental problems are accentuated by their high visibility. Limestone is extracted primarily from open pits. Ammonium nitrate explosives are used extensively in operations. Stones are dug from shattered piles by electrically powered shovels and then processed by crushing and screening the limestone to the required size.

Crushing and screening operations along with handling and storage account for more than 99 percent of the particulate emissions resulting from limestone quarrying. The remaining on-site emissions results from combustion of fossil fuels. Table 19 summarizes the environmental impacts associated with limestone quarrying. It can be seen from this table that the dominant environmental effect of limestone quarrying is particulate emissions.

Lime Production

Lime is produced by the calcination of limestone in large rotary and vertical kilns. During its passage through the kiln, any water present is driven off and the limestone decomposes to lime (calcium oxide) and carbon dioxide. The carbon dioxide passes out of the kiln with the waste gases from fuel combustion and any particulates that are lost. Particulate emissions from vertical and rotary kilns consist of lime and fly ash from coal burning and amount to 4 kg/MT and 100 kg/MT of lime produced, respectively[11]. These sources can be controlled by wet scrubbers or bag houses with a 97.1% and 93% efficiency, respectively[17]. Using these figures and the fact that rotary kilns account for 80% of lime production, particulate emission from processing are 5.62 kg/MT of lime produced. Particulate emissions

TABLE 18. MODULE SUMMARY SHEET FOR IRON ORE MINING

Basis: 1 metric ton of iron ore

	On-Site	Off-Site	Transportation	Total	Sources
WATER DISCHARGES (liter)					9
Process	15,500	8		15,508	
Mine Drainage		5		5	
AIR EMISSIONS (grams)					11,47
Particulates	3,870	41	201	4,112	
Sulfur Oxides	645	103	34	782	
Carbon Monoxide	36	65	114	215	
Hydrocarbons	12	167	164	343	
Nitrogen Oxides	178	230	243	651	
Aldehydes	1.4		11.8	13.2	
Organics	0.6		2.2	2.8	
WATER POLLUTANTS (grams)					
Dissolved Solids		26		26	
SOLID WASTES (kilograms)					48
Overburden		139		139	
Process	3,600	4		3,604	
ENERGY CONSUMPTION					16
Coal (kg)	12				
Equivalent kcal	81,600				
Liquid Hydrocarbon Fuels (ℓ)	5.76				
Equivalent kcal	56,000				
Natural Gas (m^3)	4.46				
Equivalent kcal	40,000				
Electrical Energy (kwhr)	20.56				
Equivalent kcal	61,200				
Other kcal	17,700				
Total kcal	256,500	11,200	115,000	382,700	
TRANSPORTATION (metric ton-kilometers)					17
Rail	133				
Water	508				

TABLE 19. SUMMARY SHEET FOR LIMESTONE QUARRYING

Basis: 1 metric ton of limestone

	On-Site	Off-Site	Transportation	Total	Source
WATER DISCHARGED (liters)					9
Process	57				
Mine Drainage	323			323	
AIR EMISSIONS (grams)					11,47
Particulates	2,708		21	2,729	
Sulfur Oxides	19	12	10	41	
Carbon Monoxide	5	4	222	231	
Hydrocarbons	9	10	72	91	
Nitrogen Oxides	13	17	128	158	
Aldehydes	0.6		3.2	3.8	
Organics	0.2		6.6	6.8	
SOLID WASTES (kilograms)					48
Overburden		5		5	
Processing	80			80	
ENERGY CONSUMPTION					16,21
Coal (kg)	0.073				
Equivalent kcal	500				
Liquid Hydrocarbon Fuels (ℓ)	1.06				
Equivalent kcal	9,700				
Natural Gas (m^3)	0.13				
Equivalent kcal	1,200				
Electrical Energy (kwhr)	2.8				
Equivalent kcal	8,300				
Total kilocalories	19,700	1,300	36,800	57,800	
TRANSPORTATION (metric ton-kilometer)					17
Rail	16				
Water	42				
Truck	67				

also result from primary and secondary limestone crushers and are reported to be 16.5 kg/MT of lime[11]. These sources can be controlled by baghouses with a 95% efficiency[47].

Table 20 summarizes the environmental impacts which result from the production of one metric ton of lime. It can be seen from this table that the on-site impacts consist primarily of particulate, sulfur oxide and nitrogen oxide emissions. The off-site impacts are primarily nitrogen and hydrocarbon emissions as well as solid wastes.

Blast Furnace Area

The blast furnace area consists of sinter operations, the blast furnace, and coke operations.

Sintering makes a lump feed for the blast furnace from materials which once were wasted, including: the fine removed in the upgrading of ores; flue dust, particles reclaimed from the gases in the blast furnace; and coke breeze, fine dust-like bits of coke. Powdered limestone may also be added.

All of these particles are spread out on a traveling belt which passes through a furnace. Heat fuses them together into a porous, clinker-like material called sinter. The sinter is then broken up into convenient sized pieces for feeding to the blast furnace.

Iron ore is converted into iron in the blast furnace. The charge to the furnace is iron ore, coke and limestone. Hot air enters the bottom of the furnace causing the coke to burn. The carbon of the coke unites with oxygen in the air to form carbon monoxide which then unites with the oxygen in the iron ore, liberating the iron. The limestone is heated to a molten state and combines with most of the silica and other impurities from the iron ore and coke forming a molten slag.

Coke is made by the by-product method in long, high, narrow ovens built in rows. The coal, crushed and washed, is blended and baked without air at 1150°C with the necessary heat supplied from the external combustion of fuel gases. In most cases, about 40% of the gases produced by coking are returned and used as fuel. When the coking is completed, the coke is pushed from the oven by a "pusher" into a quenching car. The coke lumps are quenched and then crushed and screened.

TABLE 20. ENVIRONMENTAL IMPACTS FOR LIME PRODUCTION

Basis: 1 metric ton of lime

	On-Site	Off-Site	Transportation	Total	Source
MATERIAL INPUTS (kilograms)					49
Limestone	2,000			2,000	
WATER DISCHARGED (liters)					50
Process	1,129	21		1,150	
Mine Drainage		30		30	
AIR EMISSIONS: (grams)					11,47
Particulates	6,450	184	15	6,649	
Sulfur Oxides	3,542	160	33	3,735	
Carbon Monoxide	45	478	302	825	
Hydrocarbons	48	1,255	79	1,382	
Nitrogen Oxides	1,033	1,447	167	2,647	
Aldehydes	3.2	1.2	4.4	8.8	
Organics	5.8	0.5	11.0	17.3	
WATER POLLUTANTS (grams)					
Dissolved Solids		137		137	
SOLID WASTES (kilograms)					15
Overburden		810		810	
Process	183	20		203	
ENERGY CONSUMPTION					50
Coal (kg)	90				
Equivalent kcal	612,000				
Liquid Hydrocarbon Fuels (ℓ)	4.2				
Equivalent kcal	42,000				
Natural Gas (m^3)	52.1				
Equivalent kcal	487,100				
Electricity (kwhr)	31				
Equivalent kcal	92,200				
Total kcal	1,233,300	40,200	64,100	1,337,600	
TRANSPORTATION					17
Rail	231				
Truck	87				

It is generally conceded that coking operations constitute the single greatest pollution problem to the steel industry. Significant air emissions are particulate coke fines, sulfur oxides, carbon monoxide and hydrocarbons. These emissions are associated with the unloading, charging, discharging (i.e., "pushing") and quenching of coke.

The distillates and fuel gases driven off during coke manufacture are recovered as by-products (phenol, ammonia, light oil, benzene, toluene, etc.) or used as fuels in the coking process, or in other areas of the plants.

Most of the fuel gases driven off from the coal during coking are burned to carry out the coking process on further batches of coal. This procedure is known as "underfiring". Battelle[51] estimates that 70% of underfiring energy is derived from the burning of coke oven gas. Coke oven gas contains a significant quantity of H_2S which is emitted as SO_2 when the coke gas is burned. The estimated uncontrolled emission rate of SO_2 during underfiring per metric ton of coal charged is given as 5 kg/MT[11].

Emission figures used for byproduct coking were obtained from Compilation of Air Pollution Emission Factors [11]. These figures were multiplied by 0.97 since 0.97 metric tons of coal are used to produce the coke used in manufacturing one metric ton of pig iron. The control methods and their respective efficiencies were obtained from Environmental Steel[52]. Emissions from unloading the coal are assumed to be controlled by enclosures, hoods and wetting. Charging and discharging emissions are controlled by smokeless charging and discharging. Emissions produced during coke cycling are controlled by tight seals. Quenching emissions are controlled by closed quenching and sulfur oxide emissions from underfiring are controlled by desulfurization.

The blast furnace itself produces copious quantities of particulates and carbon monoxide. However, blast furnace gas is recovered for fuel values and effective control of particulates by a venturi scrubber and/or an electrostatic precipitator is necessary to use the blast furnace gas. Reference (11) gives the quantity of particulates and CO as 75 and 700-1050 kg/MT of iron respectively before control and 0.75 and 0.0 kg/MT after control.

The same reference gives emissions of particulates and sulfur dioxide from the sinter plant as 1.1 kg/MT iron ore and 0.750 kg/MT iron ore respectively after control by a cyclone and electrostatic precipitator. The total on-site emissions from the blast furnace, by-product coking and the sintering plant are summarized in Table 21. The on-site water effluents shown in this table are those that will result after 1977 water effluent guidelines are met for by-product coking facilities and wash water from wet venturi scrubbing systems which are used to control blast furnace air emissions[53].

Large amounts of slag (300 kg/MT iron) remain from the smelting of ore in the blast furnace. However, it is estimated that the entire annual production of blast furnace slag is utilized for road subgrades, building aggregate and other uses[54]. The sluges and flue dusts recovered from air and water cleaning are normally recycled through the sinter strand. Therefore, the net output of on-site solid waste is zero. However, there are 8.37 metric tons of solid waste produced off-site for each metric ton of iron produced. This waste results from off-site coal mining.

Oxygen Production

The 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 use in steel making furnaces. The B.O.F. consumed 58% of the total oxygen consumed by the steel industry in 1971[55].

Gaseous oxygen of the desired purity is produced from atmospheric air by fractional distillation processes carried out at very low temperatures and elevated pressures. The process starts by compressing the air to an elevated pressure, followed by progressively cooling it to saturation temperature in steps in a series of highly efficient heat exchangers. Condensation and freezing out of moisture, carbon dioxide, and hydrocarbons takes place as the temperature is lowered, after which hydrocarbons still remaining are removed in adsorbent traps. The cold, purified air is finally separated into its components in fractionating (distillation) columns. The requirements for heat removal by refrigeration at the low temperature level are met by expansion of a portion of the cold compressed air in an expansion turbine.

Although most of the oxygen used by the steel industry is purchased (81%), most oxygen plants are located quite close to their point of consumption to minimize transportation difficulties. Therefore, transportation impacts have not been considered. Table 22 summarizes

TABLE 21. MODULE SUMMARY SHEET FOR THE BLAST FURNACE

Basis: 1 metric ton of pig iron

	On-Site	Off-Site	Total	Source
MATERIAL INPUTS (kilograms)				55
Iron Ore	1,610		1,610	
Limestone	242		242	
WATER DISCHARGED (liters)				56
Process	70,242	157	70,399	
Mine Drainage		304	304	
AIR EMISSIONS (grams)				11,52
Particulates	1,900	1,707	3,607	
Sulfur Oxides	1,670	363	2,033	
Carbon Monoxide	326	287	613	
Hydrocarbons	837	595	1,332	
Nitrogen Oxides	11	597	608	
Aldehydes	--	5.9	5.9	
Organics	--	3.8	3.8	
Ammonia	81		81	
WATER POLLUTANTS (grams)				53
Suspended Solids	14	14	28	
Dissolved Solids		1,357	1,357	
BOD	5.3		5.3	
Oil and Grease	0.1	2	2.1	
Iron		2	2	
Phenols	0.3		0.3	
Sulfide	0.2		0.2	
Ammonia	6.8		7	
Cyanide	0.1		0.1	
Fluoride	9		9	
SOLID WASTES (kilograms)				
Overburden		8,182	8,182	
Process		188	188	
ENERGY CONSUMPTION				55,56,57
Coal (kg)	972			
Equivalent kcal	6,650,000	130,600		
Liquid Hydrocarbon Fuels (ℓ)	10.65			
Equivalent kcal	106,500	12,700		
Natural Gas (m^3)	19.25			
Equivalent kcal	181,000	8,600		
Liquid Petroleum Gas (ℓ)	.20			
Equivalent kcal	1,200			
Electricity (kwhr)	39.6			
Equivalent kcal	117,900			
Input Energy kcal	7,056,600			
Output Energy kcal	2,441,000			
Total kilocalories	4,615,600	151,900	4,767,500	

TABLE 22. MODULE SUMMARY SHEET FOR OXYGEN PRODUCTION

Basis: 1000 m^3

	On-Site	Off-Site	Total	Source
WATER DISCHARGES (liters)				50
Process	34,973	188	35,161	
Mine Drainage		48	48	
AIR EMISSIONS (grams)				
Particulates		531	531	
Sulfur Oxides		2,959	2,959	
Carbon Monoxide		1,234	1,234	
Hydrocarbons		3,120	3,120	
Nitrogen Oxides		5,061	5,061	
Aldehydes		10	10	
Organics		2	2	
WATER POLLUTANTS (grams)				
Dissolved Solids		300	300	
Oil and Grease		2	2	
Iron		1	1	
SOLID WASTES (kilograms)				
Overburden		1,308	1,308	
Process		58	58	
ENERGY CONSUMPTION				50
Liquid Hydrocarbon Fuels (ℓ)	8.2			
Equivalent kcal	76,700			
Natural Gas (m^3)	71.3			
Equivalent kcal	667,000			
Electricity (kwhr)	685			
Equivalent kcal	2,039,000			
Total kilocalories	2,782,700	41,400	2,824,100	

the environmental impacts resulting from oxygen manufacture. It can be seen from this table that all the emissions, effluents and solid waste are associated with off-site effects of energy use.

Basic Oxygen Furnace

The basic oxygen furnace, as presently used by the steel industry, uses a high-pressure stream of oxygen (99.5 percent pure) to convert iron (produced from virgin material) into steel. The charge to the furnace consists of a reduced burden; pig iron and scrap; slag-forming fluxes; burned lime, fluorspar and mill scale; and sometimes an oxide charge; dry ore, sinter, pellets or mill scale.

A major advantage of the basic oxygen process is its flexibility in handling raw materials of many types and compositions. The scrap used can be either heavy or light, and the oxide charge, if used, may be dry ore, sinter, pellets, or mill scale. The process can be operated on any kind of hot metal that can be used in the basic open-hearth furnace. In 1971, 30% of the metal charge to B.O.F.'s consisted of scrap[55], the major portion of which was home scrap from later steel finishing operations.

Table 23 summarizes the environmental impacts resulting from the production of one metric ton of carbon steel in a basic oxygen furnace. Fuels for heating are derived from the blast furnace area and their environmental impacts have been accounted for in that module.

The particulate emissions shown in Table 23 are those which will result after "new source" standards for 1975 are met[58]. The necessary control equipment is either electrostatic precipitators or high-energy venturi scrubbers. The water effluents shown are those which will result after 1977 water effluent standards are met for gas washer water from B.O.F. wet scrubbers[53].

Solid wastes from the B.O.F. operation are slag and dust or sludge from air cleaners. Approximately 132 kg of slag result per metric ton of steel produced. Because of its higher density and other properties, steel slag is not utilized to the extent that blast furnace slag is used. The dust or sludge from emissions cleaning (23 kg/MT) is either recycled to the sinter or landfilled with landfill a more common practice (15 kg/MT have been assumed to be landfilled).

TABLE 23. MODULE SUMMARY SHEET FOR THE BASIC OXYGEN FURNACE (30% HOME SCRAP)

Basis: 1 metric ton of carbon steel ingot

	On-Site	Source
MATERIAL INPUTS (kilograms)		55
Fluorspar	6.5	
Limestone	6.4	
Lime	77.5	
Other Fluxes	7.6	
Pig Iron	776	
Scrap	333	
Oxygen (m^3)	59.1	
WATER DISCHARGE (liters)		60
Process	410	
AIR EMISSIONS (grams)		58
Particulates	230	
WATER POLLUTANTS (grams)		53
Suspended Solids	5	
Fluoride	4.2	
SOLID WASTES (kilograms)		54
Processing	147	
ENERGY CONSUMPTION		59
Coke Oven Gas (m^3)	21.6	
Equivalent kcal	105,100	
Blast Furnace Gas (m^3)	54.0	
Equivalent kcal	48,000	
Tar (ℓ)	0.324	
Equivalent kcal	2,900	
Total kilocalories	156,000	

Steel From Recycled Materials

Scrap steel from obsolete autos and steel cans was assumed to be used in two ways by the steel industry in this study: (1) the scrap charge to the Basic Oxygen Furnace was increased to 40% of the total metallic charge, and (2) the scrap was consumed by electric furnaces.

Obsolete Scrap in the B.O.F.

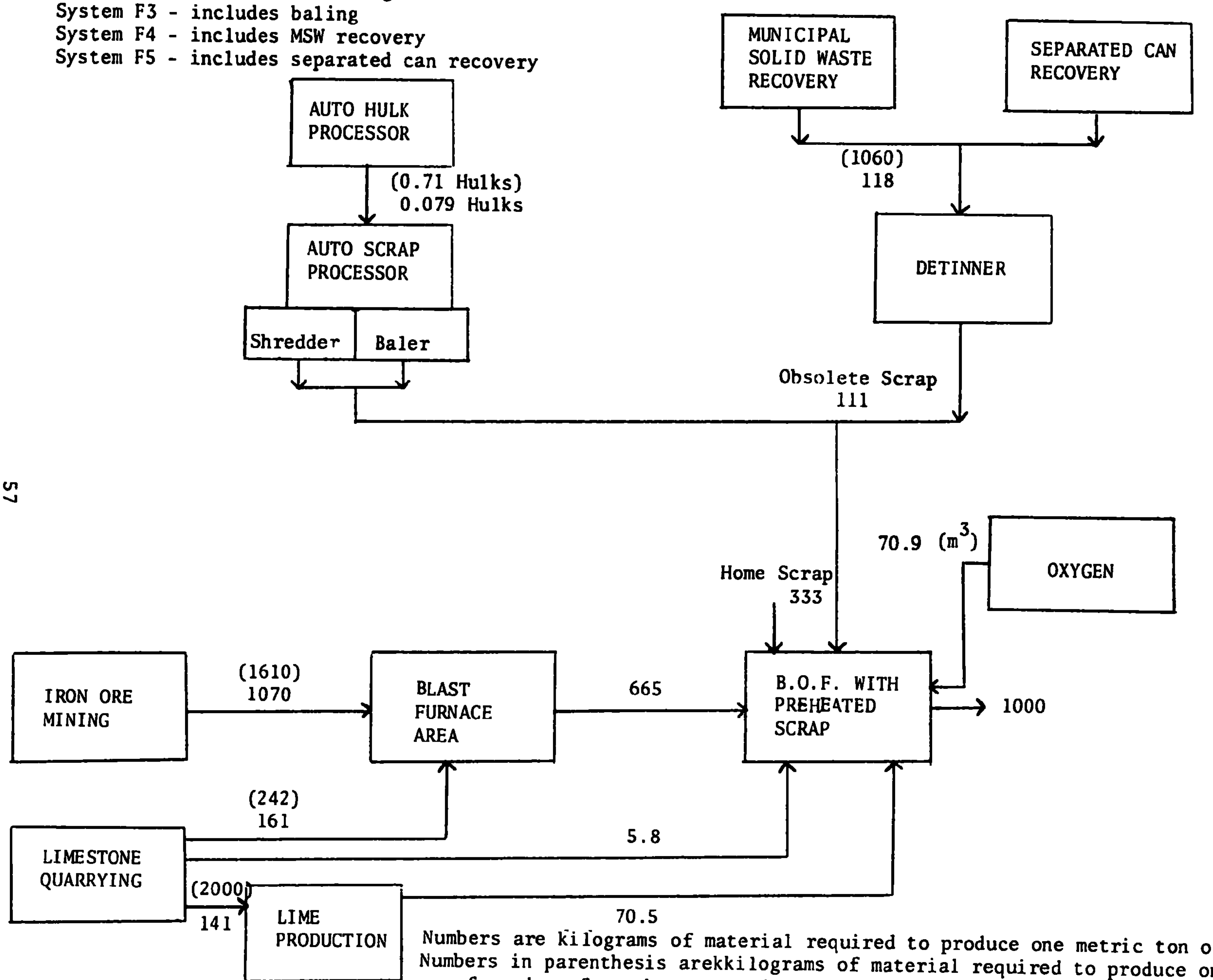
The B.O.F. uses scrap not only as a source of metallics but also as a coolant for controlling temperature. Consequently, scrap usage cannot be arbitrarily changed without adjusting other variables to maintain the thermal balance required for the fast, smooth, trouble-free operation that is characteristic of the process. One method to increase the percentage of scrap used in the B.O.F. is to preheat the scrap charge. Consultation with the steel industry has revealed that it would be realistic to increase scrap usage to 40% of the total metallic charge by preheating. This increase would allow obsolete scrap to replace 10% of the iron now used in the B.O.F. It would not be realistic for obsolete scrap to replace the home scrap now being used in the B.O.F. because this scrap would then present a solid waste problem.

Figure 3 shows the arrangement of processes necessary to produce carbon steel using a 40% scrap charge. The main difference between these systems and Figure 2 for steel production from primary materials is that resource recovery modules for obsolete scrap are included. All of the modules shown in this figure have been previously summarized with the exception for the B.O.F. with preheated scrap.

B.O.F. with Preheated Scrap. Table 24 summarizes the environmental impacts associated with producing carbon steel in the B.O.F. with preheated scrap. Comparison of this table with Table 23 for the B.O.F. reveals that the primary effect of the additional scrap charge is the need for additional fuel to preheat the scrap. This requirement increases the on-site energy requirements for the B.O.F. and results in off-site environmental effects.

FIGURE 3. STEEL PRODUCTION BY BASIC OXYGEN FURNACE USING OBSOLETE SCRAP (MIX: 30% HOME SCRAP; 10% OBSOLETE SCRAP; 60% PIG IRON)

System F2 - includes shredding
System F3 - includes baling
System F4 - includes MSW recovery
System F5 - includes separated can recovery



Numbers are kilograms of material required to produce one metric ton of steel ingot
Numbers in parenthesis arekkilograms of material required to produce one metric ton of product from the next module

TABLE 24. MODULE SUMMARY SHEET FOR THE BASIC OXYGEN FURNACE (30% HOME SCRAP AND 10% OBSOLETE SCRAP)

Basis: 1 metric ton of carbon steel ingot

	On-Site	Off-Site	Total	Source
MATERIAL INPUTS (kilograms)				55,61
Fluorspar	5.9		5.9	
Limestone	5.8		5.8	
Lime	70.5		70.5	
Other Fluxes	6.9		6.9	
Pig Iron	665		665	
Scrap	444		444	
Oxygen (m^3)	70.9		70.9	
WATER DISCHARGED (liters)				60
Process	410	17	467	
AIR EMISSIONS (grams)				58
Particulates	230	1	231	
Carbon Monoxide		3	3	
Sulfur Oxides		61	61	
Hydrocarbons		162	162	
Nitrogen Oxides		178	178	
WATER POLLUTANTS (grams)				53
Suspended Solids	5		5	
Fluoride	4.2		4.2	
SOLID WASTES (kilograms)				54
Process	155		155	
ENERGY CONSUMPTION				59,61
Natural Gas (m^3)	716			
Equivalent kcal	67,000			
Coke Oven Gas (m^3)	21.6			
Equivalent kcal	105,100			
Blast Furnace Gas (m^3)	54.0			
Equivalent kcal	48,000			
Tar (ℓ)	0.324			
Equivalent kcal	156,000			
Total kilocalories	223,000	3,200	226,200	

Obsolete Scrap in the Electric Furnace

Since the heat source for the electric furnace is electricity, thermal balance requirements do not limit the amount of scrap consumed by the electric furnace.

In 1971, 99% of the metallic charge to the electric furnace consisted of scrap[55]. The scrap consisted of in-house waste and high grade industrial waste resulting from metal discarded at various stages in manufacturing as well as post-consumer ferrous wastes. In this study the system we examined to recycle ferrous scrap in the electric furnace is shown in Figure 4. It can be seen from this figure that 70% of the scrap was assumed to come from the resource recovery modules while the other 30% was home scrap. All of the modules shown in this figure have been previously summarized with the exception of the Electric Furnace.

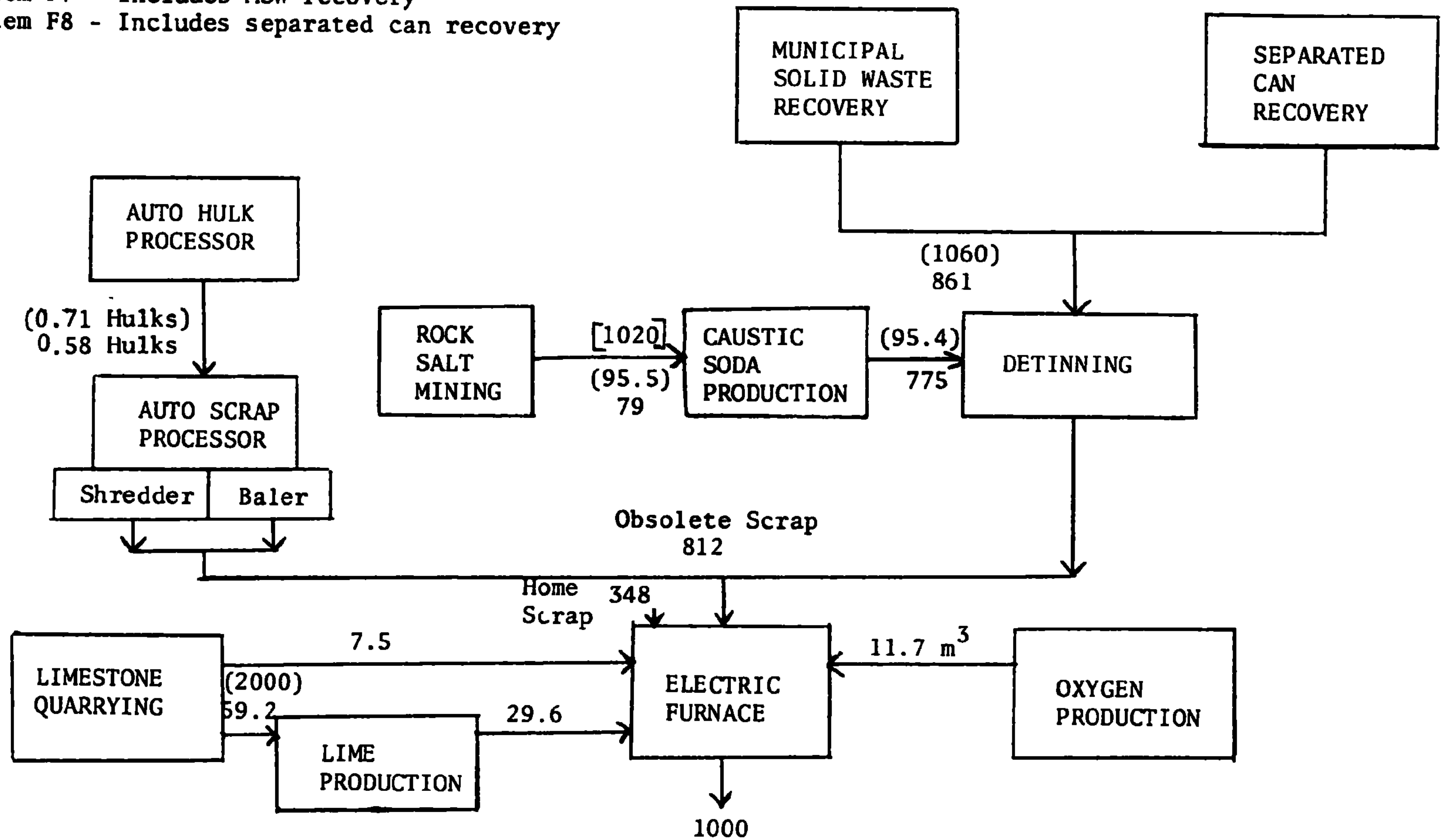
Electric Furnace. Most electric furnaces prior to 1960 did not produce carbon steel but produced various ferroalloys for special purposes. However, in 1971, 71% of the output of electric furnaces was carbon steel.[55] Scrap metal and various additives are charged into an electric furnace through its top. These materials are melted by the conversion of electric energy into heat. Current is brought into the furnace through large carbon electrodes and the energy is converted to heat in the furnace. Since electricity furnishes heat for the melting, there is no need for air to support combustion. High purity oxygen can be injected through a lance during early stages of the refining, raising the temperature and decreasing the time needed to produce the finished steel. However, the quantity of oxygen entering the furnace can always be closely controlled, thus minimizing undesirable oxidizing reactions.

The material inputs to the electric furnace, as can be seen from Table 25, are fluorspar, limestone, lime and other fluxes, scrap ferrous metal and oxygen. It can also be seen from this table that the on-site air emissions consist of particulates and carbon monoxide. These emissions are based on proposed "new source" emission standards for electric-orc furnaces[62] which are:

particulates - 0.03 kg/hr per metric ton of furnace capacity
CO - 0.03 kg/hr per metric ton of furnace capacity

FIGURE 4. STEEL PRODUCTION BY THE ELECTRIC FURNACE (MIX: 30% HOME SCRAP, 70% OBSOLETE SCRAP)

System F5 - Includes shredding
System F6 - Includes baling
System F7 - Includes MSW recovery
System F8 - Includes separated can recovery



Numbers are kilograms of material required to produce one metric ton of steel ingot.
Numbers in parenthesis are kilograms of material required to produce one metric ton of product from the next module.

TABLE 25. MODULE SUMMARY SHEET FOR THE ELECTRIC FURNACE

Basis: 1 metric ton carbon steel

	On-Site	Off-Site	Total	Source
MATERIAL INPUTS (kilograms)				55
Fluorspar	27		27	
Limestone	7.5		7.5	
Lime	29.6		29.6	
Other Fluxes	1.9		1.9	
Oxygen (m^3)	11.7		11.7	
Scrap	1,160		1,160	
WATER DISCHARGED (liters)				60
Process	63	161	224	
Mine Drainage		41	41	
AIR EMISSIONS (grams)				62
Particulates	120	446	566	
Sulfur Oxides		2,510	2,510	
Carbon Monoxide	1,200	534	1,734	
Hydrocarbons		1,290	1,290	
Nitrogen Oxides		2,818	2,818	
Aldehydes		8.3	8.3	
WATER POLLUTANTS (grams)				
Dissolved Solids		257	257	
Oil and Grease		2	2	
SOLID WASTES (kilograms)				
Overburden		1,122	1,122	
Process	70	50	120	
ENERGY CONSUMPTION				63
Electricity (kwhr)	588			
Equivalent kcal	1,750,500			
Carbon Electrode (kg)	5			
Equivalent kcal	38,800			
Total kilocalories	- 1,789,300		1,789,300	

A four-hour heat has been assumed in this study.

The best air pollution control technology consists of baghouse filters for particulate emission control with fume collection by the direct evacuation method, whereby fumes are drawn from the shell of the furnace, the CO burned, the gases cooled and then routed to the filters, plus a canopy hood for building evacuation to catch charging and tapping emissions, as well as a direct evacuation system[62]. Water effluents would result only if a wet scrubbing system were used for control of air emissions and are not listed as an on-site impact because fabric filters are assumed to be used for air emission control.

The off-site impacts shown in Table 25 result from the consumption of electrical energy.

Steel Systems Synthesis

This section summarizes the environmental impacts of nine systems which produce carbon steel. The total impacts for each system were determined using the detailed information contained in the module summaries and known yield data, the kilograms of output from each module necessary to produce one metric ton of carbon steel, as shown in the detailed flowcharts (Figures 2, 3 and 4).

Virgin Materials in the B.O.F.

Figure 2 shows the modules and the outputs from each module which are necessary to produce one metric ton of steel from virgin materials. Table 26 shows the impacts which result from the individual modules in the production of one metric ton of carbon steel from this system (System F1). The totals shown in the last column of this table are the cumulative impacts of the individual modules, the impacts of the whole system. In the case where an intermediate product such as pig iron is produced, it is shown as an output from the blast furnace area and an input to the B.O.F. The net effect is that pig iron is not treated as a material input to the total system, rather the iron ore which was used to make the pig iron in the blast furnace is the material input to the system.

TABLE 26. SUMMARY SHEET FOR CARBON STEEL PRODUCTION FROM VIRGIN MATERIALS IN THE BOF (SYSTEM F1)

Basis: 1 metric ton of carbon steel

	Iron Ore Mining	Limestone Mining	Lime Production	Blast Furnace Area	Oxygen Production	B.O.F.	Total
MATERIAL INPUTS (kilograms)							
Iron Ore				1,249			1,249
Pig Iron				- 776		776	
Scrap						333	333
Limestone			155	188		6.4	349.4
Lime			-77.5			77.5	
Fluorspar						6.5	6.5
Other Fluxes						7.6	7.6
Oxygen (m^3)					-59.1	59.1	
WATER DISCHARGED (liters)							
Process	19,370	20	89	54,630	2078	410	76,597
Mine Drainage	6	113	2	236	3		360
AIR EMISSIONS (grams)							
Particulates	5,136	953	515	2,832	31	230	9,697
Sulfur Oxides	977	14	289	1,578	175		3,033
Carbon Monoxide	269	81	64	476	73		963
Hydrocarbons	428	32	107	1,034	184		1,785
Nitrogen Oxides	813	55	205	472	299		1,844
Aldehydes	16	1	1	5	1		24
Organics	3	2	1	3			8
Ammonia				63			63
WATER POLLUTANTS (grams)							
Suspended Solids				22		5	27
Dissolved Solids	32		11	1,053	18		1,114
BOD				4			4
Oil and Grease				2			2
Iron				2			2
Phenols				0.2			0.2
Sulfide				0.2			0.2
Ammonia				5			5
Cyanide				0.1			0.1
Fluoride				7		4	11
SOLID WASTES (kilograms)							
Overburden	174	1	63	6,349	78		6,665
Process	4,501	28	16	146	3	147	4,841
ENERGY CONSUMPTION (Thousand Kilocalories)	478.0	20.2	103.7	3,699.6	166.9	156.0	4,624.4

It can be seen from Table 26 that iron ore mining and the blast furnace area account for most of the air emissions, water pollutants and solid wastes from the system. They also account for 90% of the energy used and 95% of the water discharged by this system.

Obsolete Scrap in the B.O.F.

Figure 3 shows the modules and the outputs from each module which are necessary to produce one metric ton of carbon steel in a B.O.F., using ferrous scrap to comprise 40% of the total metallic charge to the furnace. It can be seen from this figure that four systems of ferrous scrap recovery have been considered:

- F2 Ferrous scrap from an auto shredding operation
- F3 Ferrous scrap from an auto baling operation
- F4 Ferrous scrap from a municipal solid waste recovery center
- F5 Ferrous scrap from separated steel can collection

Tables 27-30 summarize the environmental impacts of these systems. These tables also show the contributions of the individual modules in each system. It can be seen from these tables that iron ore mining and the blast furnace area account for most of the impacts from these systems.

Obsolete Scrap in the Electric Furnace

Figure 4 shows the modules and the quantity of outputs from each module which are necessary to produce one metric ton of carbon steel, using 70% obsolete scrap and 30% home scrap, in an electric furnace. It can be seen from this figure that the same four sources of ferrous scrap that were considered for the B.O.F. are considered in this case.

Tables 31-34 summarize the environmental impacts resulting from the production of one metric ton of carbon steel by these systems, as well as the impacts from the individual modules. It can be seen from these tables that the electric furnace with its high electrical requirements accounts for most of the air emissions, water effluents and solid wastes from these systems as well as more than 65% of the energy consumed by these systems.

TABLE 27. SUMMARY SHEET FOR CARBON STEEL PRODUCTION IN THE B O F (30% HOME SCRAP, 10% OBSOLETE SCRAP FROM AUTO SHREDDER) SYSTEM F2

Basis: 1 metric ton of carbon steel

	Iron Ore Mining	Auto Hulk Processor	Auto Scrap Processor	Limestone Mining	Lime Production	Blast Furnace	Oxygen Production	B.O.F. with Preheat	Total
MATERIAL INPUTS (kilograms)									
Iron Ore						1,070			1,070
Pig Iron						- 665		665	
Home Scrap								333	333
Obsolete Scrap								111	111
Limestone					141	161		5.8	307.8
Lime					-70.5			70.5	
Fluorspar								5.9	5.9
Other Fluxes								6.9	6.9
Oxygen (m^3)							-70.9	70.9	
WATER DISCHARGED (liters)									
Process	16,594		1	18	81	46,815	2,493	427	66,429
Mine Drainage	5			99	2	202	3		211
AIR EMISSIONS (grams)									
Particulates	4,400	1	6	823	469	2,427	38	231	8,395
Sulfur Oxides	837	2	27	13	263	1,352	210	3	2,707
Carbon Monoxide	230	121	59	71	58	408	87	61	1,095
Hydrocarbons	367	26	23	28	97	886	221	162	1,810
Nitrogen Oxide	697	31	49	49	187	404	359	178	1,954
Aldehydes	14	1	2	1	1	4	1		24
Organics	3	1	2	2	1	3			12
Ammonia						54			54
WATER POLLUTANTS (grams)									
Suspended Solids						19		5	24
Dissolved Solids	28		2		10	902	21		963
BOD						3			3
Oil and Grease						1			1
Iron						1			1
Phenols						0.2			0.2
Sulfide						0.1			0.1
Ammonia						5			5
Cyanide						0.1			0.1
Fluoride						6		4	10
SOLID WASTES (kilograms)									
Overburden	149		7	2	59	5,441	93		5,751
Process	3,856		11	25	14	125	4	155	4,190
Post-Consumer		-121							- 121
ENERGY CONSUMPTION (Thousand kilocalories)	409.5	6.5	24.4	17.8	94.3	3,170.4	200.2	226.2	4,149.0

TABLE 28. SUMMARY SHEET FOR CARBON STEEL PRODUCTION IN THE B.O.F. (30% HOME SCRAP, 10% OBSOLETE SCRAP FROM AN AUTO BALER) SYSTEM F3

Basis.1 metric ton of carbon steel

	Iron Ore Mining	Auto Hulk Processor	Auto Scrap Processor	Limestone Mining	Lime Production	Blast Furnace	Oxygen Production	B.O.F. with Preheat	Total
MATERIAL INPUTS (kilograms)									
Iron Ore						1,070			1,070
Pig Iron						- 665		665	
Home Scrap								333	333
Obsolete Scrap								111	111
Limestone					141	161		5.8	307 8
Lime					-70.5			70.5	
Fluorspar								5.9	5.9
Other Fluxes								6.9	6.9
Oxygen (m^3)							-70.9	70.9	
WATER DISCHARGED (liters)									
Process	16,594		48	18	81	46,815	2,493	427	66,476
Mine Drainage	5			99	2	202	3		211
AIR EMISSIONS (grams)									
Particulates	4,400	1	60	823	469	2,427	38	231	8,449
Sulfur Oxides	837	2	19	13	263	1,352	210	3	2,699
Carbon Monoxide	230	121	71	71	58	408	87	61	1,107
Hydrocarbons	367	26	63	28	97	886	221	162	1,850
Nitrogen Oxide	697	31	37	49	187	404	359	178	1,942
Aldehydes	14	1	3	1	1	4	1		25
Organics	3	1	17	2	1	3			27
Ammonia						54			54
WATER POLLUTANTS (grams)									
Suspended Solids						19		5	24
Dissolved Solids	28		4		10	902	21		965
BOD						3			3
Oil and Grease						1			1
Iron						1			1
Phenols						0.2			0.2
Sulfide						0.1			0.1
Ammonia						5			5
Cyanide						0.1			0 1
Fluoride						6		4	10
SOLID WASTES (kilograms)									
Overburden	149		6	7	59	5,441	93		5,750
Process	3,856		2	11	14	125	4	151	4,18[illegible]
Post-consumer		-121							- 121
ENERGY CONSUMPTION (Thousand kilocalories)	409.5	6.5	43.9	17.8	94 3	3,170.4	200.2	226 2	4,168 5

TABLE 29. SUMMARY SHEET FOR CARBON STEEL PRODUCTION IN THE B.O.F. (30% HOME SCRAP, 10% OBSOLETE SCRAP FROM MUNICIPAL SOLID WASTES, SYSTEM F4

Basis: 1 metric ton of carbon steel

	Iron Ore Mining	Municipal Solid Waste Recovery	Detinning	Limestone Mining	Lime Production	Blast Furnace	Oxygen Production	BOF with Preheat	Total
MATERIAL INPUTS (kilograms)									
Iron Ore						1,070			1,070
Pig Iron						- 665		665	
Home Scrap								333	333
Obsolete Scrap			118						118
Detinned Scrap			-111					111	
Limestone					141	161		5.8	307.8
Lime					70.5			70.5	
Fluorspar								5.9	5.9
Other Fluxes								6.9	6.9
Sodium Hydroxide			10.6						10.6
Sodium Nitrate			0.9						0.9
Oxygen (m^3)							-70.9	70.9	
WATER DISCHARGED (liters)									
Process	16,594		2	18	81	46,815	2,493	427	66,430
Mine Drainage	5			99	2	202	3		211
AIR EMISSIONS (grams)									
Particulates	4,400	28	12	823	469	2,427	38	231	8,428
Sulfur Oxides	837	16	56	13	263	1,352	210	3	2,750
Carbon Monoxide	230	61	6	71	58	408	87	61	982
Hydrocarbons	367	20	16	28	97	886	221	162	1,797
Nitrogen Oxide	697	44	32	49	187	404	359	178	1,950
Aldehydes	14	1		1	1	4	1		22
Organics	3	2		2	1	3			11
Ammonia						54			54
WATER POLLUTANTS (grams)									
Suspended Solids						19		5	24
Dissolved Solids	28		5		10	902	21		966
BOD						3			3
Oil and Grease						1			1
Iron						1			1
Phenols						0.2			0.2
Sulfide						0.1			0.1
Ammonia						5			5
Cyanide						0.1			0.1
Fluoride						6		4	10
SOLID WASTES (kilograms)									
Overburden	149	4	9	7	59	5,441	93		5,757
Process	3,856	30	18	2	14	125	4	151	4,227
Post-consumer		-148							- 148
ENERGY CONSUMPTION (Thousand kilocalories)	409.5	18.9	26.2	17.8	94.3	3,170.4	200.2	226.2	4,163.2

TABLE 30. SUMMARY SHEET FOR CARBON STEEL PRODUCTION IN THE B.O.F. (30% HOME SCRAP, 10% OBSOLETE SCRAP FROM SEPARATED STEEL CANS) SYSTEM F5

Basis: 1 metric ton of carbon steel

	Iron Ore Mining	Separated Steel Cans	Detinning	Limestone Mining	Lime Production	Blast Furnace	Oxygen Production	BOF with Preheat	Total
MATERIAL INPUTS (kilograms)									
Iron Ore						1,070			1,070
Pig Iron						- 665		665	
Home Scrap								333	333
Obsolete Scrap			118						118
Detinned Scrap			-111					111	
Limestone					141	161		5.8	307.8
Lime					70.5			70.5	
Fluorspar								5.9	5.9
Other Fluxes								6.9	6.9
Sodium Hydroxide			10.6						10.6
Sodium Nitrate			0.9						0.9
Oxygen (m^3)							-70.9	70.9	
WATER DISCHARGED (liters)									
Process	16,594		2	18	81	46,815	2,493	427	66,430
Mine Drainage	5			99	2	202	3		211
AIR EMISSIONS (grams)									
Particulates	440	6	12	823	469	2,427	38	231	8,406
Sulfur Oxides	837	23	56	13	263	1,352	210	3	2,757
Carbon Monoxide	230	62	6	71	58	408	87	61	983
Hydrocarbons	367	24	16	28	97	886	221	162	1,801
Nitrogen Oxide	697	52	32	49	187	404	359	178	1,958
Aldehydes	14	1		1	1	4	1		22
Organics	3	2		2	1	3			11
Ammonia						54			54
WATER POLLUTANTS (grams)									
Suspended Solids						19		5	24
BOD						3			3
Oil and Grease						1			1
Iron						1			1
Dissolved Solids	28	2	5		10	902	21		968
Phenols						0.2			0.2
Sulfide						0.1			0.1
Ammonia						5			5
Cyanide						0.1			0.1
Fluoride						6		4	10
SOLID WASTES (kilograms)									
Overburden	149		9	7	59	5,441	93		576.1
Process	3,856		18	2	14	125	4	151	4,197
Post-consumer		-118							-118
ENERGY CONSUMPTION (Thousand kilocalories)	409.5	24.0	26.2	17.8	94.3	3,170.4	200.2	226.2	4,168 3

TABLE 31. SUMMARY SHEET FOR CARBON STEEL PRODUCTION IN THE ELECTRIC FURNACE (30% HOME SCRAP, 70% OBSOLETE SCRAP FROM AN AUTO SHREDDER)
SYSTEM F6

Basis: 1 metric ton of carbon steel

	Limestone Mining	Lime Production	Auto Hulk Processing	Auto Scrap Processing	Oxygen Production	Electric Furnace	Total
MATERIAL INPUTS (kilograms)							
Obsolete Scrap						812	812
Home Scrap						348	348
Limestone		59.2				7.5	66.7
Lime		-29.6				29.6	
Fluorspar						2.7	2.7
Other Fluxes						1.9	1.9
Oxygen (m^3)					-11.7	11.7	
WATER DISCHARGED (liters)							
Process	3	38		7	411	224	683
Mine Drainage	19			2	1	41	63
AIR EMISSIONS (grams)							
Particulates	162	223	9	43	6	566	1,009
Sulfur Oxides	3	111	15	201	35	2,510	2,875
Carbon Monoxide	15	24	886	430	14	1,734	3,103
Hydrocarbons	6	41	192	166	37	1,290	1,732
Nitrogen Oxide	11	78	227	356	59	2,818	3,549
Aldehydes			5	16		8	29
Organics		1	10	15			26
WATER POLLUTANTS (grams)							
Dissolved Solids		5		11	4	257	277
Oil and Grease						2	2
SOLID WASTES (kilograms)							
Overburden		27		52	15	1,122	1216
Process	5	1		79	< 1	20	105
Post-consumer			-889				-889
ENERGY CONSUMPTION (Thousand kilocalories)	3.9	39.6	47.9	178.3	33.0	1,789.3	2092.0

TABLE 32. SUMMARY SHEET FOR CARBON STEEL PRODUCTION IN THE ELECTRIC FURNACE (30% HOME SCRAP, 70% OBSOLETE SCRAP FROM AN AUTO BALER)

Basis: 1 metric ton of carbon steel

SYSTEM F7

	Limestone Mining	Lime Production	Auto Hulk Processing	Auto Scrap Processing	Oxygen Production	Electric Furnace	Total
MATERIAL INPUTS (kilograms)							
Obsolete Scrap						812	812
Home Scrap						348	348
Limestone		59.2				7.5	66.7
Lime		-29.6				29.6	
Fluorspar						2.7	2.7
Other Fluxes						1.9	1.9
Oxygen (m^3)					-11.7	11.7	
WATER DISCHARGED (liters)							
Process	3	38		35	411	224	711
Mine Drainage	19			2	1	41	63
AIR EMISSIONS (grams)							
Particulates	162	223	9	435	6	566	1,401
Sulfur Oxides	3	111	15	142	35	2,510	2,816
Carbon Monoxide	15	24	886	519	14	1,734	3,192
Hydrocarbons	6	41	192	458	37	1,290	2,024
Nitrogen Oxide	11	78	227	268	59	2,818	3,461
Aldehydes			5	24		8	37
Organics		1	10	121			132
WATER POLLUTANTS (grams)							
Dissolved Solids		5		26	4	257	292
Oil and Grease						2	2
SOLID WASTES (kilograms)							
Overburden		27		41	15	1,122	1,195
Process	5	1		13	< 1	20	39
Post-consumer			-889				-889
ENERGY CONSUMPTION (Thousand kilocalories)	3.9	39.6	47.9	321.1	33.0	1,789.3	2,234.8

TABLE 33. MODULE SUMMARY SHEET FOR CARBON STEEL PRODUCTION IN THE ELECTRIC FURNACE (30% HOME SCRAP, 70% OBSOLETE SCRAP FROM MUNICIPAL SOLID WASTE) SYSTEM F8

Basis: 1 metric ton of carbon steel

	Limestone Mining	Lime Production	Rock Salt Mining	Caustic Soda Production	MSW Recovery	Detinning	Oxygen Production	Electric Furnace	Total
MATERIAL INPUTS (kilograms)									
Obsolete Scrap						861			861
Detinned Scrap						-812		812	
Home Scrap								348	348
Sodium Nitrate						6.2			6.2
NaCl				79					79
NaOH				-77.5		77.5			
Limestone		59.2						7.5	66.7
Lime		-29.6						29.6	
Fluorspar								2.7	2.7
Other Fluxes								1.9	1.9
Oxygen (m^3)							-11.7	11.7	
WATER DISCHARGED (liters)									
Process	3	38	175	327		17	411	224	1,195
Mine Drainage	19			11		2	1	41	74
AIR EMISSIONS (grams)									
Particulates	162	223	7	116	205	89	6	566	1,374
Sulfur Oxides	3	111	9	655	117	412	35	2,510	3,852
Carbon Monoxide	15	24	34	139	444	46	14	1,734	2,450
Hydrocarbons	6	41	31	334	147	120	37	1,290	2,006
Nitrogen Oxide	11	78	58	734	319	231	59	2,818	4,308
Aldehydes				2	1	1		8	12
Organics		1	1			15			17
WATER POLLUTANTS (grams)									
Dissolved Solids		5	3	68		33	4	257	369
Oil and Grease								2	2
SOLID WASTES (kilograms)									
Overburden		27	14	293	33	66	15	1,122	1,570
Process	5	1	11	13	217	132	< 1	20	399
Post-consumer					-1,076				-1,076
ENERGY CONSUMPTION (Thousand kilocalories)	3.9	39.6	29.5	456.8	137.8	191.6	33.0	1,789.3	2,681.5

TABLE 34. MODULE SUMMARY SHEET FOR CARBON STEEL PRODUCTION IN THE ELECTRIC FURNACE (30% HOME SCRAP, 70% OBSOLETE SCRAP FROM SEPARATED STEEL CANS) SYSTEM F9

Basis : 1 metric ton of carbon steel

	Limestone Mining	Lime Production	Rock Salt Mining	Caustic Soda Production	Separated Can	Detinning	Oxygen Production	Electric Furnace	Total
MATERIAL INPUTS (kilograms)									
Obsolete Scrap						861			861
Detinned Scrap						-812		812	
Home Scrap								348	348
Sodium Nitrate						6.2			6.2
NaCl				79					79
NaOH				-77.5		77.5			
Limestone		59.2						7.5	66.7
Lime		-29.6						29.6	
Fluorspar								2.7	2.7
Other Fluxes								1.9	1.9
Oxygen (m^3)							-11.7	11.7	
WATER DISCHARGED (liters)									
Process	3	38	175	327	8	17	411	224	1,203
Mine Drainage	19			11	2	2	1	41	76
AIR EMISSIONS (grams)									
Particulates	162	223	7	116	42	89	6	566	1,211
Sulfur Oxides	3	111	9	655	170	412	35	2,510	3,905
Carbon monoxide	15	24	34	139	455	46	14	1,734	2,461
Hydrocarbons	6	41	31	334	175	120	37	1,290	2,034
Nitrogen Oxide	11	78	58	734	378	231	59	2,818	4,367
Aldehydes				2	6	1		8	17
Organics		1	1		15	15			32
WATER POLLUTANTS (grams)									
Dissolved Solids		5	3	68	13	33	4	257	382
Oil and Grease								2	2
SOLID WASTES (kilograms)									
Overburden		27	14	293	56	66	15	1,122	1,593
Process	5	1	11	13	3	132	< 1	20	185
Post-consumer					-861				-861
ENERGY CONSUMPTION (Thousand kilocalories)	3.9	39.6	29.5	456.8	175.0	191.6	33.0	1,789.3	2,718.7

Environmental Impact Comparisons

Nine systems have been considered for the production of carbon steel. It was seen in the previous section that these systems could be classified into three groups.

I. System F1. Steel Production from Virgin Materials in the B.O.F.
II. Systems F2, F3, F4 and F5. Steel Production from Virgin Materials and Obsolete Scrap in the B.O.F.
III. Systems F6, F7, F8 and F9. Steel Production from Obsolete Scrap in the Electric Furnace.

It also was seen in the previous section that the environmental impacts do vary greatly between systems in the same group. Therefore, the most meaningful analysis of the environmental impact of systems using virgin materials and/or obsolete scrap can be made if System F1 is compared with systems in Group II and then with systems in Group III.

Systems F1 Vs. Systems F2, F3, F4 and F5

Table 35 shows the environmental impacts for the systems which produce carbon steel in the BOF from virgin materials (System F1) and from virgin materials and obsolete scrap (Systems F2, F3, F4 and F5). It can be seen from this table that Systems F2, F3, F4 and F5 consume 210 to 223 kilograms less of virgin material than System F1.

It can also be seen from Table 35 that Systems F2, F3, F4 and F5 have reduced water use by at least 10,288 liters (13%) and energy consumption by 455,000 kilowatt hours (10%) as compared to System F1. Total air emissions have been reduced by at least 1268 grams (7%). However, there are slight increases in carbon monoxide, hydrocarbon and nitrogen oxide emissions from Systems F2, F3, F4 and F5 which result from the off-site impacts or natural gas use in preheating the scrap. Water pollutants are reduced by at least 153 grams (13%). Solid wastes are cut at least 1666 kilograms (14%).

Overall, there is slight reduction in all impacts from the systems using obsolete ferrous scrap in the BOF with very little to choose between the four systems. However, this result is not unexpected because the obsolete ferrous only comprises 10% (111 kilograms) of

TABLE 35. COMPARISON OF ENVIRONMENTAL IMPACTS FOR THE PRODUCTION OF CARBON STEEL USING VIRGIN AND/OR RECYCLED MATERIALS

Basis · 1 metric ton of carbon steel ingot

	F1 BOF Virgin	F2 BOF Auto Shredder Scrap	F3 BOF Auto Baler Scrap	F4 BOF MSW Scrap	F5 BOF Separated Steel Can Scrap	F6 Electric Furnace Auto Shredder Scrap	F7 Electric Furnace Auto Baler Scrap	F8 Electric Furnace MSW Scrap	F9 Electric Furnace Steel Can Scrap
MATERIAL INPUTS (kilograms)									
Total Raw Materials	1,612.5	1,390.6	1,390.6	1,402.3	1,402.3	71.3	71.3	156.5	156.5
Iron Ore	1,249	1,070	1,070	1,070	1,070				
Limestone	349.4	307.8	307.8	307.8	307.8	66.7	66.7	66.7	66.7
NaCl				10.8	10.8			79	79
Sodium Nitrate				0.9	0.9			6.2	6.2
Fluorspar	6.5	5.9	5.9	5.9	5.9	2.7	2.7	2.7	2.7
Other Fluxes	7.6	6.9	6.9	6.9	6.9	1.9	1.9	1.9	1.9
Home Scrap	333	333	333	333	333	348	348	348	348
Obsolete Scrap		111	111	111	111	812	812	861	816
WATER DISCHARGED (liters)	76,975	66,640	66,687	66,641	66,641	746	774	1,269	1,279
Process	76,615	66,429	66,476	66,430	66,430	683	711	1,195	1,203
Mine Drainage	360	211	211	211	211	63	63	74	76
AIR EMISSIONS (grams)	17,421	16,051	16,153	15,994	16,012	12,323	13,063	14,019	14,027
Particulates	9,697	8,595	8,449	8,428	8,406	1,009	1,401	1,374	1,211
Sulfur Oxides	3,033	2,707	2,699	2,750	2,757	2,875	2,816	3,852	3,905
Carbon Monoxide	963	1,095	1,107	982	983	3,103	3,192	2,450	2,461
Hydrocarbons	1,785	1,810	1,850	1,797	1,801	1,732	2,024	2,006	2,034
Nitrogen Oxide	1,844	1,954	1,942	1,950	1,958	3,549	3,461	4,308	4,367
Aldehydes	24	24	25	22	22	29	37	12	17
Organics	8	12	27	11	11	26	132	17	32
Ammonia	63	54	54	54	54				
WATER POLLUTANTS (grams)	1,165.5	1,007.4	1,009.4	1,010.4	1,012.4	279	294	371	384
Suspended Solids	27	24	24	24	24				
Dissolved Solids	1,114	963	965	966	968	277	292	369	382
BOD	4	3	3	3	3				
Oil and Grease	2	1	1	1	1	2	2	2	2
Iron	2	1	1	1	1				
Phenols	0.2	0.2	0.2	0.2	0.2				
Sulfide	0.2	0.1	0.1	0.1	0.1				
Ammonia	5	5	5	5	5				
Cyanide	0.1	0.1	0.1	0.1	0.1				
Fluoride	11	10	10	10	10				
SOLID WASTES (kilograms)	11,506	9,820	9,810	9,836	9,840	429	352	900	924
Overburden	6,665	5,751	5,750	5,757	5,761	1,206	1,195	1,570	1,593
Process	4,841	4,190	4,181	4,227	4,197	112	46	406	192
Post-consumer		-121	-121	-148	-118	-889	-889	-1,076	-861
ENERGY CONSUMPTION (Thousand kilocalories)	4,624.4	4,149.0	4,168.5	4,163.2	4,168.3	2,093 8	2,234 8	2,681.5	2,718.7

the metallic charge to the furnace. Since the pig iron charge to the furnace was dropped from 776 kilograms to 665 kilograms (14%) to allow for the increased scrap usage, the largest change in impacts by using scrap would be 14% if there were no impacts attributable to the resource recovery modules.

In summary, there is a definite decrease in environmental impacts which result from using a 10% obsolete scrap charge to the BOF. However, the changes are small because only 14% of the metallic charge coming directly from iron ore has been replaced. There is also very little difference in the environmental impacts resulting from Systems F2, F3, F4 and F5.

System F1 Vs. Systems F6, F7, F8 and F9

Table 35 shows the environmental impacts from the system which produces carbon steel in the BOF (System F1) and the four systems which use obsolete scrap to produce carbon steel in the electric furnace (Systems F6, F7, F8 and F9). It can be seen from this table that Systems F6 and F7 cut raw materials consumption by 1541 kilograms (96%) while Systems F8 and F9 cut raw materials consumption by 1456 kilograms (90%). Water use was cut by at least 75,696 liters (98%) by Systems F6, F7 F8 and F9. The decrease in energy consumption as compared to System F1 ranged from 2530.6 kilowatt hours (55%) for System F6 to 1906 kilowatt hours (41%) for System F9.

Total air emissions decreased from between 5098 grams (29%) for System F6 to 3394 grams (19%) for System F9. This decrease was primarily due to a large decrease in particulate emissions which resulted from iron ore mining and the blast furnace area of System F1. Gaseous emissions from Systems F6, F7, F8 and F9 were generally greater than those from System F1 because of increased electricity consumption by these systems.

Water pollutants resulting from Systems F6, F7, F8 and F9 decreased by at least 781 grams (67%). The largest decrease in wastes as compared to System F1 was in solid wastes produced. Changes ranged from 11,154 kilograms (97%) for System F7 to 10,582 kilograms (92%) for System F9.

It can also be seen from Table 35 that System F6 had the minimum environmental impacts of any of the systems consuming obsolete scrap in the electric furnace while System F9 had the greatest. The impacts of these systems were determined largely by the amount of energy consumed.

In summary, the environmental impacts from the systems (F6, F7, F8 and F9) using obsolete scrap in the electric furnace were less than the impacts from the system (F1) using virgin materials in the BOF. The greatest changes were seen in raw material consumption, water use, energy consumption and solid wastes.

Pollution Control Costs for Steel

An assumption basic to this study was that 1975 Air Standards and 1977 Water Standards would be met. Air emissions and water effluents were reported with this premise in mind. However, there is a real dollar cost to industry in meeting these standards. When sufficient data were available, cost estimates for meeting the standards were developed for each module. However, there were not sufficient data available to determine the total cost of meeting the standards for each system studied. Therefore, in order to keep the cost data comparable for all the systems, cost estimates were only developed for the direct cost to the steel industry in meeting 1975 Air Standards and 1977 Water Standards.

Table 36 summarizes the pollution control costs for steel production. The costs shown in this table are the net annual costs per metric ton of steel produced. The net annual cost per metric ton of steel was computed by summing the annual operating costs which include costs for power, materials, labor, maintenance, taxes, insurances and interest; with the depreciation on the capital investment, and then subtracting the credit for returned materials. The unit costs shown in column 1 of Table 36 are costs for the types of pollution control equipment which were previously discussed in the module descriptions.

It can be seen from Table 36 that the control costs for System F1, which consumes virgin materials in the B.O.F. are $5.58-6.46 per metric ton of steel. Pollution control costs for Systems F2, F3, F4 and F5 which consume virgin materials and obsolete scrap in the B.O.F. are $4.97-5.79 per metric ton of steel. The costs for Systems F2, F3, F4 and F5 are less than System F1 because these systems consumed only 84% as much pig iron as does System F1. The pollution control costs for Systems F6, F7, F8 and F9 which consume obsolete scrap in an electric furnace are only $2.30 per metric ton of steel. This lower cost results because the blast furnace area costs are not included since no pig iron is consumed by these systems.

TABLE 36. POLLUTION CONTROL COSTS FOR STEEL: NET ANNUAL COSTS

	Unit Costs	Cost to System F1 $/MT of steel	Cost to Systems F2,F3,F4&F5 $/MT of steel	Cost to Systems F6,F7,F8&F9 $/MT of steel	Source
BLAST FURNACE AREA	$/MT of iron				
Total	5.49 - 6.02	4.26 - 4.67	3.65 - 4.00		
Blast Furnace					
Air	0.32				74
Water	0.49				53
Sinter					
Air	0.84				74
Coking					
Air					74
Charging	0.62				
Pushing	0.62				
Quenching	1.69 - 2.22				
Desulfurization	0.55				
Water	0.36				53
BASIC OXYGEN FURNACE	$/MT of steel				
(Total)	1.32 - 1.79	1.32 - 1.79	1.32 - 1.79		
Air	1.23 - 1.68				58
Water	0.09				53
ELECTRIC FURNACE	$/MT of steel				
Total	2.30			2.30	
Air	2.30				62
TOTAL		5.58 - 6.46	4.97 - 5.79	2.30	

SECTION VI

ALUMINUM

Aluminum from Virgin Materials

This section describes the operations necessary to produce aluminum from virgin materials. Figure 5 shows the arrangement of processes necessary for primary aluminum production. It can be seen from this figure that bauxite ore is the basic raw material for aluminum. Lime, which is produced from limestone, and caustic soda, which is produced from rock salt, are used to convert the bauxite ore into alumina. The alumina is then smelted in electrolytic cells into aluminum.

Bauxite Mining

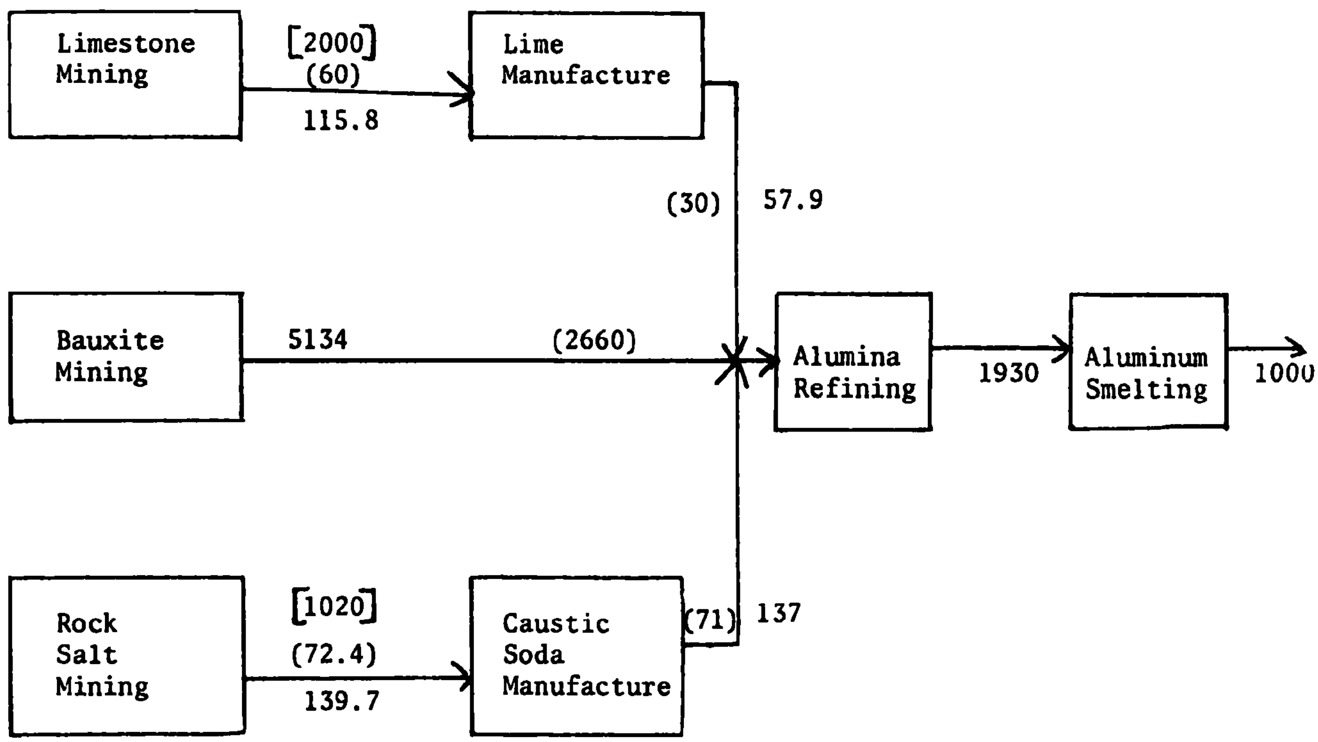
Bauxite ore is at the present time the only commercially exploited source of aluminum. Although other types of earth, including ordinary clay, contain aluminum, industry economics favor bauxite as the preferred ore. Although the United States is the world's largest consumer of bauxite, nearly 90 percent of the bauxite used here is imported.

Most bauxite is mined by open-pit methods. In Arkansas, the top domestic producing region, open-pit mining is used, with stripping ratios of 10 feet of overburden to 1 foot of ore considered minable. Underground mining is employed at one location in Arkansas. On-site treatment of bauxite usually includes crushing, classifying, washing, and dehydration. For some end uses, a more complete dehydrating process, such as calcination, is required.

The mining, crushing and dehydration of bauxite ore results in the generation of particulate air emissions, which amount to 2.7 kg/MT of bauxite.[11,47] The combustion of fossil fuels results in additional particulate emissions and gaseous emissions as shown in Table 37, which summarizes the environmental impacts of bauxite mining. It can also be seen from this table that solid wastes are the primary environmental impact of bauxite mining.

FIGURE 5. PRIMARY ALUMINUM PRODUCTION FROM VIRGIN MATERIALS

SYSTEM A1



units in kilograms: no parentheses aluminum production

( ) alumina refining,

[ ] lime or caustic soda manufacture.

TABLE 37. MODULE SUMMARY SHEET FOR BAUXITE MINING

Basis: 1 metric ton of bauxite

	On Site	Off Site	Transportation	Total	Source
WATER DISCHARGED (liters)					9
Process	66	30		96	
AIR EMISSIONS (grams)					11,47
Particulates	2,706	9	592	3,307	
Sulfur Oxides	18	45	64	127	
Carbon Monoxide	144	120	299	463	
Hydrocarbons	35	312	473	820	
Nitrogen Oxides	63	374	712	1,149	
Aldehydes	2.0	0.1	33.5	35.6	
Organics	1.9		2.0	3.9	
SOLID WASTES (kilograms)					48
Processing	2,650			2,650	
ENERGY CONSUMPTION					16
Liquid Hydrocarbon fuels (ℓ)	1.69				
Equivalent kcal	15,000				
Natural gas (m^3)	11.65				
Equivalent kcal	108,900				
Electrical Energy (kw-hr)	8.0				
Equivalent kcal	23,800				
Other fuels (kcal)	22,200				
Total kilocalories	169,900	7,300	301,700	478,900	
TRANSPORTATION (metric-ton kilometers)					17
Truck	16				
Water	1527				

Rock Salt Mining

The refining of bauxite ore to alumina employs strong caustic soda solutions. Secondary aluminum smelting operations use chlorine gas. The major raw material for caustic soda and chlorine is salt. It was assumed here that this salt is obtained by the mining of rock salt. Rock salt mines are widely distributed throughout the United States, with 17 states reporting production in 1969.[48]

Table 38 shows the environmental impacts from rock salt manufacture. It is clear from this table that the environmental impacts of rock salt mining are relatively small and are mainly off-site effects resulting from the use of electricity.

Caustic Soda and Chlorine Manufacture

Caustic soda (sodium hydroxide) and chlorine are manufactured from salt by an electrolytic process. The aqueous brine (NaCl) solution is electrolyzed to produce caustic soda, chlorine, and hydrogen gas. The chlorine and caustic soda each account for about half the output of the process, with hydrogen amounting to only 1 percent by weight. Therefore, half the impacts of the process are allocated to chlorine production and half to caustic soda production. The impacts allocated to caustic soda and chlorine manufacture are presented in Table 39.

Alumina Refining

Bauxite ore must be refined to nearly pure aluminum oxide (alumina), Al_2O_3, before it can be used in the manufacture of metallic aluminum. Virtually all of the commercially produced alumina is obtained through the Bayer Process. In this process, the beneficiated bauxite is first ground and then digested by caustic soda and lime at elevated temperature and pressure. The resulting sodium aluminate solution is separated from the insoluble tailings (red mud) by countercurrent decantation and filtration. The liquor is cooled until it becomes supersaturated and is then seeded with crystals of aluminum trihydrate. The aluminum in solution is precipitated as the trihydrate and then filtered and washed. Caustic soda, together with the unprecipitated aluminum, is recycled to the digester. The filtered and washed aluminum trihydrate is then calcined to alumina, generally in a rotary kiln.

TABLE 38. MODULE SUMMARY SHEET FOR MINING ROCK SALT

Basis: 1 metric ton of rock salt

	On Site	Off Site	Transportation	Total	Source
WATER DISCHARGED (liters)					9
Process	2178	37		2215	
AIR EMISSIONS (grams)					11
Particulates		64	25	89	
Sufur Oxides	14	36	59	109	
Carbon Monoxide		116	308	424	
Hydrocarbons	3	293	95	391	
Nitrogen Oxides	22	524	187	733	
Aldehydes	0.2		5.7	5.9	
Organics	0.5		13.1	13.6	
WATER POLLUTANTS (grams)					
Dissolved Solids		41		41	
SOLID WASTES (kilograms)					21
Overburden		179		179	
Process	132	8		140	
ENERGY CONSUMPTION					21
Liquid Hydrocarbon fuels (ℓ)	0.5				
Equivalent kcal	5,000				
Natural Gas (m^3)	4.75				
Equivalent kcal	44,400				
Electricity (kw-hr)	94				
Equivalent kcal	279,000				
Total kcal	276,400	2,100	93,500	374,000	
TRANSPORTATION (metric ton-kilometers)					17
Rail	482				
Truck	80				

TABLE 39. MODULE SUMMARY SHEET FOR CAUSTIC SODA OR CHLORINE MANUFACTURE

Basis: 1 metric ton

	On Site	Off Site	Total	Source
MATERIAL INPUTS (kilograms)				17,64
NaCl	1,020		1,020	
WATER DISCHARGED (liters)				17,64
Process	3,678	542	4,220	
Mine Drainage		139	139	
AIR EMISSIONS (grams)				
Particulates		1,503	1,503	
Sulfur Oxides		8,453	8,453	
Carbon Monoxide		1,798	1,798	
Hydrocarbons		4,308	4,308	
Nitrogen Oxides		9,474	9,474	
Aldehydes		28.1	28.1	
Organics		40	40	
WATER POLLUTANTS (grams)				
Suspended Solids		10	10	
Dissolved Solids		865	865	
BOD		10	10	
COD		28	28	
Oil and Grease		6	6	
Iron		2	2	
Phenols		0.6	0.6	
Sulfide		0.6	0.6	
Ammonia		1	1	
SOLID WASTES (kilograms)				
Overburden		3,780	3,780	
Process		166	166	
ENERGY CONSUMPTION				
Electricity (kw-hr)	1,980			
Equivalent kcal	5,894,500			
Total kilocalories	5,894,500		5,894,500	

Table 40 summarizes the environmental impacts associated with alumina production. The particulate emissions result from grinding of bauxite (3 kg/MT bauxite, uncontrolled) and from the calcining of the alumina (100 kg/MT of alumina, uncontrolled). The emissions from grinding operations were assumed to be controlled by baghouses with a 95% collection efficiency. The emissions from the calcining operation were assumed to be controlled by cyclones followed by electrostatic precipitators with overall efficiency of control of 99% in order to recover the valuable alumina. The other air emissions shown in Table 4 result from the on-site combustion of fuel for calcination.

The absence of on-site water effluents is due to 1977 Water Effluent Standards which call for zero discharge of water effluents by the total impoundment of water.[65] The 300 kg of solid wastes are the solids in mud slurries which are discharged in settling ponds for impoundment.

Primary Aluminum Smelting

Primary aluminum is produced by the electrolysis of alumina in a molten bath of cryolite and aluminum fluoride. Carbon anodes are inserted through the surface of the molten bath. The carbon lining of the cell serves as the cathode where the metallic aluminum collects. Anodes are consumed during the reaction at a rate of approximately 600 kg of material per metric ton of aluminum produced.

Two major types of electrolytic cells are the prebake and the Soderberg. Prebake furnaces require an additional facility to bake the anodes before they are used in the furnace. Soderberg cells are classified as horizontal or vertical depending on the arrangement of the steel anode studs in a vertical or horizontal position. The amounts of pollutants emitted from aluminum potlines depends on which of the above types of pots is used. Collection and treatment efficiency also differ depending on the type of potline.

The primary pollution problem at the smelter site is fluoride emissions from the cryolite baths. These occur as both particulate and gaseous atmospheric emissions, and as waterborne wastes when wet scrubbing is used for air pollution control.

The type of plant considered in this module uses a prebake anode cell. The reason for this selection was that industry has not built any new Soderberg plants in recent years because prebake cells are able to achieve higher current efficiencies.[65] Since a prebake plant was chosen as the study plant, it was also necessary to consider the anode bake furnace.

TABLE 40. MODULE SUMMARY SHEET FOR ALUMINA PRODUCTION

Basis: 1 metric ton of alumina

	On Site	Off Site	Transportation	Total	Source
MATERIAL INPUTS (kilograms)					46
Bauxite	2,660			2,660	
Caustic Soda	71			71	
Lime	30			30	
WATER DISCHARGED (liters)					17
Process	2,000	1,226		3,226	
Mine Drainage		4		4	
AIR EMISSIONS (grams)					11,47
Particulates	1,400	123	408	1,931	
Sulfur Oxides	3,125	494	133	3,752	
Carbon Monoxide	6	4,164	289	4,459	
Hydrocarbons	341	11,052	363	11,756	
Nitrogen Oxides	2,531	12,173	540	13,244	
Aldehydes	36	7.2	26.6	70	
Organics	53	2.5	11.4	67	
WATER POLLUTANTS (grams)					
Dissolved Solids		296		296	
BOD		11		11	
COD		36		36	
Oil and Grease		5		5	
Phenols		1		1	
Sulfide		1		1	
Ammonia		1		1	
SOLID WASTES (kilograms)					10
Overburden		105		105	
Process	300	5		305	
ENERGY CONSUMPTION					66
Liquid Hydrocarbon fuels (ℓ)	108				
Equivalent kcal	1,080,000				
Natural Gas (m^3)	473.8				
Equivalent kcal	4,430,000				
Electrical Energy (kw-hr)	55				
Equivalent kcal	163,700				
Total kilocalories	5,673,700	339,100	299,300	6,312,100	
TRANSPORTATION					17
Rail	884				
Water	964				

The air pollution control system for the prebake cell was assumed to be a hood with a collection efficiency of 97%-99% followed by a fluidized bed dry scrubber. No secondary control was assumed to be needed to meet 1975 standards which call for a maximum water soluble fluoride emission of 1 kg/MT (95% of fluorides are water soluble) for the entire primary aluminum smelting plant. Particulate emissions of 1.4 kg/MT aluminum and sulfur oxides of 12 kg/MT aluminum result in this situation.

Control of fluoride, organic and particulate emissions at the Carbon Anode Bake Plant was assumed to be by electrostatic precipitator, a venturi scrubber and a chamber scrubber in series. There was no data quantitatively available on the organic and particulate emissions which result from this control system.

The water pollution control technology needed to achieve 1977 standards involved: (1) Segregation of fluoride-containing waste for treatment including anode bake furnace scrubber water, water resulting from cryolite recovery from potlinings, used cathode disposal liquor and runoff from used-cathode storage area. (Scrubber water from potlines and potroom did not exist in our case because dry scrubbing was used. However, the water standards are the same for any air pollution control system.); (2) Recycling clarified liquor after precipitation of calcium fluoride cryolite; (3) Minimizing the volume of the bleed stream; and (4) Providing a holding pond or lagoon if necessary to accomplish further settling of solids in the bleed stream and providing aeration of the lagoon to accomplish oxidation of oil and grease, if necessary.[65]

The standards for 1977 are written for fluorides, suspended solids, and oil and grease. The other on-site water effluents shown in Table 41 are assumed to be uncontrolled and are an average from plants sampled in the effluent guidelines study.

It can be seen from Table 41 that although there are significant pollution problems at the smelter site, most of the impacts in the categories of atmospheric emissions, and solid wastes result from the generation of electricity and the mining of coal for fuel in electrical generation. It is clear, therefore, that the extremely high electrical requirement is the overriding environmental concern in aluminum smelting operations.

The emission factors for electrical generation--which are used for every system in this study--are based on a national average mix of fuels for electrical generation. It is true that the aluminum industry uses a relatively high proportion of hydroelectric power.

TABLE 41. MODULE SUMMARY SHEET FOR PRIMARY ALUMINUM SMELTING

Basis: 1 metric ton of wrought or cast aluminum ingot

	On Site	Off Site	Total	Source
MATERIAL INPUTS (kilograms)				46
Alumina	1,930		1,930	
Cryolite	10		10	
Aluminum Fluoride	40		40	
Fluorspar	50		50	
WATER DISCHARGED (liters)				17
Process	145,500	7,086	152,586	
Mine Drainage		1,025	1,025	
AIR EMISSIONS (grams)				11,67
Particulates	3,980	11,050	15,030	
Sulfur Oxides	19,449	59,867	79,316	
Carbon Monoxide	103	23,318	23,321	
Hydrocarbons	799	58,370	59,169	
Nitrogen Oxides	9,264	96,327	105,591	
Aldehydes	59	228	287	
Organics	77	35	112	
Fluorides	1,050		1,050	
WATER POLLUTANTS (grams)				65
Suspended Solids	1,500	95	1,595	
Dissolved Solids	11,670	6,312	17,982	
BOD	--	129	129	
COD	660	364	1,024	
Oil and Grease	250	67	317	
Iron	--	14	14	
Phenols	67	8	75	
Sulfide	--	8	8	
Ammonia	--	13	13	
Cyanide	3		3	
Fluoride	1,000		1,000	
SOLID WASTES (kilograms)				68
Overburden		27,929	27,929	
Process	25	1,195	1,220	
ENERGY CONSUMPTION				21
Coal (kg)	190			
Equivalent kcal	1,290,000			
Liquid Hydrocarbon fuels (ℓ)	7.5			
Equivalent kcal	74,000			
Natural Gas (m^3)	1,200			
Equivalent kcal	11,220,000			
Electricity (kw-hr)	13,800			
Equivalent kcal	41,082,600			
Other Fuels kcal	28,000			
Carbon electrodies (kg)	595			
Equivalent kcal	4,750,000			
Total kilocalories	58,444,600	801,000	59,245,600	

It is our judgment, however, that a study such as this should not distinguish between different "kinds" of kilowatt hours, since if the hydroelectric power were not used by the aluminum industry, it would be available as an alternative to power generated with fossil fuels. In cases where electricity is generated by the aluminum companies for captive use in their plants, the power is not included in the electrical energy category. Rather, the fuels used to generate that power are included separately.

Aluminum from Recycled Materials

There is essentially no difference between secondary aluminum metal and primary metal as long as the composition is the same. However, there is a problem in producing secondary metal having the same degree of purity as primary metal. The basis of this problem is that it is difficult and uneconomic to remove metallic impurities, except for magnesium, from aluminum by the usual melting and refining. Hence, the quality and type of aluminum scrap used largely determines the alloy produced by the scrap consumer. The essential consequence of these technological limitations is that the use of secondary aluminum is usually limited to the manufacture of castings.

Aluminum end products are classified into two main classes: (a) wrought products such as sheet, plate, rolled and continuous cast rod and bars, wire, extrusions and forging; and (b) castings, including sand, permanent mold and die castings. In general, wrought products require a lower degree of impurities than cast products because common alloying agents such as copper and silicon reduce the ductility of aluminum. However, if scrap from one type of wrought product can be segregated, the scrap can be remelted into ingots which can be used to produce more of that wrought product.

Aluminum scrap from autos and aluminum cans was assumed in this study to be used in three ways by the aluminum industry: (1) Aluminum cans remelted into wrought ingots that may be used to produce more cans, (2) Aluminum scrap from municipal solid wastes remelted into a low magnesium content casting alloy and, (3) Aluminum scrap from junk autos remelted into a low magnesium content casting alloy.

According to secondary aluminum sources, the recovery rate of aluminum is approximately 95% from heavy scrap (auto scrap) and 87% from scrap cans.[69] The scrap inputs for all the secondary aluminum modules reflect these figures. It was also assumed that the amount of flux required for melting is 10% of the scrap charge. Although fluxes usually average 47.5% NaCl, 47.5% KCl and 5% cryolite, it was assumed in this study that the flux is composed only of NaCl (rock salt).

Aluminum Cans to Wrought Ingots

Obsolete aluminum cans can be remelted into wrought aluminum ingots which can be used to produce more cans. Figure 6 shows the system assumed necessary in this case. Cans from separate can collection or from municipal solid waste were assumed to be remelted by a secondary aluminum smelter. All of the modules in this system, except the secondary aluminum smelter, have been described in earlier sections.

Secondary Aluminum Smelting: Wrought Ingots. Aluminum cans may be remelted into wrought ingots by either a primary aluminum smelter or a secondary aluminum smelter. In either case, the environmental impacts are considered to be the same. Upon arrival of the shredded cans at the smelter, the scrap is unloaded to storage, retrieved from storage, delacquered in a furnace, and then remelted, blended and refined, and cast into wrought ingots. The energy requirements shown in Table 42 are for the above steps. It can also be seen from this table that only 4 kg of chlorine are required to produce one metric ton of secondary aluminum. This small chlorine requirement is due to the fact that chlorine is only required for degassing the aluminum. It was assumed that no chlorine is required to "demag" the aluminum because the scrap cans are being used to produce more cans.

The on-site air emissions shown in Table 42 result from the combustion of fuels to fire the delacquering and remelting furnaces, particulates from these furnaces and chlorides from the degassing operation. The scrap cleaning furnace and the melting furnace are assumed to emit 7.3 and 2.15 kilograms of particulates per metric ton of secondary aluminum produced.(11) Both these sources were assumed to be controlled by baghouses or wet scrubbers with a 90% efficiency of control.(70,71) Degassing operations were assumed to emit 2 kilograms of chlorides per metric ton of aluminum,(11) which can be controlled with a 90% efficiency by alkaline wet scrubbers.(70)

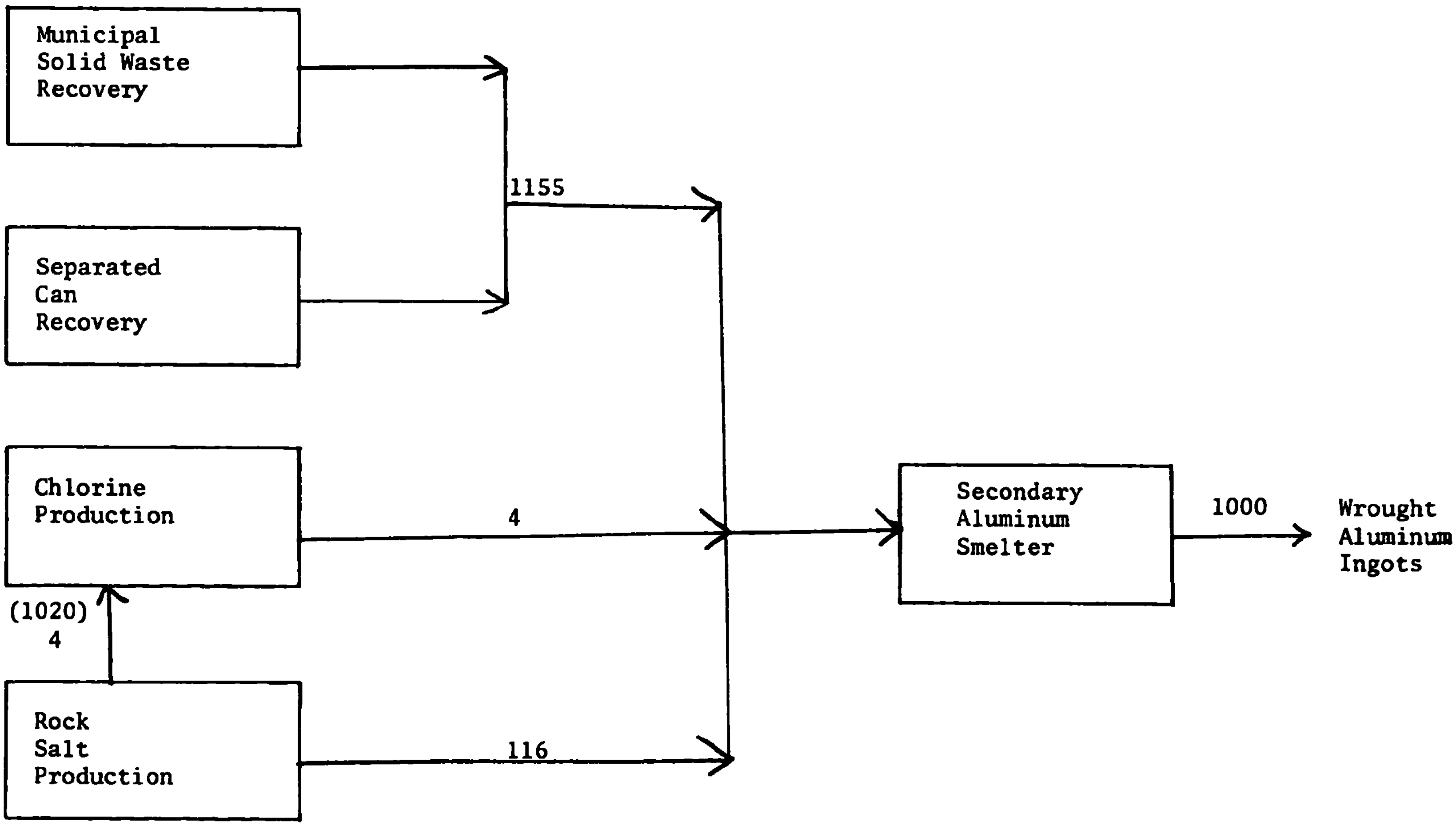
The on-site water effluents shown are those which will result when the 1977 Water Effluent Standards are met.(65) These standards for discharges from fume scrubbing processes are said to be achievable by neutralization, precipitation, supernatant recycle and solid fluoride removal.

The on-site solid wastes were determined by performing a material balance on the input materials.

FIGURE 6. SHEET ALUMINUM PRODUCTION FROM ALUMINUM CANS

SYSTEM A2 INCLUDES MUNICIPAL SOLID WASTE RECOVERY

SYSTEM A3 INCLUDES SEPARATED CAN RECOVERY



Numbers are kilograms of product required to produce one metric ton of aluminum.
Number in parentheses is kilograms of rock salt required to produce one metric ton of chlorine.

TABLE 42. MODULE SUMMARY SHEET FOR SECONDARY ALUMINUM SMELTING (CANS TO SHEET)

Basis: 1 metric ton wrought aluminum

	On Site	Off Site	Total	Source
MATERIAL INPUTS (kilograms)				69
Scrap aluminum	1,155		1,155	
Fluxes	116		116	
Chlorine	4		4	
WATER DISCHARGED (liters)				17
Process	3,344	479	3,823	
AIR EMISSIONS (grams)				11,70,71
Particulates	1,007	50	1,057	
Sulfur Oxides		200	200	
Carbon Monoxide		1,685	1,685	
Hydrocarbons	125	4,483	4,608	
Nitrogen Oxides	722	4,994	5,716	
Aldehydes	9	1	10	
Organics	22	1	23	
Chlorides	200		200	
WATER POLLUTANTS (grams)				65
Suspended Solids	175		175	
Dissolved Solids	500	12	512	
Chloride	340		340	
Cyanide	0.02		0.02	
Cadmium	0.004		0.004	
Lead	0.008		0.008	
Manganese	0.009		0.009	
SOLID WASTES (kilograms)				
Overburden		53	53	
Process	273	2	275	
ENERGY CONSUMPTION				46
Liquid Hydrocarbon Fuels (ℓ)	1.05			
Equivalent kcal	9,800			
Natural Gas (m^3)	195			
Equivalent kcal	1,820,000			
Electricity (kw-hr)	28			
Equivalent kcal	83,400			
Total kilocalories	1,913,200	87,700	2,000,900	

Aluminum Scrap from MSW to a Low Mg Casting Alloy

Figure 7 shows the combination of modules necessary to produce a low magnesium cast aluminum ingot from municipal solid waste. The primary difference between this system and the one considered in the preceding section is the large amount of chlorine required for demagging operations.

Secondary Aluminum Smelting: High Mg Scrap to Low Mg Casting Alloy. If the aluminum scrap received from the municipal solid waste recovery center is of the composition that it is impossible to further segregate the scrap so that wrought aluminum can be produced, then the magnesium content must be reduced from 4.5% to an acceptable limit of 0.1% in casting alloys.[72] Approximately 4 kg of chlorine are required to remove 1 kg of magnesium, 3 kg of which react with the magnesium and 1 kg of which reacts with aluminum.[70]

From Table 43, it can be seen that 180 kg of chlorine were assumed to be necessary to produce one metric ton of a low magnesium casting aluminum ingot. Since approximately 500 kg of particulate emissions result for each metric ton of chlorine used, [73] and these emissions are controlled with a 90% efficiency,[70] the chlorine emissions are 9 kg/MT of aluminum.

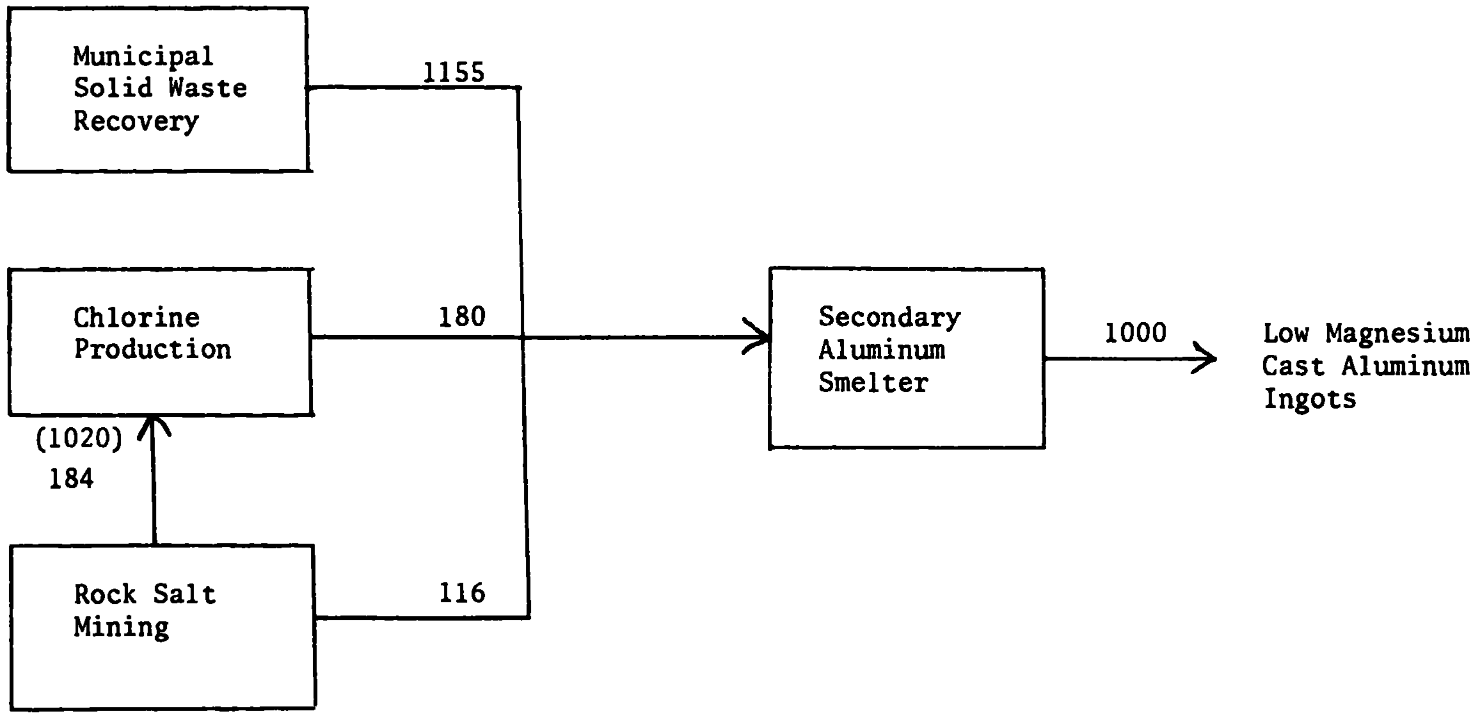
It can also be seen from Table 43 that the water effluents have increased when compared to those of the preceding section. This increase is due to the fact that the effluent guidelines are written in terms of the amount of chlorine used.

Aluminum Scrap from Junk Autos to a Low Mg Casting Alloy

Figure 8 shows the combination of modules necessary to produce a low magnesium cast aluminum ingot from aluminum scrap from junk autos. This system differs from the two preceding aluminum recycle systems in the amounts of scrap, chlorine, and fluxes required.

Secondary Aluminum Smelting: Normal Operations. The aluminum received from auto scrap processors was assumed to be of such a quality that it contains only 0.5% of magnesium which needs to be removed. From Table 44, it can be seen that 20 kilograms of chlorine are required per metric ton of aluminum produced. This chlorine use results in 10 kg of chlorine

FIGURE 7. CAST ALUMINUM PRODUCTION FROM MUNICIPAL SOLID WASTE
SYSTEM A4



NUMBERS ARE KILOGRAMS OF PRODUCT REQUIRED TO PRODUCE ONE METRIC TON OF ALUMINUM.

NUMBER IN PARENTHESES IS KILOGRAMS OF ROCK SALT REQUIRED TO PRODUCE ONE METRIC TON OF CHLORINE.

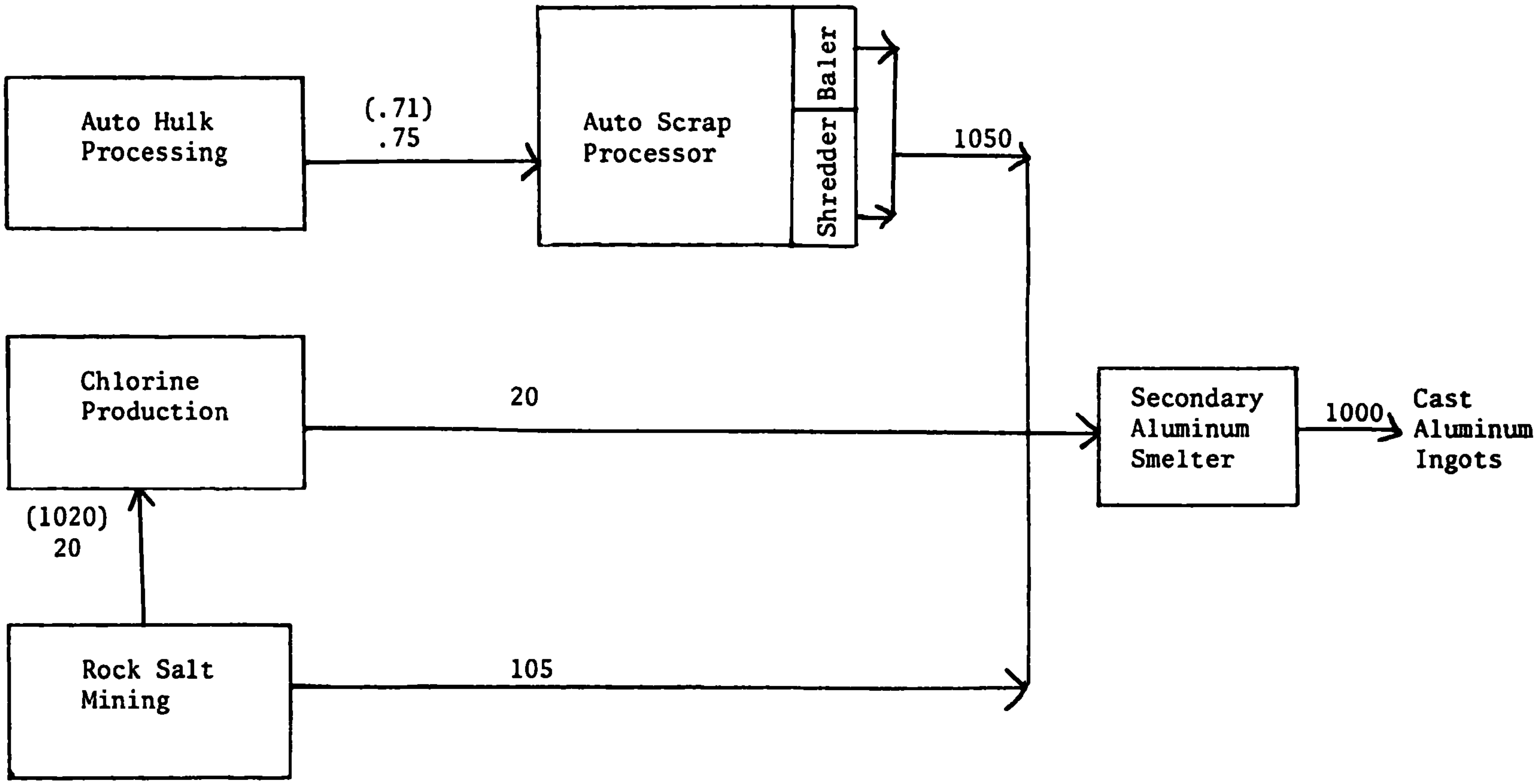
TABLE 43. MODULE SUMMARY SHEET FOR SECONDARY ALUMINUM SMELTING (CANS TO LOW Mg ALLOY)

Basis: 1 metric ton of cast aluminum ingot

	On Site	Off Site	Total	Source
MATERIAL INPUTS				69
Scrap Aluminum	1,155		1,155	
Fluxes	116		116	
Chlorine	180		180	
WATER DISCHARGED				17
Process Water	3,344	479	3,823	
AIR EMISSIONS (grams)				11,70,71
Particulates	1,007	50	1,057	
Sulfur Oxides		200	200	
Carbon Monoxide		1,685	1,685	
Hydrocarbons	125	4,483	4,608	
Nitrogen Oxides	722	4,994	5,716	
Aldehydes	9	1	10	
Organics	22	1	23	
Chlorides	9,000		9,000	
WATER POLLUTANTS (grams)				65
Suspended Solids	7,875		7,875	
Dissolved Solids	22,500	12	22,512	
Chloride	15,300		15,300	
Cyanide	0.9		0.9	
Cadmium	0.18		0.18	
Lead	0.36		0.36	
Manganese				
SOLID WASTES (kilograms)				
Overburden		53	53	
Process	405	2	407	
ENERGY CONSUMPTION				46
Liquid Hydrocarbon Fuels (ℓ)	1.05			
Equivalent kcal	9,800			
Natural Gas (m^3)	195			
Equivalent kcal	1,820,000			
Electricity (kw-hr)	28			
Equivalent kcal	83,400			
Total kilocalories	1,913,200	87,700	2,000,900	

FIGURE 8. CAST ALUMINUM PRODUCTION FROM AUTO SCRAP

SYSTEM A5 INCLUDES SHREDDING
SYSTEM A6 INCLUDES BALING



NUMBERS ARE KILOGRAMS OF PRODUCT REQUIRED TO PRODUCE ONE METRIC TON OF ALUMINUM.

NUMBER IN PARENTHESES IS KILOGRAMS OF ROCK SALT REQUIRED TO PRODUCE ONE METRIC TON OF CHLORINE.

TABLE 44. MODULE SUMMARY SHEET FOR SECONDARY ALUMINUM SMELTING (AUTO SCRAP)

Basis: 1 metric ton cast aluminum ingot

	On Site	Off Site	Total	Source
MATERIAL INPUTS (kilograms)				69
Scrap Aluminum	1,050		1,050	
Fluxes	105		105	
Chlorine	20		20	
WATER DISCHARGED (liters)				17
Process Water	3,344	479	3,823	
AIR EMISSIONS (grams)				11,70,71
Particulates	1,007	50	1,057	
Sulfur Oxides		200	200	
Carbon Monoxide		1,685	1,685	
Hydrocarbons	125	4,483	4,608	
Nitrogen Oxides	722	4,994	5,716	
Aldehydes	9	1	10	
Organics	22	1	23	
Chlorides	1,000		1,000	
WATER POLLUTANTS (grams)				65
Suspended Solids	875		875	
Dissolved Solids	2,500	12	2,512	
Chloride	1,700		1,700	
Cyanide	0.1		0.1	
Cadmium	0.02		0.02	
Lead	0.04		0.04	
Manganese	0.045		0.045	
SOLID WASTES (kilograms)				
Overburden		53	53	
Process	170	2	172	
ENERGY CONSUMPTION				
Liquid Hydrocarbon Fuels (ℓ)	1.05			
Equivalent kcal	9,800			
Natural Gas (m^3)	195			
Equivalent kcal	1,820,000			
Electricity (kw-hr)	28			
Equivalent kcal	83,400			
Total kilocalories	1,913,200		2,000,900	

emissions before control and 1 kg of chlorine emissions after 90% control. The water effluents shown in Table 44 result if 1977 water standards, which are based on chlorine use, are met. The on-site solid wastes shown in this table were determined by performing a mass balance on input and output materials.

Aluminum Systems Synthesis

This section summarizes the environmental impacts of six systems which produce wrought and/or cast aluminum products. The total impacts for each system were determined using the detailed information contained in the module summaries and known yield data, the kilograms of output from each module necessary to produce one metric ton of aluminum as shown in the detailed flow charts (Figures 5, 6, 7 and 8).

Aluminum Production from Virgin Materials

Figure 5 shows the processes necessary to produce aluminum from virgin materials. This figure also shows the quantity of material from each module which is required to produce one metric ton of wrought or cast aluminum ingots. Table 45 shows the environmental impacts which result from the individual modules in the production of one metric ton of aluminum. The totals shown in the last column of this table are the cumulative impacts of the individual modules, the impacts of the whole system. In the case where an intermediate product, such as alumina is produced, it is shown as an output from alumina production and an input to the primary aluminum smelter. The net effect is that alumina is not treated as a material input to the system, rather the bauxite which was consumed to produce the alumina is the material input to the system.

It can be seen from Table 45 that primary aluminum smelting accounts for most of the air emissions, water pollutants and solid wastes which result from the production of aluminum by System A1. Primary aluminum smelting also accounts for 79% of the total energy and 95% of total water consumed by the system.

Wrought Aluminum Production from Aluminum Cans

Figure 6 shows the modules and the quantity of output from the modules which are necessary to produce one metric ton of wrought aluminum ingots from used aluminum cans. It can be seen from this figure that two systems are considered as sources of aluminum cans: System A2 which includes municipal solid waste recovery and System A3 which includes separated aluminum can recovery.

Table 45 SUMMARY SHEET FOR ALUMINUM PRODUCTION USING VIRGIN MATERIALS (SYSTEM A1)

Basis 1 metric ton of aluminum ingot · wrought or cast

	Limestone Quarrying	Lime Production	Rock Salt Mining	Caustic Soda Production	Bauxite Mining	Alumina Production	Primary Aluminum Smelting	Total
MATERIAL INPUTS								
Limestone		115.8						115.8
Lime		- 57.9				57.9		
Rock Salt				139.7				139.7
Caustic Soda				- 137		137		
Bauxite						5,134		5,134
Alumina						- 1,930	1,930	
Aluminum Fluoride							40	40
Cryolite							10	10
Fluorspar							50	50
WATER DISCHARGED (liters)								
Process	7	67	309	578	493	6,226	152,586	160,266
Mine Drainage	37	2		19		8	1,025	1,091
AIR EMISSIONS								
Particulates	316	385	12	206	16,978	3,727	15,030	36,654
Sulfur Oxides	5	216	15	1,158	652	7,241	79,316	88,603
Carbon Monoxide	26	48	59	246	2,377	8,606	23,321	34,684
Hydrocarbons	11	80	55	590	4,210	22,689	59,169	86,804
Nitrogen Oxides	19	153	102	1,298	5,904	25,561	105,591	138,628
Aldehydes	0	1	1	4	183	135	287	611
Organics	1	1	2	1	20	129	112	265
Fluorides							1,050	1,050
WATER POLLUTANTS (grams)								
Suspended Solids							1,595	1,595
Dissolved Solids		8		6	119	571	17,982	18,567
BOD						21	129	150
COD						69	1,024	1,093
Oil and Grease						10	317	327
Iron							14	14
Phenols						2	75	77
Sulfide						2	8	10
Ammonia						2	13	15
Cyanide							3	3
Fluoride							1,000	1,000
SOLID WASTES (kilograms)								
Overburden	1	47	25	518	77	203	27,929	28,800
Process	9	12	20	23	13,605	589	1,220	15,478
ENERGY (kilocalories)	6,700	77,400	52,200	807,600	2,458,700	12,182,400	59,245,600	74,830,600

Tables 46 and 47 show the environmental impacts which result from the production of one metric ton of wrought aluminum using scrap aluminum cans by Systems A2 and A3, respectively. It may be seen from these tables that the secondary aluminum smelter is the primary cause of most of the environmental impacts from these systems.

Cast Aluminum Production from MSW Aluminum Scrap

Figure 7 shows the modules and the quantity of output from the modules which are necessary to produce one metric ton of cast aluminum ingots from municipal solid waste. Table 48 summarizes the environmental impacts which result from the production of one metric ton of cast aluminum ingots by this system. It can be seen from this table that the secondary aluminum smelter is the greatest source of impacts from this system. However, chlorine production is also a large source of air emissions and solid wastes due to the large electrical requirements for the process.

Cast Aluminum Production from Auto Scrap

Figure 8 shows the modules and the quantity of output from each module which are necessary to produce one metric ton of cast aluminum from auto scrap. It can be seen from this figure that a stripped auto hulk may either be processed into scrap by a shredding operation (System A5) or a baling and incineration operation (System A6). Tables 49 and 50 show the environmental impact which results from the production of one metric ton of cast aluminum by these systems. It may be seen from these tables that secondary aluminum smelting is the primary source of impacts from these systems.

Environmental Impact Comparison

Six systems have been considered for the production of aluminum ingots in this study. However, it was seen in the previous section that these six systems could be classified in four groups:

I. Aluminum Production from Virgin Materials (System A1)
II. Wrought Aluminum Production from Aluminum Cans (Systems A2 and A3)
III. Cast Aluminum Production from MSW (System A4)
IV. Cast Aluminum Production from Auto Scrap (Systems A5 and A6)

Since the environmental impacts of these systems does not very much within a group, the most meaningful comparisons of systems using virgin and recycled materials will be realized if System A1 is compared with Systems A2 and A3, with System A4 and with Systems A5 and A6.

Table 46. Summary Sheet for Wrought Aluminum Production Using Scrap Aluminum Cans from MSWR System A2

Basis: 1 metric ton of Wrought Aluminum

	MSWR	Chlorine Production	Rock Salt Mining	Secondary Aluminum Smelter	Total
MATERIAL INPUTS (kilograms)					
Scrap Aluminum				1,155	1,155
Fluxes (NaCl)		4		116	120
Chlorine		- 4		4	
WATER DISCHARGED (liters)					
Process	35	17	266	3,823	4,141
Mine Drainage	9	1			10
AIR EMISSIONS (grams)					
Particulates	353	6	11	1,057	1,427
Sulfur Oxides	596	34	13	200	843
Carbon Monoxide	690	7	51	1,685	2,433
Hydrocarbons	422	17	47	4,608	5,096
Nitrogen Oxide	919	38	88	5,716	6,761
Aldehydes	10		1	10	21
Organics	21		2	23	46
Chlorides				200	200
WATER POLLUTANTS (grams)					
Suspended Solids				175	175
Dissolved Solids	55	3	5	512	575
Chloride				340	340
Cyanide				0.02	0.02
Cadmium				0.004	0.004
Lead				0.008	0.008
Manganese				0.009	0.009
SOLID WASTES (kilograms)					
Overburden	240	15	21	53	329
Processing	299	1	17	275	592
Post Consumer	- 1,444				- 1,444
ENERGY CONSUMPTION (Thousand kilocalories)	491.2	23.6	44.9	2,000.9	2,560.6

Table 47. Summary Sheet for Wrought Aluminum Production Using Scrap Aluminum Cans Collected Separately System A3

Basis: 1 metric ton of Wrought Aluminum

	Separated Can	Chlorine Production	Rock Salt Mining	Secondary Aluminum Smelter	Total
MATERIAL INPUTS (kilograms)					
Scrap Aluminum				1,155	1,155
Fluxes (NaCl)		4		116	120
Chlorine		- 4		4	
WATER DISCHARGED (liters)					
Process	27	17	266	3,823	4,133
Mine Drainage	7	1			8
AIR EMISSIONS (grams)					
Particulates	99	6	11	1,057	1,173
Sulfur Oxides	468	34	13	200	715
Carbon Monoxide	662	7	51	1,685	2,405
Hydrocarbons	357	17	47	4,608	5,029
Nitrogen Oxide	776	38	88	5,716	6,618
Aldehydes	9		1	10	20
Organics	21		2	23	46
Chloride				200	200
WATER POLLUTANTS (grams)					
Suspended Solids				175	175
Dissolved Solids	42	3	5	512	562
Chloride				340	340
Cyanide				0.02	0.02
Cadmium				0.004	0.004
Lead				0.008	0.008
Manganese				0.009	0.009
SOLID WASTES (kilograms)					
Overburden	182	15	21	53	271
Processing	8	1	17	275	301
Post-consumer	- 1,155				- 1,155
ENERGY CONSUMPTION (Thousand kilocalories)	402.2	23.6	44.9	2,000.9	2,471.6

TABLE 48. SUMMARY SHEET FOR CAST ALUMINUM INGOTS BY A SECONDARY SMELTER USING SCRAP ALUMINUM CANS FROM MSWR:SYSTEM A4

Basis: 1 metric ton of cast aluminum

	MSWR	Chlorine Production	Rock Salt Mining	Secondary Aluminum Smelter	Total
MATERIAL INPUTS (kilograms)					
Scrap Aluminum				1,155	1,155
Fluxes (NaCl)		184		166	300
Chlorine		- 180		180	
WATER DISCHARGED (liters)					
Process	35	760	665	3,823	5,283
Mine Drainage	9	25			34
AIR EMISSIONS (grams)					
Particulates	353	270	27	1,057	1,707
Sulfur Oxides	596	1,522	35	200	2,351
Carbon Monoxide	690	324	127	1,635	2,826
Hydrocarbons	422	775	117	4,508	5.922
Nitrogen Oxide	919	1,705	220	5,716	8,560
Aldehydes	10	5	2	10	27
Organics	21	1	4	23	49
Chlorides				9,000	9,000
WATER POLLUTANTS (grams)					
Suspended Solids		2		7,875	7,877
Dissolved Solids	55	156	12	22,512	22,735
Chloride				15,300	15,300
Cyanide				0.9	0.9
Cadmium				0.18	0.18
Lead				0.36	0.36
Manganese				0.41	0.41
SOLID WASTES (kilograms)					
Overburden	240	680	54	53	1,027
Processing	299	30	42	407	778
Post-consumer	- 1,444				- 1,444
ENERGY CONSUMPTION (Thousand kilocalories)	491.2	1,061.0	112.2	2,000.9	3,665.3

TABLE 49. SUMMARY SHEET FOR CAST ALUMINUM INGOTS BY A SECONDARY SMELTER USING ALUMINUM AUTO SCRAP FROM A SHREDDER: SYSTEM A5

Basis 1 metric ton of cast aluminum

	Auto Hulk Processor	Auto Scrap Processor	Chlorine Production	Rock Salt Mining	Secondary Aluminum Smelting	Total
MATERIAL INPUTS (kilograms)						
Scrap Aluminum					1,050	1,050
Fluxes (NaCl)			20		105	125
Chlorine			- 20		20	
WATER DISCHARGED						
Process		9	84	277	3,825	4,193
Mine Drainage		2	3			5
AIR EMISSIONS (grams)						
Particulates	12	56	30	11	1,057	1,166
Sulfur Oxides	20	259	169	14	200	662
Carbon Monoxide	1,146	555	36	53	1,685	3,475
Hydrocarbons	248	214	86	49	4,608	5,205
Nitrogen Oxide	293	460	190	92	5,716	6,751
Aldehydes	7	21	1	1	10	40
Organics	14	19		2	23	58
Chlorides					1,000	1,000
WATER POLLUTANTS (grams)						
Suspended Solids					875	875
Dissolved Solids		15	17		2,512	2,544
Chloride					1,700	1,700
Cyanide					0.1	0.1
Cadmium					0. 2	0 02
Lead					0.04	0.04
Manganese					0.045	0.045
SOLID WASTES (kilograms)						
Overburden		67	76	22	53	218
Process		102	3	18	172	295
Post-consumer	- 1,149					- 1,149
ENERGY CONSUMPTION (Thousand kilocalories)	61.9	230.6	117.9	46.8	2,000.9	2,458 1

TABLE 50 SUMMARY SHEET FOR CAST ALUMINUM INGOTS BY A SECONDARY SMELTER USING ALUMINUM AUTO SCRAP FROM A BALER; SYSTEM A6

Basis 1 metric ton of cast aluminum

	Auto Hulk Processor	Auto Scrap Processor	Chlorine Production	Rock Salt Mining	Secondary Aluminum Smelting	Total
MATERIAL INPUTS (kilograms)						
Scrap Aluminum					1,050	1,050
Fluxes (NaCl)			20		105	125
Chlorine			- 20		20	
WATER DISCHARGED						
Process		45	84	277	3,825	4,231
Mine Drainage		2	3			5
AIR EMISSIONS (grams)						
Particulates	12	563	30	11	1,057	1,673
Sulfur Oxides	20	184	169	14	200	587
Carbon Monoxide	1,146	671	36	53	1,685	3,591
Hydrocarbons	248	592	86	49	4,608	5,497
Nitrogen Oxide	293	347	190	92	5,716	6,638
Aldehydes	7	32	1	1	10	51
Organics	14	156		2	23	195
Chlorides					1,000	1,000
WATER POLLUTANTS (grams)						
Suspended Solids					875	875
Dissolved Solids		34	17		2,512	2,573
Chloride					1,700	1,700
Cyanide					0.1	0.1
Cadmium					0.02	0.02
Lead					0.04	0.04
Manganese					0.045	0.045
SOLID WASTES (kilograms)						
Overburden		53	76	22	53	204
Process		17	3	18	172	210
Post-consumer	- 1,149					- 1,149
ENERGY CONSUMPTION (Thousand kilocalories)	61 9	415.3	117 9	46.8	2,000 9	2,642.8

System A1 vs Systems A2 and A3

Table 51 shows the environmental impacts which result from the production of one metric ton of wrought aluminum from virgin materials (System A1) and from scrap aluminum cans (Systems A2 and A3). It may be seen from this table that Systems A2 and A3 reduce raw materials consumed by 5370 kilograms (98%), water discharged by at least 157,206 liters (97%), and energy consumption by at least 72,270,000 kilocalories (97%) when compared to System A1.

It can also be seen from Table 51 that Systems A2 and A3 also reduce air emissions by 370.4 kilograms (96%) as compared to System A1. The only increase in air emissions produced by Systems A2 and A3 are the chloride emissions. However, the environmental impact of 200 grams of chlorides is no worse than 1050 grams of fluoride. From Table 51 it can be seen that water pollutants are reduced 21.76 kilograms (95%) by Systems A2 and A3. Again, there are increases in some pollutants. However, these increases are very minimal. Solid wastes are reduced from 44,278 kilograms for System A1 to -523 or -583 kilograms for Systems A2 and A3. Therefore, instead of producing solid wastes, Systems A2 and A3 remove solid waste from the environment.

In summary, wrought aluminum production from scrap aluminum cans has minimal environmental impacts when compared to wrought aluminum production from virgin materials. A comparison of aluminum production using scrap aluminum cans from MSW (System A2) to scrap aluminum cans collected separately (System A3) shows the separated can collection to be slightly superior.

System A1 vs System A4

Table 51 shows the environmental impacts which result from the production of one metric ton of cast aluminum from virgin materials (System A1) and from municipal solid waste scrap (System A4). It can be seen from this table that System A4 reduces raw material consumption by 5190 kilograms (95%), water discharged by 156040 liters (97%), energy consumption by 71,165,300 kilocalories (95%); and solid wastes by 43,917 kilograms (99%) when compared to System A4.

It can also be seen from Table 51 that System A4 reduces air emissions by 356,821 grams (92%). However, System A4 produces 9000 grams of chlorides at the site of the secondary aluminum smelter which is usually located in urban areas. Water pollutants are increased 23,063 grams (101%) by System A4 and 15,300 grams of this increase are chloride.

In summary, it can be seen that cast aluminum production from MSW scrap (System A4) greatly reduces raw materials consumption, water discharged, energy consumption, solid wastes and air emissions when compared to cast aluminum production from virgin materials (System A1). However, increases

TABLE 51. COMPARISON OF ENVIRONMENTAL IMPACTS FOR THE PRODUCTION OF ALUMINUM USING VIRGIN OR RECYCLED MATERIALS

Basis: 1 Metric Ton of Aluminum, Wrought and/or Cast Ingots

	A1 Virgin Materials to Wrought or Cast Ingots	A2 MSW Scrap to Wrought Ingots	A3 Separated Aluminum Cans to Wrought Ingots	A4 MSW Scrap to Cast Ingots	A5 Shredder Scrap to Cast Ingots	A6 Baler Scrap to Cast Ingots
MATERIAL INPUTS (kilograms)						
Total Raw Materials	5,489.5	120	120	300	125	125
Bauxite	5,134					
Limestone	115.8					
NaCl	139.7	120	120	300	125	125
Aluminum Fluoride	40					
Cryolite	10					
Fluorspar	50					
Scrap		1,155	1,155	1,155	1,050	1,050
WATER DISCHARGED (liters)	161,357	4,151	4,141	5,317	4,198	4,236
Process	160,266	4,141	4,133	5,283	4,193	4,231
Mine Drainage	1,091	10	8	34	5	5
AIR EMISSIONS (grams)	387,263	16,827	16,206	30,442	18,357	19,232
Particulates	36,654	1,427	1,173	1,707	1,166	1,673
Sulfur Oxides	88,603	843	715	2,351	662	587
Carbon Monoxides	34,648	2,433	2,405	2,826	3,475	3,591
Hydrocarbons	86,804	5,096	5,029	5,922	5,205	5,497
Nitrogen Oxides	138,628	6,761	6,618	8,560	6,751	6,638
Aldehydes	611	21	20	27	40	51
Organics	265	46	46	49	58	195
Fluorides	1,050					
Chlorides		200	200	9,000	1,000	1,000
WATER POLLUTANTS	22,851	1,090	1,077	45,914	5,119	5,148
Suspended Solids	1,595	175	175	7,877	875	875
Dissolved Solids	18,567	575	562	22,735	2,544	2,573
BOD	150					
COD	1,093					
Oil and Grease	327					
Iron	14					
Phenols	77					
Sulfide	10					
Ammonia	15					
Cyanide	3	0.02	0.02	0.9	0.1	0.1
Cadmium		0.004	0.004	0.18	0.02	0.02
Lead		0.008	0.008	0.36	0.04	0.04
Manganese		0.009	0.009	0.41	0.045	0.045
Fluoride	1,000					
Chloride		340	340	15,300	1,700	1,700
SOLID WASTES (kilograms)	44,278	- 523	- 583	361	- 632	- 735
Overburden	28,800	329	271	1,027	218	204
Processing	15,478	592	301	778	295	210
Post-consumer		- 1,444	- 1,155	- 1,444	- 1,145	-1,149
ENERGY CONSUMPTION (Thousand kilocalories)	74,830.6	2,560.6	2,471.6	3,665.3	2,458.1	2,642.8

in chloride emissions and water pollutants are two problems associated with System A4. Although it would be more desirable to produce cast aluminum from MSW scrap than virgin materials, MSW scrap can be used with less impacts by System A2 if converted into wrought aluminum, and cast aluminum ingots can be produced from auto scrap by Systems A5 and A6 with fewer impacts.

System A1 vs Systems A5 and A6

Table 51 shows the environmental impacts which result from the production of one metric ton of cast aluminum from virgin materials (System A1) and from auto scrap (Systems A5 and A6). It can be seen from this table that Systems A5 and A6 reduce raw materials consumed by 5,365 kilograms (98%), water discharged by at least 157,121 liters (97%), and energy consumed by at least 72,188,000 kilocalories (96%).

Systems A5 and A6 also effect a net removal of 632 to 735 kilograms of solid wastes from the environment while System A1 produces 44,278 kilograms of solid waste. It can be also seen from Table 51 that air emissions are reduced by at least 368 kilograms (95%) by Systems A5 and A6, while water pollutants are reduced at least 17.7 kilograms (77%). The chloride air and water emission from Systems A5 and A6 compare to the fluoride emissions from System A1.

In summary, cast aluminum production from auto scrap (Systems A5 and A6) results in minimal environmental impacts when compared to cast aluminum production from virgin materials (System A1). The comparison of Systems A5 and A6 with each other shows the two systems to have roughly equivalent impacts.

Pollution Control Costs for Aluminum

An assumption basic to this study was that 1975 Air Standards and 1977 Water Standards would be met. Air emissions and water effluents were reported with this premise in mind. However, there is a real dollar cost to industry in meeting these standards. When sufficient data were available, cost estimates for meeting the standards were developed for each module. However, there were not sufficient data available to determine the total cost of meeting the standards for each system studied. Therefore, in order to keep the cost data comparable for all the systems, cost estimates were only developed for the direct cost to the primary and secondary aluminum industries in meeting 1975 Air Standards and 1977 Water Standards.

Table 52 summarizes the pollution control costs for aluminum production. The costs shown in this table are the net annual costs per metric ton

Table 52. Pollution Control Costs for Aluminum: Net Annual Cost

	Unit Costs	Cost to System A1 $/MT of aluminum	Cost to Systems A2, A3, A4, A5 and A6 $/MT of aluminum	Source
ALUMINA REFINING	$/MT of alumina			65
Total	0.39-0.90	0.75-1.74		
Air	0.00			
Water	0.39-0.90			
PRIMARY ALUMINUM SMELTING	$/MT of aluminum			
Total	10.16-13.59	10.16-13.59		
Air				62
Prebake Cell	7.31-10.74			
Anode Bake Furnace	2.50-4.00			
Water	2.85			65,75
SECONDARY ALUMINUM SMELTING	$/MT of aluminum			
(Total)	4.98-10.10		4.98-10.10	
Air	3.28-8.40			76
Water				65
Cooling	0.20			
Scrubber water	1.50			
TOTAL		10.91-15.33	4.98-10.10	

of aluminum produced. The net annual cost per metric ton of aluminum was computed by summing the annual operating costs which include costs for power, materials, labor, maintenance, taxes, insurances and interest; with the depreciation on the capital investment, and then substracting the credit for returned materials. The unit costs shown in column 1 of Table 52 are costs for the types of pollution control equipment which were previously discussed in the module descriptions.

It can be seen from Table 52 that the control costs for System A1 which produces aluminum from virgin materials are $10.91 to 15.33 per metric ton of aluminum. The pollution control costs for Systems A2, A3, A4, A5, and A6 which produce aluminum from obsolete scrap are $4.98 - 10.10. Systems such as A2 and A3 which use a minimum amount of chlorine would be in the low end of the range while System A4 which uses a large amount of chlorine would be in the high end of the range.

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