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INDUSTRIAL RECOVERED-MATERIALS-UTILIZATION TARGETS FOR THE METALS AND METAL-PRODUCTS INDUSTRY

MASTER

March 1980

Work Performed Under Contract No. EM-78-C-03-1692

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

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Division of Industrial Energy Conservation

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March 1980

Prepared for
U. S. Department of Energy
Assistant Secretary for Conservation and Solar Applications
Office of Industrial Programs

✓ 376 9000

Under Contract No. EC-77-C-03-1692

PRINCIPAL PARTICIPANTS IN THE STUDY

Bennett Bovarnick (Consultant)
Kirkor Bozdogan
Glenn DeSouza
Kurt Doelling
Jane Gray
Richard Hyde
David Kinneberg
David Kleinschmidt
Raymond Machacek
Stanley Margolin
Shashank Nadgauda
Edvard Ohlsson
Charles O'Neil
Krishna Parameswaran
David Wheeler (Consultant)

Assistant Project Director, Subhash Malhotra
Project Director, Ravindra Nadkarni
DOE Technical Project Officer, Lewis Newman

376 9000

This document was prepared by Arthur D. Little, Inc. under direction by the Office of Industrial Programs, Office of the Assistant Secretary for Conservation and Solar Energy, U.S. Department of Energy. The analysis and determinations indicated in this document have been used as a basis for recovered materials utilization targets for the metals and metal products industry. These targets are required to be established by Section 374A of the Energy Policy and Conservation Act as amended by the National Energy Conservation Policy Act.

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1.0 SUMMARY

1.1 INTRODUCTION

The National Energy Conservation Policy Act, signed by the President on November 9, 1978, directs the Department of Energy (DOE) to set targets for increased utilization of energy-saving recovered materials for certain industries. These industries are: metals and metal products, paper and allied products, textile mill products, and rubber. These targets are to be established at levels representing the maximum feasible increase in the utilization of recovered materials that can be achieved progressively by January 1, 1987 and is consistent with technical and economic factors. DOE is also required to consider all actions that could be taken to increase each industry's utilization of energy-saving recovered materials. In addition, the Act requires that the Chief Executive Officer of eligible corporations (i.e., those consuming over a trillion Btu per year) in these industries include in their reports to DOE a statement of the volume of energy-saving recovered materials used, and their plans, if any, to increase the utilization of such materials.

1.2 PURPOSE AND SCOPE

Arthur D. Little, Inc. is under contract to DOE to assist in implementing the various provisions of the Act for the metals sector within the time period defined in the Act. The scope of Arthur D. Little's involvement emphasizes the following four major elements:

- data preparation and methodology development;
- analysis of the technological and economic factors in the metals industry in order to prepare draft targets for the use of recovered materials;
- technical support for public hearings to be held in the summer of 1979; and
- assistance in preparing the notice of final targets for Federal Register publication prior to November 9, 1979.

1.3 APPROACH

The proposed targets were developed over a four-month period and relied principally on published information and inputs from various government and industry sources and industry trade associations listed below.

- U.S. Department of Energy
- U.S. Bureau of Mines
- U.S. Department of Commerce
- U.S. Environmental Protection Agency
- National Association of Recycling Industries, Inc.
- Institute of Scrap Iron and Steel, Inc.
- American Iron and Steel Institute
- Aluminum Recycling Association
- The Aluminum Association
- Copper Development Association

- Zinc Institute, Inc.
- Lead Industries Association, Inc.
- Brass and Bronze Ingot Institute

The following approach was used to arrive at targets for energy-saving recovered materials in each industry category.

- Wherever appropriate, the industry was subdivided for analytical convenience.
- Sources of recoverable materials were defined on the basis of data availability, whether they could replace any virgin material used by an industry subdivision, and whether such replacement was feasible before 1987.
- Technical constraints on the use of these recoverable materials were analyzed. Finally, the economic constraints on the availability of these recoverable materials were analyzed. Because of the voluntary nature of these targets, the level of utilization of recovered materials will primarily be determined by economics. Thus, a key feature of the approach is the use of econometric modeling techniques to estimate the targets for recovered materials for 1987. The modeling used 1976 as a base year. A review of available data indicated that the most complete data for recent years was available only thru 1976 and not for 1977 and 1978. Therefore, 1976 was chosen as the base year. However, data for 1977 and 1978 was considered, wherever appropriate. The technical/economic analysis considered such factors as capacity growth, impurity specifications, and other factors that would affect the demand for recoverable materials. On the supply side, the price responsiveness of the supply was evaluated in order to arrive at draft targets for these recoverable materials. The sensitivity of the targets to variations in key variables was also evaluated.

A benefit to be derived from the increased use of recoverable materials is in energy savings, as stated in the Act. Therefore, emphasis on different industries in the metals sector has been related to their energy consumption. The ferrous industry (iron and steel, ferrous foundries and ferroalloys), as defined here, accounts for approximately 83% of the energy consumed in the metals sector (i.e., SIC 33), aluminum for about 11%, copper for about 3%, and all others for the remaining 3%. Energy consumed in the lead and zinc segments is less than 1% each. Therefore, most of the effort in this study is focused on the ferrous scrap users, followed by the aluminum and copper industries.

This report has been revised to incorporate the responses to the comments received by DOE during the public hearing and presents additional analysis.

1.4 FINDINGS

1.4.1 General Discussion of Metals Recycling

The primary metals industries (i.e., those that supply metals mainly by extracting them from virgin raw materials or ores) and the secondary metals industries (i.e., those that mainly supply scrap and/or refined metals from scrap) differ from each other in many important respects, although their products are usually perfect substitutes for each other.

The primary industry relies on the exploitation of mineral deposits where a given metal is concentrated as a result of various types of geological activity. A mineral deposit is called an "ore' only if it can be exploited economically. That is, the difference between an ore deposit and a resource is that an ore deposit can be exploited economically under a given set of market conditions, whereas a resource has to wait for different market conditions before it can be exploited. Ore grade (the concentration of metal in the ore) and ore tonnage generally follow a log-normal distribution. Thus, the quantity of ore available for exploitation (ore reserves) will increase with rising prices. In the past, the richest deposits have been exploited first and, as the cost of extraction and processing decreased because of advances in technology, lower and lower grade deposits have been exploited. In this century, the reduction in the costs of extraction and processing through technological change has usually kept pace with ore grade degradation, so the real price of many metals has either remained constant or has declined somewhat. Many metallic ore deposits contain valuable byproducts such as gold, silver or molybdenum, which increase the economic value of the ore. Alternately, some ore deposits contain associated impurities, which require more complicated processing and decrease the value of the ore. Transportation costs are important in the primary metals industry; plants are usually located near the ore deposits in order to minimize transportation costs for raw materials or are in areas at nodes in existing transportation networks, or in areas that offer other benefits, such as low-cost energy.

The secondary metal industry is scrap-based and tends to locate near the source of its raw materials, which is typically near large urban centers. On an aggregate level, the raw materials used by the secondary industries can be classified into three groups: *home scrap*, *prompt industrial scrap*, and *obsolete scrap*. *Home scrap*, also referred to as *runaround*, is generated internally within a plant, usually because of downstream fabricating operations within the same plant or corporation. Home scrap, obviously compatible in composition, is remelted and used within the corporation. *Prompt industrial scrap*, also referred to as *new* scrap, generated as a result of manufacturing operations, is sold by the generator to a scrap dealer such as a scrap broker, a scrap collector, or a scrap reprocessor (which could include segments of the primary industry). Thus, home scrap and prompt industrial scrap are generated and used in identical fashion and are differentiated only by the absence or presence of a transaction. The quantity of home scrap generated in a particular industry reflects the technology of the industry, the presence or absence of vertical integration in the industry, and the geographical distribution of the plants belonging to a single corporation. Statistical data on home scrap generation and consumption are available for only a few industries; data on prompt industrial scrap are generally better. The two categories are not clear and distinct however. Essentially all the home and prompt industrial scrap is utilized directly. The supply of this scrap depends on the overall level of industrial activity in the manufacturing sector that generates the scrap, and it is quite price inelastic. Improvements in manufacturing technology have generally tended to reduce the availability of such scrap. Also, it is important to note that even more energy is saved when less *home* and *prompt industrial* scrap is generated than when this scrap is recycled.

The third category of scrap is *obsolete scrap*, recovered from materials that have reached the end of their useful life and/or have been discarded. This category of scrap is distinct from the other two categories in many ways. Because home and prompt industrial scrap are generated in specific locations and in predictable quantities, they have been reliable sources of scrap to the scrap dealers/collectors in the same fashion that ore deposits are a reliable source of raw materials to the primary industry. Obsolete scrap is also referred to as *old* scrap.

The generation of *obsolete* scrap, on the other hand, is usually very diffuse. It is often collected as a part of industrial or municipal waste collection operations. Whether this obsolete scrap is recycled or is lost to a landfill/waste dump depends a great deal on the mode of collection (e.g., source segregation vs. a single collection of mixed wastes), the prevailing economic conditions in the scrap market, and the existing infrastructure for handling scrap. This infrastructure is composed of scrap collectors, scrap preprocessors, and upgraders, who can be distinct and separate from the people that melt the scrap. Because obsolete scrap is traded, it is often mixed with prompt industrial scrap at the preprocessing stage, and available statistics do not always distinguish between the two categories. The supply of obsolete scrap is somewhat more price elastic than for the other two categories. Besides source segregation, the technology for waste processing, transportation costs, and alternative disposal costs (e.g., landfill costs) are all important factors in obsolete scrap supply.

The primary metals industries are highly concentrated on the supply side, containing features of oligopolistic market structure (i.e., capacity and output are dominated by a small number of firms selling nearly identical products). In contrast, the secondary industries, by virtue of the large number of firms in the industry, resemble more closely the competitive model of economic theory.

Processing technology in the primary industry is usually more complex than in the secondary industry, and typically involves upgrading the ore, reducing it to metallic form, and refining the metal. The primary industry is much more capital-intensive per unit of output than the secondary industry because of high capital costs associated with extraction and with processing complexity. The equipment used in upgrading, reduction, and refining is specialized and can usually use only virgin raw materials, although some scrap can sometimes be substituted. Generally, equipment for melting, based on an external heat source, can substitute virgin and scrap materials freely; equipment based on internally-generated heat (pneumatic processes in the steel and copper industries) requires a fixed amount of scrap for thermal balance.

The equipment used in the secondary industry is generally designed for the treatment of metallic materials and usually involves equipment for melting and for refining to remove impurities. This equipment cannot accept ores or concentrates since it is generally not capable of performing upgrading and reduction functions.

Both industries, and the secondary industry in particular, rely on the dilution of impurities in order to meet product specifications. The pedigree of prompt industrial and home scrap is easier to trace than that of obsolete scrap. Therefore, the dilution technique can be used with the first two scrap sources in a predictable fashion. Of course, some impurities are valuable (gold and silver in copper scrap) and require refining techniques for their recovery.

In recent years, the economics of both primary and secondary industries have been affected by more stringent requirements for controlling in-plant emissions as well as emissions to the environment. Requirements for air pollution control are significant for most high-temperature operations. The emissions from the secondary industry tend to be complex because of the nature of the feedstock (especially obsolete scrap). Furthermore, the small size of secondary plants and the batch nature of most secondary processes, lead to other problems not faced by the primary industry.

1.4.2 Economics of Scrap Recycling

Since the amount of new scrap generated is a function of technological factors in the metal-producing and metal-fabricating industries and is totally price inelastic in both the short and long run, the problem of recycling can best be addressed by considering the market for old scrap, which is the output of past production. During any given period, the market clears at some level of scrap delivery and price. This price-quantity combination will be determined primarily by the steepness of the supply and demand curves (i.e., their degree of price responsiveness or elasticity), by the length of the market period being considered, ("short-run" curves may well be different from "long-run" curves), and by exogenous factors such as levels of economic activity that move the two curves around.

The Demand Curve: Basically, the steepness of the demand curve for old scrap is set by the ease with which new ore or primary metal can be substituted for it in production at prevailing price levels. The greater the degree of substitution, the flatter the demand curve. This steepness is not immutable of course. It depends fundamentally on the mix of metal-using activities in the economy and the technical conditions of production that prevail at any given time. It is also likely that the short-run demand curve for scrap will be steeper than the long-run curve.

The Supply Curve: The scrap supply curve can also be thought of in terms of slope and position. Over longer periods, the price responsiveness of the old scrap supply is likely to be greater than in the short run. Just as in the case of the demand curve, the supply curve can also shift in response to changes in exogenous factors. Technical progress in the design of scrapping equipment will result in an outward shift of the supply curve as production of any quantity of scrap becomes less costly. On the other hand, increased prices for a number of factors (e.g., wages, implicit rental rates for capital) will cause an inward shift of the curve. Finally, the curve can shift around significantly in response to yearly fluctuations in scrapping as a result of variable investment rates in the distant past.

Market Dynamics: Obviously, the determination of price and output in the secondary scrap industry is a complex phenomenon, and no simple explanation for changes in the rate of recycling is possible. With some significant degree of inelasticity of both supply and demand for scrap, however, one thing is clear: natural demand-side fluctuations from the present business cycle and supply-side fluctuations from past business cycles are themselves sufficient to guarantee substantial price instability in the scrap market. Furthermore, these major sources of instability are largely unpredictable to scrap suppliers, so a substantial element of risk is inescapable in the industry. Scrap suppliers generally run small-scale operations and, in the absence of appropriate insurance or buffering mechanisms, must tend to be somewhat averse to risk.

Econometric Estimation: As noted earlier, a key feature of the approach used in this study is the use of econometric modeling for the estimation of the targets for recovered materials which address the question of how much more scrap will be forthcoming if scrap prices rise. The models used in this report, while limited by the availability of data resources and time, have been specified and estimated taking into account the "simultaneity" problem, the "identification" problem, and the statistical validity of the estimated parameters.

1.4.3 Ferrous Industry

Industry Definition: The ferrous industry is defined as that collection of industries that consume iron and steel scrap. The major segments in this industry are:

- The iron and steel industry (SIC 3312, 3315, 3316, and 3317). This segment includes fully integrated establishments engaged in manufacturing iron and steel from virgin sources as well as from scrap (including blast furnaces) as well as cold metal shops that rely on scrap and the fabricators of iron and steel into basic shapes by hot or cold rolling.
- Ferrous foundries (SIC 3321, 3322, 3324, and 3325). This segment includes establishments that produce gray iron, ductile iron, malleable iron, and steel castings.
- Ferroalloys (SIC 3313). This segment includes establishments engaged in ferroalloy manufacture by blast furnace, electro-metallurgical, or metallo-thermic processes.

Selection of Recoverable Materials: In each of the sectors, four general types of recoverable materials can potentially be consumed: ferrous scrap (home, prompt industrial, and obsolete); slags (from any smelting operation); dusts and sludges (generated from air pollution control or water pollution control operations); and mill scale (generated during fabrication operations). Of these, the principal marginal source of recoverable materials, whose utilization could increase in the near term, is obsolete scrap. Tables 4.2-9, 4.2-11, and 4.2-13 present data on the consumption of these recoverable materials by process units within each industry category.

The recycling of recovered materials can be constrained by the limitations of existing process equipment and/or by limitations imposed by the impurity content of the recoverable material. For sinter strands and blast furnaces, any limitations on the use of recovered material primarily derive from the impurity content, although there are also other process limitations. The quantity of ferrous scrap in the basic oxygen furnace (BOF) process is limited by the amount of energy available for melting. In current practice, a BOF can use no more than about 30% scrap without the addition of fuel energy to the furnace or to the scrap. Other processes do not have such a thermal process constraint but only constraints imposed by the impurity content of the recovered material.

Economic Considerations: In 1976, the ratio of ferrous scrap consumption to production of raw steel and castings (hot metal equivalent) was about 50%. Whether this percentage can be raised by 1987 depends on the demand and supply dynamics of the ferrous scrap market. On the demand side, the amount of scrap that can be utilized is constrained by such technical factors as the split in steelmaking capacity between BOF's, open hearths, and electric furnaces. The supply consists of new scrap generated by current industrial activity and old scrap extracted from discarded steel-containing products. New scrap generation is a function of technological factors and should be totally price-inelastic in both the short and long run. The supply of old scrap, however, would be price-elastic.

We have prepared an eclectic econometric model of the ferrous scrap market incorporating both engineering and economic parameters in an attempt to depict realistically the technological and microeconomic factors that characterize the dynamics of demand and supply. This model incorporates information on the process characteristics of scrap-using and scrap-generating activities, the inventory of obsolete iron and steel, and the price elasticity of obsolete scrap supply, in order to generate draft targets that are both technically feasible and economically achievable.

Any target for the ferrous industry is affected by a number of factors, such as the growth rate of the industry to 1987, the mix of steelmaking processes in 1987, scrap demand coefficients for the basic oxygen furnace and foundries, availability of scrap substitutes, and scrap exports. Because of this complexity, nine different scenarios were tested in the Arthur D. Little model. The results of these nine scenarios are shown in Table 4.2-25 reproduced here for convenience. Case I, the base case, is considered the most likely; the other cases are considered plausible. Cases II, III, V, VIII and IX are based on variations in the mix of steelmaking furnaces. Cases IV and VI presume a higher foundry scrap charge coefficient; and Case VII projects a lower overall annual growth rate for the iron and steel sector. In order to minimize the number of scenarios, the percentage of continuous cast steel has been fixed at 25% of total steel production for all cases. It is important to note that scrap exports are a major factor; the estimated target could change significantly if the level of scrap exports were to change. Sensitivity analysis indicated that if exports reduced to below 5 million or increased above 15 million tons, it would have a noticeable impact in the scrap market. Table 1.4-1 presented on page 1-9 shows the 1987 base case targets for the ferrous and other industries.

1.4.4 Aluminum Industry

Industry Definition: The aluminum industry includes the following segments.

- Primary aluminum (SIC 3334) — establishments that produce aluminum from alumina.
- Secondary smelting and refining (SIC 3341 — aluminum-related sector only) — establishments involved in the production of aluminum and aluminum-based alloys from scrap or dross.
- Aluminum foundries (SIC 3361) — establishments primarily engaged in manufacturing castings of aluminum and aluminum-based alloys.
- All others (SIC 3353, 3354, 3355, 3357, 3361, 3399, and 3463).

Many of these establishments are primarily engaged in fabrication of aluminum and generally send the scrap generated during fabrication to the other segments. However, some fabricators with melting facilities are also able to use aluminum scrap.

Selection of Recoverable Materials: Several types of recoverable materials can potentially be used. These include scrap (home, prompt industrial, and obsolete — with several subcategories based on chemical composition); low-grade drosses, skimmings and residues; and other solid wastes that contain metallics or that could be new non-bauxite sources of alumina. Of these, the principal marginal source of recoverable material is old scrap, whose availability could increase between now and 1987. The three major categories of old scrap where an increase is possible are: aluminum recovered via source segregation of beverage cans and other aluminum items; aluminum recovered from municipal solid wastes in resource recovery systems; and mixed scrap recovered from automobile shredding. Table 3.3-8 presents the available data on the consumption of these materials by the different sectors within the aluminum industry.

TABLE 4.2-25

RECYCLING RATIOS FOR FERROUS INDUSTRY FOR NINE SCENARIOS - 1987

	Target Expressed As Ratio Of:								
Scenario	Total Scrap Consumed[1] to Pig Iron and Scrap Charged[3]	Purchased Scrap Consumed[2] to Pig Iron and Scrap Charged[3]	Obsolete Scrap Consumed to Pig Iron and Scrap Charged[3]	Total Scrap Consumed[1] to Raw Metal Equivalent[4]	Purchased Scrap Consumed[2] to Raw Metal Equivalent[4]	Obsolete Scrap Consumed to Raw Metal Equivalent[4]	Total Scrap Consumed[1] to Product Shipments[5]	Purchased Scrap Consumed to Product Shipments[5]	Obsolete Scrap Consumed to Product Shipments[5]
1975 =	0.507	0.224	0.115	0.591	0.261	0.134	0.866	.382	0.196
1976 =	0.509	0.226	0.117	0.588	0.261	0.135	0.847	.376	0.194
1987 =									
Case I: Base case	0.536	0.264	0.137	0.597	0.294	0.153	0.839	.413	0.214
Case II: Base case except - Production by open hearth furnaces equals 10% total raw steel production.	0.538	0.266	0.139	0.600	0.297	0.156	0.843	.418	0.219
Case III: Base case except - Growth in raw steel production split 2:1 between basic oxygen and electric arc shops.	0.520	0.249	0.122	0.581	0.278	0.136	0.816	.390	0.191
Case IV: Base case except - Scrap demand coefficient for foundries equals 1.3 ton/ton shipments.	0.539	0.269	0.143	0.605	0.302	0.160	0.849	.424	0.225
Case V: Base case except - Growth in raw steel production split 2:1 between basic oxygen and electric arc shops. - Production by open hearth furnaces equals 10% total raw steel production.	0.522	0.251	0.124	0.584	0.281	0.139	0.820	.394	0.195
Case VI: Base case except - Growth in raw steel production split 2:1 between basic oxygen and electric arc shops. - Scrap demand coefficient for foundries equals 1.3 ton/ton shipments.	0.524	0.254	0.128	0.588	0.285	0.144	0.826	.400	0.202
Case VII: Base case except - Growth rate for finished steel production equals 1.6% per annum.	0.533	0.261	0.135	0.593	0.291	0.150	0.834	.409	0.211
Case VIII: Base case except - 30% raw steel production by electric furnaces.	0.552	0.279	0.152	0.613	0.310	0.169	0.861	.436	0.237
Case IX: Base case except - 33% raw steel production by electric furnaces	0.568	0.296	0.168	0.630	0.328	0.186	0.885	.461	0.262

1. Includes home, prompt industrial and obsolete scrap.
2. Includes prompt industrial and obsolete scrap.
3. Charged to steelmaking furnaces, ferrous foundries and ferroalloy plants.
4. Raw steel plus hot metal equivalent in the ferrous foundries.
5. Finished steel plus ferrous casting shipments.

SOURCE: Arthur D. Little, Inc.

TABLE 1.4-1

RECOVERED MATERIAL TARGETS FOR 1987

Industry Segment	Target $\left(\frac{\text{Recovered Material}}{\text{Production*}} \times 100 \right)$
Ferrous	41.3%
Aluminum	34.7%
Copper	50.4%
Zinc	36.0%
Lead	60.0%

* Domestic shipments or primary and secondary production.

TABLE 3.3-8

CONSUMPTION OF ALUMINUM SCRAP BY TYPE - 1976*

(1,000 short tons)**

Type of Scrap	Secondary Smelters	Primary Producers and Others***	Total
New Scrap			
Solids and Clippings	231	350	581
Borings and Turnings	136	16	152
Foil	1	6	7
Dross and Skimmings	126	104	230
Other	24	61	85
Total New Scrap	518	537	1,055
Old Scrap			
Castings, Sheet and Clippings	121	35	156
Aluminum Cans	8	101	109
Other****	30	17	47
Subtotal	159	153	312
Sweated Pig	82	17	99
Total Old Scrap	241	170	411
TOTAL	759	707	1,466

*Includes imported scrap. The reporting companies reported that 6.62% of total receipts of aluminum-based scrap or 97,800 short tons was received on toll arrangements.

**Rounded to the nearest thousand.

***Others include foundries, fabricators, and chemical plants.

****Includes data on aluminum-copper radiators.

Source: Aluminum, Preprint from Minerals Yearbook, 1976.

In general, recycling can be constrained by limitations of existing process equipment and by limitations imposed by the impurity content of the recoverable materials. All industry subdivisions utilize melting furnaces and there is no process constraint concerning the amount of scrap that can be melted in the furnaces. However, the furnaces used by some segments of the industry are better suited for melting given types of scrap than others. The principal refining step in the recycling of aluminum-based scrap is the removal of magnesium by treating the molten metal with chlorine or aluminum fluoride. Any other impurities in the metal are usually controlled by dilution of the charge with pure metal. Stainless steel and zinc are considered the major metallic impurities, while nonmetallic contaminants such as paint, oil, plastic, insulation, and rubber have a nuisance value because they are a major source of air pollution.

Economic Considerations: Table 4.3-5 shows the balance of sources and uses for purchased aluminum scrap for 1976. In that year, old scrap accounted for about 11.6% of supply. Whether the amount of old scrap consumed can be raised by 1987 depends on the supply and demand dynamics of the aluminum market. On the demand side, technology imposes no relevant physical constraint. The economic aspects of scrap demand relate to the price of scrap in relation to the price of virgin aluminum.

A simple model has been designed to predict the volume of aluminum scrap that will be generated under a variety of scenarios. This volume is then used to calculate the target. The model contains five equations that predict the supply of scrap from new scrap, obsolete scrap from cans, as well as the withdrawal rate for other old scrap from the inventory of aluminum available for scrapping. This inventory is adjusted to allow for the contribution by the increasing aluminum content of cars and Class I trucks. U.S. scrap consumption is calculated by adding scrap supply as predicted and subtracting exogenous scrap exports. These data are then used to calculate the targets.

The targets are directly affected by the maximum withdrawal rate for old scrap and by variations in new scrap generation, scrap reclamation from cans, scrap recovery from municipal solid waste, growth rate in aluminum consumption, and the level of imports. Table 4.3-10 presents the recycling targets for 1987, where the targets are expressed as different ratios to domestic primary plus domestic secondary production. Case I, the base case, is considered the most likely; the other cases are considered plausible. Case II is identical to the base case except that the real price of scrap is higher. In Case III, exports are assumed to drop to zero to simulate a policy of restricting scrap exports. In Case IV, new scrap generation rate is assumed to be lower, consistent with predicted improvement in fabrication yields. The base case target is also shown in Table 1.4-1.

1.4.5 Copper Industry

Industry Definition: The copper industry is defined as that group of industries that consume copper-bearing scrap. The major segments in this industry are:

- Primary copper industry (SIC 3331)— This segment includes establishments engaged in producing copper from virgin ore sources.
- Secondary copper industry (SIC 33412)— This segment includes establishments engaged in recovering copper from copper and copper-based scrap.

TABLE 4.3-5

1976 MATERIAL BALANCE FOR ALUMINUM SCRAP
(Millions of Pounds)

Sources		Uses	
Purchased Scrap		U.S. Consumption of Purchased Scrap[1]	3,482
New Scrap[1]	2,490	U.S. Consumption of Home Scrap[3]	6,675
Old Scrap		Exports[2]	218
Aluminum Cans[1]	217		
Other Old Scrap[1,2]	993		
Purchased Scrap	3,700		
Home Scrap[3]	6,675		
Total	10,375	Total	10,375

Source: Arthur D. Little, Inc. estimates derived from:

[1] Aluminum, Preprint 1976 Minerals Yearbook.

[2] Aluminum Statistical Review, 1976.

[3] Communication, The Aluminum Association, May 8, 1979.

TABLE 4.3-10

RECYCLING RATIOS FOR ALUMINUM INDUSTRY
FOR FOUR SCENARIOS - 1987

Scenario	Old Scrap Consumption	Old Scrap Metallic Recovery	Total Scrap Consumption	Total Scrap Metallic Recovery
	Target Expressed as Ratio of			
	to Domestic Primary Production Plus Secondary Metallic Production			
1976 =	0.087	0.073	0.304	0.257
1987 =				
Case I Base Case	0.118	0.100	0.347	0.293
Case II Base Case except Price of scrap=13.1¢/lb WD = 0.00461	0.146	0.123	0.373	0.315
Case III Base Case except Exports = 0	0.129	0.109	0.357	0.302
Case IV Base Case except New Scrap Generation Coefficient = 0.19	0.118	0.100	0.333	0.281

- Fabricators (SIC 3351)— This segment includes establishments engaged in rolling, drawing and extruding copper in copper-based alloys.
- Foundries (SIC 3362)— This segment includes establishments engaged in casting of copper-based alloys.

Selection of Recoverable Materials: The materials available for recycling cover a range of scraps varying from No. 1 wire, which is essentially pure copper, to low-grade scrap, and include a wide variety of unalloyed and alloyed copper scrap grades. A somewhat special category is the utilization of mine waste by leaching for extraction of additional copper; copper produced in this fashion is normally considered primary copper. Table 4.4-3 shows available data on the consumption of these recoverable materials in each industry subcategory.

The secondary industry relies primarily on scrap, and its different segments purchase and handle the entire range of high- and low-grade alloyed and unalloyed scrap as well as residues. Thus, there are no constraints other than those imposed by the impurity content of the scrap. The scrap-handling ability of the primary smelters is limited. Although smelting furnaces can, in principle, accept scrap, they are actually designed to accept only finely powdered materials. Low-grade scrap can be added to the converter, and higher-grade scrap is acceptable in any amount at the cathode melting stage. Brass mills and foundries do not have process constraints, but only technical constraints based on the composition of the recoverable materials.

Economic Considerations: As with other metals, obsolete copper scrap is the principal source of incremental recoverable material. In the past, obsolete scrap has played an important role in meeting fluctuating levels of excess demand as indicated in Table 4.4-5. Table 4.4-10 shows that the recycling ratio (defined as copper from recovered materials divided by copper from recovered material plus primary copper production) has been relatively stable between 1970 and 1976. The econometric results given in the literature, price and output projections that incorporate the anticipated impact of pollution abatement legislation during the coming decade, and the size of the recoverable copper reservoir have been used to calculate the draft target that appears technically and economically feasible. Table 4.4-9 shows the draft target for 1987.

1.4.6 Zinc Industry

Industry Definition: The zinc industry is defined here as:

- Establishments engaged in primary smelting and refining of zinc (SIC 3333)
- Establishments engaged in smelting zinc from scrap materials (SIC 33414)
- Zinc Foundries (SIC 33691).

Selection of Recoverable Materials: The zinc industry recovers zinc (and zinc oxide) from a broad spectrum of home, prompt industrial, and obsolete scrap. Zinc can also be recovered from steelmaking dusts, although this process is not practiced on any significant scale in this country. As with other metals, obsolete scrap represents a principal marginal source of recoverable material. Table 4.5-3 presents data on consumption of different grades of recoverable material within each industry subcategory.

Different types of processes are used by different segments of the zinc industry and each process has certain constraints. For example, oxidized zinc materials are acceptable to vertical

TABLE 4.4-3

CONSUMPTION OF RECOVERABLE MATERIALS 1976 - COPPER INDUSTRY[1]
(Gross Weight in Tons)

Industry Subdivision	No. 1 Wire	No. 2 Wire	Composition	Railroad Car Box	Yellow Brass	Cartridge Cases	Auto Radiators	Bronze	Nickel Silver	Alum. Bronze	Low Brass	Refin. Brass	Low Grade Scrap	Home Scrap	Mine Waste[2]
Secondary Smelters	27,028	59,900	58,605	1,852	46,217	195	57,823	19,920	3,085	567	2,882	-	78,712	0	-
Primary Producers	117,669	128,340	-	-	-	-	-	-	-	-	-	4,230	175,551	0	126,144
Brass Mills	159,250	71,778	-	-	269,074	78,028	-	4,219	33,791	355	45,959	-	-	0	-
Foundries, Chemical Plants and Other Manufacturers	29,187	9,928	4,518	4,325	8,048	-	10,258	598	82	449	1,455	-	64	0	-

[1]U.S. Bureau of Mines Minerals Yearbook 1976, Copper - Table 23

[2]Net Weight of Copper, U.S. Bureau of Mines, Minerals Yearbook 1976, Copper - Table 7.

TABLE 4.4-10

COPPER RECYCLING RATIOS, 1970-1976*

Year	Ratio
1970	45.6%
1971	48.5%
1972	46.4%
1973	47.4%
1974	49.4%
1975	44.8%
1976	46.9%
Mean Ratio:	47.0%

* Ratios derived from Table 4.4-7.

TABLE 4.4-9

RECOVERED MATERIAL TARGET FOR COPPER INDUSTRY (1987)

$$\frac{\text{Recovered Material*}}{\text{Domestic Primary \& Secondary Production}} \times 100 = 50.4\%$$

* Prompt industrial and old scrap, plus precipitate copper from mine waste.

TABLE 4.5-3

CONSUMPTION OF RECOVERABLE MATERIALS - 1976

ZINC INDUSTRY

Types of Recovered Materials in Tons of Zinc Contained

Process	Galvanizers' Residues	New Die Cast Scrap	Chemical Residues	Home Scrap	Old Die Cast Scrap	General Scrap	Total
Electrolytic Reduction				NA			NA
Vertical Distillation Reports	31,500		10,500	NA			43,000
Secondary Distillers	55,800	7,900	1,500	NA	53,300	10,800	129,300
Foundries				NA	2,200		2,200
Chemical and Pigment Plants	8,300		22,700	NA	0		31,000

NA: Data not available.

Source: Estimates based on unpublished Tables 13, 14, 15 for Zinc to be in the 1976 Mineral Yearbook, Volume I, Metals, Minerals and Fuels, U.S. Department of the Interior, Bureau of Mines.

distillation retorts and to chemical and pigment plants. The foundries recover zinc from scrap that has a high metallic content and controlled impurities. The secondary distillers process all zinc scrap but can recover only metallic zinc in the scrap. The primary electrolytic reduction plants do not consume any recoverable material. The major constraints from the viewpoint of product quality are in the foundries and in other applications such as galvanizing and zinc oxide products.

Economic Considerations: Economic considerations were not evaluated for the zinc industry, but are incorporated in the assumptions used in this analysis. Increased recovery of zinc will center on old scrap, particularly old die castings recovered from automobiles. Table 4.5-4 shows the estimated target for 1987. This target, equivalent to 36% of the domestic zinc smelted by 1987, is sensitive to galvanizer zinc consumption, the rate of increase in automobile shredders where nonferrous fractions are separated, and any increase in recovery of flue dust chemical residues and changes in domestic production rates.

1.4.7 Lead Industry

Industry Definition: The lead industry is defined in this report as:

- Establishments engaged in the primary smelting and refining of lead (SIC 3332)
- Establishments engaged in the secondary smelting and refining of lead (SIC 3341)

Selection of Recoverable Materials: The recoverable materials fall broadly into four groups — namely, new scrap, old scrap, slags and dusts. Table 4.6-2 presents available data on the consumption of these materials in the lead industry.

Theoretically, there is no technical limit to the amount of recoverable material that can be recycled. There are, however, constraints dictated by the composition of the recoverable materials. For example, high-antimony lead batteries are normally recycled back into the same product. Similarly, blast furnaces cannot accept a large quantity of dust without agglomeration.

Economic Considerations: Economic factors were not directly evaluated in this industry analysis, but they are incorporated in the assumptions used. Table 4.6-5 shows the draft target for the lead industry (defined as the recycling ratio; that is, the ratio of secondary production to primary plus secondary production) for 1987. The two most critical assumptions are that primary lead production will remain at 700,000 short tons annually, and that the ultimate recovery rate for scrap batteries is 0.75. The other variables have relatively little effect on the target.

1.5 IMPACT OF GOVERNMENT ACTIONS ON RECYCLING

Many government policies can potentially have an impact on the degree of recycling in all types of primary and secondary metals industries. The significant areas are:

- Tax Policy
- Freight Rates
- Product Specifications
- Residuals (Pollution Control)
- Market Structure
- Export Controls on Scrap
- Beverage Container Deposit Legislation

The available studies indicate that policy changes that equalize primary and secondary metals in terms of tax policy, freight rates and market structure will have a minor impact on the overall rates of recycling in the near term. In other cases, the legislation has been enacted recently and is yet to be fully implemented through regulations or further research, and analyses are needed to evaluate the effectiveness of Federal policymaking.

TABLE 4.5-4

RECOVERED MATERIAL TARGET FOR ZINC INDUSTRY
(1987)

$$\frac{\text{Recovered Material*}}{\text{Domestic Primary \& Secondary Production}} \times 100 = 36\%$$

* Purchased scrap, i.e., prompt industrial and obsolete scrap.

TABLE 4.6-2

SCRAP CONSUMPTION IN THE LEAD INDUSTRY (1970-1976)
(Gross Tons)

	1970	1971	1972	1973	1974	1975	1976
New Scrap:							
Drosses & Residues	121,766	143,382	158,881	154,682	129,400	136,066	141,923
Home Scrap	NA	NA	NA	NA	NA	NA	NA
Old Scrap:							
Battery Plates	512,030	486,792	509,858	544,438	614,364	623,448	589,797
Cable Lead	26,544	29,455	26,775	26,397	45,507	50,569	47,738
Soft Lead	52,426	48,925	46,668	36,279	33,641	32,642	29,172
Hard Lead	19,015	27,254	27,641	51,992	54,778	26,912	30,395
Type Metal	32,001	25,813	23,690	27,950	25,745	19,820	14,292
Mixed Common Babbitt*	11,799	11,665	11,049	13,534	12,025	8,552	7,839
Solders & Tinny Lead	10,640	11,464	9,815	11,991	13,663	11,250	3,517
Slag :							
Secondary Reverberatory				NA			
Dust :							
Primary Blast Furnace				NA			
Secondary Blast Furnace				NA			
Secondary Reverberatory				NA			

*includes consumption at foundries

NA: Not available.

Source: U.S. Bureau of Mines Minerals Yearbook, 1976.
Arthur D. Little, Inc.

TABLE 4.6-5

RECOVERED MATERIAL TARGET FOR LEAD INDUSTRY
(1987)

$$\frac{\text{Recovered Material*}}{\text{Domestic Primary \& Secondary Production}} \times 100 = 60\%$$

* Purchased scrap, i.e., prompt industrial and obsolete scrap.

2.0 INTRODUCTION

This chapter provides an introductory discussion of the factors that affect the recovery and reuse of secondary materials and the competition between the primary and secondary metals industries.

Section 2.1 discusses these industries in terms of resource characteristics, industry technology, pollution control requirements, market structure, the economics of recycling, and the issues involved in econometrically estimating scrap supply response behavior.

Section 2.2 presents the methodology established by the Department of Energy (DOE) for the metals, textiles, rubber, and pulp and paper industries, which was adapted to this study.

Section 2.3 notes the areas in which government policies might have a significant impact on the utilization of primary and secondary metals and, therefore, on any recycling targets between now and 1987.

2.1 GENERAL DISCUSSION OF METALS RECYCLING

The primary metals industries (i.e., those that supply metals mainly by extracting them from virgin raw materials or ores) and the secondary metals industries (i.e., those that mainly supply scrap and/or refined metals from scrap) differ from each other in many important respects. Although their products are usually perfect substitutes for each other, the two industries differ in terms of sources of feedstocks and feedstock availability, supply response, market structure, growth rates over the historical period, and, in some cases, somewhat specialized end-use applications, in spite of the non-differentiated nature of their products. The discussion below examines the differences between the two industries and the way in which such differences might affect the selection of economically feasible targets for increasing the use of energy-saving recovered materials.

2.1.1 Resource Characteristics

The primary industry relies on the exploitation of mineral deposits where a given metal is concentrated as a result of various types of geological activity. A mineral deposit is called an "ore" only if it can be exploited economically. That is, the difference between an ore deposit and a resource is that an ore deposit can be exploited economically under a given set of market conditions, whereas a resource has to wait for different market conditions before it can be exploited. Ore grade (the concentration of metal in the ore) and ore tonnage generally follow a log-normal distribution. Thus, the quantity of ore available for exploitation (ore reserves) will increase with rising prices. In an operating mine, prevailing economic conditions define the "cut-off" grade for a given deposit. Any operating mine always contains rock that is below the cut-off grade, which is removed and dumped in surface mining or is left in place in underground mining. (Thus, in general mine waste in surface mining does not meet prevailing economic criteria for extraction and is not an economic source of energy-saving recovered material at the time of mining for primary metal recovery.)

Thus, any portion of the deposit above the cut-off grade may be exploited economically, while those portions of the deposit below the cut-off grade are treated as sub-marginal and are not extracted. In the past, the richest deposits have been exploited first and, as the cost of extraction and processing decreased because of advances in technology, lower and lower grade deposits have been exploited. In this century, the reduction in the cost of extraction and processing through technological change has usually kept pace with ore grade degradation, so the real price of many metals has either remained constant or has declined somewhat. As economic conditions (prices) change, the cut-off grade is increased or decreased, with an equivalent change in total economic reserves. That is, supply response is conditioned by the prevailing as well as the expected metal price. At the present time, the cut-off ore grades in the major metals industries are: at least 30% iron for magnetite ores and up to 65% iron for direct shipping ores; 30% alumina for bauxite; 0.4% copper for sulfide ores; and 2-3% metal for lead and zinc ores. Many metallic ore deposits contain valuable byproducts such as gold, silver or molybdenum, which increase the economic value of the ore. Alternately, some ore deposits contain associated impurities, which require more complicated processing and decrease the value of the ore. Transportation costs are important in the primary metals industry; plants are usually located near the ore deposits in order to minimize transportation costs for raw materials or at nodes in existing transportation networks, or in areas that offer other benefits, such as low-cost energy.

The secondary metal industry is scrap-based and tends to locate near the source of its raw materials, which is typically near large urban centers. On an aggregate level, the raw materials used by the secondary industries can be classified into three groups: home scrap, prompt industrial scrap, and obsolete scrap.

Home scrap is generated internally within a plant, usually because of downstream fabricating operations within the same plant or corporation. Home scrap is also referred to as runaround scrap. Home scrap, obviously compatible in composition, is remelted and used within the corporation.

Prompt industrial scrap, generated as a result of manufacturing operations, is sold by the generator to a scrap dealer such as a scrap broker, a scrap collector, or a scrap reprocessor (which could include segments of the primary industry). Prompt industrial scrap is also referred to as new scrap. Home scrap and prompt industrial scrap are generated and used in identical fashion and are differentiated only by the absence or presence of a transaction. The quantity of prompt and home scrap generated in a particular industry reflects the technology of the industry, the presence or absence of vertical integration in the industry, and the geographical distribution of the plants belonging to a single corporation. Statistical data on home scrap generation and consumption are available for only a few industries; data on prompt industrial scrap are generally better. The two categories are not clear and distinct however. Essentially all the home and prompt industrial scrap is utilized directly. The supply of this scrap depends on the overall level of industrial activity in the manufacturing sector that generates the scrap, and it is quite price inelastic. Improvements in manufacturing technology have generally tended to reduce the availability of such scrap. Also, this reduction in home and prompt scrap generation contributes more towards energy saving than scrap recycle.

Obsolete scrap is recovered from materials that have reached the end of their useful life and/or have been discarded. It is also referred as old scrap or post-consumer scrap. This category of scrap is distinct from the other two categories in many ways. Because home and prompt industrial scrap are generated in specific locations and in predictable quality and quantities, they have been reliable sources of scrap to the scrap dealers/collectors in the same fashion that ore deposits are a reliable source of raw materials to the primary industry.

The generation of obsolete scrap, on the other hand, is usually very diffuse. It is often collected as a part of industrial or municipal waste collection operations. Whether this obsolete scrap is recycled or is lost to a landfill/waste dump depends a great deal on the mode of collection (e.g., source segregation vs. a single collection of mixed wastes), the prevailing economic conditions in the scrap market, and the existing infrastructure for handling scrap. This infrastructure is composed of scrap collectors, scrap preprocessors, and upgraders, who can be distinct and separate from the people that melt the scrap. Because obsolete scrap is traded, it is often mixed with prompt industrial scrap at the preprocessing stage, and available statistics do not always distinguish between the two categories. The supply of obsolete scrap is somewhat more price elastic than for the other two categories. Besides source segregation, the technology for waste processing, transportation costs, and alternative disposal costs (e.g., landfill costs) are all important factors in obsolete scrap supply. It is important to note that if products are exported, the obsolete scrap will be generated in the country that purchased the product and not the country that manufactured them.

2.1.2 Industry Technology

Processing technology in the primary industry is usually more complex than in the secondary industry, and typically involves upgrading the ore, reducing it to metallic form, and refining the metal. The primary industry is much more capital-intensive per unit of output than the secondary industry because of high capital costs associated with extraction and with processing complexity. The equipment used in upgrading, reduction, and refining is specialized and can usually use only virgin raw materials, although some scrap can sometimes be substituted. Generally, equipment for melting, based on an external heat source, can substitute virgin and scrap materials freely; equipment based on internally-generated heat (pneumatic processes in the steel and copper industries) requires a fixed amount of scrap for thermal balance.

The equipment used in the secondary industry is generally designed for the treatment of metallic materials and usually involves equipment for melting and for refining to remove impurities. This equipment cannot accept ores or concentrates since it is generally not capable of performing upgrading and reduction functions.

Both industries, but the secondary industry in particular, rely on the dilution of impurities in order to meet product specifications. The pedigree of prompt industrial and home scrap is easier to trace than that of obsolete scrap. Therefore, the dilution technique can be used with the first two scrap sources in a predictable fashion. Of course, some impurities are valuable (gold and silver in copper scrap) and require refining techniques for their recovery.

2.1.3 Pollution Control

In recent years, the economics of both primary and secondary industries have been affected by more stringent requirements for controlling in-plant emissions as well as emissions to the environment. In the primary industries, solid waste generation is heaviest at the mining and concentration stage, while air and water pollution control requirements affect the different segments to varying degrees. Requirements for air pollution control are significant for most high-temperature operations.

The emissions from the secondary industry tend to be complex because of the nature of the feedstock (especially obsolete scrap). Furthermore, because of the small size of secondary plants and the batch nature of most secondary processes, the economic impact of pollution control requirements tends to be more severe on the secondary industry.

2.1.4 Market Structure

The primary metals industries are highly concentrated on the supply side, containing features of oligopolistic market structure (i.e., capacity and output are dominated by a small number of firms selling nearly identical products). In contrast, the secondary industries, by virtue of the large number of firms in the industry, resemble more closely the competitive model of economic theory.

A recent study has shown that market structure of these industries and the degree of competition does not have much bearing on the rate of recycling.[1] In the nonferrous metals industries, the degree of recycling is determined primarily by:

- the structure of the end-use spectrum peculiar to each metal;
- the magnitude and average age of the in-service inventory of each metal;
- the price of both primary and secondary metal; and cyclical fluctuations in the level of economic activity.

The study concludes that positive actions designed to increase the rate of recycling will have to focus on the demand side (i.e., on the end-use spectrum) for each metal and that the rapidly rising cost of energy will provide a stimulus for increasing nonferrous metals scrap recovery.

2.1.5 Economics of Scrap Recycling

The supply of scrap consists of "new" scrap (home and prompt industrial) and "old" or obsolete scrap. The amount of new scrap generated is a function of technological factors in the metal-producing and metal-fabricating industries and is totally price inelastic in both the short and long run.

The problem of recycling, therefore, can best be addressed by considering the market for old scrap, which is the output of past production. (New scrap may be regarded as a byproduct of current production and cannot be said to have a market in any meaningful sense.) During any given period, the market clears at some level of scrap delivery and price. This price/quantity combination will be determined primarily by the steepness of the supply and demand curves (i.e., their degree of price responsiveness or elasticity), by the length of the market period being considered ("short-run" curves may well be different from "long-run" curves), and by exogenous factors such as the level of economic activity that move the two curves around.

2.1.5.1 The Demand Curve

Basically, the steepness of the demand curve for old scrap is set by the ease with which new ore or primary metal can be substituted for it in production at prevailing price levels. The greater the degree of substitution, the flatter the demand curve. (Intuitively, this means that a fairly small increase in the price of old scrap at a given ore price will result in a relatively large drop in the demand for old scrap as users substitute toward primary sources, and, conversely, as the old scrap price decreases.) This steepness is not immutable of course. It depends fundamentally on the mix of metal-using activities in the economy and the technical conditions of production that prevail at any given time.

It is also likely that the short-run demand curve for scrap will be steeper than the long-run curve. In the short run, industrial plants may be set for a particular rate of scrap input, and higher scrap prices will not have any immediate impact on the sales of scrap-using products. In the longer run, however, production processes can be adjusted to use less scrap (and more ore). At the same time, price-responsive market demand will shift in favor of products from relatively ore-intensive as opposed to scrap-intensive processes. For both these reasons, long-run demand for scrap will be considerably more price-responsive than short-run demand.

While the steepness of the demand curve depends on substitutability in aggregate metals production as well as the length of the time period being considered, the position of the curve is affected by the price of new ore and the level of demand for metal products (which is itself a function of the generalized price of metal products). The higher the price of new ore, the more scrap will be demanded at any given scrap price. Similarly, the higher the demand for metal products, the higher the demand for scrap at any given price.

2.1.5.2 The Supply Curve

The scrap supply curve can also be thought of in terms of slope and position. Basically, the steepness of the curve in the short run will reflect the extra cost at which variable production inputs can be obtained. Short-run response may require the payment of overtime wages or multiple shifting of the available facilities, with a consequent increase in the rate of depreciation. Furthermore, the stock of "minable" refuse for scrap recovery is limited in any period, and diminishing returns are bound to apply (unit increases in supply will require ever-greater intensities of extraction effort, since the most readily available scrap will be utilized first).

Over longer periods, the price responsiveness of the old scrap supply is likely to be greater than in the short run. More labor can be hired at the going (non-overtime) wage, and old, relatively inefficient, scrapping equipment can be profitably pressed back into service. In addition, users of capital equipment will adjust their scrapping rates to the higher scrap value of their equipment so that a higher volume of scrap will be forthcoming.

Just as in the case of the demand curve, the supply curve can also shift in response to changes in exogenous factors. Technical progress in the design of scrapping equipment will result in an outward shift of the supply curve as production of any quantity of scrap becomes less costly. On the other hand, increased prices for a number of factors (e.g., wages, implicit rent rates for capital) will cause an inward shift of the curve. Finally, the curve can shift around significantly in response to yearly fluctuations in scrapping as a result of variable investment rates in the distant past.

2.1.5.3 Market Dynamics

Obviously, the determination of price and output in the secondary scrap industry is a complex phenomenon, and no simple explanation for changes in the rate of recycling is possible. With some significant degree of inelasticity of both supply and demand for scrap, however, one thing is clear: natural demand-side fluctuations from the present business cycle and supply-side fluctuations from past business cycles are themselves sufficient to guarantee substantial price instability in the scrap market. Furthermore, these major sources of instability are largely unpredictable to scrap suppliers, so a substantial element of risk is inescapable in the industry. Scrap suppliers generally run small-scale operations and, in the absence of appropriate insurance or buffering mechanisms, must tend to be somewhat averse to risk. Thus, any factor that would reduce this price instability would tend to increase the equilibrium production level for scrap even if the average price remained unchanged.

2.1.6 Econometric Estimates of Scrap Supply Elasticity

2.1.6.1 Introduction

The scrap market plays an essential role in recycling, and it is important to know how much more scrap will be forthcoming if scrap prices rise. While econometric models of scrap metals markets are obviously useful in this context, they must be properly specified and estimated if they are to yield meaningful results. This discussion provides an introduction to the econometric analysis of scrap supply.

2.1.6.2 The Simultaneity Problem

At any given time, the markets for scrap, ore, and metal products are observed to clear simultaneously at some set of prices and quantities. Since all of these quantities and prices are established interdependently, it is not possible to observe the behavior of one market in isolation from the others and draw any firm conclusions. In econometric parlance, this is known as "the simultaneity problem," and any attempt to estimate the parameters of an equation that describes one part of the system must take simultaneity into account.

In attempting to focus on the supply schedule for scrap, i.e., how the quantity of scrap supplied varies with price, it is not sufficient simply to observe the time paths of scrap price and quantity delivered and hope that this information will yield adequate information about price responsiveness. Demand-side variables will inevitably have intervened, as will exogenous forces that have shifted the supply schedule. Shifts in the price of metal products and ore may have shifted the demand curve, for example, while the introduction of new equipment or shifts in the costs of other inputs to scrap production (e.g., labor, capital) may well have acted on the supply side. Thus, the observed path of prices and delivered quantities in the scrap industry is the result of a simultaneous interaction of supply and demand schedules for scrap. This interaction might well generate a time path of prices and quantities as shown in Figure 2-1.

It is along the supply curve in this figure that any demand-induced increase in price will have to trace out its consequences for the output of scrap. Although it is not immediately obvious how to deduce the shape of the supply curve from the record of price-quantity combinations generated by the interaction of supply and demand, econometricians have developed a series of methods for doing so. No econometric estimates of price responsiveness on the supply side can be taken seriously unless they have been generated by a technique which takes this problem of "simultaneity" into account.

2.1.6.3 The Problem of Supply Equation Specification

A second major problem in estimating price-responsiveness in the scrap industry is the identification of short-run and long-run behavior. While a sudden change in price may not have

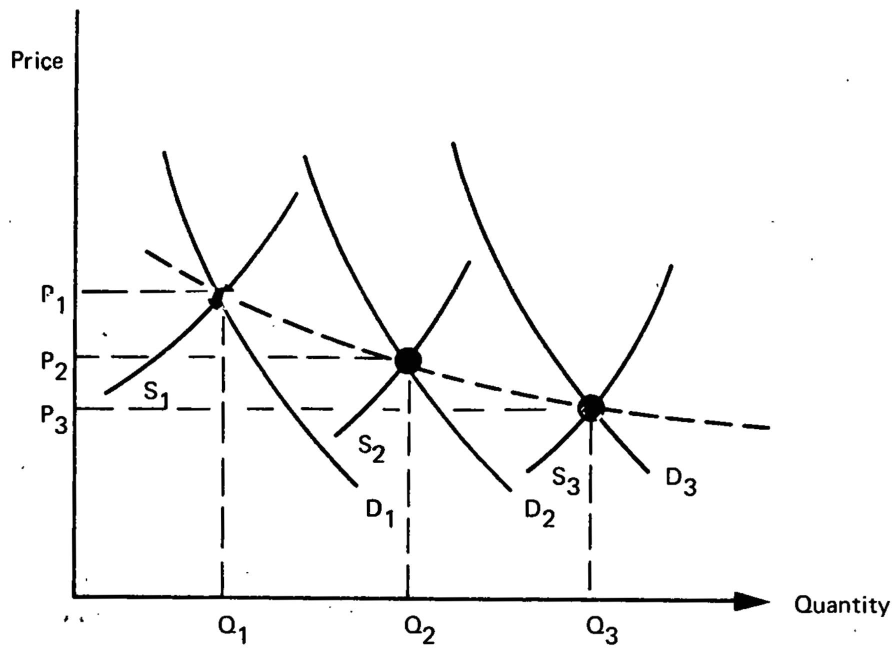


FIGURE 2–1 AN ILLUSTRATION OF THE SIMULTANEITY PROBLEM

much immediate effect on supply, adjustments of factor inputs over a somewhat longer time period will often permit a significant response. It is therefore necessary to specify the scrap supply equation in such a way that the difference between short- and long-run responsiveness can be accounted for. The way in which this is generally done can be described with the aid of a brief example.

In modeling the price-responsiveness of scrap, the problem of simultaneity has been corrected for by the appropriate means. Estimates of the price-responsiveness of scrap supply in both short-run and long-run terms could then be obtained by econometrically estimating an equation of the following type:

$$Q_t = \beta_0 + \beta_1 P_t + \beta_2 Q_{t-1} \tag{1}$$

where Q_t = quantity of scrap supplied at time t

Q_{t-1} = quantity of scrap supplied during the previous time interval t-1

P_t = price of scrap at time t

$\beta_0, \beta_1, \beta_2$ = constants

Here, the present quantity of scrap supplied is taken to be a function both of the present price of scrap and of the supply of scrap in the period immediately preceding the present. It may be helpful to think of this latter term as an "inertia factor" which describes the importance of recent activity levels in determining the current level. Given this specification of the price-quantity relationship, it is easy to follow through the effects of an increase in the price of metal. The immediate impact of the price increase is indicated by the response parameter β_1, which predicts some resulting increase in scrap output during the period in question.

Now, note that the current period's output Q_t will become Q_{t-1} in the next period. The price increase will therefore make itself felt again in the future, and some "echo" effects will still be present several periods hence. This is the simplest sort of dynamic equation, which can be solved by considering the situation after a once-for-all price increase has worked its way through the system. Once the transient price effect has been completely dampened by the passage of time, the condition $Q_t = Q_{t-1}$ will prevail. Substituting appropriately into the original equation gives the following long-run equilibrium condition:

$$\begin{aligned} Q_t &= \beta_0 + \beta_1 P_1 + \beta_2 Q_t \\ Q_t - \beta_2 Q_t = (1 - \beta_2)\, Q_t &= \beta_0 + \beta_1 P_t \\ Q_t &= \beta_0/(1 - \beta_2) + P_t\, \beta_1/(1 - \beta_2) \end{aligned} \tag{2}$$

The appropriate measure of the long-run impact of the price increase now appears to be the parameter $\beta_1/(1-\beta_2)$. Thus, the appropriate means for estimating the long-run effect is implicit in the original specification of the scrap supply equation.

While this kind of lagged-effect model is quite useful for distinguishing between short- and long-run price responsiveness, it is subject to another set of serious econometric problems that must be accounted for. Professor Ray Fair has developed an appropriate correction technique.[2] Any estimation of an equation of the above type that does not employ the Fair technique is not to be trusted because the parameter values will be biased away from the true values in systematic ways.

Some attention should also be devoted to the units in which the relevant variables are measured. Equation (1) above is in what is generally termed the "linear" form, and the parameter values indicate the short- and long-term changes in scrap output (measured in whatever units have been employed for the econometric work — most probably thousands of tons) that will result from a one-unit change in scrap price (generally, price is measured in cents/lb, or $/ton). Although it has been convenient to use this linear equation form in introducing the notion of short- and long-run response measurement, the implied relationship between scrap supply and scrap price is not, in fact, a very realistic one. Generally, the workings of the market are captured much better by equations that describe responsiveness in proportional terms. Equations that are linear in the logarithms of the relevant variables have this property. Suppose, for example, that the original supply equation was respecified in the following way:

$$\text{Log } Q_t = \beta_0 + \beta_1 \text{ Log } P_t + \beta_2 \text{ Log } Q_{t-1} \tag{3}$$

In this "log-linear" form, the estimated parameters can be interpreted as ratios of percentage changes. Thus, β_1 in this revised form would measure the percent change in quantity that would result from a percent change in price in the short run, and similarly for $\beta_1/(1-\beta_2)$ in the long run. Since these interpretations coincide precisely with the standard definition of price elasticity of supply, the log-linear specification is quite convenient for empirical work.

2.1.6.4 Statistical Questions

Typically, the parameter values for equations like those above are estimated using a computer algorithm that minimizes the sum of the squared differences between the actual supply observations and the observations that would be predicted by the simple model specified. These "least-squares" estimates are no more than approximations, of course, and the history they describe is only one sample from a multitude of possible outcomes. Had history been allowed to repeat itself, the observed supply levels would undoubtedly have been different, even if the associated prices had been exactly the same. To acknowledge this is simply to acknowledge the role of random changes in the environment for which the simple model does not compensate.

Thus, observations used for "least-squares" estimation are really random draws from the population of possible outcomes, and the resulting parameter estimates must be subject to uncertainty. Using linear algebra and the Central Limit Theorem of Statistics, econometricians have been able to devise a means for estimating the range within which the "true" parameter values for any equation probably lie, given only the assumption that intervening changes in the environment are essentially random. In most reports of econometric results, the estimated uncertainty level is presented as the "standard error" of the estimated parameter. A good rule of thumb for constructing the range within which the true parameter could plausibly lie is to double the reported standard error, add it to the estimated parameter value to form the upper bound for the plausible range, and subtract it from the estimated parameter to form the corresponding lower bound. As an example, suppose that a log-linear supply equation has been estimated for scrap with the following results (the estimated standard errors are included in parentheses underneath the estimated parameter values):

$$\text{Log } Q_t = 1.26 + \underset{(0.09)}{0.49} \text{ Log } P_t + \underset{(0.15)}{0.27} \text{ Log } Q_{t-1}$$

Using the calculated standard errors, the interval within which the true short-run price elasticity can be plausibly supposed to lie will be:

$$0.31 \leq \beta_1 \leq 0.67$$

At the same time, the best estimate of the long-run elasticity will be:

$$(\beta_1/1 - \beta_2) = 0.49/\ 1 - 0.27 = 0.67$$

Obviously, there is an illusory degree of certainty that will prevail if only the estimated parameter values themselves are considered. At the same time, there is a good argument for considering the actual parameter estimates as the best ones, if only one prediction of the consequences of a price change is needed.

As a conclusion to this general discussion of econometric estimation of price responsiveness equations, a word should be said about the interpretation of R^2, which is commonly used as the measure of the degree to which an equation has successfully "explained" the observed variation in the behavior of some variable (in this case, the supply of scrap). In econometric work that involves the analysis of movements of variables through time, $\bar{R}^2$ is frequently of little practical use. Given the tendency of variables such as output to exhibit persistent strong trends and the fact that conventional supply equations frequently specify present output as a function of past output (among other things), it is not at all surprising that such equations tend to exhibit very high R^2 values. Such a high value obviously does not mean much when the behavior of a variable is being "explained" by its own behavior in the immediate past. Thus, the important measures in econometric estimates of supply behavior are the parameter values and the standard errors, not the estimated R^2 values.

2.2 METHODOLOGY

2.2.1 Methodology Overview

This section describes the general methodology established by DOE for the metals, pulp and paper, rubber, and textile industries.[3]

Figure 2-2 indicates a series of steps required for developing draft targets for recoverable materials (RM) for all industries. These steps are discussed below.

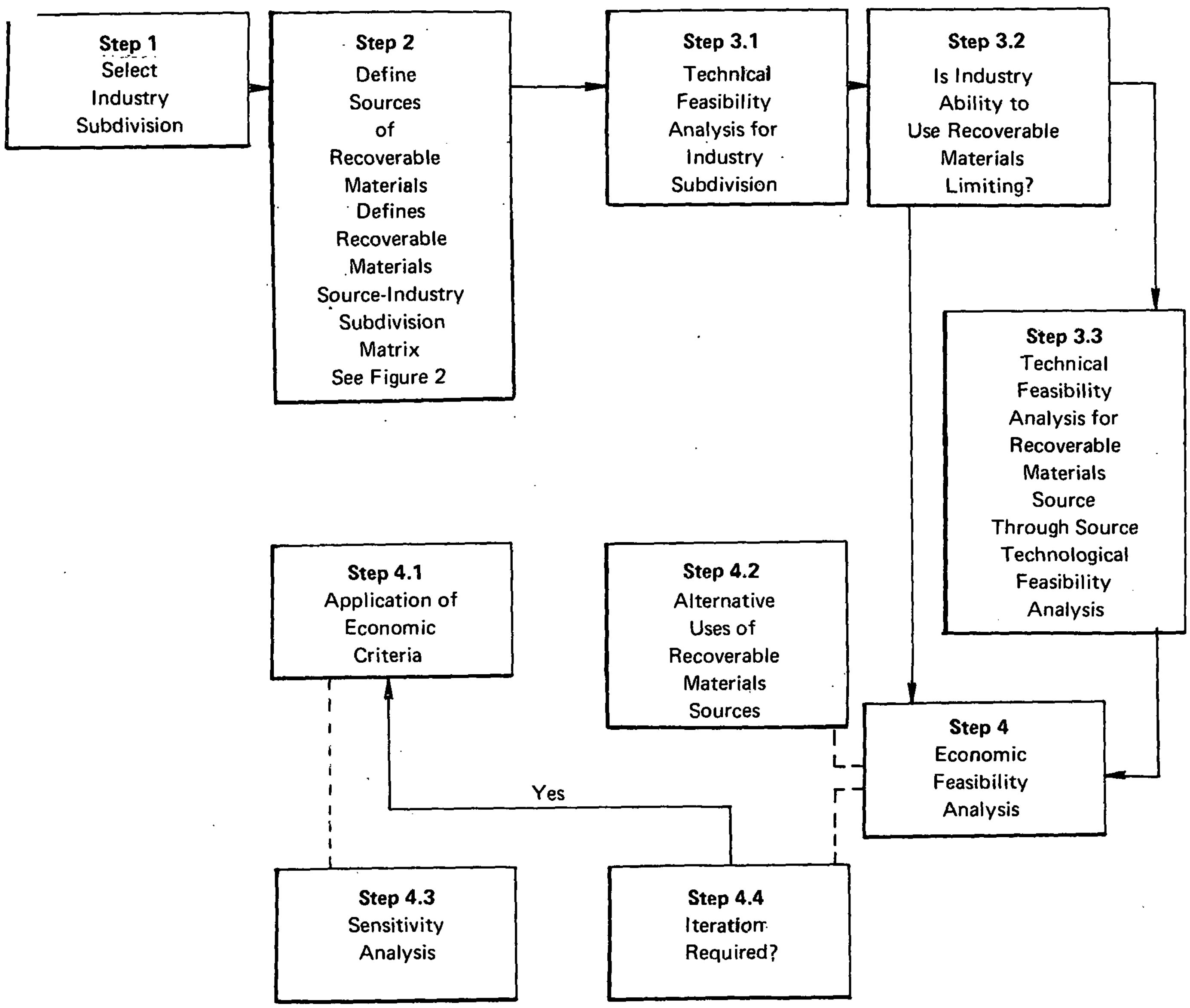


FIGURE 2–2 METHODOLOGY NETWORK ENERGY SAVING RECOVERED MATERIALS TARGETS

Step 1: Select Appropriate Industry Subdivisions

A. The following factors were considered in determining portions of an industry to be studied further:

1. Historical and current use of recovered materials in the industry
2. Sales of industry components
3. Energy consumption levels
4. Parts of the industry that historically and currently use recovered materials
5. Potential for use of recovered materials between now and 1987
6. All materials identified in the legislation.

B. Portions of the industry (e.g., fabricating plants) were excluded from further consideration since additional study of these segments would not contribute anything useful to the results.

C. Each industry segment was carefully studied to determine whether an SIC, process, product type (other than SIC) or some other sub-division of the industry was most appropriate.

D. The result of Step 1 was one ordinate of the "industry RM source matrix," shown in Figure 2-3.

Step 2: Select Sources of Recoverable Materials

A. The following factors were considered in determining sources of recoverable materials:

1. Quality of waste
2. Dispersion of waste
3. Quantity of waste
4. Potential new sources, and their quality, dispersion, quantity, etc.
5. Changes in existing sources.

B. Sources of RM do include:

1. Wastes that contain materials listed in the Act (e.g., mine wastes). (As discussed in Section 2.2.1, however, mine wastes do not meet the economic feasibility criterion in the legislation.)
2. Wastes from outside the United States (none were found).
3. Any waste that may provide RM to replace any virgin material used by any of the industry subdivisions defined in Step 1.

C. Sources of RM do not include:

1. Waste materials not among those listed in the Act (none were found).
2. Situations where a clear case can be made that the potential sources will never be realistically used as RM, for whatever reason — technical, economic, institutional, etc.

Sources of Recoverable Materials

Industry Subdivisions (IS)	A	B	C	D	E	F	G	H
1		*			*		*	
2								
3			*			*		
4				*			*	
5								
6		*	*					
7							*	
8	*				*			

Objective: Define ^{x}/output of IS, where x is the economically feasible amount of recovered materials for each Industry Subdivision.

FIGURE 2–3 RECOVERABLE MATERIALS SOURCES – INDUSTRY SUBDIVISION MATRIX

3. Waste materials generated and introduced back into the process within the same plant. Because home scrap and prompt industrial scrap are identical except for the absence/presence of a transaction, home scrap was tracked as a separate category when data were available. Since almost all home scrap is recycled, this does not affect any draft target.

D. The result of Step 2 is completion of the basic "industry RM source matrix," shown in Figure 2-3. This figure shows present and future sources for recovered materials for an industry subdivision.

Step 3: Technological Feasibility Analysis

A. Current and historical use of RM within each industry sub-division, by source of RM, for each source defined by a marked cell in the matrix was quantified wherever data were available.

B. Present technical limits on industry's ability to utilize RM were analyzed. Typically, such limits are related to an industry's existing equipment and plant (capital stock).

C. Future technical limits represented by decisions already made (e.g., plant expansions, new plant construction, etc.) were determined.

D. Realistic technologies that could alter these technical limits were assessed if they could be physically in place and operational between now and 1987, and could have some minimum level of impact on use of the recovered material.

Step 4: Economic Feasibility Analysis

The approach used in the economic analysis by Arthur D. Little, Inc., was adapted from DOE's guidelines. Arthur D. Little's approach used econometric techniques to estimate the supply of scrap in 1987. Since the purpose of this project is to increase energy savings via the use of recovered materials, it is important to remember that the ferrous industry (iron and steel, ferrous foundries, and ferroalloys), as defined here, accounts for approximately 83% of the energy consumed in the metals sector (i.e., SIC 33), aluminum for about 11%, copper for about 3%, and all others for the remaining 3%. Energy consumed in the lead and zinc segments is less than 1% each. Therefore, most of the effort in econometric modeling was focused on the ferrous scrap users, followed by aluminum and copper. For lead and zinc, draft targets were estimated on the basis of published forecasts of trends in these industries relating to growth rates, changes in industry structure and changes in market structure.

A. Actions that affect the target: Major actions that could realistically increase the use of RM by a defined industry subdivision were addressed. These incentives could be financial, regulatory, institutional, etc. in nature.

B. Sensitivity analysis: The sensitivity of the target to key economic variables was addressed.

C. Upon completion of Step 4, the economically feasible level of RM use by each industry subdivision was defined.

2.3 IMPACT OF GOVERNMENT ACTIONS ON RECYCLING

Many government policies can potentially have an impact on the degree of recycling in all types of primary and secondary metals industries. Of the potential actions discussed below some have been debated for years and have yet to be passed as legislation. In other cases the legislation has been enacted recently and is yet to be fully implemented through regulations. Finally, in still other cases the government policies and associated regulations have been fully implemented and their effect is already prevalent within the existing economy.

2.3.1 Federal Policy

It has been claimed that there is at present a de facto federal policy which appears to favor the use of virgin materials over recovered materials because of different treatment under the federal tax code. Relevant components include: percentage depletion tax reductions; expensing of certain exploration and development costs; capital gains; domestic international sales corporation allowances; foreign tax credits; and western hemisphere trade corporation allowances. It has been argued that each of these components has the effect of reducing the costs of producing virgin materials and has resulted in inefficient allocation of capital and price distortion by causing the supply curves for metals to be lower than would prevail in the absence of favorable tax treatment. According to Page,[4] the long run effects of favorable tax treatment of the primary industries are: lowered prices, increased rents, and more exploration and other investments in the extractive industries. A recent report has estimated the increase in recycled materials which would result from equalization of tax treatment between the primary and secondary industries.[5] The results show that the percent increase in recycling would be 0.42% for scrap steel; 0.35% for copper; 1.0% for aluminum, and 0.75% for lead.

The Office of Technology Assessment[6] has assessed the potential effect of five economic policies for stimulating recycling and reducing the rate of disposal of municipal solid wastes (MSW). These are:

- product charge — an excise tax levied on material goods on the basis of a measure of ultimate disposal cost.
- recycling allowance — a tax incentive to producers or users of recycled materials.
- severance tax — a tax on virgin materials.
- percentage depletion allowance — a deduction from income before taxes for extraction of certain specified minerals.
- capital gains treatment of income from standing timber.

The OTA believes the product charge and the recycling allowance to be the most effective if they could be made to work; however, both pose major administrative barriers to successful implementation. The OTA believes that the repeal of the depletion allowance for hardrock minerals and of the capital gains treatment for timber income would increase recycling by only a small amount and not significantly reduce the generation of waste. Overall, the OTA report favors the removal of existing preferences for virgin materials to establishing new ones for recycled materials from the perspectives of equity, economic efficiency and administrative burdens.

2.3.2 Freight Rates

It has been argued that railroad freight rates discriminate against recovered materials. A recent study by the Office of Technology Assessment[6] has found that the determination of discrimination depends on both the material concerned and more importantly on the basis chosen for the definition of discrimination. This study has found that if the discrimination were eliminated (using fully allocated costs as the indicator of maximum discrimination) shipments of scrap steel would increase from 0.5 to 2.9% and the shipments of scrap aluminum would increase by 0.06%. In spite of these small projected increases, OTA favors rate adjustment on the basis of equity and economic efficiency.

2.3.3 Product Specifications

Product specifications (in favor either of virgin or in favor of secondary materials) can lead to a market inefficiency. In the past, product specifications have generally discriminated against recovered materials. The secondary metals industry and its customers have more or less successfully moved away from specifications based on source or pedigree towards specifications based on chemical composition and/or performance. A government policy of reinstituting "pedigree" type specifications would lead to a market inefficiency that would favor one or the other type of material. The Office of Technology Assessment[6] believes that specifications for the quality of recovered resources are needed mainly to facilitate trade and not for the purposes of protecting consumers. They believe that the current state of activity concerned with voluntary standards is such that there seems to be no need for government action beyond that authorized under the Resource Conservation and Recovery Act. These actions are likely to favor recovered materials.

2.3.4 Pollution Control Costs

Government policies on controlling pollution have had a major impact on increasing the operating cost of plants treating primary and secondary materials. Many secondary sectors have been more severely impacted because of the small scale of operation and frequently, the complex nature of the raw materials. As operating costs increase, one would expect the rate of recycling to decrease (all else equal) since it would no longer be economically feasible to process marginal scrap. Consequently, this scrap would be discarded. If higher costs result in higher prices, material conservation would be promoted because demand would decrease in response to the higher price.

2.3.5 Market Structure

Since the primary industries are concentrated, it has been argued that this "market inefficiency" would result in higher prices, lower output, and increased profit. Higher prices, on the one hand, would be expected to slow down the rate of extraction of the non-renewable resources and provide a price umbrella for secondary materials that are close substitutes. This would not only lead to reduced primary production but would also induce recycling. Thus, this behavior, if it occurs, would promote materials conservation. However, it is not clear that this discretionary pricing power would be used to limit output. Fink[1] has shown that the degree of competition does not appear to have much bearing on the rate of recycling.

Government policy to change the competitive structure of the concentrated industries is not expected to have a long-term effect on the rate of recycling, but might have some short-run effects.

2.3.6 Beverage Container Deposit Legislation

The OTA report[6] has reviewed the available studies on beverage container deposit legislation (BCDL). They find that such legislation would accomplish the goals of BCDL to some degree, i.e., a reduction in litter, in MSW, and in the consumption of energy and raw materials. However, OTA states that considerable uncertainty exists regarding the ultimate effects of BCDL on container market shares and on return and recycling rates. It is felt that BCDL would lead to an increased use of refillable bottles and that containers would be returned at a sufficiently high rate to ensure that its goals would be achieved.

REFERENCES

REFERENCES: SECTION 2.0 INTRODUCTION

1 Fink, D.A., Market Structure and Recycling in the Nonferrous Metals Industries, Resource Conservation, D.W. Pearce & I. Walter eds., New York: New York University Press, 1977.

2 Fair, Ray C., Estimation of Simultaneous Equation Models with Lagged Endogenous Variable and First Order Serially Correlated Errors, *Econometrica, 28,* 507-516, May 1970.

3 Gross, T., Energy Saving Recovered Materials Targets Guidance to Methodology, Internal Memorandum, Department of Energy, January 10, 1979.

4 Page, T. *Conservation and Economic Efficiency,* Resources for the Future, Baltimore, Johns Hopkins University Press, p. 109 (1977).

5 Columbia University, Graduate School of Business, "Impact of the Federal Tax Code on Resource Recovery — A Condensation," prepared for Municipal Evnironmental Research Lab, Cincinnati, Ohio, August 1977, NTIS No. PB 272 329.

6 Office of Technology Assessment, *Materials and Energy from Municipal Waste,* Washington, D.C., July 1979, OTA-M-93.

3.0 INDUSTRY PROFILE

3.1 INTRODUCTION

This section presents general profiles for the major industrial segments comprising SIC 33. The profiles include such topics as industry structure, process technology, materials and recycling flow, and future trends. These profiles are designed to give a general overview of the respective industry segments as well as to provide a framework with which to analyze current and future recycling practices.

3.1.1 Definition of SIC 33

As defined by the U.S. Office of Management and Budget, this major industrial group includes "establishments engaged in the smelting and refining of ferrous and nonferrous metals from ore, pig or scrap; in the rolling, drawing and alloying of ferrous and nonferrous metals; in the manufacture of castings and other basic products of ferrous and nonferrous metals; and in the manufacture of nails, spikes and insulated wire and cable." Establishments engaged primarily in manufacturing metal forgings or stampings are classified in SIC 34 and are, therefore, excluded from this analysis.

3.1.2 Subdivision of SIC 33 by Industry Groups

In order to facilitate data collection, analysis and presentation, the major industry group, SIC 33, was subdivided into six four-digit SIC categories. Each of the four-digit SIC categories was reviewed to eliminate sections not pertinent to recycling. For example, SIC 3398 (Metal Heat Treating) does not involve recycling and is, therefore, excluded from further analysis. The remaining four-digit SIC categories were regrouped into five major industrial metal categories:

- Ferrous Industry (including Iron & Steel, Ferrous Foundries, and Ferroalloys)
- Aluminum
- Copper
- Zinc
- Lead

The resulting industry subdivisions and the SIC categories included are given below:[1]

Industry Subdivision	**SIC Categories**
Ferrous Industry	3312, 3315, 3316, 3317, 3321, 3322, 3324, 3325, 3313
Aluminum	3334, 3353, 3354, 3355, (33417) (33418)
Copper	3331, 3351, (33412)
Zinc	3333, (33414)
Lead	3332, (33413)

1. SIC 3341 has been allocated by a five-digit SIC number into the appropriate major industrial categories.

Industry profiles for each subdivision are described in the following sections.

3.2 FERROUS

3.2.1 Industry Definition

The Ferrous Industry is comprised of the following segments:

- Iron and Steel, which includes SIC 3312, 3315, 3316 and 3317;
- Ferrous Foundries, which includes SIC 3321, 3322, 3324 and 3325;
- Ferroalloys, which includes SIC 3313.

3.2.1.1 Iron and Steel

SIC 3312 includes "establishments primarily engaged in manufacturing hot metal, pig iron, silvery pig iron, and ferroalloys from iron ore and iron and steel scrap; converting pig iron, scrap iron and scrap steel into steel; and in hot rolling iron and steel into basic shapes such as plates, sheets, strips, rods, bars and tubing and cold finishing and processing these products in the same plant." Also included are merchant blast furnaces.

SIC 3315 is comprised of "establishments primarily engaged in drawing wire from purchased iron or steel rods, bars, or wire and which may be engaged in the further manufacture of products made from wire." Also included in this segment are establishments primarily engaged in manufacturing steel nails and spikes from purchased materials.

SIC 3316 includes those "establishments primarily engaged in (1) cold rolling steel sheets and strip from purchased hot rolled sheets, (2) cold drawing steel bars and steel shapes from purchased hot rolled steel bars and (3) producing other cold finished steel."

SIC 3317 is composed of those "establishments primarily engaged in the production of welded or seamless steel pipe and tubes and heavy riveted steel pipe from purchased materials."

3.2.1.2 Ferrous Foundries

The domestic ferrous foundry industry includes establishments primarily engaged in manufacturing iron and steel castings. Establishments classified in other industries frequently operate their own foundry departments to produce castings to be incorporated into such products as stoves, furnaces, plumbing fixtures, motor vehicles, etc. Establishments primarily engaged in the manufacture and rolling of steel and classified in the Iron and Steel subcategory also make steel castings.

SIC 3321 includes establishments primarily engaged in manufacturing gray iron castings, including cast iron pressure and soil pipes and fittings. SIC 3322 primarily produces malleable iron castings. SIC 3324 primarily produces steel investment castings. SIC 3325 produces steel castings not elsewhere classified. The bulk of steel castings production falls into the SIC 3325 category.

3.2.1.3 Ferroalloys

SIC 3313 contains "establishments primarily engaged in manufacturing ferro- and nonferrous additive alloys by electrometallurgical or metallothermic processes, including high percentage ferroalloys and high percentage nonferrous additive alloys." Ferroalloys produced by the blast furnace process will also be included in the analysis for this report.

3.2.2 Industry Structure

3.2.2.1 Iron and Steel

The United States consistently ranks first or second among world producers of raw steel.[2] Table 3.2-1 compares U.S. raw steel output with the world total for the years 1950-1976. Geographic distribution of raw steel production has shifted steadily and dramatically in that time; the United States produced nearly half of the world's steel in 1950, but only 17% by 1976. Compared with a consistent annual growth rate of 5.8% worldwide, U.S. steel production has had only sporadic growth on the order of 1.5-2.5% annually. In 1976, U.S. production equalled 80.9% of calculated raw steel capacity of 158 million short tons.[2]

The U.S. steel industry produces raw steel in some 165 steelmaking plants,[3] with about 85% of the production accounted for by 15 large companies.[5] Including associated steel rerolling and steel finishing plants, the U.S. industry is composed of some 400 plants employing 520,000.[6]

In 1976 reported net shipments were about 90 million short tons.[4] Total revenues for firms accounting for nearly 90% of the nation's raw steel production (128 million short tons) amounted to about $36.4 billion.[5]

The iron and steel industry consumed about 70% of all energy used in the SIC 33 classification in 1976. Purchased energy consumption by SIC category for the iron and steel industry is given in Table 3.2-2 for 1974-1976.

Plants producing raw steel may be categorized into three broad groups — fully integrated, cold metal shops and non-integrated. Fully integrated plants are engaged in both iron and steelmaking operations. The integrated plants start with iron ore and coking coal, from which pig iron (or hot metal) is produced in blast furnaces. The resulting hot metal, along with scrap, is charged into steelmaking furnaces to produce molten raw steel, which is subsequently cast and fabricated to finished steel products. In 1976, a total of 58 integrated plants were in operation.[3]

The cold metal shops operate their steel furnaces with cold metal charge — scrap, pig iron, or, more recently, sponge iron made by direct reduction — which is melted and refined in the steelmaking furnaces. These plants do not produce hot metal from ore. Most cold metal plants in the United States use electric arc furnaces, which offer economic advantages and flexibility of operation. A special group of smaller cold metal plants comprises the so-called mini-mills; many of these mills have annual capacities of less than 200,000 short tons and limit their production to bar mill products, rebars and merchant bars. In 1976, a total of 107 cold metal plants were in operation.[3]

The third category of plants in the steel industry are the non-integrated plants. These plants purchase semi-finished steel from integrated or cold metal producers for finish rolling and additional fabrication to final products. Many of the non-integrated plants are satellite finishing operations for the raw steel producers. This group includes facilities that reroll carbon steel products and others that finish alloy steel intermediates.

TABLE 3.2-1

RAW STEEL PRODUCTION: 1950-1976

Year	Production (million short tons) World	U.S.	U.S. as % of the World
1950	207	97	46.9
1952	234	93	39.7
1954	246	88	34.8
1956	313	115	36.7
1958	299	85	28.4
1960	382	99	29.5
1962	395	98	24.8
1964	479	127	26.5
1966	519	134	28.8
1968	583	131	22.5
1970	654	132	20.2
1971	640	121	18.9
1972	694	133	19.2
1973	769	151	19.6
1974	783	146	18.6
1975	712	117	16.4
1976	753	128	17.0

Source: AISI Statistical Reports, 1950-1977

TABLE 3.2-2

PURCHASED ENERGY USE IN THE IRON AND STEEL INDUSTRY BY SIC CATEGORY - 1974-1976

SIC Category	Purchased Energy Consumption, 10^{12} Btu 1974	1975	1976
3312	1599.5	1321.8	1427.4
3315	15.4	12.2	13.7
3316	19.8	13.4	15.8
3317	18.1	15.3	12.2

Source: U.S. Department of Commerce, Annual Survey of Manufacturers, "Fuels and Electric Energy Consumed", 1974-1976.

The six states bordering the Great Lakes — New York, Pennsylvania, Ohio, Indiana, Illinois, and Michigan — have historically accounted for over 75% of total U.S. steel output.[2] Within these states are about 80% of the integrated plants and 70% of the cold metal and non-integrated steel plants.[3] This industry concentration results from the favorable location of raw material sources, transportation arteries, and steel-consuming industries.[2]

3.2.2.2 Ferrous Foundries

In 1976, more than 1750 ferrous foundry plants were in operation, and the industry produced about 16.8 million short tons of castings valued at $10 billion (Table 3.2-3). The industry makes metal parts that range from tiny, specialized stainless steel heart valves to huge components for machine tools and hydroelectric turbines. Purchased energy consumption by ferrous foundries for 1976 equalled 155.0 x 10^{12} BTU equivalents. Of this amount, gray (including ductile) iron foundries consumed 67%, steel foundries 23% and malleable iron foundries 10%.[7]

Gray iron foundries are the largest segment of the ferrous foundry industry with 68% of total output in 1976.[6]

In 1976, a total of 1195 foundries poured gray iron as their major product. About 80% of these foundries were small, employing fewer than 250 employees.[6] However, the number of small foundries has dropped dramatically over the past 15 years and this trend is expected to continue.

Gray iron foundries are concentrated in the Great Lakes region, but the industry is dispersed across the nation with plants located in all 50 states. Gray iron foundries have a strong jobbing orientation, and 62% of the establishments sell all of their output to outside customers.[6]

Production of ductile iron castings started in the United States in the late 1940's, and has had the highest growth rate of all cast ferrous materials over the last 20 years.[6] The physical properties of ductile iron are close to those of carbon steel, and can be produced in a manner similar to gray iron. Consequently, a large part of the growth of ductile iron has been at the expense of other ferrous castings.

In 1976, 88 foundries produced ductile iron as their major metal product. Of these, 42% had 50-250 employees and 37% had 10-49 employees.[6] Most of the ductile iron foundries are located in the Great Lakes and East South Central regions and most are job-oriented with 60% of the foundries selling all of their output.[6]

Malleable iron has been produced since the 1800's. Its position in the industry is now relatively minor in terms of tonnage and value of shipments. Because production of malleable iron is energy-intensive, its position in the future will be even less competitive.

In 1976, 59 foundries produced malleable iron castings as their major product. Most of these were large foundries with about half having more than 250 employees.[6] The malleable iron foundries are concentrated in the Great Lakes and Middle Atlantic regions and 66% of them are independent jobbers.[6]

Steel is the second largest segment of the ferrous foundry industry. More than 95% of production is carbon and low alloy steel, with the remainder high alloy material.[6] Most of the

TABLE 3.2-3

NUMBER OF FOUNDRIES AND CASTING SHIPMENTS - 1976

Major Metal Cast	Number of Establishments	Shipments thousands of tons	Shipments millions of dollars
Gray Iron	1,195	11,900	7,010
Ductile Iron	88	2,200	
Malleable Iron	59	850	740
Steel	422	1,800	2,330
Total	1,764	16,750	10,080

Source: Bureau of Census
Arthur D. Little, Inc., estimates
Penton Publications

output goes to railroad equipment and heavy capital goods. The main advantages of steel castings are weldability, strength, ductility, and impact resistance; premium price and casting difficulties limit its applicability.

Steel foundries have been steadily declining and numbered only 422 in 1976. Of these, about 80% had fewer than 250 employees.[6] Steel foundries are heavily concentrated around the Great Lakes and Middle Atlantic regions. These foundries are also jobbing oriented with 69% being independent producers.[6] The present trend is toward even more jobbing orientation.

3.2.2.3 Ferroalloys

In 1976, 33 companies in the United States operated a total of 54 ferroalloy-producing plants in 18 states and employed approximately 8,300 people.[3] Eleven companies operated more than one plant. A list of plants is given in Table 3.2-4. These plants produced 1.9 million short tons of ferroalloys valued at close to $1 billion (Table 3.2-5).[10] Ferroalloys containing either manganese, silicon, or chromium accounted for slightly over 90% of production.[10] These materials were produced by 19 companies, which operated 37 plants.[10]

3.2.3 Process Technology

3.2.3.1 Iron and Steel

The flow of material and the functions of the unit operations in the iron and steelmaking and steel-forming sequences of an integrated plant are portrayed in Figure 3.2-1. The left side of the figure represents the iron and steelmaking end and shows the flow of raw materials into hot metal (molten pig iron) and steel. Along with scrap (about half of which is recycled from subsequent operations) the hot metal may be fed into any of three different types of refining furnaces to produce molten steel. The molten steel is then either cast into ingots and rolled in primary breakdown mills to semifinished forms by conventional practice, or direct cast into semifinished forms (blooms, slabs, or billets) by the continuous casting process. As indicated in the figure, the semifinished raw steel is routed through various rolling mills to be finished into a wide range of products such as structural shapes, bars, plates, and hot or cold rolled sheet.

The principal components of the iron and steel technology that are relevant to this study are:

- Sinter plant
- Blast furnace (for producing pig iron)
- Direct reduction (for producing prereduced iron)
- Basic oxygen furnace
- Open hearth furnace
- Electric arc furnace
- Continuous casting
- Rolling and finishing operations

TABLE 3.2-4

FERROALLOY PRODUCERS IN 1977

PRODUCER	PLANT LOCATIONS	PRODUCTS	FURNACE TYPE
AIRCO ALLOYS DIV. Airco, Inc. 3801 Highland Ave. Niagara Falls, NY	Calvert City, KY Charleston, SC Mobile, AL Niagara Falls, NY	FeCr, FeMn FeCrSi, FeSi, SiMn	electric
ALABAMA ALLOY CO, INC Bessemer, AL	Bessemer, AL Woodward, AL	FeMo FeSi	electric
CHROMIUM MINING & SMELTING CORP. DIV. Chromasco Ltd. Memphis, TN	Woodstock, TN	FeCr, FeSi	electric
CLIMAX MOLYBDENUM CO. Div. of Amax, Inc. 1270 Ave. of Americas New York, NY	Langeloth, PA	FeMo	metallothermic
DIAMOND SHAMROCK CORP. Chemetals Div. 711 Pittam Road Baltimore, MD	Kingwood, WV	FeMn	electrolytic
DUVAL CORP. 900 Southwest Tower Houston, TX	Sahuarita, AZ	FeMo	metallothermic
ENGLEHARD MINERALS & CHEMICALS CORP. 299 Park Avenue New York, NY	Rockwood, TN Strasburg, VA	FeMn, FeSi FeV	electric metallothermic
FMC CORP. Industrial Chemicals Div 633 Third Avenue New York, NY	Pocatello, ID	FeP	electric
FOOTE MINERAL CO. Ferroalloys Div. Route 100 Exton, PA	Cambridge, OH Graham, WV Keokuk, IA New Johnsonville, TN	FeCrSi, FeV FeCr, FeSi FeSiMg, Mn CaSi, silvery pig iron	electric

TABLE 3.2-4 (Continued)

PRODUCER	PLANT LOCATIONS	PRODUCTS	FURNACE TYPE
GLOBE METALLURGICAL DIV. Interlake, Inc. 1556 Union Commerce Bldg Cleveland, OH	Beverly, OH Selma, AL Toledo, OH	FeSiMg, SiMn SiCr, FeCrSi FeCr, FeSi	electric
GULF & WESTERN INC. New Jersey Zinc Co. 2045 City Line Rd. Bethlehem, PA	Palmerton, PA	Spln	electric
HANNA MINING CO. 100 Erieview Plaza Cleveland, OH	Riddle, OR Wenatchee, WA	FeNi, Si, FeSi	electric
HOOKER CHEMICAL DIV. Occidental Petroleum 600 Union Street Niagara Falls, NY	Columbia, TN	FeP	electric
INTERNATIONAL MINERALS & CHEMICAL CORP. Tennessee Alloys Div. 818 Hamilton Bank Bldg Chattanooga, TN	Bridgeport, AL Kimball, TN	FeSi	electric
KAWECKI BERYLCO IND. P.O. Box 1462 Reading, PA	Springfield, OR Revere, PA	Si FeCb	electric metallothermic
KERR McGEE CHEMICAL Kerr McGee Center Oklahoma City, OK	Oklahoma City, OK	Mn	
METALLURG, INC. Shieldalloy Corp. West Boulevard Newfield, NJ	Newfield, NJ	FeV, FeCb, FeTi, FeAl, FeB	electric, metallothermic
MOBIL CHEMICAL CO. Mobil Oil Corp. 150 E. 42nd Street New York, NY	Nichols, FL	FeP	electric
MOLYCORP, INC. 280 Park Avenue New York, NY	Washington, PA	FeB, FeMo FeW	electric metallothermic

TABLE 3.2-4 (Continued)

PRODUCER	PLANT LOCATIONS	PRODUCTS	FURNACE TYPE
MONSANTO COMPANY Industrial Chemicals 800 N. Lindbergh Blvd. St. Louis, MO	Columbia, TN Soda Springs, ID	FeP	electric
NATIONAL NICKEL ALLOY Seven Parkway Center Pittsburgh, PA	Marietta PA	NiCr, NiCrMo	electric
OHIO FERRO ALLOYS 839 30th St., N.W. Canton, OH	Brilliant, OH Philo, OH Powhatan Pt., OH Montgomery, AL	FeB, FeMn FeSi, Si, SiMn	electric
THE PESSES COMPANY 29605 Hall Street Solon, OH	Pepper Pike, OH Newcastle, PA	FeSiAl, FeSiMg, FeSiT, FeSiZr, FeAl, FeB, FeCb	electric, metallothermic
REACTIVE METALS & ALLOYS Niles, OH	West Pittsburgh, PA	FeSi, FeTi	electric
READING ALLOYS P.O. Box 53 Robesonia, PA	Robesonia, PA	FeCb, FeW	metallothermic
REYNOLDS METALS Richmond, VA	Sheffield, AL	Si	electric
SABIN METAL CORP. 310 Messerole St. Brooklyn, NY	Brooklyn, NY	FeNi, FeW	
SATRALLOY INC. 625 Stanwix Street Pittsburgh, PA	Steubenville, OH	FeCr, FeMn, FeCrSi	electric
STAUFFER CHEMICAL CO Industrial Chemicals Div Nyala Farm Road Westport, CT	Mt. Pleasant, TN Silver Bow, MT Tarpon Springs, FL Muscle Shoals	FeP	electric
TENN-TEX ALLOY CORP Div. of Sandgate Corp. 13501 Industrial Road Houston, TX	Houston, TX	FeMn, SiMn,	electric

TABLE 3.2-4 (Continued)

PRODUCER	PLANT LOCATIONS	PRODUCTS	FURNACE TYPE
TENNESSEE VALLEY AUTHORITY Muscle Shoals, AL	Muscle Shoals, AL	FeP	electric
UNION CARBIDE CORP. Metals Division 270 Park Avenue New York, NY	Alloy, WV Ashtabula, OH Marietta, OH Niagara Falls, NY Portland, OR Sheffield, AL	FeB, FeCr FeCrSi, FeMn, FeSi, FeV, FeW, Si	electric
UNITED STATES STEEL CORP 600 Grant Street Pittsburgh, PA	McKeesport, PA Clairton, PA	FeMn	blast

Sources: Steel Industry in Brief: Databook, U.S.A. 1977. Institute for Iron and Steel Studies, W.E. Pietrucha and R.L. Deily, 1977. U.S. Bureau of Mines, Minerals Yearbook, 1977.

TABLE 3.2-5

FERROALLOYS PRODUCED AND SHIPPED - 1976

	1976 Production		1976 Shipments	
	Gross Weight (short tons)	Alloy Element Contained (average %)	Gross Weight (short tons)	Value (thousands $)
Ferromanganese	482,662	79	494,222	$207,505
Silicomanganese	128,917	66	132,362	52,649
Ferrosilicon	860,799	57	890,844	409,726
Chromium Alloys				
Ferrochromium				
High carbon	167,125	66	161,757	82,774
Low carbon	28,140	69	30,912	39,059
Ferrochromium-silicon	54,182	37	50,680	32,620
Other Alloys	19,800	60	20,195	21,481
TOTAL	269,247	60	263,544	175,934
Ferrocolumbium	1,205	65	933	6,359
Ferrophosphorus	110,903	24	92,689	11,178
Others	56,485	xx	50,942	134,322
GRAND TOTAL	1,910,218	xx	1,925,538	997,668

Source: U.S. Bureau of Mines Minerals Yearbook, 1976.

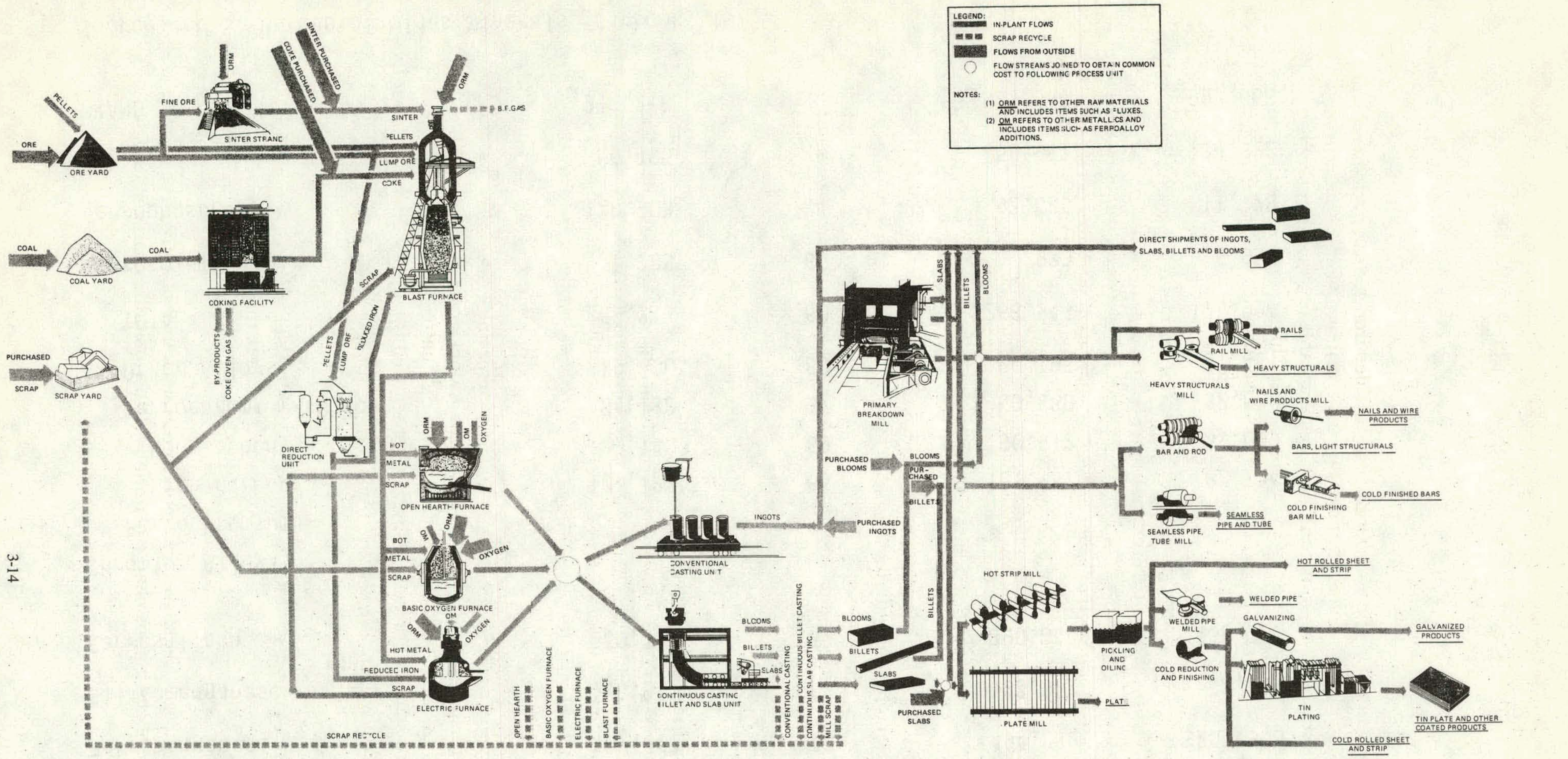


FIGURE 3.2–1

PICTORIAL REPRESENTATION OF PROCESS UNIT INTERRELATIONSHIPS – IRON AND STEELMAKING AND STEEL FORMING

3.2.3.1.1 Sinter Plant

A sinter plant has the dual function of beneficiating finely divided iron ore and agglomerating various iron-bearing materials such as blast furnace flue dust, mill scale, and similar iron units generated within a steel plant. Sintered materials are more suitable for blast furnace feed than untreated materials because of improved physical properties, higher iron content, less moisture and, in some cases, less sulfur. The use of sinter in blast furnaces has significantly improved furnace performance and productivity.

A sinter machine is a continuous traveling grate. A mixture of fine ore and fine powders from various carbon sources (e.g., anthracite and coke breeze) is placed on a grate traveling over a series of windboxes. The mixture is ignited with a burner and the ignition zone moves down through the mixer as air is drawn through the ore by fans. The generated heat sinters the ore particles together into a relatively hard, porous mass.

3.2.3.1.2 Blast Furnace

The blast furnace is the workhorse of the iron and steel industry and is the basic process unit of all integrated steel plants. It is a vertical shaft reactor that burns solid carbon fuel (coke) and liquid or gaseous hydrocarbons (oil, tar, natural gas) in the presence of iron oxide rich raw materials (ore, pellets and sinter) and flux (limestone and dolomite), reducing the iron oxide to metallic iron as the burden descends. Furnace off-gases are cleaned to supply some of the plant fuel needs, and the recovered flue dust is usually sent to the sinter plant for recycling. As a result of improvements, blast furnace production records have increased markedly from about 1200 to 10,000 short tons per day over the past 30 years.(11)

3.2.3.1.3 Direct Reduction

Many direct reduction processes have been developed, but only a few have been commercialized. Of these, the static bed reduction processes and shaft furnace account for most of the world's installed direct reduction capacity. Both processes utilize gaseous reductants. The only static bed process used on a commercial basis is the HyL process. The shaft furnace processes now operated in this country are the Midrex process and the Armco process, while other available processes include the Purofer process, as well as several others.

Direct reduction/arc-furnace combination plants may be increasingly attractive to the developing countries in the future as an alternative route to conventional steelmaking, especially in the lower capacity ranges, and when plentiful supplies of low-cost natural gas or other fossil fuels are readily available. However, at the present time direct reduced iron is not a large scale viable alternative in the U.S. mainly because of the limited supply of natural gas.

3.2.3.1.4 Basic Oxygen Furnace

The BOF process was first introduced into the United States in 1954; since that time raw steel production by this process has grown to more than 80 million short tons.[4] This growth has been largely at the expense of the less economical open hearth shops. This is shown in Table 3.2-6.

Hot metal from blast furnaces is the largest and most important source of iron for the BOF, and usually comprises 70-80% of the ferrous charge materials.[4] Other metallic charge materials include scrap and cold pig iron.

TABLE 3.2-6

BASIC OXYGEN STEEL PRODUCTION - 1957-1976

(thousand)

Year	Total Raw Steel Production	Basic Oxygen Production	Basic Oxygen Steel as % of Total Raw Steel Production
1957	112,715	611	0.5
1958	85,255	1,323	1.6
1959	93,446	1,864	2.0
1960	99,282	3,346	3.4
1961	98,014	3,967	4.0
1962	98,328	5,553	5.6
1963	109,261	8,544	7.8
1964	127,076	15,442	12.2
1965	131,462	22,879	17.4
1966	134,101	33,928	25.3
1967	127,213	41,434	32.6
1968	131,462	48,812	37.1
1969	141,262	60,236	42.6
1970	131,514	63,330	48.2
1971	120,443	63,943	53.1
1972	133,241	74,584	56.0
1973	150,799	83,260	55.2
1974	145,720	81,552	56.0
1975	116,642	71,801	61.6
1976	128,000	79,918	62.4

Source: AISI Annual Statistical Reports, 1956-1976

After charging the furnace with metallics, oxygen is injected and lime and fluorspar fluxes are added. Carbon, ferromanganese, ferrosilicon, aluminum, etc. may be added as the steel is tapped into a ladle. Occasionally, alloys are charged to the furnace immediately before tap, but these are usually metals that do not readily oxidize — such as nickel, copper and molybdenum.

The Q-BOP process is one of the variants of the BOF process. In this process oxygen is introduced through a bottom blowing tuyere which is surrounded by natural gas or light hydrocarbons flowing through an outer tube surrounding the tuyere. Since the Q-BOP furnace has a supply of fossil fuel and oxygen, it can be used as a scrap preheater. However, despite published expectations, the Q-BOP process has not been able to accommodate increased scrap in its charge in relation to the BOF process. It is unlikely that the Q-BOP or any other variant of the BOF process will significantly affect the increased use of scrap in the furnace charge by 1987.

3.2.3.1.5 Open Hearth Furnace

The open hearth process, for many years the mainstay of the domestic steel industry, has yielded to the dominance of the basic oxygen processes during the last ten years. In fact, because of relatively unfavorable economic and environmental factors surrounding the operation of open hearth furnaces, it is doubtful whether any more such plants will be built in the United States.

Scrap with hot metal is charged to the furnace and heated to melting. Ordinarily, the percentages of scrap and hot metal vary between 40% and 70% of the charge, although the furnace is capable of running the full range up to 100% scrap or hot metal. The melt is then "worked" by adding the necessary fluxing and oxidizing materials to refine the bath.

3.2.3.1.6 Electric Arc Furnace

The first electric arc furnace in the U.S. iron and steel industry was installed in 1906. By 1976, electric furnace steel production was 24.6 million short tons or 19.3% of domestic raw steel production.[2]

Steel scrap is the principal raw material for electric furnace steelmaking. Sponge iron from direct reduction has also been found to be practical for up to 100% of the charge; if this raw material is available at a competitive price, it is expected to be more important in the future.[12]

The capacity of electric arc furnaces has increased from the 4 short tons per heat of the original 1906 furnace to 400 short tons per heat in what is believed to be the world's largest electric arc steelmaking furnace.[3]

The process is characterized by flexibility of operation and close control of heat chemistry. Therefore, it may be used to produce the full range of carbon, alloy, structural, specialty, stainless and tool steels, and even some superalloys.

3.2.3.1.7 Continuous Casting

In continuous or strand casting, molten steel is converted directly into billets, blooms, or slabs in one continuous operation. This process bypasses the traditional steps of ingot casting, heating the solidified ingots in soaking pits, and primary shaping of the ingots in suitable mills to smaller semifinished forms. The process can result in improved product, superior surface conditions, and better metallurgical quality as well as considerable energy savings.[12]

Continuous casting affects the quantity of home scrap generated in the U.S. steel industry and therefore, the consumption of purchased scrap. In 1976 about 12% of steel in the United States was produced by continuous casting.[12] This proportion is expected to grow in the years ahead.

3.2.3.1.8 Rolling and Finishing Operations

The rolling and finishing operations in the steel industry can be broken down into:

- Primary Breakdown Mills
- Hot Strip Mills
- Cold Strip Mills
- Bar and Rod Mills
- Pipe and Tube Mills
- Major Structural Mills

The massive ingot (which usually weighs from a few short tons up to 40 short tons) cast from raw steel must be rolled or forged to convert it to the shapes and dimensions desired by the steel consumers. Thus, the first step in the processing of the ingot in the primary shaping operation is hot rolling to intermediate shapes suitable for further processing.

The basic primary mill is a blooming mill. Most blooms have square or rectangular cross-sections, but they can also be round. The cross-section edge dimension or diameter of a bloom usually ranges from 6 inches up to one foot or more. Blooms are similarly converted to billets with section edge dimensions reduced to a few inches, which are subsequently rolled to smaller intermediate shapes, or directly to rod, bar, heavy structural shapes or rails. About one-third of the industry's ingots cast in 1976 were processed through blooming mills for conversion to "long" products — e.g., structurals, bars, rods, and wire.[18]

Generally, the first step in producing flat rolled products from ingots is rolling the ingot into slabs. Modern slabbing mills have rated rolling capacities from over one million short tons to greater than three million short tons per year of finished slabs.[3] The finished slabs from a slabbing mill (or a continuous casting operation) are transferred to a slab yard for cooling, inspection, conditioning, and storage. The slabs are rolled to plate, whose size is limited by the dimensions of the starting slab, or to hot strip, most of which is subsequently pickled, cold rolled, oiled, and sold as such, or is coated with zinc (galvanized), tin or other materials. Some hot strip, depending on final size, is used to make welded pipes and tubes.

A third type of primary breakdown mill is the billet mill, which reduces a bloom or small ingot to a straight, square, or round billet. Billets are the feedstock for conversion to bar, rod, wire and seamless pipes. Capacities of billet mills range from about 100,000 short tons to over one million short tons per year.[3]

After passing through the primary breakdown mill, blooms, billets and slabs are ready to be converted to semifinished and finished products. This is accomplished either by hot rolling or by hot rolling followed by cold reduction.

Hot strip rolling mills account for about half the steel products. A modern hot strip rolling mill consists of in line roughing mill stands in tandem through which a slab is passed sequentially to reduce the starting thickness of several inches. A hot strip mill can produce semi-finished strip to widths over 6 feet and a range of thicknesses from over one-half inch down to about 0.05 inch.

To produce thin-gauge steel, the hot rolled strip or hot band must be further reduced. Since the hot strip has already been rolled to the limits of the hot strength of the metal, any further rolling must be done by cold rolling. The normal range of reduction in a tandem cold mill is about 80-93% of the original hot-band thickness. The cold rolled strip is cleaned and annealed for optimum properties.

Because of increased demand for lighter-gauge stock, current practice is to follow the annealing operation with a second cold reduction of the cold-rolled strip intended for tin plate. A temper mill is used to harden the surface, to restore "temper" to the annealed stock, and to prevent or minimize strain marking or breaking of the surface during subsequent operations as well as for the double reduction for thin tin plate. For applications requiring corrosion resistance, pickled sheet and strip are galvanized by either dipping or passing the sheet through a molten bath of zinc.

Bar mills are among the oldest types of rolling units used in the steel industry. Such units have progressed from the single-stand, two-high configuration to the current multi-stand continuous mills. No other mill type has such a wide range of general-purpose products.

The rod mill was evolved along with the bar mill, and the development of looping (i.e., taking the work piece in a second pass through an intermediate stand) made possible the rolling of small rounds. The fully continuous rod mill can process longer and heavier billets and produce heavier rod bundles than older mill designs.

Bar and rod mills are other important finishing operations in the iron and steel industry. Bar mills produce bars for use in the construction industry. The important product of the rod mills is small-diameter rod for drawing to wire. Wire is made by drawing the rod through successively smaller dies. The drawn wire is then fabricated to wire products such as fencing and nails.

Seamless pipe and tube make up another important segment of the steel industry. They are produced on unique equipment specifically designed to produce only these products. Several types of welded pipe are made from hot-rolled flat stock whose width and thickness are appropriate for the size and grade of pipe.

The major structural shapes produced by the steel industry are angles, I-beams, H-columns, channels, T's, Z's and pilings, all of which are used in bridges, buildings, ships, freight cars, etc. These are produced in special mills designed for the appropriate structural shape.

3.2.3.2 Ferrous Foundries

A typical foundry can be divided into some ten interconnected operations:

- Raw materials storage and handling
- Patternmaking
- Sand preparation
- Molding
- Coremaking
- Melting
- Pouring
- Cooling
- Shakeout
- Cleaning and finishing

Figure 3.2-2 shows the relationships among these operations. The principal melting methods used in the ferrous foundry industry are used as shown in Table 3.2-7.

A cupola is a vertical, steel-shaft melting furnace, normally circular in cross-section. The cupola is the most important melting method in the iron foundry industry. It works on purchased scrap, pig iron; and home scrap. Coke and fluxes are the other important charge components.

An electric arc furnace is the most important melting device for steel foundaries and is an important one for iron foundries. It consists of a steel-encased refractory hearth on which materials can be melted by heat from electric arcs. Arc furnaces used in foundries vary in diameter from a few feet up to 15 feet. Arc furnaces normally operate on 100% scrap charge.

An induction furnace is a refractory-lined vessel in which the metal charge is melted by induction, i.e., by transforming electrical energy into heat. Induction furnaces are used in the melting of both iron and steel. Because induction furnaces are essentially melting and not refining furnaces they operate only on clean scrip. Induction furnaces are generally smaller than other types of melting furnaces and are either batch or semi-continuous operations. Induction furnaces are also used as holding furnaces.

A reverberatory air furnace is a rectangular or cylindrical steel shell, refractory-lined throughout the inside, in which the heat source is above the shallow metal bath. It is used to a very limited extent only in malleable iron foundries.

The open-hearth furnace used in the foundry industry is similar to that used in steel mills. It varies in capacity from as little as 10 short tons to more than 200 short tons. The use of the open-hearth is limited to a few plants in the steel foundry industry.

3.2.3.3 Ferroalloys

In 1976, ferroalloys were produced in the United States by electrolytic and metallothermic processes, in blast furnaces, and electric furnaces. One plant used the fused salt electrolytic process to produce low carbon ferromanganese.

3.2.3.3.1 Blast Furnace

The use of the blast furnace was limited to ferromanganese production. Two plants of this type, both owned by steel companies, were in operation in 1976. Neither is currently operating.

The ferromanganese blast furnace is of the same type used to produce pig iron. In fact, a furnace used to produce one of these products is sometimes converted to the other. However, the trend in the United States is from the blast furnace to the electric furnace due to technological and economic factors.

3.2.3.3.2 Electric Furnace

Roughly 100 electric furnaces are distributed among 38 ferroalloy plants. The submerged-arc furnace, the most widely used electric type, accounts for more than 75% of all U.S. ferroalloy production.

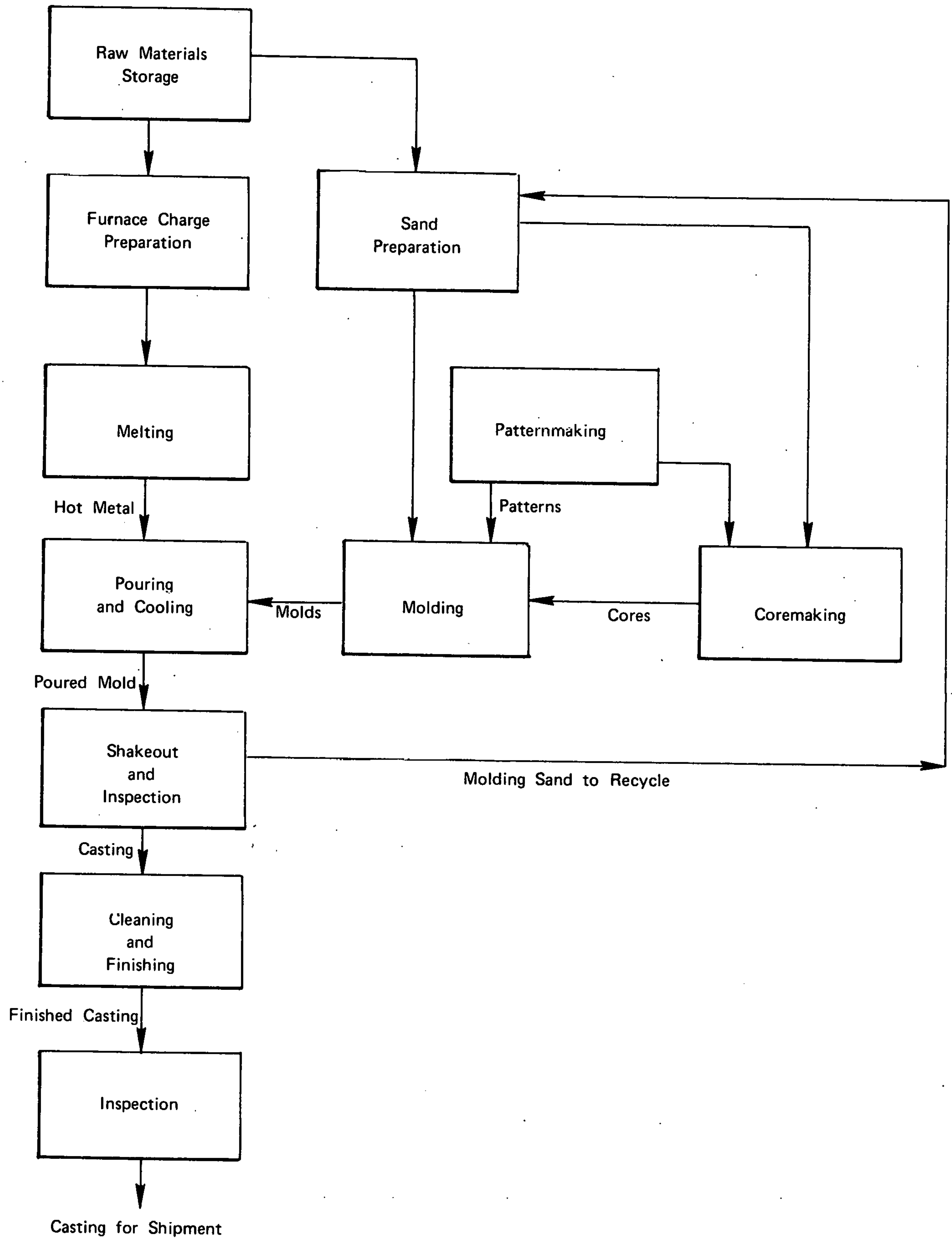


FIGURE 3.2–2 PROCESS FLOW DIAGRAM OF A TYPICAL FOUNDRY

TABLE 3.2-7

MELTING METHODS USED IN FERROUS FOUNDRIES

Major Product	Gray Iron	Ductile Iron	Malleable Iron	Steel	Total Ferrous Fdys.
Melting Method		(percentage of foundries)			
Cupola	73.3	36.4	40.7	1.3	53.9
Electric Arc Furnace	8.5	10.2	18.6	52.8	19.5
Coreless Induction	21.5	44.3	44.1	42.4	28.4
Air Furnace	0.5	0.0	45.8	0.5	2.0
Reverberatory	7.4	12.5	0.0	2.1	6.1
Open Hearth	0.0	0.0	0.0	5.0	1.2
Number of Foundries In Major Product Classification	1195	88	59	422	1764

Source: Penton Publications Foundry Data Base, Cleveland, Ohio, 1978
Arthur D. Little, Inc., estimates

The submerged-arc furnace is cylindrical, and may be as large as 50 feet in diameter. These furnaces require careful preparation of charge material. The charge could include ore, slag-forming materials such as lime, iron and steel borings and turnings, and coal or coke. Raw materials contain 10-20% free moisture and may be dried prior to charging.

Some ferroalloys, such as low-carbon ferromanganese and low-carbon ferrochromium, are produced using two submerged-arc electric furnaces or may be produced by other methods not necessarily involving liquid metal. The furnaces are arranged in such a way that the slags, which inevitably contain high concentrations of the expensive metal, are not wasted but are used as a feed material to a furnace producing a different grade of the same ferroalloy. Sequential submerged-arc furnaces or a combination of submerged-arc and open-arc furnace cycles may be used.

An example of a combination of a submerged-arc and a direct arc (or open-arc) furnace is shown in Figure 3.2-3. The direct arc furnace produces medium carbon ferromanganese (82% Mn) and sends a manganese-rich slag to a submerged-arc furnace producing silicomanganese where the manganese units are recovered. Some of the silicomanganese, in turn, is sent to the furnace producing medium-carbon ferromanganese where it is used as a reducing agent. The remaining silicomanganese is sold. As a result, the discarded slag contains only about 6% manganese.

3.2.4 Materials Flow

3.2.4.1 Iron and Steel

In 1976, the United States iron and steel industry produced 128 million short tons of raw steel,10% more than in 1975 but 12% less than in 1974. Total shipments of all grades of steel products in 1976 equaled 89.4 million short tons.[11] The flow of raw materials and intermediate products necessary in the production of this finished steel is briefly described in this section. Also included is a classification of recoverable material as pertains to the iron and steel industry as well as a general profile of the industry's recycling activities.

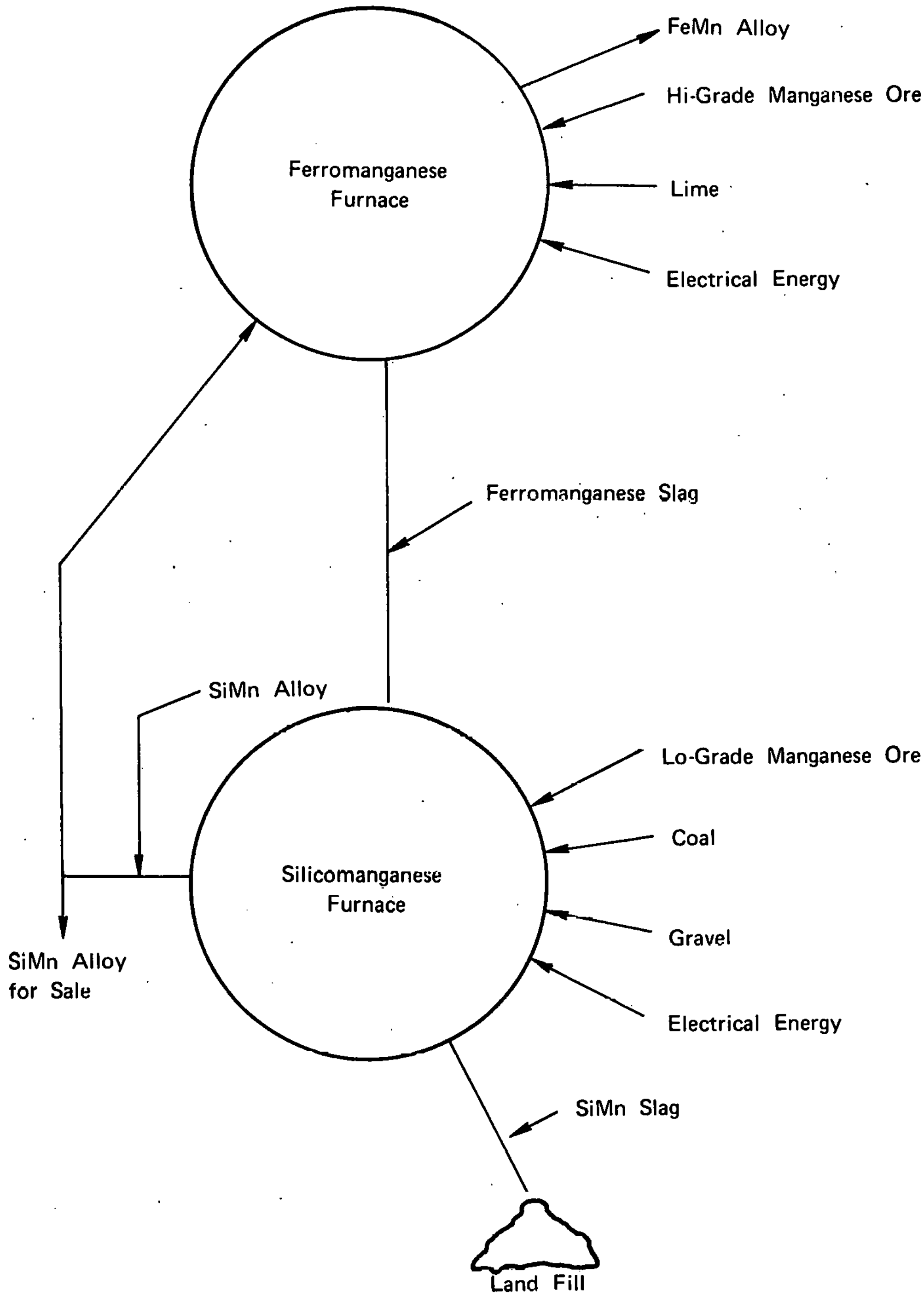
3.2.4.1.1 General

Figure 3.2-4, constructed from U.S. Bureau of Mines and AISI data in conjunction with Arthur D. Little Inc. estimates, gives a detailed flow of all materials within the iron and steel industry in 1976.

3.2.4.1.1.1 Production of Pig Iron

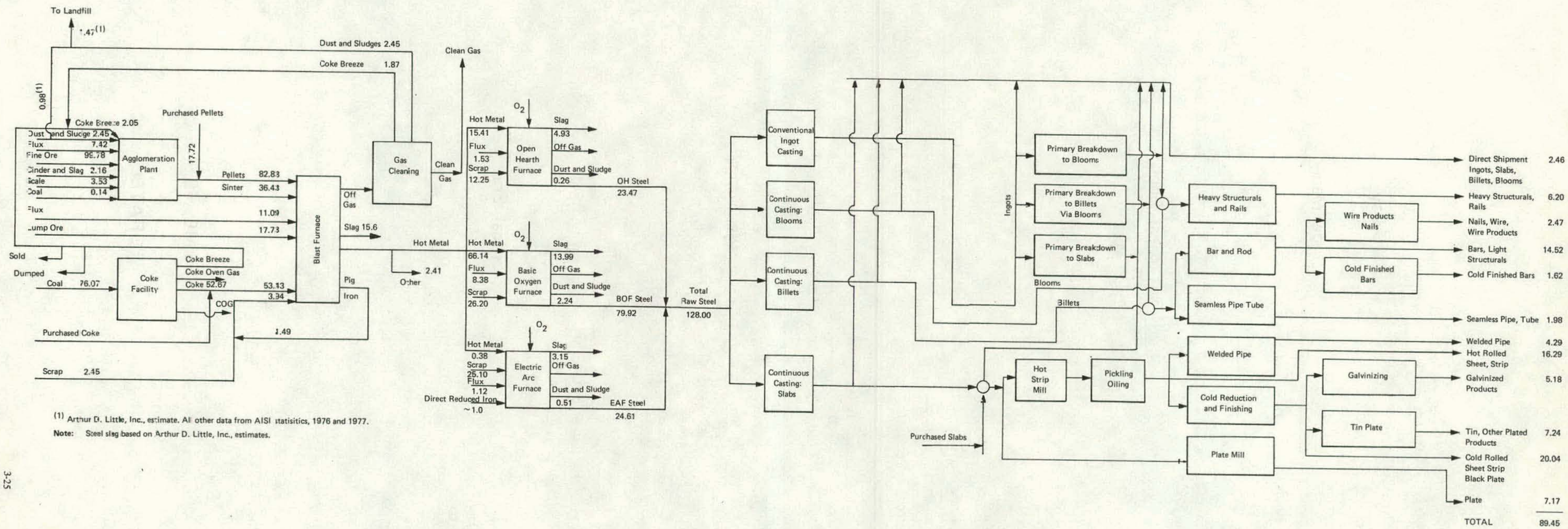
Domestic production of pig iron totaled 86.8 million short tons in 1976, an increase of 7 million short tons or 9% more than in 1975. Of this amount, about 82 million short tons were consumed by steelmaking processes.[2,4]

Raw materials to blast furnaces included pellets and sinter, flux, lump ore, coke and scrap. For every ton of pig iron produced in 1976, approximately 1.7 short tons of metalliferous materials were consumed in blast furnaces. Iron ore consumption, including agglomerates, totaled 136.8 million short tons. Sinter plants at or near the blast furnaces consumed 25.8 million short tons of iron ore in producing 36.4 million short tons of sinter. The remainder consisted of coke breeze, dusts and sludges, limestone and dolomite, cinder and slag, and scale. Domestic pellets charged equaled 69.5 million short tons and sinter charged was 36.4 million short tons. Imported pellets and sinter amounted to 17 million short tons.



Source: Special Arc Preprints, 32nd Electric Furnace Conference, AIME, 1974, p. 22

FIGURE 3.2–3 SCHEMATIC ILLUSTRATION OF AN INTEGRATED MANGANESE SMELTING AND REFINING FACILITY



(1) Arthur D. Little, Inc., estimate. All other data from AISI statisitics, 1976 and 1977.

Note: Steel slag based on Arthur D. Little, Inc., estimates.

FIGURE 3.2–4 MATERIALS FLOW IN THE IRON AND STEEL INDUSTRY – 1976
All Data in Millions of Tons

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Consumption of oxygen in blast furnaces totaled 26.9 billion cubic feet in 1976 compared with 25.9 billion cubic feet in 1975. Through tuyere injection, blast furnaces consumed 9.7 billion cubic feet of coke oven gas; 445 million gallons of oil; 133 million gallons of tar, pitch, and miscellaneous fuels; and 157,671 short tons of bituminous coal.[2,4]

Besides pig iron, blast furnaces produce slag, dusts and sludges, and coke breeze. In 1976, approximately 15.6 million short tons of slag were produced, most of which were processed for the recovery of slag scrap prior to disposal in landfills. Pollution control equipment associated with blast furnace operations collected 2.4 million short tons of dusts and sludges and 1.9 million short tons of coke breeze.

3.2.4.1.1.2 Production of Steel

According to the American Iron and Steel Institute (AISI), production of raw steel in 1976 equaled almost 81% of industry capacity of 158 million short tons. This compares with a 76.2% utilization of 153 million short tons in 1975. Of the total raw steel production, 62.8% was produced by the basic oxygen process, 18% by open hearth furnaces, and 19% by electric furnaces. The trend toward basic oxygen and electric furnaces and away from open hearths continued in 1976.

Total shipments of steel products for 1976 equaled 89.4 million short tons, 12% more than in 1975. Shipments to the automotive industry totaled 21.4 million short tons, 40% higher than in 1975, and shipments to service centers were up 15% to 14.6 million short tons. Shipments were down 15% and 8%, respectively, to the oil and gas industries and to the construction market.[11]

Metalliferous materials charged to steel furnaces in 1976 averaged 1280 pounds of pig iron, 993 pounds of scrap, and 22 pounds of iron ore (including agglomerates) per short ton of steel produced. Nonmetallic materials charged to steelmaking furnaces in 1976 included 0.6 million short tons of fluorspar, 1.5 million short tons of limestone, 7.6 million short tons of lime and 1.3 million short tons of other fluxes. Oxygen consumption totaled 196.3 billion cubic feet compared with 178.4 billion cubic feet in 1975.

AISI statistics indicated that open hearth furnaces consumed 15.4 million short tons of pig iron, 12.3 million short tons of scrap, 1.5 million short tons of fluxes, and 40.6 billion cubic feet of oxygen in 1976. Open hearth products included 23.5 million short tons of raw steel, about 4.9 million short tons of slag, and 0.3 million short tons of dusts and sludges. Basic oxygen furnaces consumed 66.1 million short tons of hot metal, 26.2 million short tons of scrap, 8.4 million short tons of fluxes and 149.2 billion cubic feet of oxygen to produce approximately 14.0 million short tons of slag, 79.9 million short tons of raw steel and 2.2 million short tons of dusts and sludges. Electric furnaces consumed 0.4 million short tons of pig iron, 25.1 million short tons of scrap, 1.1 million short tons of fluxes and 6.4 billion cubic feet of oxygen. Products included 24.6 million short tons of raw steel, 3.2 million short tons of slag and 0.5 million short tons of dusts and sludges.

According to AISI, steel melting furnaces in 1976 consumed 185.5 million gallons of fuel oil, 80.6 million gallons of tar and pitch, 52.8 billion cubic feet of natural gas and 5.3 billion cubic feet of coke oven gas. Total consumption of electric power by the iron and steel industry in 1976 equaled 54.3 billion kilowatt hours.

3.2.4.1.2 Classification of Recoverable Materials

The materials containing iron units presently being recycled in the iron and steel industry fall into four categories: ferrous scrap, mill scale, dust and sludge, and slag.

3.2.4.1.2.1 Ferrous Scrap

Ferrous scrap is composed of three types of waste and scrap material. These are: home or revert scrap, prompt industrial scrap, and obsolete scrap. Collectively, prompt industrial and obsolete scrap are referred to as purchased scrap.

Home scrap is generated within the iron and steel industry as a result of melting, casting and processing operations. Most of it consists of ingot and bloom scrappings; billet, pipe and bar ends; hot metal spills and runnings; and plate shearing and sheet trimmings. Prompt industrial scrap is generated directly by metalworking firms in the fabrication of industrial and consumer products. It consists for the most part of clips, turnings, borings, punchings, stampings, trimmings and drillings. In contrast, obsolete scrap is generated by consumers of finished steel products. It is the processed form of ferrous waste resulting from discontinued economic use. This material is metallurgically very heterogeneous and can be contaminated with elements that are detrimental to steelmaking. Prompt industrial scrap is generally the preferred type of purchased scrap, depending on such factors as price, availability and products being produced.

In 1976, the iron and steel industry consumed 68.4 million short tons of ferrous scrap. Consumption by grade of scrap for 1975 and 1976 is given in Table 3.2-8.

3.2.4.1.2.2 Mill Scale

Mill scale contains over 50% iron and is collected by the water pollution control facilities associated with the following:

- Primary reduction mill
- Continuous casting
- Hot rolling mill
- Cold rolling mill

In addition to iron, these scales can contain small concentrations of trace metals, including chromium, copper, manganese, nickel, lead, and zinc. Mill scales can also contain as much 0.4% oil and grease. Because of the contained iron units, the scales are usually recycled to the sinter strand. Small amounts of scale are also recycled to the blast furnace via the agglomeration plant to steelmaking furnaces for recovery of iron and to promote lime or limestone dissolution.

3.2.4.1.2.3 Dust and Sludge

Dusts and sludges are the products in process gas cleaning and metal preparation as well as emission control devices associated with the major process steps in iron and steel industry. These materials are produced by coke plants, blast furnaces, steelmaking furnaces, and the various operations in finishing mills.

Blast furnace dusts and sludges consist predominantly of iron oxides, carbon, silica, and lime. (They also contain traces of alkali components.) Dusts and sludges produced by the basic oxygen and open hearth furnaces contain iron oxide, lime, silicon, some lead and zinc, and small

TABLE 3.2-8

CONSUMPTION OF FERROUS SCRAP BY GRADE

(Thousands of net tons)

	1975	1976
Carbon Steel:		
Low phosphorous plate & punchings	733	987
Cut structurals & plate	478	393
No. 1 heavy melting steel	22,205	23,984
No. 2 heavy melting steel	3,064	3,421
No. 1 & electric furnace bundles	7,597	8,870
No. 2 & all other bundles	2,324	2,584
Turnings & borings	1,608	1,339
Slag scrap (Fe content)	4,082	4,180
Shredded or fragmentized	2,014	2,064
All other carbon steel scrap	11,711	12,933
TOTAL CARBON STEEL	55,816	60,755
Stainless Steel	687	1,020
Alloy steel (stainless)	1,869	1,829
Iron scrap	3,275	3,770
Other grades or types of scrap	1,189	1,053
TOTAL SCRAP	62,836	68,427

Source: Annual Statistical Report, American Iron and Steel Institute, 1976 and 1977.

amounts of carbon. In order to recycle this fine material it must be agglomerated. The sinter plant is particularly suited for recycling these materials for the recovery of iron and carbon units.

In contrast, electric furnace dust and sludge is not recycled. These dusts and sludges contain significant amounts of lead and zinc, and occasionally other deleterious elements. In addition, sinter plants are usually not located near electric furnaces, thus precluding any simple "in-house" recycle scheme. For both of these reasons, electric furnace dusts and sludges will probably not be recycled in the near future, and therefore these materials will not be considered in this study.

Sludges are also produced in various operations in steel milling facilities. Primary reduction mills, continuous casting units, hot rolling mills, cold rolling mills, tin plating mills, and galvanizing mills produce sludges as a result of water pollution control operations at a rate ranging from 0.1 to 10 kg/MT of finished steel.

Because published data are not available on dusts and sludges, they are excluded from the target analysis.

3.2.4.1.2.4 Slag

Slags are produced by blast, open hearth, electric arc, and basic oxygen furnaces. In varying amounts, all of these materials are recycled within the iron and steel industry. Blast furnace slag is not included in this study as a recoverable material, because it is usually sold to slag processors who recover by magnetic separation the iron units entrained in the slag. This material, known as slag scrap, is sold back to the iron and steel industry for processing. Such slag scrap is included in the category of ferrous scrap.

Open hearth and BOF slags are sometimes partially recycled to the sinter plant or used directly in the blast furnace. Reasons for this recycle include recovery of contained iron values. Lime values are also recovered to enhance sinter basicity. Electric furnace slag is recycled to a small extent, primarily to maintain a protective slag layer within the electric arc furnace during charging.

3.2.4.1.3 Recycle Profile

The U.S. iron and steel industry currently recycles substantial amounts of ferrous waste/scrap along with smaller amounts of slags, dusts and sludges, and scales. Unit operations to which these recyclable materials return include the sinter plant, the blast furnace, and all three types of steelmaking furnaces. In this section, the patterns of consumption of recyclable materials for each unit operation are described. Types of materials, quantities recycled, and technological reasons for their utilization are given. Thus a general recycle profile for the iron and steel industry is developed.

3.2.4.1.3.1 Sinter Plants

Materials currently being recycled to sinter plants include BOF and OHF slag, dust and sludge from the blast furnace, and mill scale. These materials are recycled both to recover iron units and fluxes, and to a small extent, to improve the basicity and binding characteristics of the sinter. In 1976, sinter plants consumed 2.2 million short tons of cinder and slag, 2.5 million short tons of dusts and sludges, and 3.5 million short tons of mill scale, according to AISI statistics.

3.2.4.1.3.2 Blast Furnace

Materials recycled to blast furnaces include rolling mill scale, steelmaking slag, and ferrous scrap. In 1976, blast furnaces consumed 4.2 million short tons of mill cinder and roll scale, along with small amounts of various miscellaneous items. Net scrap consumption equaled 2.5 million short tons. About 1.5 million short tons of home scrap was also produced in 1976.

Roll scales — oxides that form on the surface of steel during heating for rolling — are recycled to blast furnaces to recover iron units that otherwise would be lost. This material is a source of relatively pure iron oxide, although in some mills it becomes contaminated with refractory and oily substances.

BOF slag contains about 25% iron oxide by weight, and an excess of bases over acids. It is recycled primarily to recover iron units and secondarily to replace a given amount of basic fluxes in the blast furnace burden. BOF slag also contains sufficient manganese to make it a useful source of this element. It is sometimes desirable to add BOF slag to blast furnace burdens in order to increase the manganese content where the hot metal is deficient and thereby prevent "slopping" in the BOF. The use of BOF slag is limited by the specification for the maximum phosphorus content of the hot metal produced. Furthermore, since its use increases the total quantity of slag per ton of hot metal, its use is limited by the blast furnace's slag capacity.

Ferrous scrap is recycled to blast furnaces both for the recovery of iron units and to increase the production of hot metal. This scrap is purchased or is produced by the blast furnace itself from slag processing or by subsequent operations within the plant complex.

3.2.4.1.3.3 Basic Oxygen Furnaces

In 1976, basic oxygen furnaces consumed 26.3 million short tons of ferrous scrap. The breakdown by type of scrap (home, purchased) is not known. Scrap is recycled to basic oxygen furnaces primarily to recover iron units and secondarily to serve as a sink for thermal energy. On the average, basic oxygen charges consist of approximately 28% scrap, by weight.

In addition to scrap, mill scale is recycled to recover iron and to promote the dissolution of lime or limestone into the molten slag. A minor reason for recycling this material is to control furnace temperature by absorption of heat.

3.2.4.1.3.4 Electric Arc Furnaces

Recyclable materials consumed by electric furnaces include mill scale, electric furnace slag, and ferrous scrap. Mill scale is used to a limited (and undetermined) extent to lower the carbon content of the melt. Electric furnace slag is recycled to a small extent in order to maintain a protective slag layer within the furnaces to increase hearth life. Within the iron and steel industry, electric arc furnaces rank first in consumption of purchased scrap and second to BOF furnaces in the consumption of total (purchased and home) scrap. In 1976, electric arc furnaces consumed 25 million short tons of ferrous scrap versus only 0.4 million short tons of pig iron.

3.2.4.1.3.5 Open Hearth Furnaces

Recyclable materials consumed by open hearth furnaces in 1976 included 12.25 million short tons of ferrous scrap and much smaller quantities of open hearth slag and scale.

3.2.4.2 Ferrous Foundries

3.2.4.2.1 General

The general materials flow in the ferrous foundry industries is shown in Figure 3.2-5.

3.2.4.2.2 Classification of Recoverable Materials

The major types of solid wastes generated in the iron and steel foundries are:

- Waste sand
- Core butts
- Dust and sludge
- Slag
- Floor sweepings
- Refractories
- Home scrap

The amounts of the above solid wastes generated in 1976 are shown in Table 3.2-9. The generation factors are estimated average values for all foundries in each of the three major foundry categories.

3.2.4.2.3 Recycling Profile

Of the solid wastes generated in the ferrous foundry industries as given in Table 3.2-9, only home scrap and to a certain degree waste sand are recycled. The scrap is recycled almost entirely within the foundry where it is generated. Only very minor amounts of generated home scrap are sold back to the scrap industry (see Figure 3.2-5). The other types of solid wastes generated, which all contain various amounts of iron along with traces of heavy minerals that depend on type of foundry product, are not recycled at all because of technical/economic limitations.

3.2.4.3 Ferroalloys

3.2.4.3.1 General

3.2.4.3.1.1 Ferrosilicon

Feeds to the ferrosilicon furnace include quartzite, gravel, coal, coke, and ferrous scrap. Almost all the quartzite and gravel used is obtained from sources in the United States. Purchased ferrous scrap is consumed at a rate of 0.30 short tons per ton of ferrosilicon. Revert ferrous scrap is consumed at the rate of 0.30 short tons per ton of ferrosilicon. Revert ferrous scrap is consumed at the rate of 0.02 short tons per short ton of ferrosilicon.

Slag is not generated in the production of ferrosilicon. Particulates are emitted from furnaces at the rate of 0.45 short tons per short ton of 75% ferrosilicon and 0.23 short tons per short ton of 50% ferrosilicon. Recovery of particulates is about 90%. The resulting dust is disposed of in open dumps.

3.2.4.3.1.2 Ferrochromium

Feeds to a ferrochromium furnace include chromium ore, quartzite, coal, coke, limestone and ferrous scrap. Very little ore is domestically produced. Major suppliers of chromite are South

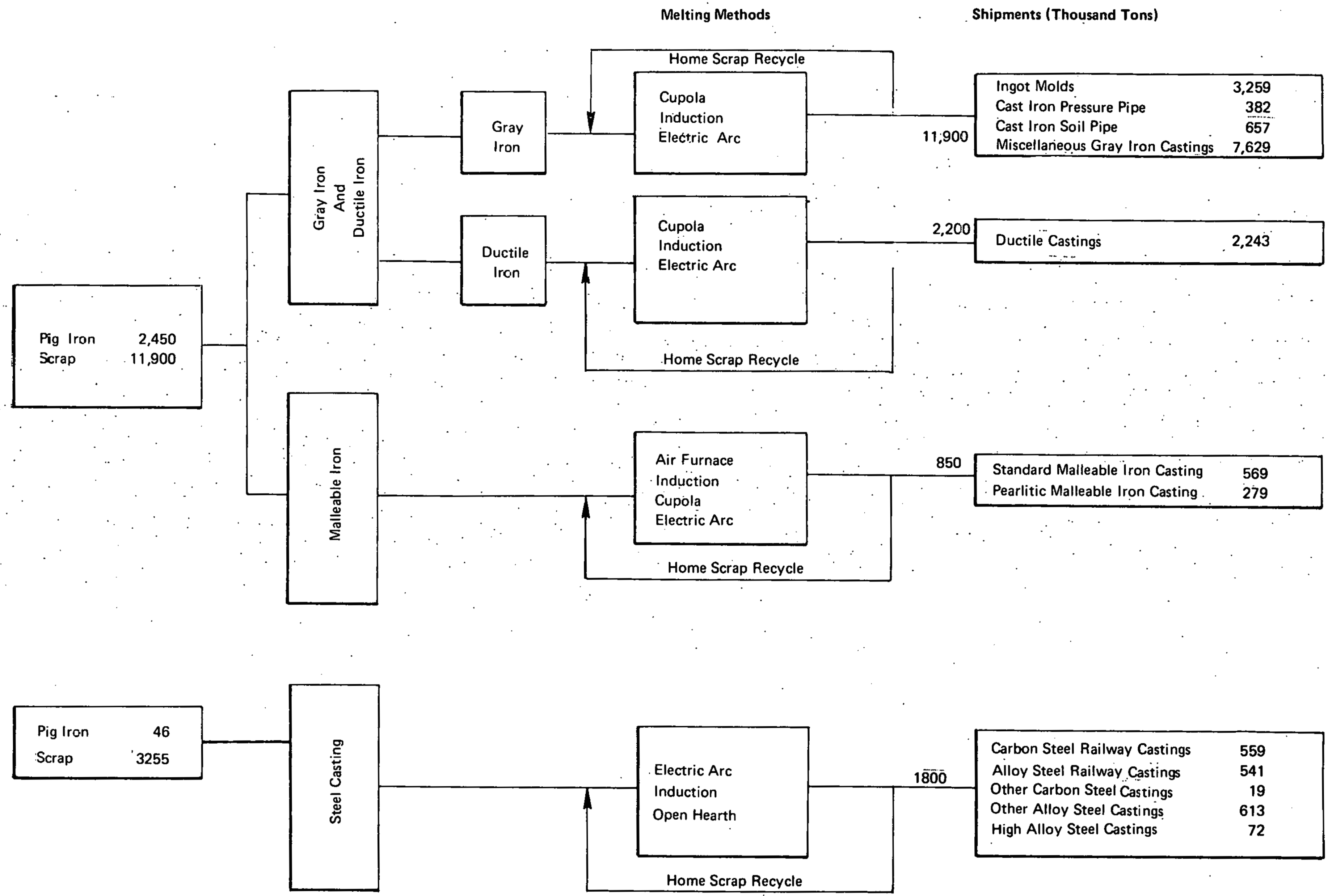


FIGURE 3.2–5 MATERIALS FLOW—FERROUS FOUNDRIES

TABLE 3.2-9

WASTE GENERATION FACTORS AND 1976 WASTE GENERATION - IRON AND STEEL FOUNDRIES

Foundry	Type of Waste	Generation[1] Factor lbs/ST of Finished Castings	1976 Waste Generation Tons X 10^3
Gray and Ductile Iron	Slag	125.9	888.0
	Sludge	65.6	463.0
	Dust	131.3	926.0
	Sand	1200.0	8460.0
	Refractories	27.6	195.0
	Home Scrap[2]		6300.0
Malleable Iron	Slag	111.1	47.0
	Sludge	63.8	27.0
	Dust	129.5	55.0
	Sand	1200.0	510.0
	Refractories	26.4	11.0
	Home Scrap[2]		1100.0
Steel Castings	Slag	244.1	220.0
	Sludge	72.8	66.0
	Dust	372.0	335.0
	Sand	1561.0	1405.0
	Refractories	106.1	95.0
	Home Scrap[2]		2300.0

Sources:

1. Assessment of Industrial Hazardous Waste Practices in the Metal Smelting and Refinery Industry, Volume III, No. ND-5520-M-1, Calspan.

2. "Iron and Steel Distribution in U.S.A.," Modern Casting, October 1977, p. 85.

Africa, Turkey and the USSR. A typical high-carbon chromium plant consumes 0.053 short tons of ferrous scrap per short ton of ferrochromium.

By-products of ferrochromium production are particulates and slag. Approximately 0.17 short tons of particulates are entrained in furnace gas per ton of ferrochromium produced. If a dry removal system is used about 0.15 short tons of dust containing 0.34% Cr are recovered per short ton of ferrochromium. If a wet collection system is used approximately 0.15 short tons of sludge are generated. It is estimated that between 1.5 and 2.0 short tons of slag are produced per short ton of ferrochromium. This slag is either open dumped or used in road building.

3.2.4.3.1.3 Ferromanganese

Most ferromanganese is produced in a plant containing two or three other furnaces. Silicomanganese is produced in the same plant in order to recover the manganese units from the ferromanganese slag and to serve as a reducing agent.

The furnace charge consists of manganese ore, coke, mill scale, remelted ferromanganese, and possibly scrap from outside the plant. At least one plant includes silicomanganese in the charge. Most, if not all, of the domestic ore consumed comes from shipments of government stockpile excesses. Ore from Africa, Australia, and Brazil accounted for 79% of the manganese units and 78% of the gross weight in 1976.

Furnace products include ferromanganese, particulates, and slag. Slag, containing 53% Mn, is produced at the rate of 0.60 short ton per short ton of ferromanganese. This slag can be charged to silicomanganese furnaces if the plant is integrated with silicomanganese production. About 0.36 short ton of ferromanganese slag per short ton FeMn produced is charged to silicomanganese furnaces. The remaining slag is stored for possible use in future silicomanganese production. Particulates in gaseous emissions are produced at the rate of 0.17 short ton per short ton of ferromanganese. Most of this material is disposed of by dumping.

3.2.4.3.1.4 Silicomanganese

Of the nine plants producing silicomanganese, eight were combined with ferromanganese furnaces. The charge to silicomanganese furnaces contains ferromanganese slag, manganese ore, coal, coke, dolomite, quartz, mill scale, and remelts. Ferromanganese slag is consumed at the rate of 1.34 ton per ton of silicomanganese leaving the plant.

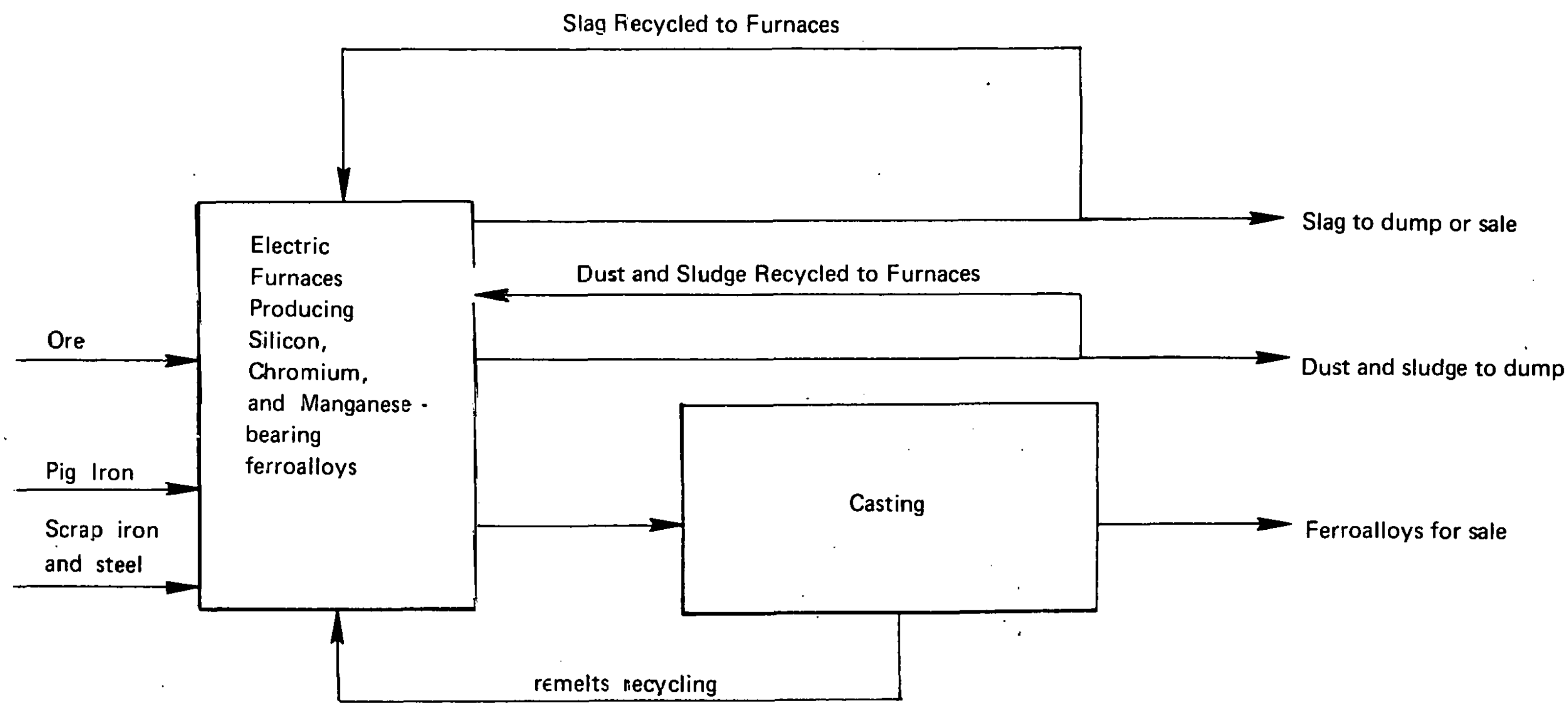
Furnace byproducts include slag and particulates. Slag is produced at the rate of 1.10 ton per ton of silicomanganese. Approximately 0.79 ton of this is used for road base and 0.32 ton is transported to open dumps.

3.2.4.3.2 Classification of Recoverable Material

Sources of recoverable materials in the ferroalloy industry are slag, dust and sludge, and ferrous scrap.

3.2.4.3.3 Recycle Profile

Figure 3.2-6 shows the paths taken by recyclable materials. Flow rates in 1976 are given in Table 3.2-10. Of major significance is the flow of manganese units in ferromanganese slag to the silicomanganese furnace.



Source: Arthur D. Little, Inc.

FIGURE 3.2–6 FLOW DIAGRAM IN THE FERROALLOYS INDUSTRY

TABLE 3.2-10

MATERIALS FLOW - 1976

FERROALLOYS SEGMENT

(Gross Weight, Short Tons)

Material	Ferrosilicon	Ferrochromium	Ferromanganese	Silicomanganese
Ferroalloy Production	860,799	269,247	482,662	128,917
Ore	NA	597,000	1,260,000	
Pig Iron	NA	NA	NA	NA
Slag - produced by electric furnaces	0	471,182	289,597	141,809
Slag - recycled to furnaces	0	NA	173,758	NA
Slag - stored for possible future use	0	NA	115,839	NA
Slag - dumped	0	NA	NA	40,609
Slag - used in road building	0	NA	NA	101,200
Dust and Sludge	290,950	45,233	80,798	14,052

SOURCES: U.S. Bureau of Mines Minerals Yearbook, 1976.
Calspan, "Assessment of Industrial Hazardous Waste Practices in Metal Smelting and Refining Industry," Volume III, 1977.

3.2.5 Future Trends

3.2.5.1 Iron and Steel

During 1976, the U.S. iron and steel industry operated plants with an effective capacity utilization of 80.9% and produced 128.0 million short tons of raw steel. Assuming that U.S. raw steel production will grow at 1.5-2.0% per year, raw steel output would be about 174 million short tons by 1987. Final product shipments would be in the neighborhood of 125 million short tons.[1]

The most significant trend within the U.S. iron and steel industry is the shift in the mix of the three principal steelmaking furnaces, i.e., basic oxygen, open hearth, and electric arc. The percent of total steel output for each of these furnaces for the years 1952-1976 is given in Table 3.2-11. Most of the BOF capacity came on-stream in the 1963-1970 period. The rate of BOF installation has since declined substantially, but, by 1976, BOF's accounted for approximately 62% of U.S. raw steel production. This percentage is expected to increase by 1987.

Most of the BOF growth has been achieved at the expense of the open hearth process, whose contribution to total domestic steel production has declined from 105.4 million short tons in 1955 (90%) to 23.5 million short tons in 1976 (18.3%). The significant attrition in the number of open hearth shops over the past few years is primarily the result of economic competition from the basic oxygen process, and of the pressure brought on the industry by environmental regulations.

A second inportant trend which has taken place is the profileration of electric furnace "mini-mills" in areas outside the traditional steelmaking centers. This growth in capacity in recent years and plans for further growth have been spurred on by a number of technological, market, and economic considerations including availability of continous casting, the application of ultra high power in arc-furnace technology, the increased scrap availability caused by the simultaneous growth in basic oxygen steelmaking and decline in open hearth capacity, and significantly smaller capital outlays required for this type of installation versus BOF steelmaking. In addition, small semi-integrated shops are able to take advantage of at least two other factors, both related to transportation costs: (1) local scrap generally costs less than that in the major steelmaking districts, and (2) costs of delivery to local markets are often lower than the cost of shipping steel from the major steelmaking centers. According to industry sources over the next decade electric arc installations may increase their share of raw steel production from the present value of 23% to about 30%.

Another significant factor in the iron and steel industry is the acceptance of continuous casting for high volume production. It is likely that most new U.S. steel plants geared to produce billets and slabs products will install continuous casting in the foreseeable future. Continuous casting capacity has increased sixfold in the period from 1969 to 1977.[18] By the end of 1978, 31 million short tons of capacity was installed in 66 steel plants in the United States. The principal reasons of this increased capacity are: (1) higher yields with improved quality and uniformity, an important factor in reducing costs, (2) lower man-hour requirements, and most importantly, (3) significantly reduced energy requirements.

3.2.5.2 Ferrous Foundries

3.2.5.2.1 Iron Castings

Historical production levels for iron castings, 1955-1976, are shown in Table 3.2-12. Gray iron production normally consists of approximately 40% ingot molds, stools, pipe, and mill rolls,

TABLE 3.2-11

RAW STEEL PRODUCTION BY PROCESS - 1952-1976

Year	Open Hearth Thousands Net Tons	Open Hearth %	Basic Oxygen Thousands Net Tons	Basic Oxygen %	Bessemer Thousands Net Tons	Bessemer %	Electric Thousands Net Tons	Electric %	Total Thousands Net Tons
1952	82,846	88.9	-	-	3,524	3.8	6,798	7.3	93,168
1953	100,474	90.0	-	-	3,856	3.5	7,280	6.5	111,610
1954	80,328	91.0	-	-	2,548	2.9	5,436	6.1	88,312
1955	105,359	90.0	307	.3	3,320	2.8	8,050	7.2	117,036
1956	102,841	89.2	506	.4	3,228	2.8	8,641	8.0	115,216
1957	101,658	90.2	611	.5	2,475	2.2	7,971	7.6	112,715
1958	75,880	89.0	1,323	1.5	1,396	1.6	6,656	7.9	86,255
1959	81,669	87.3	1,864	2.0	1,380	1.5	8,533	9.2	93,446
1960	86,368	87.0	3,346	3.3	1,189	1.5	8,379	9.2	99,282
1961	84,502	86.2	3,967	4.0	881	.9	8,664	8.9	98,014
1962	82,957	84.8	5,553	5.2	805	.8	9,013	9.2	98,328
1963	88,834	81.3	8,544	7.8	963	.9	10,920	10.0	109,261
1964	98,098	77.2	15,442	12.2	858	.6	12,678	10.0	127,076
1965	94,193	71.7	22,879	17.4	586	.4	13,804	10.5	131,462
1966	85,025	63.4	33,928	25.4	278	.2	14,870	11.0	134,101
1967	70,690	55.6	41,434	32.5	*	*	15,089	11.9	127,213
1968	65,836	50.1	48,812	37.2	*	*	16,814	12.7	131,462
1969	60,894	43.1	60,236	42.6	-	-	20,132	14.2	141,262
1970	48,022	36.6	63,330	48.2	-	-	20,162	15.2	131,514
1971	35,559	29.5	63,943	53.1	-	-	20,941	17.4	120,443
1972	34,936	26.2	74,584	56.0	-	-	23,721	17.8	133,241
1973	39,780	26.4	83,260	55.2	-	-	27,759	18.4	150,799
1974	35,499	24.3	81,552	56.0	-	-	28,669	19.7	145,720
1975	22,161	19.1	71,801	61.5	-	-	22,680	19.4	116,642
1976	23,470	18.3	79,918	62.4	-	-	24,612	19.3	128,000

Source: Annual Statistical Reports, American Iron and Steel Institute, 1952-1976.

TABLE 3.2-12

PRODUCTION OF IRON CASTINGS - 1955-1976

(thousand net tons)

Year	Gray and Ductile Castings	Malleable Castings	Total
1955	14,838	1105	15,843
1956	13,861	952	14,813
1957	12,665	863	13,528
1958	10,358	661	11,019
1959	12,308	916	13,224
1960	11,594	821	12,415
1961	10,824	723	11,547
1962	11,553	868	12,421
1963	12,764	933	13,697
1964	14,316	1001	15,317
1965	15,713	1136	16,849
1966	15,716	1131	16,847
1967	14,329	1041	15,370
1968	15,130	1007	16,137
1969	15,933	1172	17,105
1970	13,945	852	14,797
1971	14,016	882	14,898
1972	15,217	960	16,177
1973	16,958	1030	17,988
1974	15,660	912	16,572
1975	12,448	729	13,177
1976	14,140	848	14,988

Source: U.S. Department of Commerce, Bureau of Census, Current Industrial Reports, M33, 1955-1976.

with the remaining 60% miscellaneous industrial gray iron. The three largest gray iron markets are automotive, farm machinery and engines. Use of gray iron has been limited by:

- Weight reduction of automotive engine blocks
- Size reduction of air conditioner compressors
- Material substitution — aluminum, ductile iron, and plastics
- Increased production of smaller compact cars

The major market for ductile iron is pressure pipe, followed by motor vehicles, engines, and farm machinery. Ductile iron has had an historical growth rate of 10-12%, giving it the best record in the ferrous foundry industry.[6]

Projected growth is mainly based on the following areas:

- replacement of other ferrous castings, primarily malleable iron, and steel.
- replacement of forgings, such as automobile crankshafts.

Seventy-five percent of available malleable iron is consumed by the automotive industry. Other markets are valves, pipe fittings, construction machinery, farm machinery, and railroad equipment.

According to Arthur D. Little, Inc., estimates, the production of iron castings in 1987 is estimated at approximately 20 million short tons.

3.2.5.2.2 Steel Castings

Steel casting production is basically determined by the consumption in the railroad and capital goods industries. Capital goods markets for steel castings are construction machinery, mining machinery, material hauling equipment, and metal working equipment.

Table 3.2-13 gives the historical production levels of steel castings. The share of total production accounted for by the various types of steel castings is projected to shift fairly substantially. Alloy steel castings will increase their share of production at the expense of other carbon steel castings. According to Arthur D. Little, Inc., estimates steel castings production in 1987 is projected at 2 million short tons.

3.2.5.3 Ferroalloys

Consumption of ferroalloys is determined by the production of steel and cast iron. Of the total ferrosilicon consumed, 53% was used in cast irons, 17% in carbon steel, and 15% in the remaining types of steel. Of the total chromium in ferrochromium consumed, 68% was used in stainless and heat-resisting steel, and 20% in other types of steel. Of the ferromanganese consumed 77% was used in carbon steel and 17% in the remaining types of steel. Of the silicomanganese consumed, 57% was used in carbon steel, and 30% in other types of steel. Annual ferroalloy production over the last 10 years is shown in Table 3.2-14.

Future growth patterns of the major ferroalloys will be linked to the iron and steel growth projections and to the level of imports.

TABLE 3.2-13

PRODUCTION OF STEEL CASTINGS - 1955-1976
(thousand net tons)

Year	Steel Castings
1955	1531
1956	1932
1957	1766
1958	1121
1959	1413
1960	1392
1961	1217
1962	1423
1963	1504
1964	1835
1965	1961
1966	2156
1967	1857
1968	1730
1969	1897
1970	1724
1971	1589
1972	1610
1973	1897
1974	2091
1975	1937
1976	1955

Source: U.S. Department of Commerce, Bureau of Census, current industrial reports, M33, 1955-1976.

TABLE 3.2-14

FERROALLOYS PRODUCED AND SHIPPED - 1967-1976

Year	Production of Ferrosilocon (gross weight) (short tons)	Alloy Element Contained (average percent)	Production of Ferromanganese (gross weight) (short tons)	Alloy Element Contained (average percent)	Production of Chromium Alloys (gross weight) (short tons)	Alloy Element Contained (average percent)	Production of Silico Manganese (gross weight) (short tons)	(average percent)	Total Ferroalloy Production (gross weight) (short tons)
1975	860,799	57.0	482,662	79.0	269,247	60.0	128,917	66.0	1,910,218
1975	790,860	55.0	575,809	79.0	248,817	59.0	143,262	66.0	1,926,454
1974	905,274	56.8	544,361	78.0	440,660	60.3	196,140	65.2	2,283,501
1973	1,012,807	53.2	683,075	78.8	426,846	60.8	183,702	66.3	2,519,955
1972	841,386	59.8	800,723	78.3	352,305	62.0	153,234	65.3	2,526,624
1971	687,166	64.2	759,896	78.6	355,658	61.0	164,682	66.0	2,331,055
1970	709,287	59.2	835,463	78.5	405,776	63.2	193,219	66.0	2,595,188
1969	715,172	57.8	852,019	77.3	419,038	62.2	222,877	66.0	2,628,503
1968	665,383	56.6	879,962	78.0	389,572	62.6	284,499	66.0	2,621,061
1967	673,535	56.6	940,927	78.2	446,137	60.7	245,798	65.9	2,749,505

Source: U.S. Bureau of Mines, Minerals Yearbook, 1976.

3.3 ALUMINUM

3.3.1 Industry Definition

The aluminum industry comprises the following components based on SIC classification:[2]

- SIC 3334 — Primary Production of Aluminum includes establishments primarily engaged in producing aluminum from alumina. The products from these establishments are:
  - — Aluminum ingot and/or molten metal: primary
  - — Extrusion ingot, aluminum: primary

- The part of SIC 3341 — Secondary Smelting and Refining of Nonferrous Metals that are involved in the production of aluminum and aluminum base alloys from scrap or dross. It comprises establishments primarily engaged in recovering aluminum metal and aluminum-base alloys from new and old scrap and dross. The products/activities (aluminum related) of these establishments are:
  - — Aluminum extrusion ingot: secondary
  - — Aluminum ingot and/or molten metal: secondary
  - — Aluminum notched bar/shot for dioxidation.

- SIC 3353 — Aluminum Sheet, Plate and Foil include establishments primarily engaged in flat rolling aluminum and aluminum-based alloy basic shapes such as sheet, plate, and foil, including establishments producing welded tube. Also included are establishments primarily producing similar products by continuous casting. The products from these establishments are as follows:
  - — Coiled, sheet: aluminum
  - — Foil, plain: aluminum
  - — Plate: aluminum
  - — Sheet: aluminum
  - — Tube, welded: aluminum

- SIC 3354 — Aluminum Extruded Products include establishments primarily engaged in extruding aluminum and aluminum-based alloy basic shapes such as rod and bar, pipe and tube, and tube blooms, including establishments producing tube by drawing. The products from these establishments are:
  - — Bar, aluminum: extruded
  - — Extruded shapes: aluminum
  - — Pipe, aluminum: extruded
  - — Rod, aluminum: extruded
  - — Tube, aluminum: extruded or drawn
  - — Tube blooms, aluminum: extruded

- SIC 3355 — Aluminum Rolling and Drawing, Not Elsewhere Classified includes establishments primarily engaged in rolling, drawing, and other operations resulting in the production of aluminum ingot, including extrusion ingot, and aluminum and aluminum-based alloy basic shapes, not elsewhere classified, such as rolled and continuous cast rod and bar. The products from these establishments are:

— Bar, aluminum: rolled
— Rod, aluminum: continuous cast
— Ingot, aluminum: made in rolling mills
— Rod, aluminum: rolled
— Rod, aluminum: continuous cast
— Slugs, aluminum
— Structural shapes: rolled aluminum
— Wire, aluminum: made in rolling mills

- A part of SIC 3357 — Drawing and Insulating of Nonferrous Wire that Produces Aluminum Based Wire includes establishments primarily engaged in drawing, drawing and insulating, and insulating wire and cable of aluminum from purchased wire bar, rod, or wire. The products from these establishments are: (aluminum based only)

  — Automotive and aircraft wire and cable, aluminum
  — Cable, aluminum: bare, or reinforced, conductor
  — Coaxial cable
  — Communications wire and cable
  — Shipboard cable
  — Signal and control cable
  — Weatherproof wire and cable
  — Wire, insulated, or covered (mec)

- SIC 3361 — Aluminum Foundries (Castings) includes establishments primarily engaged in manufacturing sand, permanent mold, and die castings of aluminum and aluminum-based alloys.

- A part of SIC 3399 — Primary Metal Products Not Elsewhere Classified includes establishments primarily engaged in the production of aluminum nails, brads, spikes, powder, flake and paste.

In addition, bauxite mining (SIC 1051) and bauxite refining (SIC 2819) provide the alumina for primary aluminum production. Similarly, activities for manufacturing aluminum products are included in SIC 34, e.g., part of SIC 3463 deals with aluminum forgings.

3.3.2 Industry Structure

The aluminum industry can be divided into four segments:

- Primary Aluminum (SIC 3334)
- Secondary Aluminum (SIC 3341 — Aluminum-related sector only)
- Aluminum Foundries (SIC 3361)
- Others (SIC 3353, 3354, 3555, 3357, 3361, 3399, and 3463)

The primary, secondary and foundry segments of the aluminum industry are described briefly in this section. The establishments engaged in other activities covered by the industry are so numerous and diverse that it is extremely difficult to characterize them. Because the primary, secondary and foundry generate aluminum scrap that is sent to primary, secondary smelters or to foundries for recovery, it is more appropriate to understand the industry structure related to these three segments. Some fabricators having melting facilities are also able to use aluminum scrap in their operations. The aluminum production process and the inter-relations among the four segments of the aluminum industry are shown schematically in Figure 3.3-1.

3.3.2.1 Primary Aluminum Industry

The most important activities carried out by the industry are:

- Production of alumina from bauxite by the Bayer process
- Reduction of alumina to aluminum metal by the Hall-Heroult electrolytic reduction process.

These two activities are carried out at entirely separate locations (Figure 3.3-2).

Within the United States there are nine alumina production plants, with a total capacity estimated to be equivalent to 4 million short tons/year of aluminum (or approximately 7.7 million short tons/year of alumina) in 1976. The breakdown by companies and their plants is shown in Table 3.3-1. There are 32 aluminum reduction plants in the United States, operated by 12 companies, five of which are also alumina producers. The total aluminum production capacity is estimated at 5 million short tons/year for 1976. The details are shown in Table 3.3-2.

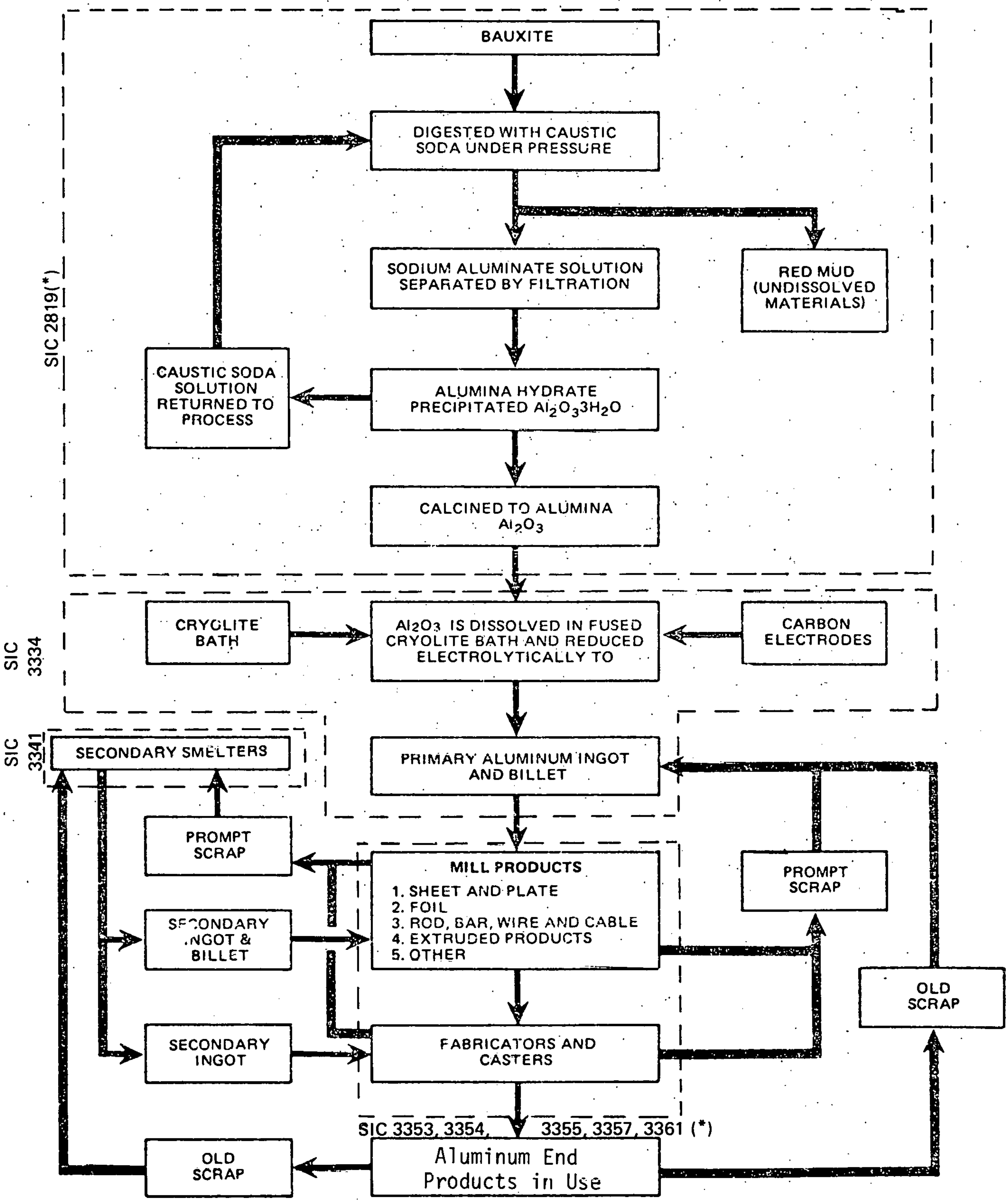
The 12 domestic firms are of unequal size and are multiplant, vertically integrated corporations. The three largest domestic companies (Alcoa, Reynolds, and Kaiser) accounted for 65% of domestic primary aluminum capacity in 1976. Aluminum Company of Canada, Ltd., via its U.S. subsidiary, Alcan Aluminum Corporation, is the fourth largest U.S. aluminum fabricator and an important seller of primary ingot in the country.[1] Consequently, Alcan, even though it does not have a primary smelter in the United States, plays a significant role in domestic aluminum shipments.

3.3.2.2 Secondary Aluminum Industry

The secondary aluminum industry comprises:

- Producers of alloy ingot and hot metal for foundries and die casters and bar and shot for steel deoxidation, and
- Producers of secondary extrusion ingots for extrusion plants.

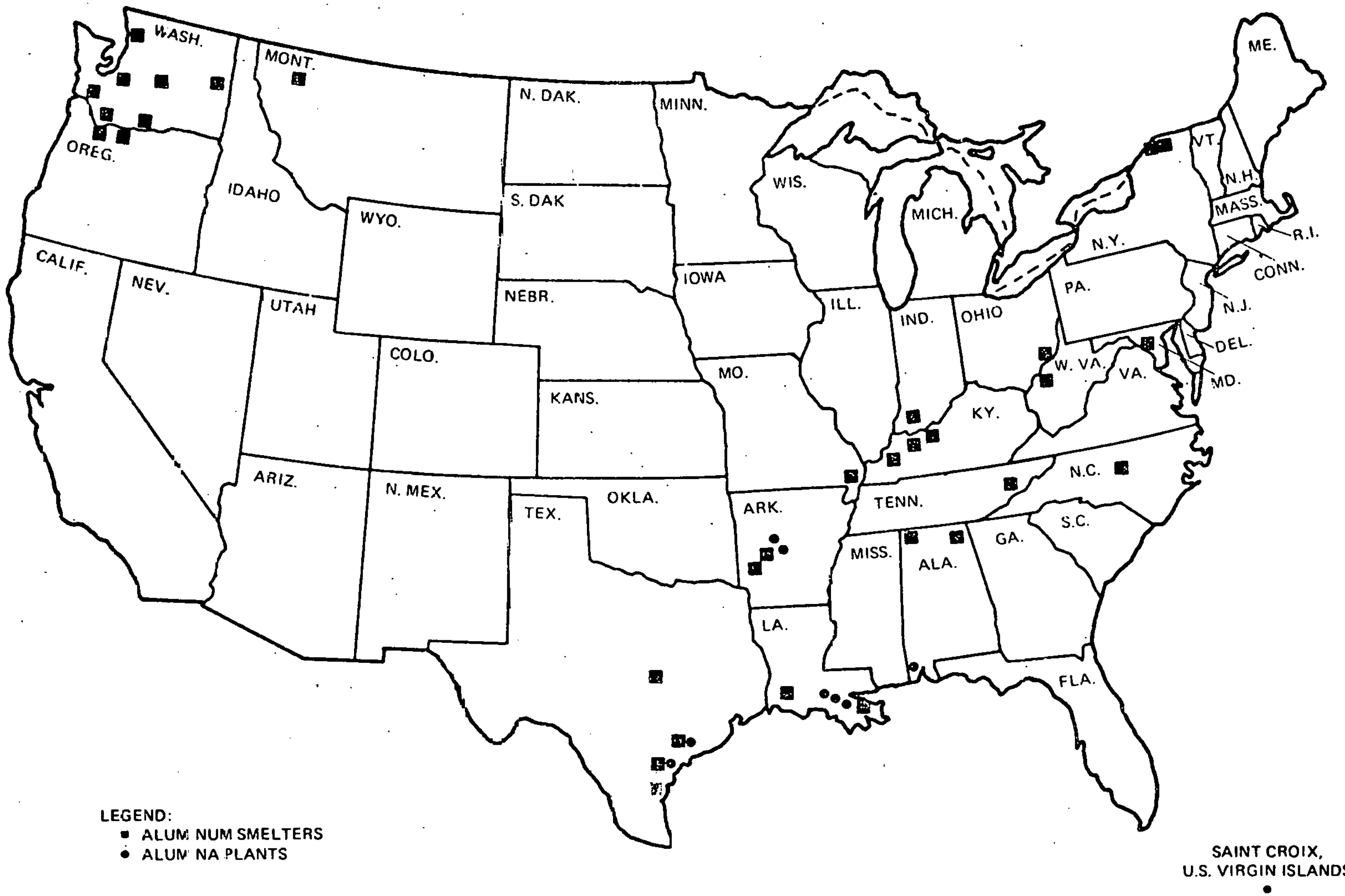
Most firms in the secondary aluminum industry have one plant and are either family-owned or owned by small corporations. The minority of firms, which represent a large portion of the production, however, are either large corporations, or subsidiaries of large corporations and are generally multiplant operations. The integration level of these firms is low, with the exception of extrusion ingot manufacturers who produce extruded products such as siding, doors, and windows. With the exception of those firms owned by conglomerates, the level of diversification of most of the companies involved in secondary aluminum smelting is low. In 1972,the four largest secondary aluminum companies accounted for 50 and 80% of the value of secondary ingot and extrusion ingot shipments, respectively.[2]



(*)**Note:** Some of the major primary aluminum producers use bauxite. The major primary and secondary companies also produce mill products, fabricated products and castings to varying degrees.

Source: *Aluminum Prices 1974-75 Executive Office of the President Council on Wage and Price Stability,* Staff Report September 1976.

FIGURE 3.3–1 ALUMINUM PRODUCTION PROCESS



Source: *Environmental Considerations of Selected Energy Conserving Manufacturing Process Options:* Vol. VIII. *Alumina/Aluminum Industry Report,* U.S. EPA, EPA–60017–76–034h, December 1976.

FIGURE 3.3–2 LOCATION OF ALUMINA PLANTS AND ALUMINUM SMELTERS

TABLE 3.3-1

ALUMINA PLANTS

Company and Plant	Capacity in 1976 (Equivalent Aluminum) Thousand Short-Tons/Year Plant	Company
Aluminum Company of America		1,405
Mobile, AL	515	
Bauxite, AR	195	
Point Comfort, TX	695	
Martin Marietta		237
St. Croix, VI	237	
Kaiser Aluminum and Chemical		951
Baton Rouge, LA	534	
Gramercy, LA	417	
Reynolds Metals Company		1,160
Hurricane Creek, AR	438	
Corpus Christi, TX	722	
Ormet Corporation*		313
Burnside, LA	313	
Total U.S.		4,066**

*A 66-34 joint venture between Consolidated Aluminum Corporation and Revere Copper and Brass, Inc.

**At an equivalency factor of 1.89 ton alumina per ton of aluminum, the total capacity in 1976 is approximately 7.7 million short tons per year.

Source: Mineral Commodity Profile, MCP-14, May 1978 and Arthur D. Little, Inc. estimates.

TABLE 3.3-2

PRIMARY ALUMINUM PLANTS

Company and Plant	Capacity in 1976 (Thousand Short Tons/Year) Plant	Company
Aluminum Company of America		1,675
Alcoa, TN	215	
Badin, NC	125	
Evansville, IN	290	
Massena, NY	215	
Point Comfort, TX	185	
Rockdale, TX	310	
Vancouver, WA	115	
Wanatchee, WA	205	
Palestine, TX	15	
Anaconda Aluminum		300
Columbia Falls, MT	180	
Sebree, KY	120	
Consolidated Aluminum		179
New Johnsonville, TN	141	
Lake Charles, LA	38	
Martin Marietta		210
The Dalles, OR	90	
Goldendale, WA	120	
Eastalco*		176
Frederick, MD	176	
Intalco*		260
Bellingham, WA	260	
Kaiser Aluminum and Chemical		724
Chalmette, LA	260	
Mead, WA	260	
Ravenswood, WV	163	
Tacoma, WA	81	

TABLE 3.3-2 (Continued)

PRIMARY ALUMINUM PLANTS

Company and Plant	Capacity in 1976 (Thousand Short Tons/Year) Plant	Company
Ormet**		260
Hannibal, OH	260	
Noranda		140
New Madrid, MO	140	
National Southwire Aluminum***		180
Hawesville, KY	180	
Revere Copper and Brass		114
Scottsboro, AL	114	
Reynolds Metals Company		975
Arkadelphia, AR	68	
Corpus Christi, TX	114	
Jones Mills, AR	125	
Listerhill, AL	202	
Longview, WA	210	
Massena, NY	126	
Troutdale, OR	130	
Total U. S.		5,193

* ALUMAX, Inc. and Howmet Aluminium Corp. each have a 50% interest in Eastalco and Intalco.

** Ormet is owned jointly by Consolidated Aluminum Corp. (66%) and Revere Copper and Brass (34%).

*** National Southwire Aluminum is owned jointly by National Aluminum Company (50%) and Southwire Company (50%).

Source: Mineral Commodity Profile MCP-14, May 1978, and Arthur D. Little, Inc., estimates.

In 1976, 91 plants produced secondary alloy ingot, hot metal, and extrusion ingot.[3] Most of the secondary plants are located near heavily industrialized areas that give them proximity to a supply of scrap as well as to their customers. This is especially advantageous for the plants that provide "hot metal" to the automobile companies' casting operations. About 35% of the U.S. secondary aluminum production is done within a 100-mile radius of downtown Chicago; another 20% can be found within a similar radius of Cleveland; and the remaining 45% is located primarily near New York City and Philadelphia, in the S.W. United States and in California.[5] Production in individual secondary aluminum plants can range from 3,000 to 55,000 short tons per year.[5]

3.3.2.3 Aluminum Foundries

In the United States about 1400 foundrics produce aluminum castings as the major metal; half of which cast aluminum exclusively. About 80% of aluminum foundries are jobbers. About 923,000 tons of aluminum castings, valued at $2.75 billion, were produced in 1976, representing about 40% of all nonferrous castings.[6]

Because of their light weight, castability, machinability, and high strength-to-weight ratio, aluminum castings serve such important markets as automotive, appliance, and aerospace. The automotive industry consumed approximately half of all aluminum castings in 1976.

Aluminum foundries are heavily concentrated in the Great Lakes States where most automotive plants are located. The Pacific States, centers of the aerospace industry, also have a large number of aluminum foundries.

About 80% of aluminum foundries employ fewer than 50 people, and about half of these have fewer than 10 employees.

3.3.2.4 Others

Besides the primary and secondary aluminum producers and foundries, there are a number of companies producing a wide variety of aluminum products. Table 3.3-3 is based on unofficial directories currently prepared by the U.S. Department of Commerce Domestic and International Business Administration. The figures show the number of companies and plants involved in the manufacture of each product. In many instances, one company operates more than one plant. No totals are shown since some plants produce more than one product. The data also include captive plants, i.e., those producing only for one company's use. In many instances, the companies that own these plants are generally small and are scattered around the country. The companies exhibit little or no concentration.

3.3.3 Process Technology

3.3.3.1 Primary Metal Production

Primary aluminum metal is produced from alumina by the Hall-Heroult electrolytic reduction process. Alumina is produced by refining bauxite via the Bayer process. Both these processes are briefly described below.

3.3.3.1.1 Bayer Process

In the Bayer process, finely ground bauxite (-35 mesh), usually wet ground in spent digestion liquor, is digested at elevated temperatures under pressure. The digesting liquor contains sodium aluminate and free caustic.

TABLE 3.3-3

DISTRIBUTION OF COMPANIES AND PLANTS INVOLVED IN THE MANUFACTURE OF VARIOUS ALUMINUM PRODUCTS (January 1978)

Products	Number of Companies	Number of Plants
Primary Ingot	12	32
Secondary Ingot	69	89
Master Alloys	9	9
Sheet and Plate	29	49
Foil	18	27
Extruded Shapes	149	222
Rolled and Continuous Cast Rod and Bar	16	31
Wire, Bare, Conductor and Nonconductor	59	125
ACSR and Cable, Bar	28	59
Wire and Cable, Insulated or Covered	41	90
Drawn Tube	18	22
Welded Tube	25	32
Flake, Powder and Paste	13	18
Forgings	64	74
Impacts (including collapsible tubes and cans)	25	29

Source: Directory of Aluminum Suppliers in the United States, U.S. Department of Commerce, Industry and Trade Administration, Bureau of Domestic Business Development Office of Basic Industry.

The Bayer process is shown schematically in Figure 3.3-3. The ranges of raw materials and energy required per short ton of alumina produced in the U.S. Bayer plants are shown in Table 3.3-4.

3.3.3.1.2 Hall-Heroult Process

This is an electrolytic reduction process in which alumina is continuously dissolved in molten cryolite in the cell wherein aluminum is liberated at the cathode and oxygen at the anode. The oxygen liberated at the anode reacts with the carbon anode to produce a mixutre of carbon monoxide and carbon dioxide.

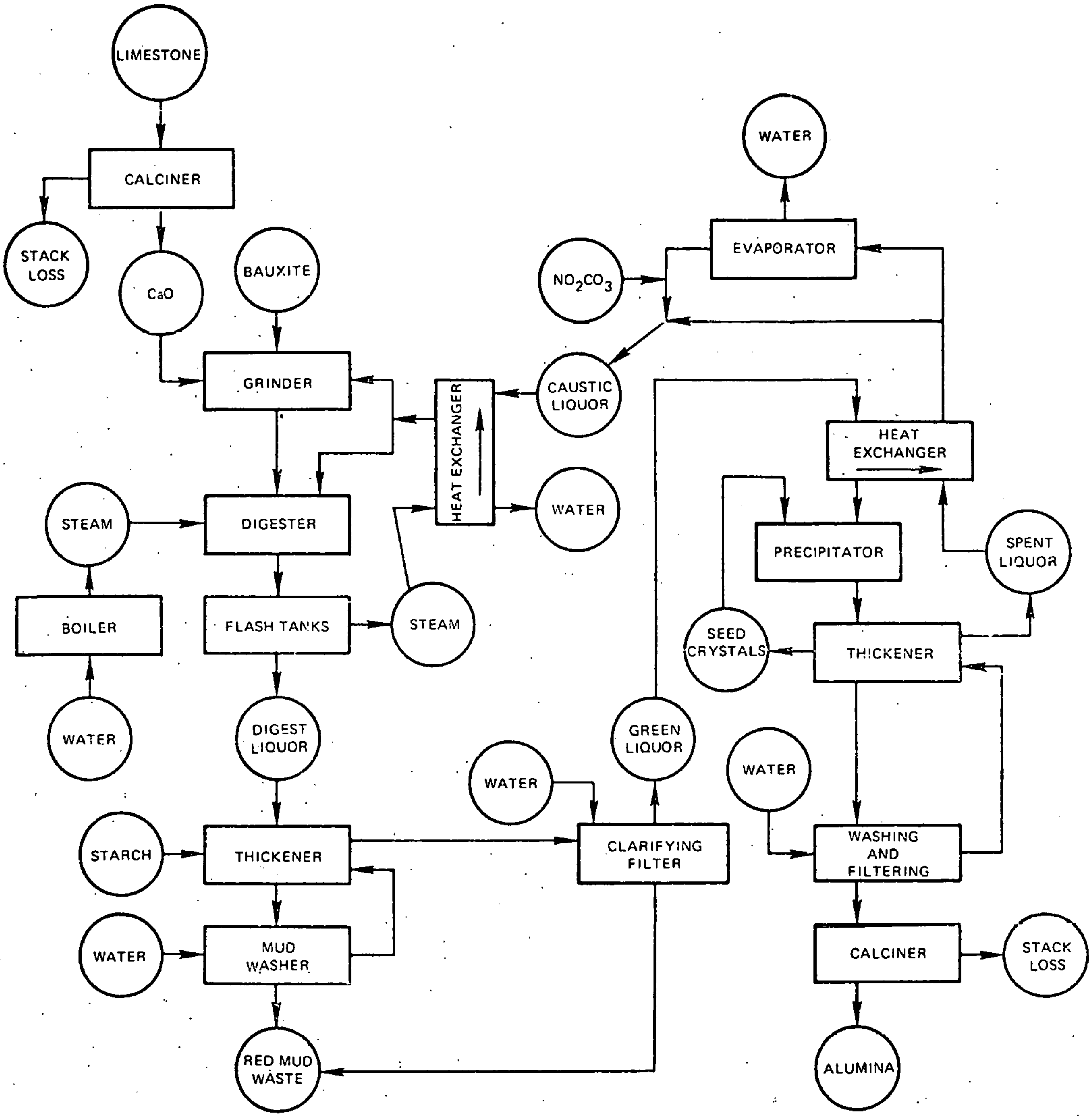
Modern Hall-Heroult electrolytic cells are large steel boxes lined with insulating refractory and carbon. Carbon blocks at the bottom of the cell serve as the cathode in the electric circuit and form a connector to steel conductor support members that eventually connect to the cathode bus. During electrolytic reduction, aluminum metal is deposited as liquid on the surface of the carbon cathode at the bottom of the cell. This pool of molten aluminum is the active cathode. Cathodes are more or less a permanent installation. Typically, the cathodes last three to six years, about the same as the life of the cell itself, after which time the cell is taken out of service, rebuilt, and refitted. Cathodes are purchased from carbon producers, while anodes are produced at the aluminum plants.

The anodes are also carbon, suspended in the electrolyte on steel conncector rods that connect to the anode bus. The carbon anodes used in the reduction cells are produced by two methods, Soderberg or prebake, both of which use a combination of petroleum pitch and petroleum coke. In the Soderberg system, "Soderberg paste" is fed semi-continuously into the top of the steel casing, in which the heat from the cell and current flow bakes the paste and removes the volatiles.

In the prebake system, prebaked anodes are manufactured in a separate installation from high-purity petroleum coke, which is ground, calcined, and blended with pitch to produce a paste that can be pressed into high-density shapes. Approximately 1975 pounds of petroleum coke plus about 444 pounds of pitch are required to produce a short ton of anode carbon. The pressed anode blocks are then baked at temperatures up to 2000°F for as long as 30 days (baking and cooling period) and fitted with steel connector rods to support the anode and provide a connection to the anode bus. Molten cast iron is poured into the anode socket to make a good electrical connection between the steel rod and the carbon anode. The prebake system has a number of advantages over the Soderberg system. It requires significantly less energy than the Soderberg system and because the anodes are baked in separate facilities, it is easier to recover the volatiles released from the anode paste.

Aluminum reduction cells operate continuously with periodic additions of alumina and electrolyte additives, replacement of anodes, and removal of molten aluminum. Aluminum is removed periodically at one- to three-day intervals and blended with the output of other cells to attain a uniform purity level. The blended material is degassed and cast into ingots or sows or is delivered as molten metal to fabricating plants.

The ranges of raw materials and energy required for U.S. primary aluminum plants are shown in Table 3.3-5.



Source: *Environmental Considerations of Selected Energy Conserving Manufacturing Process Options:* Vol. VIII. *Alumina/Aluminum Industry Report,* U.S. EPA, EPA–60017–76–034h, December 1976.

FIGURE 3.3–3 BAYER PROCESS FOR PRODUCING ALUMINA

TABLE 3.3-4

BAYER PLANTS - RANGES OF RAW MATERIALS AND ENERGY REQUIREMENTS

	Range
Raw Materials:	ton/ton Alumina
Bauxite	2.05 - 2.63*
Limestone	.09 - .18
Soda Ash	.05 - .1
Starch	.005 - .01
Power:	kWh/ton Alumina
	200 - 300
Fuel:	10^6 Btu/ton Alumina
Steam generation	4.4 - 11.3
Lime calcination	.21 - .43
Alumina calcination	2.8 - 5.0

*Bauxite consumption varies from 2.05-2.37 for South American bauxite and 2.41 2.63 for Caribbean bauxite.

Source: Environmental considerations of Selected Energy Conserving Manufacturing Process Options: Vol III, Alumina/Aluminum Industries Report, EPA, December 1976.

Mineral Commodities Profile, MCP-14, May 1978.

TABLE 3.3-5

PRIMARY ALUMINUM PLANTS - RANGES OF RAW MATERIALS AND ENERGY REQUIREMENTS
(Prebaked Operation)

	Range
Raw Materials:	ton/ton Aluminum
Alumina	1.91 - 1.95
Calcined Petroleum coke	0.43 - 0.60
Pitch	0.10 - 0.20
Cryolite	0.01 - 0.05
Aluminum Fluoride	0.01 - 0.05
Calcium Fluoride	
Power:	kWh/ton Aluminum
	14,000 - 18,000
Fuel:	10^6 Btu/ton Aluminum
Baking Anodes	2.3 - 3.6
Casting	1.5 - 11.0

Source: Environmental considerations of Selected Energy Conserving Manufacturing Process Options: Vol III, Alumina/Aluminum Industry Report, EPA, December 1976.

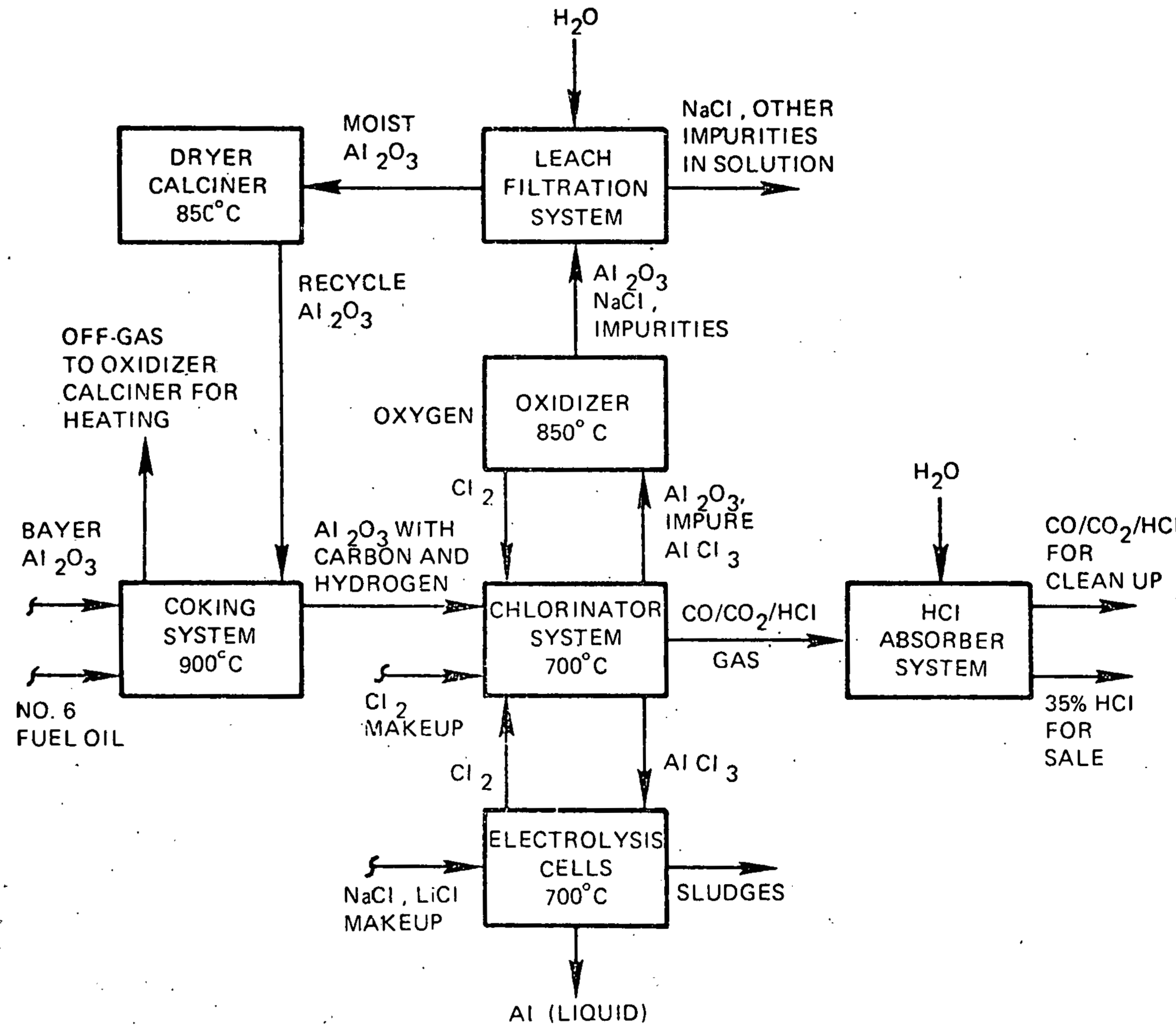
3.3.3.1.3 New Processes

The possibility of producing alumina from such domestic alumina-bearing raw materials as alunite, kaolin and anorthosite clays is of increasing interest. Nitric acid and hydrochloric acid leaching processes were identified by the U.S. Bureau of Mines as the most economic for producing alumina from domestic clays.[7] Clay chlorination, as in the Toth alumina process, and the Alcoa chloride process, also offers an alternative to the Bayer process and appears to be commercially viable for primary aluminum production, based on the limited information available.

Alcoa announced its new electrolytic chloride process for aluminum smelting in 1973. The process involves the electrolysis of aluminum chloride from an electrolyte consisting of alkali and alkali earth chlorides. Alcoa has built a demonstration plant in Palestine, Texas with an annual capacity of 15,000 short tons per year and possible expansion to 30,000 short tons per year. The Alcoa chloride process starts with pot feed alumina from the Bayer process. Specifications call for a minimum purity of 99.426% alumina. This alumina is chlorinated in the presence of carbon to form volatile aluminum chloride. This, in turn, is purified and fed to the electrolytic cells to produce molten aluminum at the cathode and chlorine at the anode. The chlorine is recycled to the chlorination system. The Alcoa chloride process is shown schematically in Figure 3.3-4. The advantages of this process over the existing Hall oxide electrolysis appear to be:

- Because the decomposition voltage and the bath resistivity are both lower for the chloride melt, the electrical energy requirement is sharply reduced.
- Because oxygen is eliminated from the system, it is not necessary to fabricate and replace the consumable carbon anodes. Permanent graphite electrodes can be used, and the expensive energy-consuming anode baking facilities are eliminated.
- Because electrodes can now be permanently emplaced, it is possible to design chloride process cells with multiple sheet electrodes stacked one above another (the so-called "multipolar" electrode configuration). One cell then becomes the equivalent of several single cells, with consequent savings afforded by the much more compact cell design.
- Because no cryolite or fluoride materials are used in the chloride process, fluoride emissions are completely avoided.
- The chloride cell operating temperature is about 1292°F rather than the 1742°—1832°F temperature of the Hall process.

Several refractory hard metals have been considered in the past to replace the carbon cathodes in the conventional Hall-Heroult process. So far, the principal interest has been in titanium diboride because of its superior electrical conductivity, and the fact that it is wetted by molten aluminum and cryolite in the cell. Also, in the pure state it is not corroded by the electrolyte. Thus, there is hope that this material, properly fabricated, would last at least four years since the cell itself has a normal life of four years. Recently, interest has shifted to replacing not only the iron and carbon, but also the molten aluminum pad so that the titanium diboride would provide connections between the cathode bus and the electrolyte. The aluminum produced at the cathode could be rapidly removed or drained from the cathode with only a thin film of molten aluminum remaining on the cathode.



Source: *Environmental Considerations of Selected Energy Conserving Manufacturing Process Options:* Vol. VIII. *Alumina/Aluminum Industry Report,* U.S. EPA, EPA–60017–76–034h, December 1976.

FIGURE 3.3–4 ALCOA CHLORIDE PROCESS (ASSUMED SCHEME)

It appears that a power saving of the order of 20-25% might be achieved. This would result from reducing the anode/ cathode distance, thereby reducing the voltage drop and the resistance losses. At least two companies, Kawecki Berylco Industries, Inc. and PPG Industries, believe that past difficulties with titanium diboride have now been overcome, and that they could demonstrate 3-4 years cathode life and the advantages of titanium diboride cathodes to the primary aluminum companies.

3.3.3.2 Secondary Metal Production

The production of secondary aluminum consists of three steps: presmelting, smelting, and pouring and cooling of products. These steps are briefly described below.

3.3.3.2.1 Presmelting

The preliminary treatment in preparing scrap for smelting depends on the type of scrap fed to the smelter. There are seven types of scrap as follows:

- New Scrap
  - — Solids and Clippings
  - — Borings and Turnings
  - — Dross and Skimmings (Residues)
  - — Other (includes foil and high-iron scrap)

- Old Scrap
  - — Castings, Sheet and Clippings
  - — Aluminum Cans
  - — Other (includes aluminum-copper radiators and other high-iron scrap).

New solids and clippings are largely uncontaminated and require little presmelter treatment. Iron inclusions or other non-aluminum contaminants, are removed either manually or mechanically (shredding and magnetic separation). Scrap consisting of borings and turnings is often contaminated with cutting oils. It is first shredded in ring crushers and then dried in rotary-kiln type dryers. The borings are then passed over magnetic separators where iron is removed and the clean dry borings are sent to storage for later use.

Drosses and skimmings are generated when aluminum ingot or scrap is melted or when molten aluminum is handled. The primary constituents of dross are aluminum metal and alumina, but significant quantities of other constituents may be present. These include aluminum carbide and aluminum nitride; other metals and their oxides, depending on the alloy composition of the melt; fluorine compounds, if the aluminum comes from a reduction cell; and residues of fluxes used to control melt loss or alloy properties, or to treat dross in the melting or holding furnace. The most valuable constituent of dross is the free aluminum .

When dross is formed in the furnace the metal content is usually high (about 60-80%), but it is much lower by the time it is skimmed off because aluminum oxide has formed. Hence the method of cooling and handling dross has an important bearing on the metal content of dross. Dross cooling machines have been adopted by the industry. The dross is skimmed into a suitably designed dross pot which is then taken to a cooler where some metal may be drained off and the remainder is broken up into small pieces and cooled rapidly on a water cooled, steel-faced, shaking conveyor. By these means the metal content of the dross, half of which may be lost if the hot dross is dumped on the floor in the dross room, is conserved.[8] In a melting or holding furnace, if the melt is fluxed with gaseous chlorine or fluxes such as fluorides, exothermic reactions occur, which cause the aluminum entrained in the dross to drain out. The resultant dross usually contains 20-30% aluminum.

The most common method for processing drosses, skimmings, and slags containing 30% metallics consists of milling, screening and magnetic separation to obtain a concentrate containing 60-70% metal. This concentrate is suitable for charging to a melting furnace. Oxides and dust are loosened from the metallics by crushing in a ball mill, rod mill, or hammer mill and are removed by screening or air-separation. The undersize fraction containing oxides and five metallics is sold as an exothermic material for hot-topping ingots or is discarded. Rich metallic skims do not require milling prior to use.

A wet process has been used, principally for drosses and skimmings containing salt flux.[9] The dross is fed into a long drum and washed with water to dissolve the salts. The washed residue is then screened, dried, and poured through a magnetic separator before being fed to the melting furnace. The salt-containing solution is evaporated to recover the salt flux.

In addition, drosses have been processed in a rotary salt bath furnace. The oxides are removed by salt flux to produce a slag and the entrained metal drains out. A recent development consists of using a low-frequency coreless induction furnace to recover metal from dross using a salt flux. This process provides good metallic recovery for drosses containing more than 50% metal.

Old scrap consisting of castings and sheet is sometimes baled or briquetted, or large pieces may be added to the melting furnace. When it has enough iron rivets, bushings and other tramp contaminants, the scrap is usually shredded and subjected to magnetic separation.

Old aluminum cans may be shredded, or baled for shipment and then shredded at the smelter. Another operation that may be practiced as a separate step is delacquering, which involves heating the cans at a temperature below the melting point to remove the organics. Alternatively, the shredded cans are charged directly to the melting and holding furnace along with virgin aluminum, prepared new scrap and runaround scrap.

Presmelting preparation of other scrap (new and old) consists of size reduction (crushing or shredding) and magnetic separation or "sweating." Sweating consists of selectively melting the aluminum alloy (melting point of about 1100°F) at a temperature below the melting point of iron or steel and letting the molten aluminum fraction flow into a ladle or mold while the iron-containing portion is raked out of the furnace. Aluminum wire scrap is first chopped and is then used for alloying or as a deoxidant in steelmaking.

3.3.3.2.2 Smelting

In smelting scrap, only those elements that are higher than aluminum in the electromotive series can be removed from the melted scrap charge. In producing the secondary aluminum alloy, then, the smelter has to add primary ingots (or high-purity scrap) to the molten scrap charge to bring the composition up to the desired specification.

The smelting of aluminum takes place in a reverberatory furnace or in a rotary furnace. The reverberatory furnace ranges in capacity from 30,000 to 180,000 lb, and may be either gas-fired or have dual-firing (gas and oil) capability. Some furnaces have one or two external charging wells or forewells (for charging scrap), separated from the main hearth of the furnace by a refractory wall called a "hot wall." Other furnaces have removable lids for charging of scrap. The hot wall has two openings, connecting the hearth and the charging wells, which are sometimes covered with a skim gate (external) to prevent scrap and skimmings on the molten metal surface from getting inside the furnace. Heat is conveyed from the burner flame by convection and radiation from the roof and sidewalls to the molten metal inside the furnace hearth, and by convection, radiation, and conduction to the scrap in the charging well.

Scrap is charged to the furnace either manually or mechanically through side doors, or the top of the furnace or the forewell depending on furnace design. A "molten heel" — molten metal of known composition left over in the bottom of the furnace from a previous heat — can be used to shorten the heat time. If a liquid heel is not maintained in the furnace, heavy solids are first charged into the furnace. The material must then be completely melted, skimmed, sampled, and assayed before other materials can be added. After each charge, the slag is skimmed off and the metal is sampled to determine its composition. It is normally economical to minimize the need for using alloying elements, such as copper and silicon, by charging scrap as close in composition to the alloy being produced as possible.

Because molten aluminum oxidizes rapidly, it is sometimes covered with a flux to retard oxidation. Once the oxides are trapped in the flux they are removed by skimming. Alloying agents (such as copper and silicon) are normally added after the metal composition has been determined, and the melt is brought to specification.

The specifications for most of the major alloys supplied to the diecastings industry call for a magnesium content of less than 0.1%. In spite of the fact that scrap is carefully selected so that the charge will meet product specifications, the bath still usually contains 0.5% to 0.8% magnesium. Excess magnesium is removed from the bath through the addition of aluminum fluoride or chlorine gas referred to as demagging. Finally, the metal is degasified by bubbling nitrogen, chlorine, or a mixture of the two. The molten bath is then ready for pouring. The overall metal recovery of the reverb melting scheme is around 90%. With very clean scrap, metal recovery could be as high as 98%. Metal losses are mostly to the slag, which is stored until shipped to a residue processor, reprocessed by the company, or dumped.

Alloys for extrusion billet manufacture are also melted in reverb furnaces, but the scrap used is restricted to certain alloys that require the addition of magnesium and, possibly, primary aluminum ingot to dilute the bath to specification.

In production of deoxidizers for the steel industry, reverb melting is utilized. Because the magnesium content is not critical, demagging is not required. These alloys are produced as notched bars or shot.

Hardeners are produced in the form of small notched bars and are used to introduce precise amounts of metals such as titanium, boron and chromium for alloying purposes. These bars are produced in small induction furnaces of 2,000-pound capacity. Since this aluminum must be of high purity, ordinary aluminum scrap cannot be used. Chopped aluminum wire or ACSR conductor with the iron core removed is generally used. Casting is done at temperatures of 2000°F-2200°F after the metal is skimmed to remove oxides.

3.3.3.2.3 Pouring and Cooling of Products

The molten aluminum is either cast into shapes such as ingots, billets and notched bar, or is made into shot. Metal is also delivered to a customer as "hot metal." Hot metal is tapped from a reverb furnace directly into preheated ladles at approximately1550°F. Refractory-lined ladles are placed on a special flat-bed trailer capped with a screw-down lid and chained rigidly to the truck bed. The hot metal is hauled by truck directly to the customer and discharged into the customer's holding furnace at a temperature of about 1350°F. The average load of hot metal is 30,000-35,000 pounds. Ladles have bottom-tap arrangements so that the metal can be poured directly into the customer's furnaces using the ladles, instead of by removing the ladle from the trailer.

3.3.3.4 Aluminum Foundry Technology

Most aluminum foundries (over 90%) have less than a 5 tons per hour melting capacity. Although 65% use sand casting and only 25% use die casting, a much larger proportion of castings are produced by die casting (about 65%) than sand castings (about 13%). The rest are produced by permanent mold techniques. Oil sand, carbon dioxide process, and shell core are the principal coremaking techniques used in the aluminum foundry industry.

Though crucible melting is the most common melting method — used in over 80% of the foundries, the largest share of the melting capacity is tied with the reverberatory furnaces.

3.3.4 Materials Flow

3.3.4.1 General

Materials flow in the aluminum industry exhibits a complex pattern. In 1976, domestic primary metal production was 4.3 million short tons, valued at approximately $3.79 billion. Of this, the domestic bauxite supply was sufficient for about 0.4 million short tons of aluminum. The remaining 3.9 million short tons (or 90.9% of the total primary) were obtained from imported bauxite and alumina.[10] The 1976 domestic secondary recovery was an estimated 1.5 million short tons.[11] This primary and secondary production, together with the imports and inventory change, constituted the aluminum metal flow. Figure 3.3-5 shows schematically the aluminum metal flow in 1976.

3.3.4.2 Classification of Recoverable Material

Figure 3.3-5 shows that aluminum-based scrap is an important element in the flow pattern. Scrap may be pure (unalloyed), segregated (one alloy type), or mixed (two or more alloys). New scrap is generated in the manufacture of primary aluminum, semifabricated aluminum mill products, or finished industrial and consumer products. This new scrap includes solids, such as new casting scrap, clippings or cuttings of new sheet, rod, wire, and cable; borings and turnings from the machining of aluminum parts; and residues, drosses, skimmings, spillings, sweepings, and foil.

New scrap is further defined as either "runaround" (home) scrap or purchased scrap. Runaround or home scrap is new scrap generated by fabricators of aluminum mill products or by aluminum castings foundries and recovered or recycled by the same company that generates it.

MINERAL COMMODITY PROFILES

ALUMINUM

ALUMINUM METAL FLOW, 1976

THOUSAND SHORT TONS OF METAL

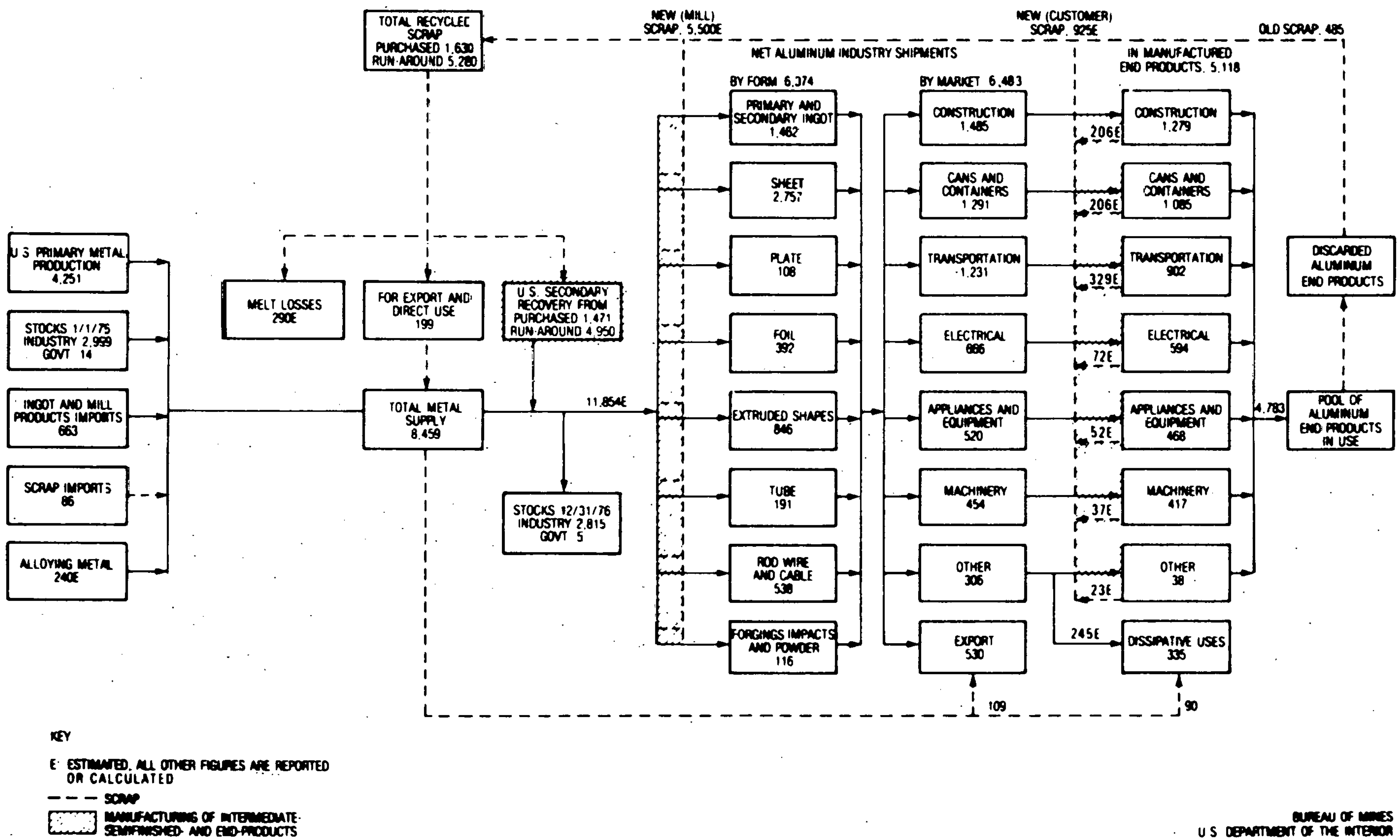


FIGURE 3.3-5 ALUMINUM METAL FLOW - 1976

Source: U.S. Bureau of Mines Mineral Commodity Profiles - Aluminum, 1978, p. 18.

Primary smelters also create and use runaround scrap. Such scrap, by definition, never leaves the company generating it and therefore is never marketed as scrap. Purchased scrap is new scrap purchased, imported, or treated "on toll" by secondary smelters, the original aluminum product suppliers, or others. New aluminum scrap purchased from manufacturers of end products may be referred to as customer scrap. Purchased scrap is sometimes referred to as prompt industrial scrap.

Old scrap, all of which is considered as purchased, comes from discarded, used, and wornout products. It includes aluminum pistons or other aluminum engine or body parts from junked cars, used aluminum cans and utensils, siding, awnings and other building products, and old wire and cable. Sweated pig is scrap that has been sweated or melted into a pig or ingot form for convenience and economy in shipping. Obsolete scrap is unused, but technologically obsolete aluminum parts, outdated inventory materials, production overruns, and spare parts for machines and equipment no longer being used. In the United States both sweated pig and obsolete scrap are considered old scrap.[9]

Table 3.3-6 shows the classification of purchased aluminum base scrap; typical contents, origin, and the level of recycling followed in the industry. Since the runaround or home scrap does not enter the market, there are no data on this scrap.

3.3.4.3 Recycling Profile

Figure 3.3-5 shows that aluminum-based scrap is an important element in the flow pattern. More than 90% of the new scrap generated in the production of end products is recycled to the production cycle almost immediately.[10] The total supply of new scrap is a direct function of aluminum production levels. The market supply of new scrap depends on total supply, the amount reused within the generating plant, and the amount of scrap "buy-back" under toll conversion agreements.

The recycle time for old scrap, virtually all of which is purchased, varies considerably depending on the form and end use, and is normally much longer than for new scrap.[10] The potential supply of old scrap is a direct function of the stock of aluminum goods and their age. The actual supply of old scrap is a function of the price of scrap, technological considerations, and transportation costs.[5]

Table 3.3-7 shows the consumption of purchased new and old scrap, and sweated pig. Of the total scrap consumed in 1976, 51.8% was used by secondary smelters and 24.9% by primary producers. Table 3.3-8 shows the reported purchased scrap consumption in 1976 by type of scrap. Of the total 1.5 million short tons purchased scrap (as reported) new scrap represented 1.06 million short tons (71.9% of the reported total). The remainder was made up by old scrap, including sweated pig.

The Aluminum Association reported that in 1976, based on partial industry coverage, 106,000 short tons of aluminum representing 4.8 billion aluminum cans were reclaimed.[8] In 1977, 140,000 short tons of aluminum were reclaimed representing 6.4 billion aluminum cans.[8] Reynolds, in 1977, reclaimed about 48% of total aluminum cans recycled and represented more than 55% of the total number of cans produced by Reynolds.[12]

TABLE 3.3-6

CLASSIFICATION OF ALUMINUM BASE PURCHASED SCRAP

Scrap*	Typical Contents	Origin	Level of Recycling Followed **
New Scrap			
Solids and Clippings	Clippings-painted & containing Cu and Zn alloys in a segregated (by alloy) or mixed form; forgings; special casts and alloy solids.	Aircraft industry; fabricators and manufacturers.	High
Borings and Turnings	Borings--segregated or mixed; turnings--contaminated or clean.	Machining of castings, rods, bars, etc.; aircraft and automobile industries.	Moderate to high
Foil	-	Manufacturers	Moderate
Drosses and Skimmings	Aluminum oxide, metallic aluminum and aluminum salts.	Primary and secondary aluminum producers.	Moderate
Other	Scrap containing high iron content.	Fabricators & manufacturers	Low to Moderate
Old Scrap			
Castings, Sheet and Clippings	Cast & sheet products; cable-insulated, steel reinforced.	Manufacturers & end-users.	Low
Aluminum Cans	-	Consumers, collectors of cans & municipal refuse.	Moderate
Automotive, Other	Aluminum-copper radiators.	Automobile junk yards.	Low
Sweated Pig	Mixture of aluminum base scrap.	Manufacturers & fabricators.	Low

*Scrap categories are those published by Bureau of Mines.

**Preliminary Arthur D. Little, Inc. estimates.

TABLE 3.3-7

CONSUMPTION OF AND RECOVERY FROM PURCHASED NEW AND OLD ALUMINUM SCRAP - 1976

Class	Consumption*	Calculated Aluminum Recovery
Secondary Smelters	758,992	598,765
Primary Producers	365,190	314,248
Fabricators	121,212	107,506
Foundries	99,907	86,458
Chemical Producers	120,161	46,139
Total	1,465,462	1,153,116

*As reported by companies to U.S. Bureau of Mines. On a full industry coverage basis, the total scrap consumption is estimated to be 1,741,000 short tons, with calculated aluminum recovery of 1,371,000 short tons and a metallic recovery of 1,471,000 short tons.

Source: Aluminum, Preprint from Minerals Yearbook, 1976.

TABLE 3.3-8

CONSUMPTION OF ALUMINUM SCRAP BY TYPE - 1976*
(1,000 short tons)**

Type of Scrap	Secondary Smelters	Primary Producers and Others***	Total
New Scrap			
Solids and Clippings	231	350	581
Borings and Turnings	136	16	152
Foil	1	6	7
Dross and Skimmings	126	104	230
Other	24	61	85
Total New Scrap	518	537	1,055
Old Scrap			
Castings, Sheet and Clippings	121	35	156
Aluminum Cans	8	101	109
Other****	30	17	47
Subtotal	159	153	312
Sweated Pig	82	17	99
Total Old Scrap	241	170	411
TOTAL	759	707	1,466

*Includes imported scrap. The reporting companies reported that 6.62% of total receipts of aluminum-based scrap or 97,800 short tons was received on toll arrangements.

**Rounded to the nearest thousand.

***Others include foundries, fabricators, and chemical plants.

****Includes data on aluminum-copper radiators.

Source: Aluminum, Preprint from Minerals Yearbook, 1976.

3.3.5 Future Trends

Aluminum is a relatively new metal. Its historical growth for each market and application can be attributed to two main factors — economics and properties. Table 3.3-9 shows the historical aluminum shipments by markets for 1972 through 1977, as reported by the Aluminum Association. Building and construction, transportation, and containers and packaging markets accounted for approximately 50-65% of the total shipments in 1977. The term "statistical adjustment" in Table 3.3-9 refers to net shipments of aluminum reported by the Bureau of Census, which the Aluminum Association believes were overstated (or understated in 1977) by the percentages shown.

In recent years, increasingly refined statistical data has been published by the industry associations and the federal government. Because of the complexity of the aluminum metal flow and the nature of the industry, statistics on future growth from different sources should not be combined arbitrarily. In this section, for illustrative purposes, the future growth scenario is excerpted from the information published by the Bureau of Mines.[10]

The Bureau of Mines has estimated that total demand for aluminum in metal and non-metal form will be 10.7 million short tons in 1985 and 20 million in 2000. The apparent aluminum metal consumption data for 1972 through 1977, as well as the projected demand by the Bureau of Mines are shown in Table 3.3-10. This table does not include non-metal aluminum demand. The apparent aluminum metal consumption is defined by the Bureau as the difference between apparent aluminum supply available for domestic manufacturing and aluminum metal recovery from purchased new scrap. The secondary metal reported in Table 3.3-10 reflects recovery from old scrap only. Between the base year of 1976 for this study and 1985, secondary metal recovery from old scrap is projected to increase from 409,000 short tons to 900,000 short tons (approximately 7.4% annual growth).

3.4 COPPER

3.4.1 Industry Definition

The domestic copper industry is defined here to encompass all firms included in the following SIC categories:

SIC 3331 — Primary Smelting and Refining of Copper
SIC 33412 — Secondary Copper
SIC 3351 — Rolling, Drawing and Extruding of Copper
SIC 3362 — Brass, Bronze and Copper Foundries

3.4.1.1 Definition of SIC Classifications

- SIC 3331 Primary Smelting and Refining of Copper — includes establishments primarily engaged in smelting copper from the ore, and in refining copper by electrolytic or other processes.

- SIC 33412 Secondary Copper — includes establishments primarily engaged in recovering copper from copper and copper-based alloy scrap by utilizing a variety of melting and refining methods. (Establishments primarily engaged in assembling, gathering, and breaking up scrap metal without smelting and refining are classified in trade industries.)

TABLE 3.3-9

ALUMINUM SHIPMENTS BY MARKETS - 1972-1977*

	% of Total Shipments					
	1972	1973	1974	1975	1976	1977
Building Construction	26.5	24.7	22.9	22.6	23.1	23.0
Transportation	18.5	19.2	17.8	17.2	19.3	21.7
Containers & Packaging	15.0	14.0	16.5	20.2	20.2	20.8
Electrical	12.7	12.6	13.4	12.2	10.3	10.0
Consumer Durables	9.4	9.1	8.4	7.6	8.1	8.0
Machinery & Equipment	6.2	6.5	7.6	6.6	7.1	6.9
Other Markets	6.9	5.9	5.4	5.3	4.8	4.5
Statistical Adjustment	+0.1	+1.6	+1.0	+0.1	+0.5	-0.3
Domestic, total	95.3	93.6	93.1	91.8	93.4	94.6
Export	4.7	6.4	6.9	8.2	6.6	5.4
Total %	100.0	100.0	100.0	100.0	100.0	100.0
Total Shipments (Thousand Short Tons)	6,023	7,343	6,866	4,965	6,374	6,678

*The data are published by the Aluminum Association. For 1976, the revised data as reported in Aluminum Monthly, October 1978 is used in the table.

Source: Aluminum Statistical Review, 1976, for 1972 through 1975.
Aluminum Monthly, October 1978, for 1976 and 1977.

TABLE 3.3-10

HISTORICAL AND PREDICTED APPARENT CONSUMPTION OF ALUMINUM METAL*

(Thousand Short Tons)

Year	Primary	Secondary	Total	Ref.	Remarks
1972	4,676	250	4,926	(14)	
1973	5,560	265	5,825	(14)	
1974	5,124	304	5,428	(14)	
1975	3,570	337	3,907	(14)	
1976	4,704	409	5,113	(11)	
1977	4,937	502	5,439	(13)	
1985	8,850	850	9,650	(10)	
1987	9,200	900	10,100	-	**
2000	15,800	2,000	17,800	(10)	

*Apparent Consumption = Apparent Supply - Recovery from Purchased New Scrap. The numbers for 1975 and 1976 in this table reflect the revisions made by the Bureau in Reference 8. Secondary metal is the amount obtained from old scrap.

**Calculated by Arthur D. Little, Inc. based on the projections made by the Bureau for 1985 and 2000.

- SIC 3351 Rolling, Drawing and Extruding of Copper — includes establishments primarily engaged in rolling, drawing and extruding copper, brass, bronze, and other copper-based alloy basic shapes, such as plate, sheet, strip, bar, and tubing. (Establishments primarily engaged in recovering copper and its alloy from scrap or dross are classified in industry 3341.)

- SIC 3362 Brass, Bronze and Copper Foundries — includes establishments primarily engaged in casting of brass, bronze and copper-based alloys.

3.4.2 Industry Structure

Although significant transactions in copper concentrates or blister do take place, mined copper is generally processed to refined form for consumer use. Refined copper is marketed in regular or standard shapes consisting largely of wire bars, cathodes, ingots and ingot bars, cakes, slabs, and billets. Market transactions in refined copper, therefore, define the relevant copper market for the industry as a whole.

The domestic copper industry is segmented into "primary" and "secondary" sectors on the basis of whether the copper product has originated from mined copper (virgin ore) or from scrap. By this definition, firms in the primary sector predominantly transform mined copper into refined copper; firms in the secondary sector either predominantly process scrap into secondary refined copper or prepare it for direct consumption in the form of unrefined copper scrap.

Production of refined copper in the United States from all sources is detailed in Table 3.4-1, for 1974, 1975, and 1976, based on data from the U. S. Bureau of Mines. Domestically mined copper constituted 74% of the total United States refined copper supply stream; refined copper from scrap, produced both by refineries and by "secondary plants" (i.e., numerous small smelters of scrap copper), contributed another 20%.

Production of refined copper in the United States by primary and secondary producers, 1950-1976, is given in Table 3.4-2. Estimated production of secondary refined copper by both primary and secondary producers, 1960-1976, is given in Table 3.4-3. The 1974-1976 production of secondary copper in the United States which is recovered from purchased scrap is given in Table 3.4-4.

3.4.2.1 Primary Copper Industry

The primary sector consists principally of 12 firms, vertically integrated to different degrees from mining to refining and semifabrication. Several independent mining firms are also included in the primary sector.

Mine production of copper was the principal product of nearly 200 mines in 1972. Most of the domestically mined copper is produced in five western states — Arizona, Utah, New Mexico, Montana and Nevada. Arizona, Utah and New Mexico together account for more than 80% of total U. S. mine production. Well over half (about 63% in 1976) the total U. S. mine production of recoverable copper comes from Arizona.

Mills are almost always located close to the mines to minimize transportation costs. The value of the concentrates is high enough to allow some flexibility in smelter location. Most

TABLE 3.4-1

PRODUCTION OF REFINED COPPER BY SOURCE - 1974-1976*
(thousands of short tons)

SOURCE	1974 TOTAL	1974 Produced by: Refineries	1974 Produced by: Secondary Plants****	1975 TOTAL	1975 Produced by: Refineries	1975 Produced by: Secondary Plants*****	1976 TOTAL	1976 Produced by: Refineries	1976 Produced by: Secondary Plants*****
TOTAL (primary and secondary)	2,151,566	2,067,177	84,389	1,787,864	1,714,258	73,606	1,911,668	1,825,874	85,794
Primary (new) refined copper produced in the United States	1,654,658	1,654,658	-	1,443,378	1,443,378	-	1,537,188	1,537,188	-
from domestic ores, as reported by refineries**	1,420,905	1,420,905	-	1,286,189	1,286,189	-	1,420,603	1,420,603	-
from foreign ores, matte, etc., as reported by refineries**	233,753	233,753	-	157,189	157,189	-	116,585	116,585	-
Secondary refined copper produced in the United States***	496,908	412,519	84,389	344,486	270,880	73,606	374,480	288,686	85,794
from new scrap	NA	229,328	NA	NA	139,230	NA	NA	144,215	NA
from old scrap	NA	183,191	NA	NA	131,650	NA	NA	144,471	NA

NOTES AND SOURCES:

*U.S. Bureau of Mines, Mineral Industry Surveys, "Copper in 1976" (April 15, 1977), p.4.

**The separation of refined copper into metal of domestic and foreign origin is only approximate, as accurate separation is not possible at this stage of processing.

***Includes copper reported from foreign scrap.

****U.S. Bureau of Mines, 1974 Minerals Yearbook, Copper, Preprint, p. 29.

*****U.S. Bureau of Mines, Mineral Industry Surveys, "Copper in December 1976" (March 10, 1977), p. 3.

NA: Not available on a consistent basis from public sources.

TABLE 3.4-2

PRODUCTION OF REFINED COPPER BY PRIMARY AND SECONDARY PRODUCERS, 1950-1976
(thousands of short tons)

Year	Total Refined Production	Primary Producer Refined	Secondary Producer Refined
1950	1446.4	1300.8	145.6
1951	1362.5	1247.2	115.3
1952	1320.5	1220.2	100.3
1953	1504.0	1345.6	158.4
1954	1418.4	1249.1	169.3
1955	1562.8	1355.4	207.4
1956	1687.8	1501.3	186.5
1957	1676.1	1467.4	208.7
1958	1579.5	1389.3	190.2
1959	1331.5	1087.9	243.6
1960	1794.6	1565.3	229.3
1961	1813.9	1623.9	190.0
1962	1884.5	1689.4	195.1
1963	1884.4	1648.9	235.5
1964	1990.4	1750.3	240.1
1965	2214.8	1946.6	268.2
1966	2183.3	1905.8	277.5
1967	1526.6	1255.2	271.4
1968	1839.0	1565.4	273.6
1969	2214.9	1951.8	263.1
1970	2242.7	1991.0	251.7
1971	1962.4	1747.6	214.8
1972	2258.5	2006.3	252.2
1973	2312.6	1963.8	348.8
1974	2151.6	1769.5	382.1
1975	1775.0	1550.5	224.5
1976	1995.0	1739.8	255.2

Source: Economic Impact of Environmental Regulations on the United States Copper Industry. January 1978, Table III-8.

Predicast Basebook, 1978.

TABLE 3.4-3

ESTIMATED SECONDARY REFINED COPPER PRODUCED BY PRIMARY AND SECONDARY PRODUCERS - 1960-1976
(thousands of short tons)

Year	Total Production of Refined Copper from Scrap	Copper Refined from Scrap by Secondary Producers	Copper Refined from Scrap by Primary Producers	Copper Refined from Scrap by Secondary Producers (%)
1960	291.7	229.3	62.4	76.8%
1961	270.4	190.0	80.4	70.3
1962	289.7	195.1	94.6	67.4
1963	302.0	235.5	66.4	78.0
1964	351.1	240.1	111.0	68.4
1965	445.1	268.2	176.9	60.3
1966	491.3	277.5	213.8	56.5
1967	406.6	271.4	135.2	66.8
1968	416.6	273.6	143.0	65.7
1969	499.1	263.1	236.0	52.7
1970	511.6	251.7	259.9	49.2
1971	400.7	214.8	185.9	53.6
1972	423.2	252.2	171.0	59.6
1973	465.1	348.8	116.3	75.0
1974	496.9	382.1	114.9	76.9
1975	344.5	224.5	120.0	65.2
1976	375.2	255.2	120.0	68.0

Source: Economic Impact of Environmental Regulations on the United States Copper Industry. January 1978, Table III-7.

U.S. Bureau of Mines, Minerals Yearbook, 1976.

TABLE 3.4-4

PRODUCTION OF SECONDARY COPPER, REFINED AND UNREFINED
RECOVERED FROM PURCHASED SCRAP, 1974-1976
(thousands of short tons of copper content)

	1974	1975	1976
Total secondary copper produced in the United States*	1,344,320	971,965	1,106,000
recovered as unalloyed copper	513,308	355,512	374,000
recovered as alloys**	831,012	616,453	732,000
Less:			
Total refined copper produced from scrap in the United States***	496,908	344,486	374,480
Equals:			
Total secondary copper produced in the United States which is used directly	847,412	627,479	731,520

* U.S. Bureau of Mines, Mineral Industry Surveys, "Copper in 1976" (April 15, 1977), p. 4. Includes copper recovered from both copper-base scrap and other than copper-base scrap.

** Includes copper in chemicals as follows:
1974: 2,649
1975: 2,480
1976: 4,007
U.S. Bureau of Mines, Ibid.

*** Refer to Table 3.4-1.

smelters are located near the mills that supply them or on tidewater or railhead in order to receive concentrates from distant mills. With the major copper mines centered in the western states, most of the smelting capacity is in that region. Refineries can be located anywhere between smelters and fabricators, since transportation costs for blister and refined copper are about the same.

The basic data on the primary producers, i.e., mine production of recoverable copper, and refinery capacity for the years 1974-1976 are given in Table 3.4-5.

3.4.2.1.1 Industry Concentration

The U.S. copper industry is highly concentrated. In 1974, four firms accounted for 64% of total U.S. mine production. Eight companies, including these four, accounted for 88% of the total. Seven firms together represent virtually all of the U.S. smelter and primary refinery capacity.

3.4.2.1.2 Vertical Integration

Several of the domestic primary producers participate either directly or through subsidiaries in all five stages of production: mining, milling, smelting, refining, and fabrication. Productive capacities, however, are not always matched between the different stages of production.

3.4.2.2 Secondary Copper Industry

In the secondary copper smelting and refining industry in the United States, there are approximately 50 producers of either brass and bronze ingots or secondary refined copper operating approximately 70 plants. The plants in this industry fall into two fairly distinct segments: (1) producers of brass and bronze ingots and (2) producers of unalloyed copper.

3.4.2.2.1 Types of Firms

Most of the firms in the secondary copper industry are small, individually owned operations having only one plant; only a few are publicly held. A minority of the firms (but still representing a large fraction of the production) are either subsidiary operations of large mining companies or are subsidiaries of conglomerates.

For the 1963-1972 period, the four largest firms accounted for about 40% of the value of shipments; the eight largest companies accounted for 69%; the 20 largest, for about 85%; and the 50 largest for almost all of the value of shipments.

3.4.2.2.2 Types of Plants

There are 63 plants in the brass and bronze ingot segment. These producers manufacture a wide variety of specification alloys. These alloys generally fit a series of specifications that have been outlined by both ASTM and the Brass and Bronze Ingot Institute (BBII) and are in the form of 30-pound brass or bronze ingots. Some of the smelters also produce a series of materials in the form of shot that are sold to factories for the inoculation of gray iron. The shot may be pure copper or copper-nickel alloys of various types.

The plants are usually small, with production ranging from 500-1500 short tons per month and employment ranging from 10-500 people. The facilities vary in age; some plants are 40-50

TABLE 3.4-5

BASIC DATA ON PRIMARY PRODUCERS OF COPPER 1974-1976

	1974	1975	1976
Mine Production of Recoverable Copper (short tons)	1,597,002	1,413,366	1,605,586
Refinery Capacity* (annual short tons)	2,848,000	2,907,000	2,739,000

* Capacity includes that for processing scrap.

Source: U.S. Bureau of Mines, Mineral Industry Surveys, "Copper in 1974" and "Copper in 1976."

American Bureau of Metal Statistics, Inc., Nonferrous Metal Data for 1974, 1975, and 1976.

years old, with additions and renovations made over the years. Several of these plants are diversified, being involved as well in other secondary metal processing operations, such as secondary aluminum, lead, and zinc. In the normal sense of production, however, the secondary brass and bronze ingot-making segment of the industry is non-integrated. None of the smaller smelters is integrated to the point of producing a finished or semi-finished product.

There are seven producers of unalloyed copper, which may be in the form of blister copper, fire-refined copper, cathode copper, wire bar, continuous cast, or a finished product, depending on both the production scheme and the needs of the customer. Also, several precious metals are usually recovered as a result of electrorefining to produce cathode copper.

Plant sizes range from 1500-18,000 short tons production per month; the work force ranges from 100-1800 people. Although the facilities are 40-50 years old, they generally utilize sophisticated technology and equipment and are integrated toward producing finished products, such as tubes and rods. Many of the firms are completely integrated, using copper scrap as a raw material and turning out a finished product, such as electrical wire, valve fittings, and copper tubing.

Producers of brass and bronze ingots are located mostly in the northeastern, Pacific Coast, and east north central states. Producers of unalloyed copper are also located in heavily industrialized areas, mostly in the northeastern states, with one plant in the south and two in Illinois.

3.4.2.2.3 Percent of Industry Represented by Each Segment

Segment 1 (brass and bronze ingots) represents 53% of the plants in the secondary copper smelting and refining industry, 46% of the employees, and 32% of the production. Segment 2 (unalloyed copper) contains only 10% of the plants in the industry, but accounts for about 65% of the production, and 44% of the employment.

3.4.3 Process Technology

3.4.3.1 Primary Copper Industry

Production of primary copper involves four basic activities: mining, milling, smelting, and refining. Refined copper is then fabricated for various end-use markets. The four stages of primary production are:

- Mining — where ore containing approximately 0.4-2% copper is mined;
- Milling — where the copper-containing minerals are separated from waste rock to produce a concentrate containing about 25% copper;
- Smelting — where concentrates are melted and reacted to produce 98% pure "blister" copper; and
- Refining — where blister copper is refined electrolytically to produce 99.9% pure cathode copper. Some of the new hydrometallurgical processes combine the functions performed by smelting and refining.

A generalized flowsheet for copper extraction from sulfide ores is shown in Figure 3.4-1.

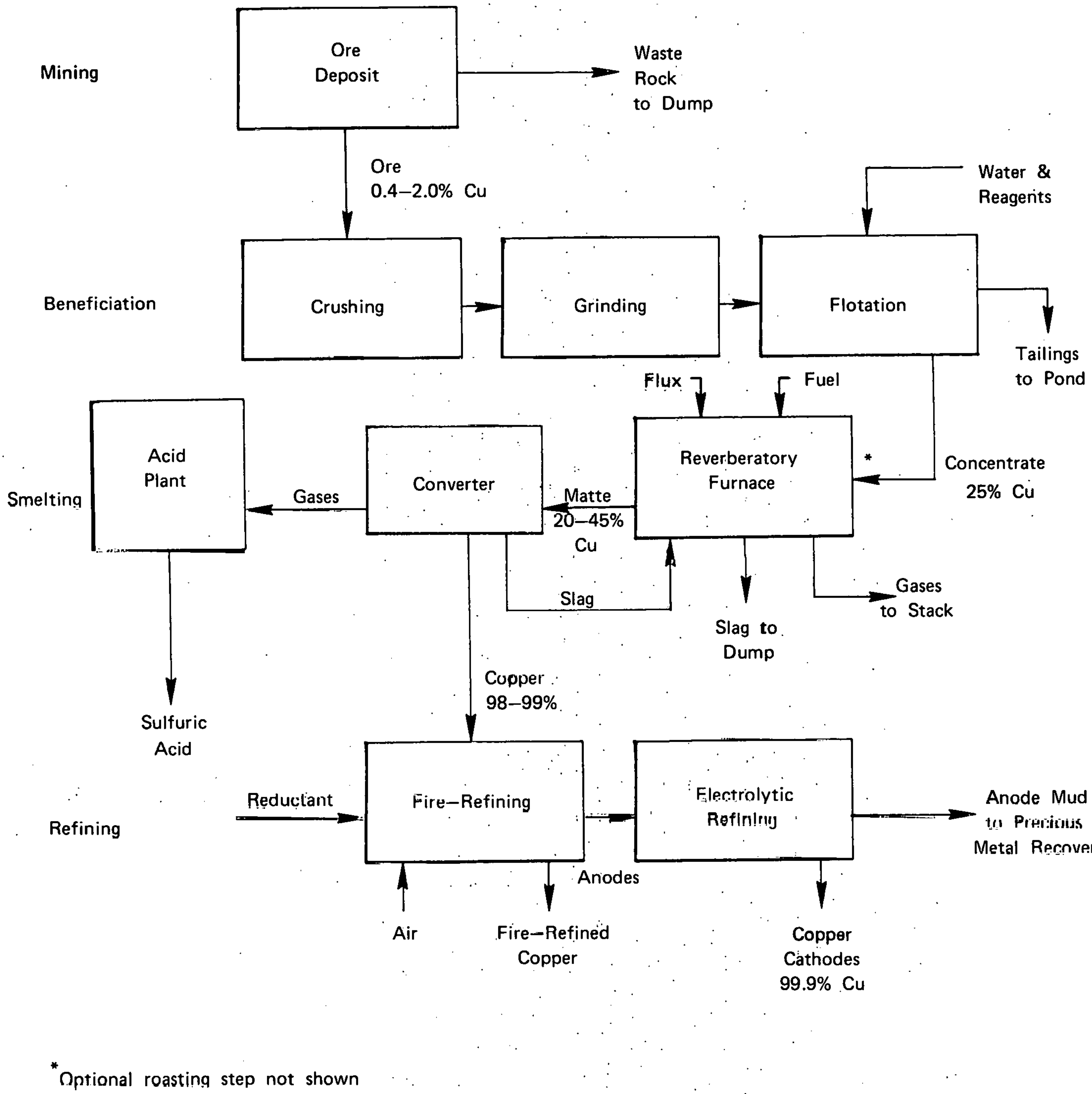


FIGURE 3.4–1 GENERALIZED FLOWSHEET FOR COPPER EXTRACTION FROM SULFIDE ORES

3.4.3.1.1 Mining and Beneficiation

About 85% of the copper ore mined comes from open pits, and the rest from underground mines. Underground mining methods for copper ores involve caving and/or cut-and-fill mining.

From a processing viewpoint, copper ores can be classified in three categories — sulfide, native copper, and oxide. Each category requires different beneficiation processes. The sulfide ores are treated primarily by crushing, grinding, and froth flotation to produce a concentrate (or several concentrates) of sulfide minerals; worthless "gangue" is rejected as tailings. Generally, only sulfide ores are amenable to concentration procedures. The output of this beneficiation process, concentrates, may contain 11-32% copper.

In native copper ores the copper occurs in metallic form. The Lake Superior district in Michigan is the only major source of ore of this type. Although the reserves of this ore are extensive, they contribute only a small portion of the total U.S. mine production of copper.

Oxide ores are treated primarily by leaching with dilute sulfuric acid. Copper is recovered in metallic form from leach solution by precipitation on iron scrap (cementation) or by electrowinning from the solution.

3.4.3.1.2 Smelting

Because most U.S. copper is extracted from low-grade sulfide ores that require concentration, current pyrometallurgical practice for recovery of copper is fairly uniform from smelter to smelter and is adapted to treating fine-grained sulfide concentrates consisting mainly of copper and iron sulfides and gangue. Copper's strong affinity for sulfur and its weak affinity for oxygen compared with that of iron and other base metals in the ore are the basis for the three major steps in producing copper metal from sulfide concentrates: roasting, smelting, and converting.

About half the copper smelters in the U.S. roast their charge prior to feeding the smelting furnace. The older smelters use multiple-hearth roasters for this purpose while the new smelters use fluidized bed roasters.

Roasted or unroasted dried concentrates are smelted in a smelting furnace. The reverberatory furnace (reverb) is the traditional smelting furnace used in the United States. The charge is heated by burning fuel in the furnace cavity. Most of the reverbs in the U.S. use natural gas, fuel oil, or powdered coal, as a fuel. In newer smelting processes, the heat required for smelting is supplied by the oxidation of a portion of the charge or by electric resistance heating of the slag.

In the smelting furnace, copper and sulfur form the stable copper sulfide, Cu_2S. Excess sulfur unites with iron to form a stable ferrous sulfide, FeS. The combination of the two sulfides, known as matte, collects in the lower area of the furnace and is removed. Such mattes may contain from 15-50% copper, with a 40-45% copper content being most common, and they may also contain impurities such as sulfur, antimony, arsenic, iron, and precious metals.

The remainder of the molten mass containing most of the other impurities and known as slag floats on top of the matte, being of lower specific gravity, and is drawn off. Reverb and electric furnace slags are discarded, while slags from other types of smelting furnaces are treated by milling/froth flotation or in an electric furnace for copper recovery. The copper contained in the discard slag is a major cause of copper loss in pyrometallurgical practice.

Matte produced in the reverberatory furnace is transferred to the converters in order to convert it to blister copper. Air is blown through the matte, to oxidize the FeS to FeO and Fe_3O_4 and remove sulfur with the off-gases as SO_2. Silica flux is added to the converter to form a fluid iron silicate slag. When all the iron is oxidized, the slag is skimmed from the furnace leaving behind "white metal" or molten Cu_2S. This white metal is then oxidized to blister copper. The blister copper is removed from the converter and cast or subjected to additional fire refining prior to casting.

3.4.3.1.3 Refining

The blister copper produced by smelting is too impure for most applications and must be refined before use. It may contain silver and gold as well as such other elements as arsenic, antimony, bismuth, lead, selenium, tellurium, and iron. Two methods are used for refining copper-fire refining and electrolysis.

The fire-refining process employs oxidation, fluxing and reduction. The molten metal is agitated with compressed air; sulfur dioxide is liberated, and some of the impurities form metallic oxides, which combine with added silica to form a slag. After this slag has been skimmed off, copper oxide in the melt is reduced by inserting green-wood poles or gaseous reductants below the bath surface. If the original material does not contain sufficient gold or silver to warrant its recovery, or if a special-purpose copper-containing silver is desired, the fire-refined copper is cast directly into forms. If it is of such a nature as to warrant the recovery of precious metals, fire refining is carried out only to insure homogeneous anodes for subsequent electrolytic refining.

A major portion of U.S. blister output is electrolytically refined. In electrolytic refining, blister copper, cast in anode shape, and cathodes (thin copper sheets prepared separately) are hung alternately in plastic-lined or lead-lined concrete electrolytic cells that contain the electrolyte—essentially a solution of copper sulfate and sulfuric acid. When current is applied, copper is dissolved from the anode and an equivalent amount of copper plates out of solution on the cathode. Such impurities as gold, silver, platinum-group metals, and the selenides and tellurides fall to the bottom of the tank and form anode slime or mud. Arsenic, antimony, bismuth, and nickel enter the electrolyte. The electrolyte has to be treated to prevent the buildup of these impurities, which would have a deleterious effect on cathode purity. After the plating cycle is finished, the cathodes are removed from the tanks, melted, and cast into commercial refinery shapes. Anode scrap is remelted to form fresh anodes. The copper produced has a minimum purity of 99.9%.

3.4.3.1.4 Hydrometallurgy of Oxides

About 10-15% of U.S. copper production comes from oxide sources. The hydrometallurgical treatment of such ores with dilute sulfuric acid to dissolve the contained copper is an old established technology. Since surplus sulfuric acid is available near the mines as a result of pollution control measures at smelters, acid leaching of mine waste dumps and mill tailings is widely practiced, as well as leaching of oxide ores mined specifically for this purpose. Since many of these materials contain limestone, such a leaching process indirectly disposes the acid by neutralization.

Once in solution, copper is recovered either by precipitating on iron scrap or via LIX (liquid ion exchange) and electrowinning. Precipitated copper or cement is usually shipped to a smelter for processing.

3.4.3.2 Secondary Copper Industry

3.4.3.2.1 Raw Materials

The basic raw material of the secondary copper industry is copper and copper-based alloy scrap. About two-thirds of the amount of secondary copper recovered is in the form of either brass or bronze, while one-third is in the form of unalloyed copper.

Copper sold to manufacturers is returned to the producers either as new scrap or old scrap. New scrap is returned directly from the manufacturers or via collectors and scrap brokers. Old scrap is returned from consumers of copper. Purchased scrap may move from one location to another within the same company, or from one company to another.

3.4.3.2.2 Sorting Scrap

Sorting scrap according to the classification shown in Table 3.4-6 is one of the most important steps in raw material preparation for the ultimate recovery of secondary copper. Small scrap yards usually segregate scrap to a few basic types, but larger yards find it practicable to segregate their scrap completely, according to all of the common grade specifications. Several methods have been developed for determining the approximate compositions of the thousands of items that pass through the scrapyards. The complexity of the tests ranges from simple recognition of known compositions to chemical analyses. The simplest method of segregating scrap is by recognition of its source or previous use, for example, copper wire, radiator fins, brass fittings, etc.

3.4.3.2.3 Scrap Preparation

Before the scrap metal is blended in a furnace to produce the desired ingots, the raw material must be sampled. Removal of some of the non-metallic contaminants or, in some instances, preprocessing the raw material to permit more efficient and economical utilization of the scrap may be desirable. These processes may be either mechanical, pyrometallurgical, or hydrometallurgical.

Many types of scrap are prepared for smelting or melting by mechanical methods. Insulation and lead sheathing are removed from electrical conductors by special stripping machines. Wire, thin-plate, and wire-screen scraps are usually compressed into briquettes, bales, or bundles. Large, solid items are reduced in size by pneumatic cutters, electric shearing machines, or manual sledging. Brittle springy turnings, or borings, and long chips are crushed in hammer mills or ball mills. Slags, drosses, skimmings, foundry ashes, spills, and sweepings are ground to liberate prills or other metallics from the gangue so that they can be recovered by gravity concentration or other physical means. Small-size materials, such as drillings, clippings, and crushed turnings, are often run over a magnetic separator to remove tramp iron.

Many types of scrap must be given a preliminary furnace treatment before actual melting and refining operations begin. Oil and other organic impurities and moisture are removed by heating in muffle furnaces or kilns. Scrap, such as journal bearings, lead-sheathed cable, and radiators, can be sweated to remove low melting point components, such as babbitt, lead, and solder as valuable byproducts which would otherwise contaminate a melt. Sweating is performed in a conventional sloping-hearth, gas-fired furnace or in a rotary kiln. The process can be a continuous or batch operation.

TABLE 3.4-6

TYPES OF COPPER-BEARING SCRAP

1 No. 1 Copper Wire
2 No. 2 Copper Wire
3 No. 1 Heavy Copper
4 Mixed Heavy Copper
5 Light Copper
6 Composition or Red Brass
7 Red Brass Composition Turnings
8 Genuine Babbitt-Lined Brass Bushings
9 High-Grade, Low Lead Bronze Solids
10 Bronze Papermill Wire Cloth
11 High-Lead Bronze Solids and Borings
12 Machinery or Hard Red Brass Solids
13 Unlined Standard Red Car Boxes (Clean Journals)
14 Lined Standard Red Car Boxes (Lined Journal)
15 Cocks and Faucets
16 Mixed Brass Screens
17 Yellow Brass Scrap
18 Yellow Brass Castings
19 Old Rolled Brass
20 New Brass Clippings
21 Brass Shell Cases without Primers
22 Brass Shell Cases with Primers
23 Small Brass Arms and Rifle Shells, Clean Fires
24 Small Brass Arms and Rifle Shells, Clean Muffled (Popped)
25 Yellow Brass Primer
26 Brass Pipe
27 Yellow Brass Rod Turnings
28 Yellow Brass Rod Ends
29 Yellow Brass Turnings
30 Mixed Unsweated Auto Radiators
31 Admiralty Brass Condenser Tubes
32 Aluminum Brass Condenser Tubes
33 Muntz Metal Tubes
34 Plated Rolled Brass
35 Manganese Bronze Solids
36 New Cupro-Nickel Clippings and Solids
37 Old Cupro-Nickel Solids
38 Soldered Cupro-Nickel Solids
39 Cupro-Nickel Turnings and Borings
40 Miscellaneous Nickel Copper and Nickel-Copper-Iron Scrap
41 New Monel Clippings and Solids
42 Monel Rods and Forgings
43 Old Monel Sheet and Solids
44 Soldered Monel Sheet and Solids
45 Soldered Monel Wire, Screen and Cloth
46 New Monel Wire, Screen and Cloth
47 Monel Castings
48 Monel Turnings and Borings
49 Mixed Nickel Silver Clippings
50 New Nickel Silver Clippings and Solids
51 New Segregated Nickel Silver Clippings
52 Old Nickel Silver
53 Nickel Silver Castings
54 Nickel Silver Turnings

The blast furnace is used extensively in secondary smelters for smelting low-grade copper and brass scraps, refinery slags, drosses, and skimmings to produce black copper (80-90% Cu). The conventional secondary copper blast furnace is a top-charged, bottom-tapped shaft furnace heated by coke burning in a blast of air introduced through tuyeres placed symmetrically around the bottom of the shaft.

The black copper (80-90% Cu) produced in the blast furnace is converted to blister copper by blowing air into the molten charge. In contrast to the converting operation in a primary copper smelter where two blowing stages are needed, only the second stage, or "blister" blow, is required in secondary copper converting.

Copper-rich metallics are also separated by gravity. This technique involves grinding, screening, and gravity separation in a water medium. Although the total loss of metal is often greater than in the blast furnace, gravity separation is well adapted to fines that might be blown out of the furnace.

3.4.3.2.4 Melting and Alloying Intermediate Grade Copper Scrap

About two-thirds of the secondary copper production in the United States is used in ingot plants and foundries to make brass and bronze alloys by simple melting and refining methods. The amount of refining is usually small if the scrap is well sorted so that impurities or excess alloy constituents can be diluted to composition specifications with high-grade scrap or virgin metals. These conditions are not easily maintained, however, because certain impurities, such as aluminum and silicon, have exceedingly low permissible limits in the product. Both aluminum and silicon are difficult to remove by refining. Impurities such as iron, sulfur, cadmium, bismuth, zinc, phosphorus, and manganese are not as difficult to remove by common refining techniques.

Melting, refining, and alloying procedures are essentially the same for reverberatory, rotary or crucible furnaces. Capacities of stationary reverberatory furnaces used in secondary smelters range from a few thousand pounds to 100 short tons or more. The side- or end-charged arched-roof tapping furnace is the type most extensively used. Reverberatory furnace slags usually contain metal values that can be recovered in the blast furnace. Slags produced by small secondary plants are frequently sold to primary smelters on the basis of copper content only. Some plants grind the slag and recover metallic constituents in milling operations before the slag is sold.

The rotary furnace is designed to provide efficient melting and refining and convenient pouring of fairly large melts. Furnace capacity ranges from several short tons to 50 or more short tons of nonferrrous metals. It may have a particular advantage over stationary furnaces for melting loose or baled light scrap, because the rotary mixing action promotes better heat transfer to the melt and causes a more rapid coalescence of melted globules.

A fairly large tonnage of secondary copper is produced in crucible furnaces, heated by gas, oil, coke or electricity. The once popular, coke-fired pit furnace is seldom used today. Crucible furnaces are used in the secondary-copper industry for melting clean, well-segregated scrap — mostly in foundries. Very little fire-refining is performed in crucibles.

The stationary reverberatory is the most practicable furnace for making very large tonnages of standard alloys from scrap. The rotary furnace is more flexible than the reverberatory, but the capacity is limited to moderate tonnages. Tilting and stationary crucible furnaces, either gas or electric, are used to advantage for making small melts of special alloys. Electric induction furnaces are increasing in popularity at ingot plants and foundries where special high-grade alloys are made. The advantages of electric furnaces include higher melting speed and precise temperature control, which help to defray the relatively higher cost of electrical equipment.

Melting furnaces are always associated with other equipment designed to receive the melt. Melts are usually tapped from furnaces into feeder ladles, which transport the metal to a mold line for making conventional ingots. The mold line is a series of ingot molds placed on a rack that may be stationary or movable. If stationary, the molds are filled with metal poured from a portable ladle.

An automatic mold line is an endless mold-conveying system in line with, or on the periphery of, a large circular rack known as a casting wheel.

Melting and refining furnaces are operated frequently in conjunction with a plant or mill to produce items such as rods, tubes, sheet, and similar products. In this case, the furnaces are tapped into special billet molds to make shapes for subsequent milling operations.

3.4.3.2.5 Refining High-Grade Copper Scrap

The refining furnace is either a stationary reverberatory or cylindrical tilting type with a capacity of 20 to 300 short tons. Full fire refining is often required to produce billets, slabs, cakes and bars for manufacturing plates, sheets, rods, and so forth. The fire-refining procedure is identical to that used in the primary industry. The electrolytic copper refining is also similar to that in the primary industry, described earlier.

3.4.4 Materials Flow

3.4.4.1 General

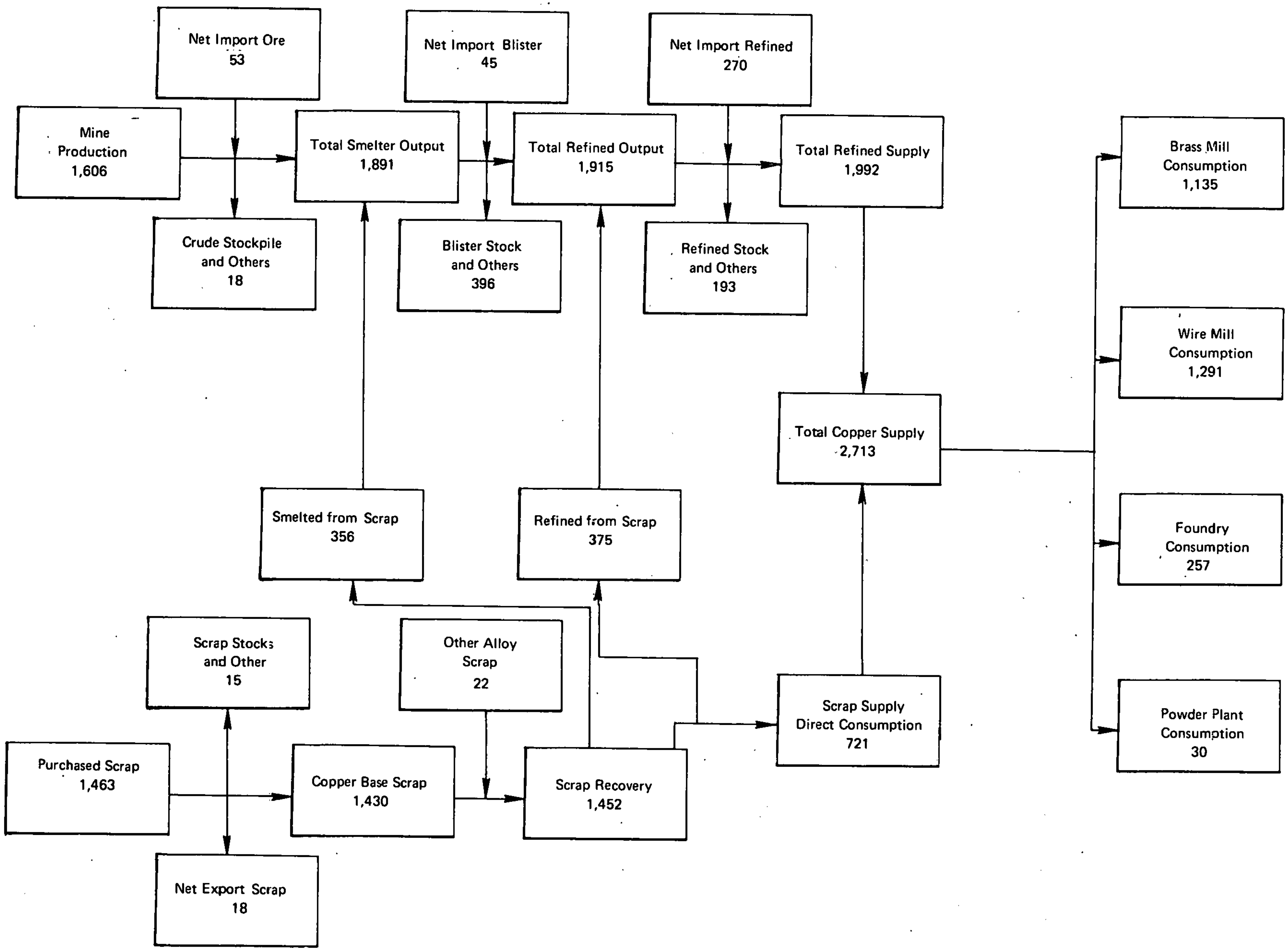
The flow of copper in the copper industry in the United States for 1976 is shown in simplified form in Figure 3.4-2. The two major sources of copper supply are domestic and imported ore and copper-based scrap.

The following observations of the flow of copper in 1976 can be made:

- Refined copper accounted for 73.4% of the total copper supply of the United States; and
- Semifabricators and end users utilized 50% of the recovered scrap directly, without further refining; the remainder was smelted and refined.

3.4.4.2 Classification of Recoverable Materials

Both the secondary copper industry and the American Society for Testing Materials have made a continuing effort over the past 35 years or so to reduce the number of varieties of copper-based alloys. At one time, more than 500 commercial copper-based alloys were made in the United States. Sorting and grading mixed scrap with no uniform standards was a major problem in the industry. Of the many hundreds of copper-based alloys that become available for reuse through scrap recovery channels, 54 primary types are now included in the standards published by the National Association of Recycling Industries (NARI, previously NASMI). These are listed in Table 3.4-6.



Sources: U.S.B.M. Minerals Industry Surveys, Copper Industry in Dec. 1977.
U.S.B.M. Minerals Industry Surveys, Copper in 1977.
Arthur D. Little, Inc., estimates.

FIGURE 3.4–2 MATERIALS FLOW IN THE COPPER INDUSTRY, U.S. 1976
(Thousands of Short Tons of Copper)

Briefly, this copper-bearing scrap can be summarized as follows:

No. 1 copper: Scrap from unalloyed copper, clean and free of contaminants. It must not be less than 1/16 inch thick or below No. 16 B&S wire gauge. Included in this category are wire and cable (excluding burnt wire), copper clippings, punchings, busbars, commutator segments, and copper tubing.

No. 2 copper: Miscellaneous unalloyed copper scrap having a nominal 96% copper content (minimum 94%).

Light copper: Miscellaneous unalloyed copper scrap having a nominal 92% copper content (minimum 88%), such as sheet copper, gutters, downspouts, kettles, boilers, and similar scrap.

Refinery brass: Scrap containing a minimum of 61.3% copper and a maximum of 5% iron. Included are brass and bronze solids, turnings, and alloyed and contaminated copper scrap.

Copper-bearing scrap: Miscellaneous copper-containing skimmings, grindings, ashes, iron-containing brass, and copper residues and slags.

Brass and Bronze scrap: This category is usually kept segregated by the type of alloy in a large number of categories, such as red brass; high-grade, low-lead bronze solids; high-lead bronze solids and borings; yellow brass scrap; yellow brass castings; new brass clippings; mixed nickel silver clippings; manganese bronze solids; and the like.

3.4.4.3 Recycling Profile

The main consumers of copper and copper-based alloy scrap are smelter/refineries, ingot manufacturers, and brass and bronze mills. Refiners use both low-grade and high-grade scrap as raw material. Higher grades of scrap are introduced in the later stages of processing. For example, No. 2 copper is generally introduced at the anode melting step before electrorefining and No. 1 copper at the cathode melting step. The cathodes are melted and cast into refinery shapes. Brass and bronze ingot-makers make casting alloy ingots mainly from brass and bronze scrap supplemented by other materials such as No. 1 and No. 2 copper scrap, small amounts of refined copper, and alloying additives such as tin and zinc. Brass mills make wrought alloys that are then fabricated to finished mill products, such as sheets, tubes, rods, and pipe. Brass mills use purchased brass and bronze scrap and No. 1 and No. 2 copper scrap, along with significant quantities of home-generated scrap, refined copper, and such alloying additives as slab zinc, lead, tin, and nickel, as shown in Table 3.4-7.

In 1976 primary and secondary copper producers consumed 767,000 short tons of scrap, as shown in Table 3.4-7. Of this, No. 1 copper made up about 19%, No. 2 mixed heavy and light accounted for 24%; low-grade scrap and residues accounted for 33%; and brass and bronze scrap, including auto radiators, made up the remaining 24%. Old scrap made up 59% of the total.

In order to estimate the total amount of copper-based scrap available for recycling in 1976, a 1969 Battelle estimate[1] has been updated. The estimate of copper scrap recycled in 1969 was

TABLE 3.4-7

PURCHASED COPPER-BASE SCRAP CONSUMED - 1976*

Class of Consumer and Scrap Item	Consumption (000 Short Tons)	Old Scrap %	New Scrap %
Secondary Copper Smelters			
No. 1 wire and heavy	25.0	87.5	12.5
No. 2 wire, mixed heavy and light	58.0	72.3	27.7
Composition or soft red brass	58.0	77.1	22.9
Railroad-car boxes	2.0	100.0	0
Yellow brass	46.0	88.9	11.1
Cartridge cases	-	100.0	0
Auto radiators (unsweated)	49.0	100.0	0
Bronze	20.0	82.9	17.1
Nickel, silver and cupronickel	3.0	89.7	10.3
Low brass	2.0	33.2	66.8
Aluminum bronze	-	23.8	76.2
Low-grade scrap and residues	77.0	16.9	83.1
TOTAL	340.0	68.5	31.5
Primary Producers			
No. 1 wire and heavy	118.0	48.0	52.0
No. 2 wire, mixed heavy and light	129.0	27.5	72.5
Refinery brass	4.0	50.4	49.6
Low-grade scrap and residues	176.0	72.9	27.1
TOTAL	427.0	52.0	48.0
Brass Mills			
No. 1 wire and heavy	156.0	17.7	82.3
No. 2 wire, mixed heavy and light	73.0	2.6	97.4
Yellow brass	272.0	0	100.0
Cartridge cases and brass	78.0	0	100.0
Bronze	4.0	0	100.0
Nickel, silver and cupronickel	29.0	0	100.0
Low brass	46.0	0	100.0
Aluminum bronze	-	0	100.0
TOTAL	658.0	4.5	96.5
TOTAL ALL PRODUCERS	1425.0	34.0	66.0

* Total figures for three classes of consumer and figures for breakdown by type of scrap for brass mills based on 1976 Bureau of Mines data. Figures for breakdown by type of scrap for secondary copper smelters and primary producers are thur D. Little estimates based on 1974 data in U.S. Bureau of Mines Minerals arbook chapter dealing with copper.

based on estimates of the life cycles for the various products providing copper scrap. Another assumption in the Battelle study is that new, or industrial scrap is 100% recycled. Our estimate of the amount of scrap available for recycling in 1976 is given in Table 3.4-8, which shows that approximately half of the scrap available was recycled in 1976, and that the major source of copper available but not recycled was low-grade scrap and residues. This study has used the Battelle estimates with minor adjustments based on the positive trends toward recycling in the 1970's. Consequently, we have not taken into consideration the time lag in the Battelle study, i.e., we have not estimated the consumption of copper at the beginning of the various life cycles to derive the actual supply in 1976. The estimates of the amounts of various forms of copper scrap available for recycling should therefore only be taken as order-of-magnitude figures since any copper that remains in productive use beyond the average life cycle will be available in the future and not necessarily lost. Another fact that should be observed is that during a year with low scrap consumption, e.g., 1976, certain types of copper scrap may be stockpiled.

Using the life cycle method of estimating available supply results in inaccurate figures for certain forms of scrap during such low demand periods. This would be particularly true for No. 1 and No. 2 wire which are almost 100% recycled.

3.4.5 Future Trends

3.4.5.1 Technological Trends

The only significant technological trend foreseen for the near future is the change-over in the primary industry from reverberatory smelting to newer smelting processes such as flash smelting, electric smelting, the Noranda, Outokumpu and Mitsubishi processes. This change-over is necessitated by pressure to meet ambient air quality standards. Given the present state of the copper industry, and the fact that there are no firm plans for any new smelter construction in the United States, we do not expect any new smelters to come on-stream until 1985. Furthermore, since the industry seems to be favoring flash smelting rather than electric smelting, technological trends should have no impact on the 1987 recycling target.

3.4.5.2 Industry Structure Trends

Some of the larger oil companies are now investing in the primary copper industry. We do not believe, however, that this change in ownership will have any significant impact on either total industry capacity or the relation between primary and secondary segments of the industry. Consequently, we do not believe that the industry structure will have any impact on the 1987 recycling target.

3.4.5.3 Industry Growth

The output of primary refined copper is expected to be 2,010,400 short tons by 1987. This estimate is based on a 1974 production level of 1,654,658 short tons and an Arthur D. Little, Inc. projected growth rate of 21.5% or 1.5% annually.

TABLE 3.4-8

ESTIMATED COPPER SCRAP AVAILABLE FOR RECYCLING - 1976

Scrap Item	Recycled* Copper Scrap (OCO Short Tons)	Recycled Copper** Scrap as % of Copper Scrap Available for Recycling	Copper Scrap Available for Recycling (000 Short Tons)	Not Recycled Copper Scrap as % of Copper Scrap Available for Recycling	Not Recycled Copper Scrap (000 Short Tons)
No. 1 Wire and Heavy	299	86	348	14	49
No. 2 Wire Heavy and Light	260	87	299	13	39
Composition, Red Brass	58	36	161	64	103
Railroad Car Boxes	2	100	2	-	-
Yellow Brass	318	77	413	23	95
Cartridge Cases	78	63	124	37	46
Auto Radiators	49	92	53	8	4
Bronze	24	38	63	62	-39
Nickel, Silver, Coppernickel	32	81	40	19	8
Low Brass	48	95	51	5	3
Refinery Brass	4	38	11	62	7
Low Grade Scrap, Residues	253	19	1332	81	1079
TOTAL	1425	49	2897	51	1472

* Refer to Table 3.4-7.

** Estimation based on Battelle study "A Study to Identify Opportunities for Increased Solid Waste Utilization", 1972.

3.5 ZINC

3.5.1 Industry Definition

The zinc industry under the SIC 33 code system includes the following:

- SIC 3333 — Primary Smelting and Refining of Zinc — establishments primarily engaged in smelting zinc from the ore and in refining zinc by any process. Establishments primarily engaged in rolling, drawing, or extruding zinc are classified in industry 3356.
- SIC 33414 — Secondary Smelting and Refining of Zinc — establishments primarily engaged in smelting zinc from scrap materials by any process.
- SIC 33691 — Zinc Foundries - establishments primarily engaged in manufacturing castings and die castings.

Of the above SIC classifications, the primary (3333) and secondary (33414) smelters are producers of zinc metal. The zinc foundries (33691) do not produce any metal, but cast the metal into more useful forms. Zinc metal enters the manufacturing field in four major areas: galvanizing, brass and bronze products, castings, and rolled zinc. In addition to metallic applications, significant quantities of zinc are consumed as pigments or other chemicals.

3.5.2 Industry Structure

About 85% of the zinc smelting capacity in the United States is concentrated in six large plants. Table 3.5-1 details the company, location, production method, rated capacity, and age for all smelters in operation in 1976. All of the plants are fairly large, with the smallest plant accounting for almost 10% of the total capacity and the largest for about 29%.

The owners of the zinc smelters are large corporations with diverse interests in other aspects of zinc production and outside the zinc industry. Five of the six owned mines that produced 75% of the domestic zinc concentrates, and refineries that produced 90% of the domestic primary slab zinc. Examples of corporations that have interests outside of the zinc industry include:

- ASARCO and AMAX Inc., diversified corporations that mine and smelt many metals.
- Gulf Resources and Chemical Corporation, the owner of Bunker Hill Company.
- Engelhard Minerals and Chemical Corporation, the owner of National Zinc Company.
- Gulf and Western Industries, the owner of New Jersey Zinc Company.
- St. Joe Minerals Corporation, the owner of St. Joe Zinc Company.

The total primary zinc capacity in the United States is 653,000 short tons of zinc slab per year.

The secondary zinc smelting industry, with about 15% of U.S. capacity is composed of a comparatively large number of smaller operations. Table 3.5-2 shows a sample of secondary smelters in the United States. These companies buy scrap from 3000 independent dealers and processors who collect, sort, store, and ship scrap to the smelters.

TABLE 3.5-1

PRIMARY ZINC SMELTERS - 1976

Name of Company	Location	Method	Rated Capacity	Year First Operated
Asarco, Inc.	Corpus Christi, TX	Electrolytic	100,000 tons	1941
Amax Zinc Co.	Sauget, IL	Electrolytic	84,000 tons	1941 rebuilt 1973
The Bunker Hill Co.	Kellogg, ID	Electrolytic	104,000 tons	1928
National Zinc Co.	Bartlesville, OK	Electrolytic	57,000 tons	1977
New Jersey Zinc Co.	Palmerton, PA	Pyrometallurgical	118,000 tons	1899
St. Joe Zinc Co.	Monaca, PA	Pyrometallurgical	190,000 tons	1938
Total Capacity			653,000 tons	

Source: Statement on Behalf of Canadian Slab Zinc Suppliers in United States International Trade Commission Investigation TA-201-31; Unalloyed Unwrought Zinc, March 21, 1978.

TABLE 3.5-2

SECONDARY ZINC DISTILLERS

Alger Pattern Work, Inc.	Indianapolis, IN
Arco Die Cast and Metal, Inc.	Detroit, MI
Asarco	
Federated Metals Division:	
Sand Springs Plant	Sand Springs, OK
Trenton Plant	Trenton, NJ
Whiting Plant	Whiting, IN
Belmont Smelting and Refining Works	Brooklyn, NY
W. J. Bullock, Inc.	Fairfield, AL
Gulf Reduction Corporation	Houston, TX
T. L. Diamond Company	
Meadowbrook Metal & Chemical Division	Spelter, WV
Hugo Neu-Proler	Los Angeles, CA
Illinois Smelting and Refining Company	Chicago, IL
New England Smelting Works Company	West Springfield, MA
Pacific Smelting Company	Torrance, CA
Proler Company	Houston, TX
Prolerizer-Schiabo-Neu Corporation	Bayonee, NJ
S. G. Metals Industries	Kansas City, KS

Source: Mineral Yearbook 1975, Volume I, Metals, Minerals and Fuels, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1977, p. 1486.

3.5.3 Process Technology

Reduction of the ores and concentrates to zinc in primary smelting and refining is accomplished by electrolytic deposition from a sulfate solution or by distillation in retorts. For either method the zinc concentrate is first roasted to eliminate most of the sulfur and produce impure zinc oxide.

At electrolytic zinc plants, roasted zinc concentrate is leached with dilute sulfuric acid to form a zinc sulfate solution. This solution is then purified and piped to electrolytic cells, where the zinc is deposited on aluminum cathodes. The electrolysis of the solution produces sulfuric acid, which is used again in leaching. Byproducts are cadmium recovered from the leach liquor and lead, gold, and silver recovered from residues. The residues are usually shipped to a lead smelter, where the lead, gold, and silver content is recovered in lead bullion.

The primary zinc industry uses two types of distillation retorts, both of which are of a vertical continuous feed construction. One type of vertical retort is heated externally by fuel while the other uses electrical resistance heating through the retort charge. Both distillation retorts use coke to reduce the zinc ore to metal. The zinc metal vaporizes and is collected as liquid zinc metal in condensers. The liquid zinc can be further purified for special applications in a distillation column or cast directly into slab zinc.

The average energy consumption in the primary zinc industry from mines to slab zinc is 65 million Btu per short ton of zinc, with the lowest energy consumption in the electrolytic reduction cells (60 million Btu per short ton)[1] and the highest for the electric heated vertical retort (72 million Btu per short ton).[1]

The secondary zinc industry uses three major types of equipment: retort distillation, muffle furnace distillation, and pot melting. Both the retort distillation and muffle furnace are batch processes where the zinc scrap is heated externally by fuel, causing the zinc metal in the scrap to vaporize and be collected in a condenser. One major process difference in the secondary retorts is that there is very little reduction of zinc oxides to zinc metal. Since little energy is supplied for reducing oxides to metal, the energy per short ton of zinc is much lower in the secondary industry with distillation retorts requiring 24 million Btu per short ton of zinc and muffle furnaces about 20 million Btu per short ton.[2] This includes all energy required in scrap collection, preparation, and transportation, as well as the smelting itself. Pot melting of clean die-cast scrap for realloying is a very simple process that melts zinc scrap without vaporization and thus has a very low energy consumption of about 2.5 million Btu per short ton of zinc.[2] Significant savings result for each short ton of zinc recovered from scrap metal zinc rather than from ore concentrates. However, some scrap —flue dusts and galvanizer ashes, which are oxidized — must be processed in primary smelters.

3.5.4 Materials Flow

3.5.4.1 General

The different segments of the U.S. zinc industry use differing mixes of raw materials and produce differing mixes of zinc products.

Primary electrolytic refineries start with ore concentrates, both domestic and imported, as their primary raw material. They process very little scrap material. The extremely pure grade of slab zinc produced at electrolytic refineries is used where metal impurities could be detrimental, such as in zinc die castings. Primary distillation retorts also process ore concentrates, but supplement their feed with a significant amount of recoverable materials, especially new scrap from galvanizing operations. The basic type of slab zinc from distillation retorts, prime western grade, is used primarily in galvanizing steel products. The distillation retorts also produce zinc dust and zinc oxide for chemical use.

The secondary distillers and pigment plants use a wide variety of scrap and byproduct as raw material. They produce a small amount of slab zinc, but they are significant sources of zinc oxide and zinc powder.

3.5.4.2 Classification of Recyclable Materials

Zinc scrap is classified as prompt industrial scrap if it comes from a fabricating or semi-fabricating operation and old scrap if it comes from discarded products. The prompt industrial scrap and old scrap are further subdivided into the following six categories:

Prompt Industrial Scrap:

Galvanizers (primarily drosses, zinc skimmings, sal skimmings and ashes) is the largest scrap category.

New Die Cast includes defective new castings and skimmings produced from castings.

Chemical Residues and Flue Dusts is a miscellaneous category of recoverable materials which includes all zinc-bearing residues from chemical manufacture and flue dusts from all ferrous and nonferrous smelters. The flue dust should contain about 30% zinc by weight.

Home includes scrap recovered and reprocessed by producers of zinc products

Old Scrap:

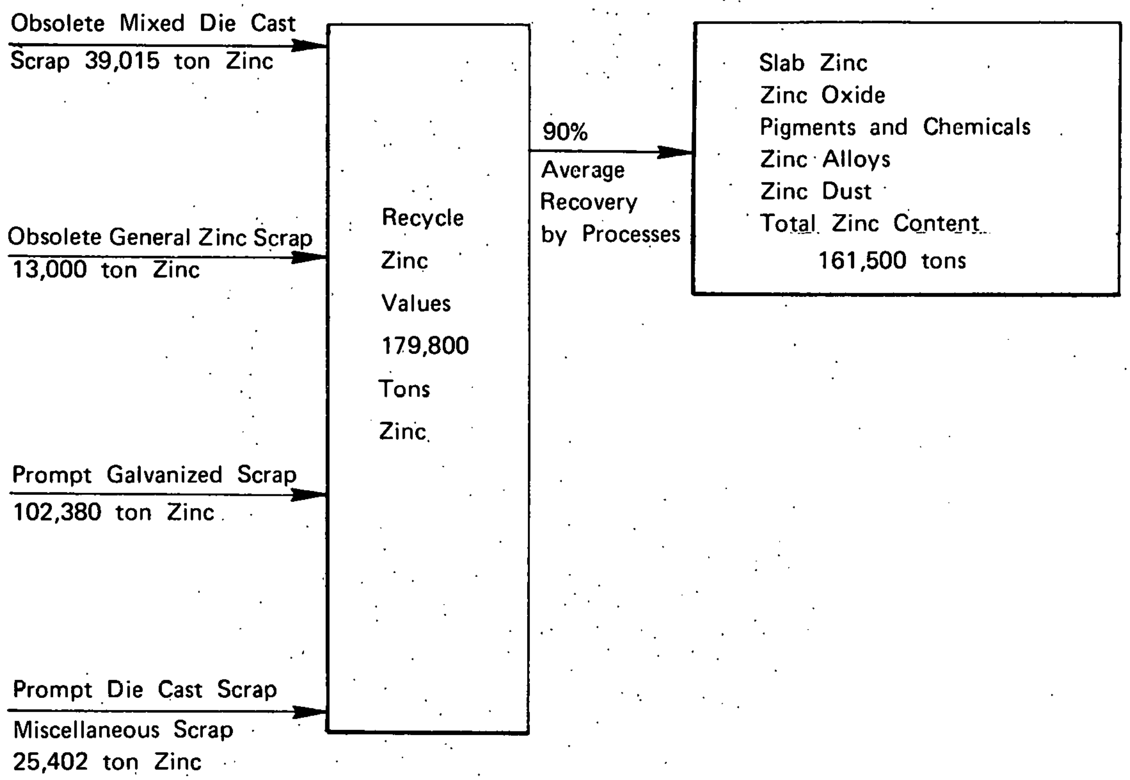
Mixed Die Cast consists of such products as auto shredders' scrap, old auto parts, and old appliance parts. It forms a substantial portion of the total old zinc scrap supply.

General Zinc includes such items as old zinc and engravers' plates. This scrap category is a relatively minor element in the secondary zinc industry.

3.5.4.3 Recycling Profile

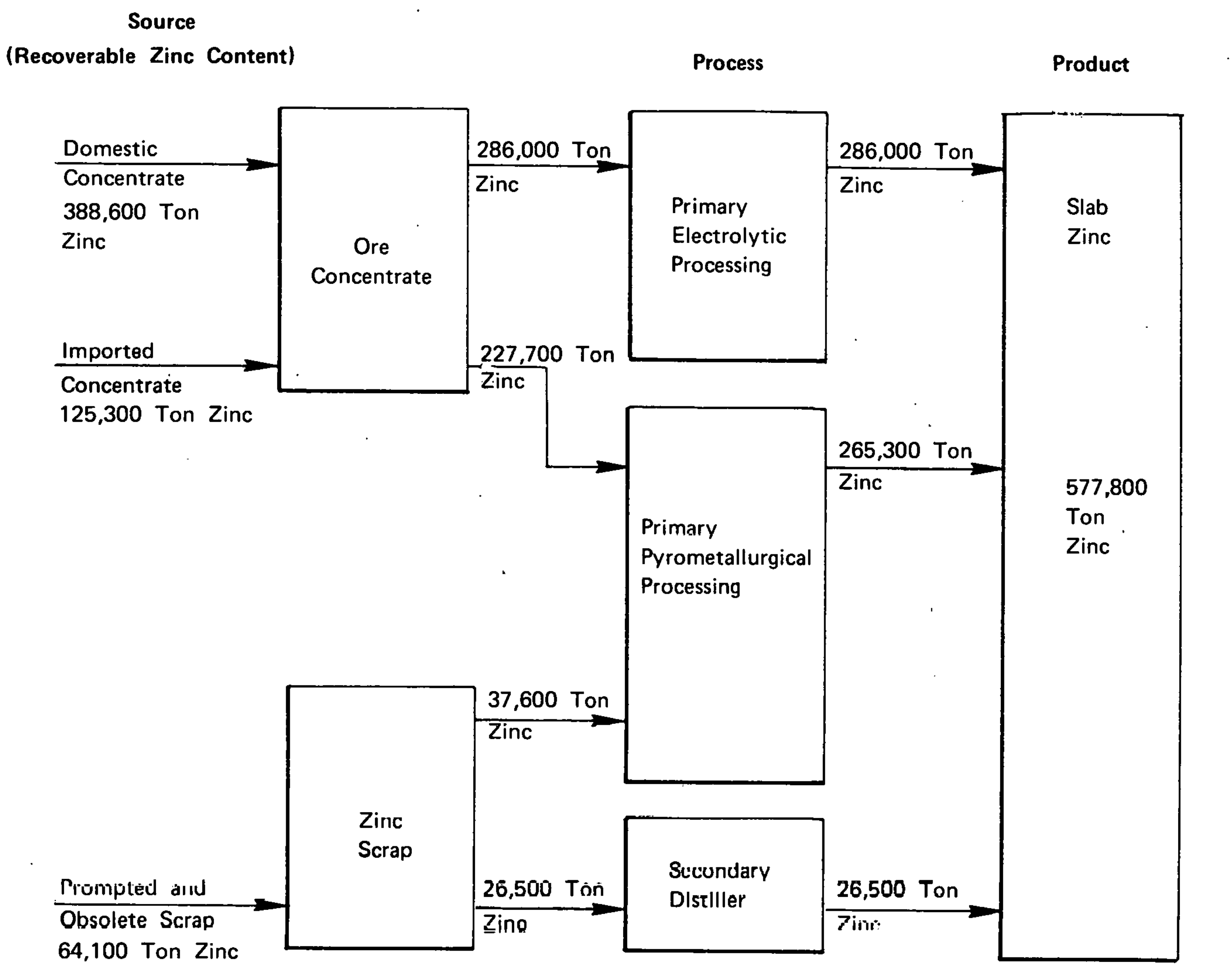
Both prompt industrial scrap and old zinc scrap are recovered to produce a series of products including slab zinc, zinc oxide, pigments, chemicals, zinc based alloys, and zinc dust. Zinc metal contained in scrap was recovered with an average yield of 90%, as shown in Figure 3.5-1. Most of the scrap, 128,000 short tons, was prompt industrial scrap from industries that consume zinc like galvanized scrap, and ashes and die-cast scrap. About 58,000 short tons of zinc were recovered from old scrap; a major source was obsolete die-cast scrap from automobiles that have been shredded.

The five figures starting with Figure 3.5-2 outline the material flows for both the primary and secondary segments of the zinc smelting industry.



Source: *Nonferrous Metal Data 1976,* American Bureau of Metal Statistics Inc. New York, N.Y. 1977, p. 66 and *Energy Use Patterns for Metal Recycling* U.S. Department of the Interior, Bureau of Mines, Contract Number JO–166–143, January 1978

FIGURE 3.5–1 SCRAP COLLECTION BY SOURCE–1976



Source: *Nonferrous Metal Data 1976,* American Bureau of Metal Statistics, Inc. New York, N.Y. 1977, p. 66.

FIGURE 3.5–2 SLAB ZINC FLOW DIAGRAM 1976

In summarizing the data in the figures, the following observations can be made:

Figure 3.5-2 shows that 10% of slab zinc comes from zinc scrap.

Figure 3.5-3 shows that 11% of zinc oxides come from zinc scrap.

Figure 3.5-4 shows that 54% of zinc pigments and chemicals come from scrap.

Figure 3.5-5 shows that 2% of zinc alloys come from scrap.

Figure 3.5-6 shows that 75% of zinc dust comes from zinc scrap.

The recovered materials replace both ore concentrates and slab zinc in the various product applications.

3.5.5 Future Trends

The United States has been an importer of either zinc ore concentrates or slab zinc since 1941. Table 3.5-3 shows U.S. mine production compared with zinc demand in the United States from 1957 to 1977, and estimates for 1985.[3] The United States will have had to import about 0.4-1.0 million short tons per year of zinc values during this 28-year period. Any increase in recycling of domestic scrap and wastes may reduce the import requirements. Present trends indicate demand will increase about 2% per year from 1977 to 1985 and mine production will increase by 2-5% per year over the same period.

The U.S. primary smelting capacity dropped from 1.2 million short tons per year in 1968 to 0.6 million short tons per year in 1976. In 1978 a new 90,000 ton-per-year electrolytic plant came on stream. All of the obsolete horizontal retort primary plants have closed, as have most of the very old smelters. Most of the U.S. present and future shortage in domestic zinc production will be made up by importing slab zinc. Slab zinc imports amounted to 695,000 short tons in 1976 and imported zinc concentrates contained another 125,000 short tons of zinc.

Most zinc markets will face increasing competition from aluminum and plastics. The competition from substitutes will be most severely felt in die cast materials.

3.6 LEAD

3.6.1 Industry Definition

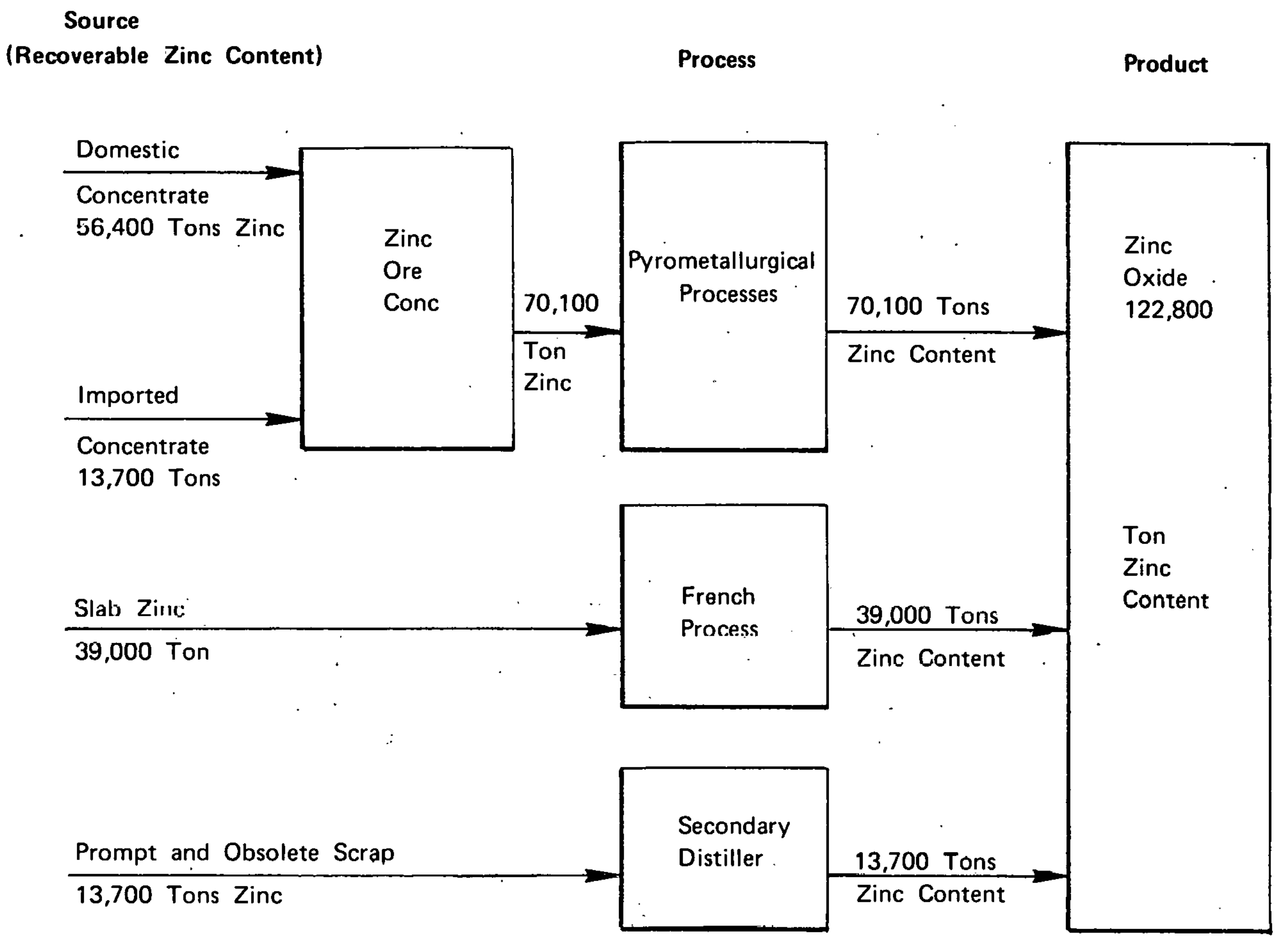
The lead industry as defined in this study includes plants in the following SIC categories:

- SIC 3332 — Primary smelting and refining of lead — establishments primarily engaged in smelting lead from the ore and in refining lead by any process.

- SIC 3341 — Secondary smelting and refining of nonferrous metals — establishments primarily engaged in recovering lead and lead alloys from new and used scrap and dross.

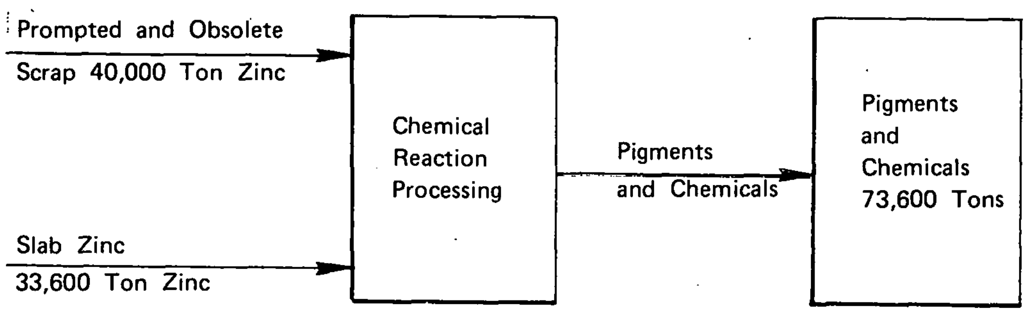
- SIC 3356 — Rolling and drawing of nonferrous metals (N.E.C.) — establishments primarily engaged in producing lead and lead base alloy mill shapes.

- SIC 3369 — Nonferrous Foundries (N.E.C.) — establishments primarily engaged in producing lead die castings.



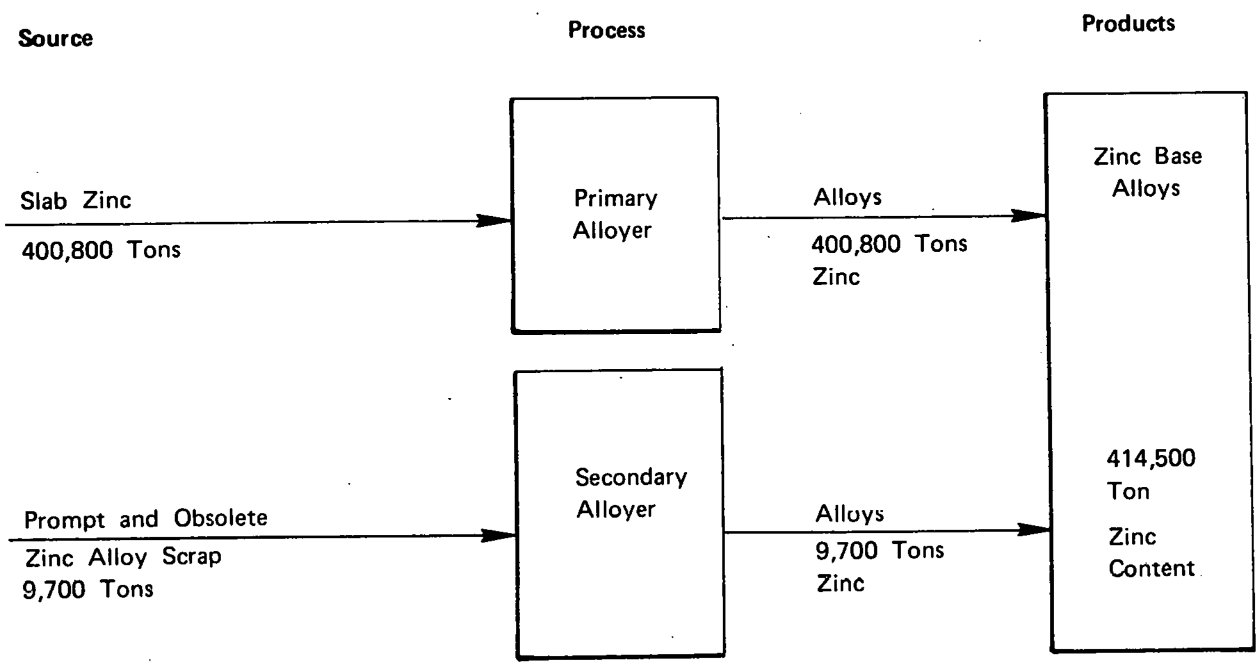
Source: *Nonferrous Metal Data 1976,* American Bureau of Metal Statistics, New York, N.Y. 1977, p. 66.

FIGURE 3.5–3 ZINC OXIDE FLOW DIAGRAM



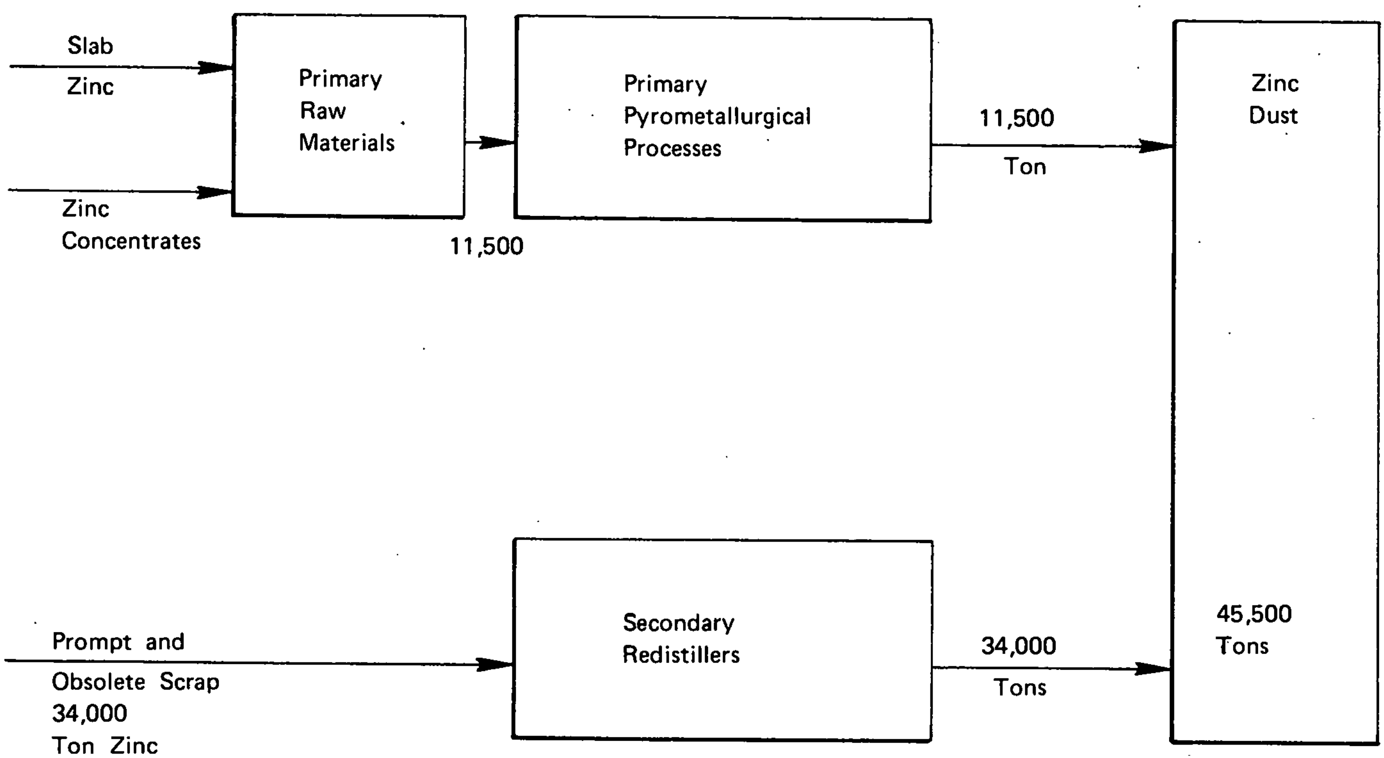
Source: *Nonferrous Metal Data 1976,* American Bureau of Metal Statistics Inc. New York, N.Y. 1977, p 66.

FIGURE 3.5–4 ZINC CHEMICALS FLOW DIAGRAM 1976



Source: *Nonferrous Metal Data 1976,* American Bureau of Metal Statistics Inc. New York, N.Y. 1977, p. 66.

FIGURE 3.5–5 ZINC BASE ALLOYS FLOW DIAGRAM



Source: *Nonferrous Metal Data 1976,* American Bureau of Metal Statistics. New York, N.Y. 1977, p.66.

FIGURE 3.5–6 ZINC DUST FLOW DIAGRAM 1976

TABLE 3.5-3

COMPARISON OF DOMESTIC ZINC PRODUCTION AND DEMAND

1957-1977 and 1985

(Thousands short tons, recoverable zinc)

Year	U.S. Primary Demand	Domestic Mine Production
1957	974	532
1958	948	412
1959	1,053	425
1960	956	435
1961	977	464
1962	1,107	505
1963	1,103	529
1964	1,111	575
1965	1,349	611
1966	1,467	573
1967	1,322	549
1968	1,411	529
1969	1,500	553
1970	1,290	534
1971	1,242	503
1972	1,438	478
1973	1,564	479
1974	1,452	500
1975	1,072	469
1976	1,276	485
1977	1,228	458
1985	1,500	529-600

Source: V. Anthony Cammarota, Zinc Mineral Commodity Profiles, U.S. Department of the Interior, Bureau of Mines, MCP-12, May 1978, p. 24.

Of the plants in the above SIC categories, the primary (3332) and secondary (3341) lead smelters account for most of the value of production and energy consumption. Therefore, only these two SIC categories are considered in this analysis.

3.6.2 Industry Structure

The United States is the largest producer and consumer of refined lead in the world. U.S. mines produce more lead than any other country in the world. U.S. primary production is greater than in any other country, and U.S. secondary production is larger than total production of any other country. In addition, significant quantities of ores, concentrates, base bullion, and pig lead are imported into the United States.

An overview of the domestic lead industry is presented in Figure 3.6-1. Lead is principally consumed in batteries, gasoline, cables, pigments, and ammunition, with batteries accounting for over 50% of total consumption (see Table 3.6-1). The demand for lead is a derived demand; it is demanded for use in the production of other commodities. Since lead usually represents only a small portion of the total cost of the commodity, lead demand is not very sensitive to price in the short run. Secondary lead competes with primary metal in all but a few uses.

The four major types of lead products are: soft lead (pig), antimonial lead, miscellaneous alloys, and lead oxides, pigments and chemicals. Most of the standard grades of soft lead (pig) can be or are produced from scrap. Antimonial lead is a generic name for a number of lead alloys containing antimony and used mainly in battery manufacturing. It is usually produced from battery scrap by secondary smelters. Miscellaneous alloys include babbit, solders, and type metals, which are normally produced to user or standardized specifications or under brand names, usually from both secondary and primary materials. Lead oxides, which are used in battery manufacturing; lead pigments; and lead chemicals, which are used as gasoline antiknock additives, are usually produced from primary soft lead.

3.6.2.1 Primary Producers

Lead is produced by the primary industry from lead-bearing ore, most of which is mined in the United States although some is imported from Australia, Canada, and Peru. About 80% of the domestically mined lead is produced in Missouri; most of the remainder comes from Idaho, Colorado, and Utah. The lead smelters tend to be located near the mines and can be differentiated as either Missouri, or non-Missouri smelters. Missouri lead ores contain zinc as a co-product, byproduct copper, and small amounts of silver and bismuth but few other impurities. Smelters treating Missouri ores have been constructed to handle only low levels of these impurities, and consequently cannot utilize Western ores with their much higher impurity levels. Non-Missouri smelters have much more extensive refining facilities and handle the higher byproduct levels found in the Western ores.

Four companies operating six smelters and five refineries produce primary lead metal in the United States (see Table 3.6-2). They are large, integrated, multi-plant companies producing a variety of non-ferrous metals and other products. They are generally not integrated into fabrication, although there are some specific exceptions.

Bunker Hill operates a 140,000 short ton per year (stpy) lead smelter and a 130,000 stpy refinery in Kellogg, Idaho. Bunker Hill is integrated backward into mining, by itself and in joint

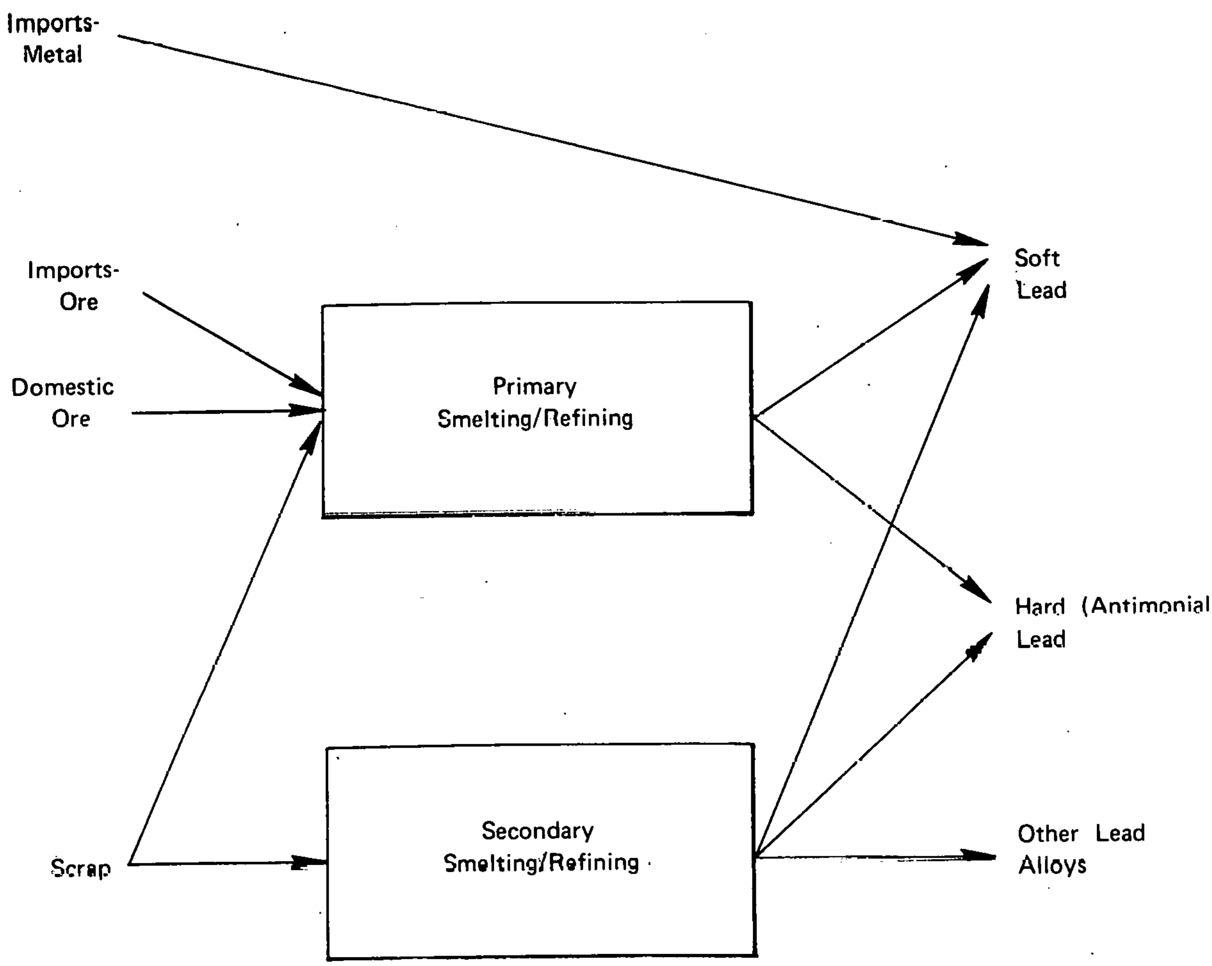


FIGURE 3.6.1 INDUSTRY STRUCTURE – LEAD

TABLE 3.6-1

LEAD CONSUMPTION BY END-USE MARKET - 1976

	SHORT TONS
Gasoline Additives	240,000
Batteries	822,000
Pigments	106,000
Ammunition	73,000
Other	249,000
Total	1,490,000

Source: American Bureau of Metal Statistics, 1977

TABLE 3.6-2

LEAD SMELTERS/REFINERS

Company	Location	Facility	Annual Capacity
Asarco, Inc.	Omaha, Nebraska	Refinery	180,000 ST (a)
Bunker Hill	Kellogg, Idaho	Refinery	130,000 ST (a)
Bunker Hill	Kellogg, Idaho	Smelter	390,000 ST (b)
Asarco, Inc.	East Helena, Montana	Smelter	420,000 ST (b)
Asarco, Inc.	El Paso, Texas	Smelter	420,000 ST (b)
Asarco, Inc.	Glover, Missouri	Smelter/Refinery (c)	110,000 ST (a)
Amax-Homestake	Boss, Missouri	Smelter/Refinery (c)	140,000 ST (a)
St. Joe Lead Co.	Herculaneum, Missouri	Smelter/Refinery (c)	225,000 ST (a)

(a) refined lead

(b) charge capacity

(c) limited to the refining of Missouri concentrates

Source: American Bureau of Metal Statistics, 1976 ventures. In 1976, about 30% of the concentrate used at Bunker Hill was from its own mines. The rest was purchased from other mines in the area and smelted on a custom basis. Bunker Hill is not forward integrated into fabrication.

Asarco, Inc. operates lead smelters at El Paso, Texas, East Helena, Montana, and Glover, Missouri; they have a lead refinery in Omaha, Nebraska, which refines the lead bullion from El Paso and East Helena. Asarco is extensively integrated horizontally with various plants and divisions smelting and refining a large number of metals including lead, zinc, copper, a variety of precious metals, and high-purity metals. Asarco is integrated back to the mine level but acquires most of its concentrate on a custom or toll basis. In 1976, only 6% of the lead produced by Asarco was from its own mines. Asarco also owns Federated Metals Corporation which produces lead and other metals and alloys from secondary materials and also operates some fabrication facilities.

St. Joe Minerals operates a lead smelter in Herculaneum, Missouri, which is almost totally self-sufficient on company production of lead concentrate. St. Joe occasionally does some custom smelting, but is not forward-integrated into fabrication.

The smelter at Buick, Missouri, is a joint venture of Amax, Inc. and Homestake Mining Company. Half of the capacity at Buick is committed on a tolling contract to an outside source of concentrates. The remainder is used to treat concentrate from the Amax-Homestake mine, not all of which can be treated at Buick because of capacity limitations.

3.6.2.2 Secondary Producers

The secondary lead industry produces soft (refined) lead and lead alloys (principally antimonial lead) from lead scrap. Lead scrap can be either new (generated in the process of refining, casting, or fabricating leaded materials), or old (from obsolete materials that have reached the end of their useful life).

Secondary smelters receive about 75% of their old scrap from batteries; in fact much of their production is destined for battery plates and oxides. In the secondary sector, some vertical integration exists among large battery producers who smelt their own lead. Such integration provides a more secure supply of scrap from recycling old batteries. Nevertheless, the trend in vertical integration is not yet far enough advanced to affect entry conditions significantly.

Because scrap resources are widely distributed in urban areas, require no special technological expertise to collect, are more homogeneous than many ores, and require less complex smelting and refining plants than primary sources, entry into the secondary industry is relatively easy.

There are about 85 companies operating more than 100 plants to produce lead from scrap. The secondary smelting industry is dominated by large vertically or horizontally integrated producers interspersed with a number of regional independent producers.

Most of the independent producers are less efficient than the large integrated producers. The principal integrated secondary lead smelters and refineries are listed in Table 3.6-3. Major independent smelters and refineries (not a subsidiary of a vertically or horizontally integrated company) are shown in Table 3.6-4.

TABLE 3.6-3

INTEGRATED SECONDARY LEAD SMELTERS AND REFINERS*

Asarco (Federated Metals Division)

Contract Manufacturing (Chloride Metals)

General Battery

Gould, Inc.

NL Industries

RSR

Western Electric (Nassau Recycle)

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* Note: This is not a complete listing.

Source: Preliminary Technological Feasibility, Cost of Compliance and Economic Impact Analysis of the Proposed OSHA Standard for Lead. John Short and Associates, January 4, 1977.

TABLE 3.6-4

INDEPENDENT SECONDARY LEAD SMELTERS AND REFINERS*

ALCO Mining

Allied Smelting

East Penn Manufacturing Co.

Florida Smelting

Gopher Smelting & Refining

Gulf Coast Lead

Hyman Viener & Sons

Inland Metals

Lead Products Co.

Roth Brothers Metal Co.

Schuykill Metals

Seitzinger's Inc.

Willard Smelting Co.

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* Note: This is not a complete listing.

Source: American Bureau of Metal Statistics, 1977.

Two of the integrated companies (NL Industries, Inc. and RSR Corporation) account for about 60% of secondary lead capacity. Thirteen other companies operating about 25 plants produce most of the remainder.

RSR operates five secondary smelters located in Texas, Indiana, California, New York, and Washington State. Some of the lead is converted to oxides or fabricated into products (two fabrication plants and two oxide plants). Both soft and alloyed lead are produced with the split approximately 70-30%.

NL is a large diversified company, producing lead, oxides, and fabricated products in more than 20 plants scattered throughout the United States. Most NL lead is sold to battery manufacturers.

The large integrated national producers are surrounded by independents serving regional markets. Most of the remainder of the plants are small and scattered, although a few are the result of vertical integration of the battery industry. These smaller regional firms have an average of about 60 employees and produce an average of approximately 8000 short tons of lead per plant per year.

The secondary industry actively competes with the primary lead companies both nationally and internationally. Secondary producers can and do sell abroad, and they can compete favorably with primary producers.

The small secondary firms have smaller capacity, which limits the number of large customers they can serve, leaving them to serve primarily the smaller, more competitive regional market. When the domestic price leaders increase prices, the smaller secondaries will usually follow. On the other hand, when attempts are made to support prices by limiting the supply of lead, the smaller secondaries have shown little hesitation in taking full advantage of the support price without limiting their output.

3.6.3 Process Technology

3.6.3.1 Primary Smelting and Refining

Although all of the lead smelters in the United States are essentially based on the same process, the Western smelters employ more complicated flowsheets because of the more complex nature of the Western concentrates and other imported material, and the smelters' relationship with copper and zinc plants. Figure 3.6-2 depicts a generalized flowsheet of a primary lead smelter.

The primary raw material is lead sulfide concentrate. This is mixed with direct smelting ore rich in silica, zinc plant residues, siliceous and limestone flux, and small quantities of scrap iron if necessary. The charge is prepared by mixing, sizing and crushing. Recycled sinter fines are also blended in with the charge to form the feed to the sintering operation.

The purpose of sintering is the elimination of the sulfur in the charge and the production of a dustfree lumpy charge suitable for treating in a blast furnace. The charge to the blast furnace consists of coarse sinter with about 10-12% lump coke. Low pressure air is blown into the blast

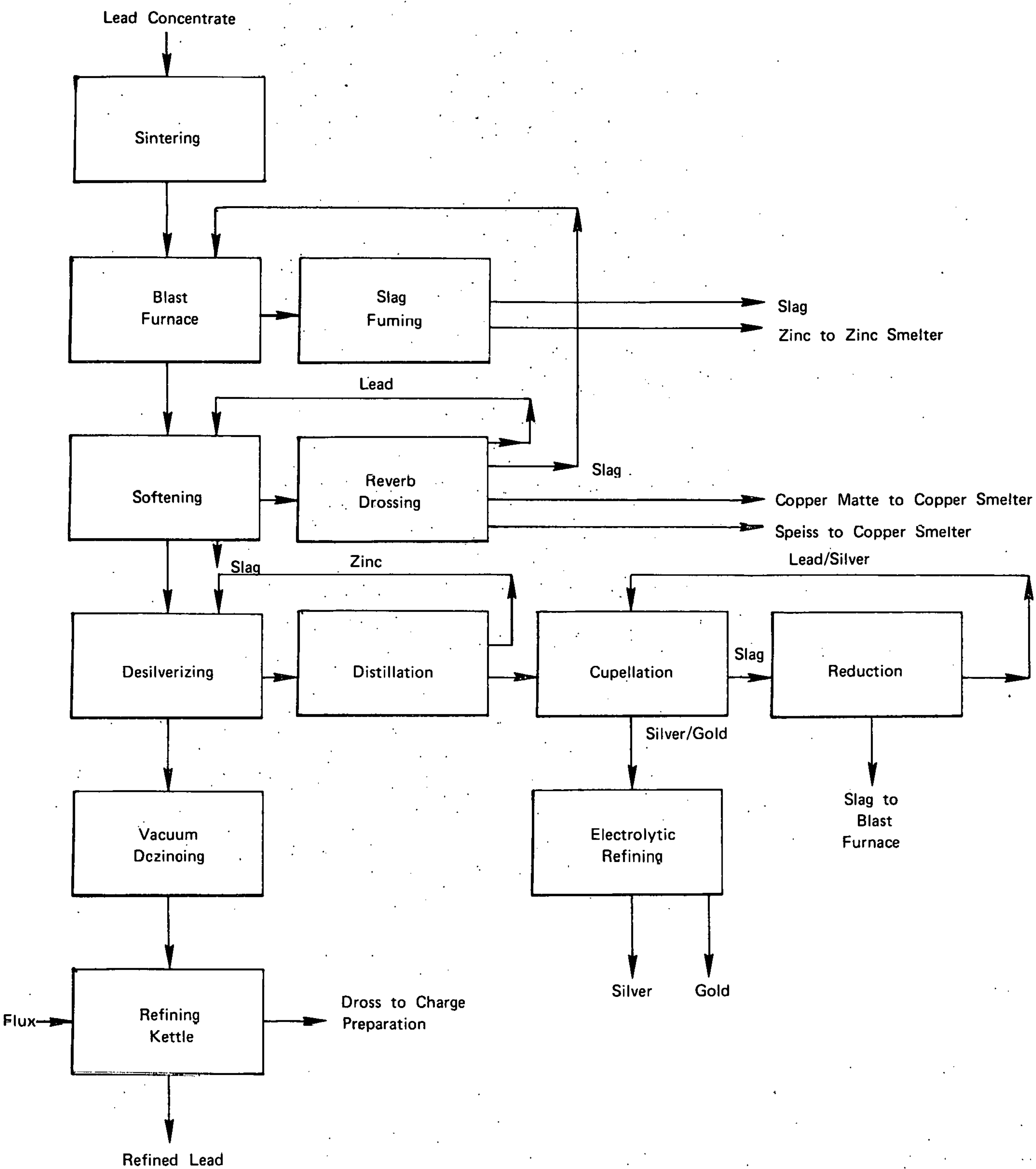


FIGURE 3.6.2 PRIMARY PRODUCTION OF LEAD

furnace. Lead oxide in the sinter is reduced to metallic lead by carbon monoxide formed by the partial combustion of the coke. The heat for melting the charge is derived from the combustion of coke or carbon monoxide to carbon dioxide. Under the mildly reducing conditions in the furnace, zinc oxide is not reduced to the metal and accumulates in the slag.

The liquids from the blast furnace are tapped continuously to an external settler. In the settler, the liquid separates into two layers, molten lead and a molten slag. If the charge contains a sufficient number of other impurities, there will be intermediate layers of "matte" and "speiss." The matte layer is predominantly copper, iron, nickel, and cobalt sulfides while the speiss layer contains a mixture of complex copper arsenides and antimonides. Cadmium in the charge is volatilized. When the slags contain over 8-10% zinc, they are retreated in slag fuming furnaces to recover the zinc and any remaining lead. Western smelters treat high zinc materials and require slag fuming facilities while the Missouri smelters do not.

Lead bullion from smelters operating on Missouri ore is pure enough for most commercial uses without complex refining. Lead bullion produced from Western and most foreign ore contains enough gold and silver to make recovery profitable. It also contains various base metal impurities that must be removed before the lead is marketable for end use. Processing for impurity removal consists of softening, desilverizing, dezincing, and final refining of the lead bullion.

Softening consists of the removal of copper, tin, antimony, and arsenic in a drossing or refining kettle. Copper is removed by heating the bullion to just above the melting point and skimming copper dross from the surface. Agitation and addition of elemental sulfur causes any remaining copper to rise to the surface as a black copper sulfide dross which is skimmed off. The copper drosses undergo further treatment to maximize lead recovery. After copper drossing, the temperature of the bullion is raised and the bath is agitated to induce surface oxidation. Tin, arsenic, and antimony are oxidized and the oxides rise to the surface with some lead oxide and are skimmed off as slag.

The softened bullion is usually desilverized by the Parkes process (stirring metallic zinc into the bullion). Gold and silver combine with the zinc, and the resultant alloys, on cooling, rise to the surface and are skimmed off. The zinc remaining in the lead after desilverizing is removed by vacuum distillation. Remaining traces of zinc, arsenic, bismuth and antimony are removed by the Harris process and the lead is cast as bullion.

The recovery of byproducts is subject to many variations in practice but they are beyond the scope of this discussion.

3.6.3.2 Secondary Lead Processing

The secondary lead industry processes lead scrap into three grades of lead ingot; refined lead (soft lead), antimonial lead (hard lead), and remelt lead and various types of specification alloy. Refined lead is produced from scrap from which elements like antimony, copper, tin, and arsenic have been removed to a level consistent with primary refined lead. Antimonial lead is produced from battery plate scrap and contains 2-7% antimony and small controlled quantities of arsenic, copper, and tin. Remelt lead is melted-down lead scrap that is pure enough or meets the necessary alloy specification so as not to require processing.

Lead processing in the secondary industry consists of scrap preparation, melting, and refining, as shown in Figure 3.6-3.

3.6.3.2.1 Scrap Preparation

Whole battery scrap is customarily decased by sawing or guillotining to produce battery plate and separator scrap and to remove the connectors and posts. Plates and separators go into storage, and the acid drains off into a sump where it is neutralized with lime or ammonia. The battery top, containing the connectors and posts, is fed to a crusher and then to an air separator where the casing material is removed. The scrap prepared from this operation is called plate and separator scrap.

Some of the more recent concepts in battery scrap preparation consist of breaking the whole battery and separating the various components (lead, lead oxide, casing material) by heavy media separation and hydrometallurgical techniques. A new scheme, outlined by Paul Bergsoe and Son A/S of Denmark consists of acid removal by cracking the whole battery before charging it to the smelting furnace.

Prompt industrial scrap such as drosses, skimmings, etc., needs no preparation before processing in the furnaces. Most of the general lead scrap like cable sheating also requires little preparation.

3.6.3.2.2 Scrap Smelting/Refining

Three major smelting schemes are used to treat lead scrap: blast furnace, reverb/blast furnace combination, and pot melting.

The blast furnace is the workhorse of the secondary lead industry. It is similar in construction to the cupola used in the iron foundry industry, with cross sectional areas ranging from 5 to 16 square feet at the tuyeres. The smelting zone is water jacketed: about half the furnaces also have jacketing above the smelting zone.

The charge normally consists of lead-bearing materials, such as battery plates and separators, refining drosses, slags, and battery manufacturers' scrap, as well as coke, limestone, sand, and scrap iron. Slag and matte are tapped from the furnace at regular intervals, while molten lead is removed continuously. The furnace metal is either cast into 1- to 2-ton blocks that are transported to the refinery, or are directly tapped into receiving kettles. Metal tapped into kettles is refined using various fluxes and alloyed to produce the desired specifications. Overall recovery of the blast furnace process scheme is over 95%, with the difference accounted for by lead in the slag, matte, and dust.

The reverb/blast furnace scheme involves a reverberatory furnace to process most of the incoming lead scrap, and a blast furnace to recover lead and antimony values from the reverb slag. The reverb furnace is a refractory-lined, shallow-hearth, rectangular structure, fired from one end with natural gas or oil. The dust in off-gases is collected in baghouses and recycled. The reverb furnace produces a low antimony lead (less than 1% antimony) and a high antimony slag (4-12% antimony; 65-90% lead). The lead is transported to kettle refining for fluxing and alloying to meet final specifications. The reverb slag is cast, cooled, and charged to the blast furnace along with coke, limestone, scrap iron, sand, rerun slag, and some lead-bearing materials. The lead produced in the blast furnace contains from 2-7% antimony.

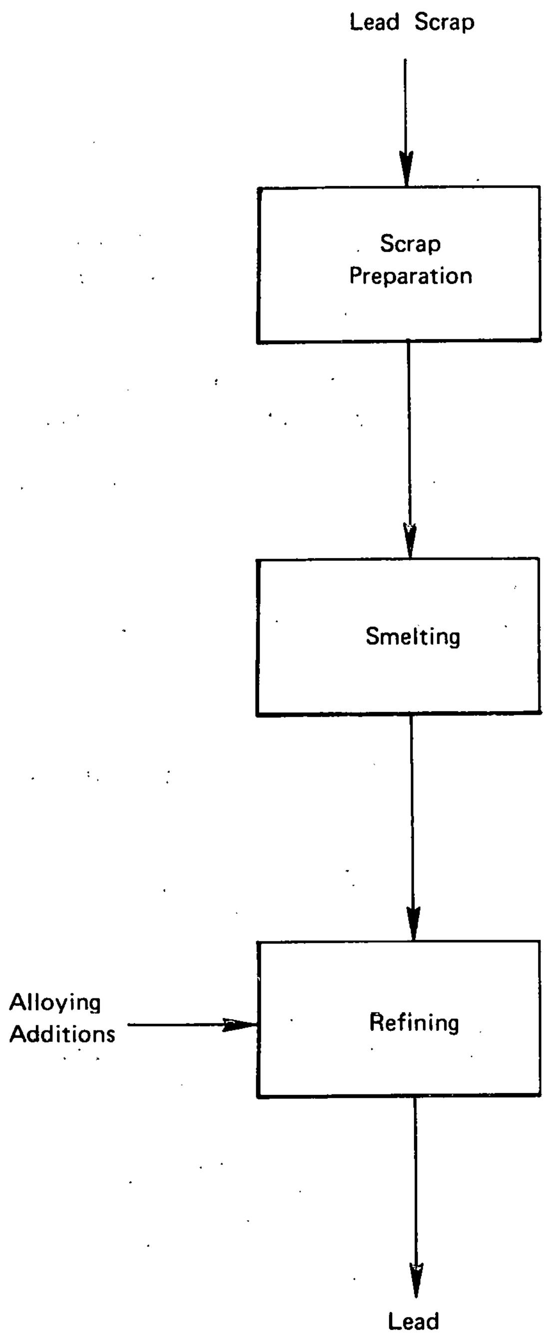


FIGURE 3.6.3 SECONDARY PRODUCTION OF LEAD

The lead from the reverb and blast furnaces is refined in steel kettles to produce "soft" (low antimony) and "hard" (high antimony) leads. Various types of fluxes, such as sodium hydroxide, sulfur, and sodium nitrate, with alloying elements, such as copper, tin, antimony, and arsenic, are added to the kettle charge to refine the lead to meet customer specifications. Overall recovery of the reverb/blast furnace scheme is over 95%. The lead metal loss occurs as lead in blast furnace slag, matte, and dusts.

A very small sector of the secondary lead industry relies solely on the reverb furnace for processing lead scrap. This method is actually the front-end of a reverb/blast furnace scheme. The slag produced in the reverb furnace contains about 65-80% lead and therefore has to be treated by a blast furnace at another smelter to recover the lead.

Pot melting involves the melting of general lead scrap in an indirectly-fired steel kettle. This process is used whenever the quality of lead is unimportant (96-99% lead), for example, for boat keels and weights. Lead recovery in this process is over 95%. Pot melting operations handle very small quantities of lead compared to other smelting schemes described above.

The recent introduction of maintenance-free batteries has brought into the market a certain amount of lead scrap containing calcium and tin. The treatment of this scrap is similar to that employed for regular battery scrap, but it requires care in the refining and alloying operations.

Recently, rotary furnaces have been introduced for processing lead RM. However, their use is not widespread at present.

3.6.4 Materials Flow

3.6.4.1 General

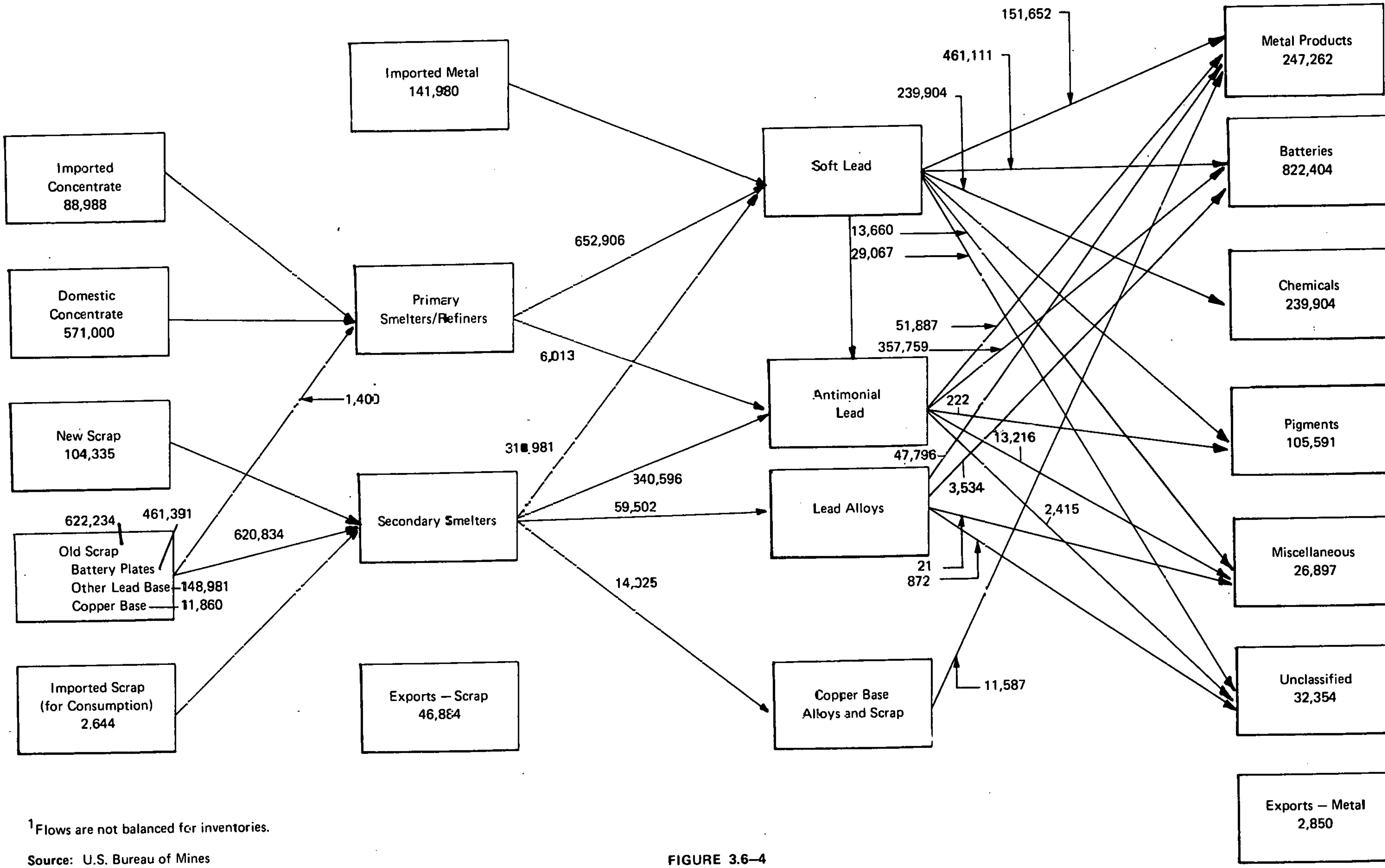
The flow of material in the U.S. lead industry is depicted in Figure 3.6-4. Primary smelters use both domestic and imported concentrates as raw material. Some scrap is also consumed by primaries but only in very small amounts. Primaries produce soft (refined) lead, the bulk of which is used in batteries or gasoline (as TEL). The primaries also produce some antimonial lead but only very small amounts.

The secondary smelters and refiners use various types of scrap and byproducts as raw material. By far the largest single source is battery scrap. The second source of scrap is drosses and residues from manufacturing operations. Secondaries are capable of producing soft (refined) lead, antimonial lead, or other alloys, but traditionally have produced mostly hard (antimonial) lead for use in batteries.

3.6.4.2 Classification of Recyclable Material

Until recently the supply of and demand for lead scrap has been highly oriented toward specific end use segments of the overall lead industry. However, the introduction of maintenance free batteries is changing this.

Battery manufacture is the largest consumer of lead, and old batteries are the source of over half the total secondary lead processed. Antimonial lead, produced almost entirely by secondary smelters, is used for battery grids, posts, and connectors; most of the lead oxide used in batteries is prepared from primary lead.



[1]Flows are not balanced for inventories.

Source: U.S. Bureau of Mines
Arthur D. Little, Inc.

FIGURE 3.6–4

MATERIAL FLOW – LEAD INDUSTRY[1]
1976 – ST CONTAINED LEAD

Over the long term, an average of 75% of the lead consumed in batteries is recovered as scrap about three years later. The actual consumption of battery scrap is influenced by the price of lead, however.

The major sources of old lead scrap other than batteries consists of construction scrap, type metal, cable covering, solder, and bearing and casting metals. Construction scrap includes caulking lead, pipe, and sheet lead from industrial and residential construction. Recovery is about 45% of the lead used in these products 20 years earlier. Type metals are returned as lead scrap in approximately the same quantity as shipments of new type metals with essentially 100% recovery. Lead is recovered from solder at a rate of about 17% of the lead consumed for production of solder 10 years earlier. The uses for solder are automotive, cans, electrical, electronic, and miscellaneous uses. Use in the automotive industry is principally for body solder (5 pounds per car) and radiators (about 3 pounds). Cable lead is returned at a rate equivalent to 25% of the cable lead used 20 years earlier. Scrap from other metal products currently supplies the equivalent of 50% of the lead that was consumed to produce bearing and casting materials 10 years earlier. Most of the lead in collapsible tubes is not recovered in the normal scrap channels. Lead in brass and bronze is not recovered as lead scrap and does not return to the secondary lead industry.

New lead scrap consists of drosses and residues, principally generated in the manufacture of various metallic lead products. Historically, recovery of lead from drosses and residues has been equivalent to about 10% of the lead consumed for metal products (battery plates, ammunition, solder, cable coverings, type metal, construction and other applications).

3.6.4.3 Recycling Profile

3.6.4.3.1 Primary Industry

In the primary lead industry two lead-containing wastes are produced and are recycled or disposed of in varying degrees: blast furnace slag, and gas cleaning wastes.

Molten slag from the blast furnace is recycled to sinter (70%); about 30% is passed through a slag fuming furnace to remove zinc and some residual lead, then granulated by water quenching before going to the slag dump. Some smelters do not fume slag; untreated granulated slag then goes directly to the dump.

Although gas cleaning practice varies widely from plant to plant, the bulk of the dry dusts and wet slurries resulting from primary gas cleaning operations are recycled. Slurry is settled in a lagoon, which is dredged periodically. This sludge is produced at a rate of 19 Kg/MT of lead product.[1] At some plants this material is recycled to sinter; at others the material is not recycled but is disposed of on land as a solid waste.

A portion of the dusts collected from sintering, blast furnacing, and other operations in baghouses and other dry dust collectors is not slurried but is recycled in dry condition to the sinter machine. It has been estimated that 20,900 short tons per year are handled in this manner from the typical plant.[1] Recycle is immediate and no solid waste disposal is necessary. Approximately 10% of dusts are land stored before recycle.[1]

3.6.4.3.2 Secondary Industry

In the secondary lead industry, slag and dusts are generated in both reverberatory furnaces and blast furnaces. In making soft lead, byproduct slag from the reverb is sent to a blast or cupola furnace as input for antimonial lead (i.e., hard lead) production. The emissions from the reverberatory furnace are collected in a baghouse and immediately recycled.

In the blast furnace, smelting of the reverberatory slag, along with other scrap, generates blast furnace slag having approximately the following composition: FeO, 35%; CaO, 15%; SiO_2, 30%; and Pb, <1%. Trace metals include zinc, copper and antimony.

With direct blast furnace smelting of scrap battery waste to produce antimonial lead, sulfur in the scrap is scavenged by iron resulting in the formation of a matte and slag together with the molten metal. About 25% of the slag is recycled as flux for subsequent smelting, the remainder is discarded. Typical chemical composition of the slag is similar to that given above. Typical chemical composition of the matte is: Fe, 61%; Pb, 4.5%; and S, 15%.[1]

3.6.5 Future Trends

3.6.5.1 Technology

Technological changes in the metals industry take a long time and a large investment in building new facilities. Accordingly, we expect few major changes in the technology of the lead industry between now and 1987.

There is a technological shift occurring in the battery industry, however, that may have serious repercussions for lead producers. The introduction of maintenance-free batteries has decreased the demand for antimonial lead and increased the demand for pure lead.

Antimonial lead has traditionally been produced by the secondaries from scrap while the bulk of the pure lead has been produced by primaries. Secondaries can also produce pure lead but for technical and economic reasons they prefer antimonial. The decrease in antimonial demand is increasing competition in the secondary industry, and causing secondaries to switch their product mix to a greater proportion of pure lead, which puts them in competition with the primary producers.

This change in market structure may, in turn, affect the mix of primaries and secondaries in the industry. Additionally the emphasis on pure lead may lead to the development of new technology to produce pure lead from scrap more efficiently. (The current reverb/blast furnace combination is geared toward production of antimonial lead.) Although the primary/secondary mix will probably be altered by 1985, we do not anticipate significant new technology by then.

3.6.5.2 Demand

The consumption pattern for lead in 1976 is given in Table 3.6-1. Domestic demand can probably be met by domestic sources in the foreseeable future. The U.S. Bureau of Mines projects an overall growth rate of 1.8% annually through the year 2000.

An estimated 1987 breakdown is given in Table 3.6-5. A decrease in consumption of lead in TEL is expected as EPA regulations force this phaseout although the changing energy situation and the lead specifications for gasoline could affect the decrease in the short term. Use of lead in paint decreased as a result of increased awareness of the toxic qualities attributed to lead in paint. Other end uses will probably remain about equal to the 1976 levels.

TABLE 3.6-5

ESTIMATED 1987 LEAD CONSUMPTION

Batteries	1,277,000 ST
Other Metal Products	194,000 ST
Gasoline Additives	100,000 ST
Other Miscellaneous	269,000 ST
Total	1,840,000 ST

Source: Arthur D. Little, Inc.

REFERENCES

REFERENCES: SECTION 3.2 FERROUS

1 Steel and the Environment — A Cost Impact Analysis. Arthur D. Little, Inc., 1975.

2 AISI Annual Statistical Report, 1977.

3 Pietruch, W.E., and R.L. Deily, Steel Industry in Brief: Databook, U.S.A., 1977, Institute for Iron and Steel, 1977.

4 AISI Annual Statistical Report, 1976.

5 Classification by Firm, 1977 Steel Industry Financial Analysis, Iron Age, April 4, 1977.

6 U.S. Department of Commerce, Bureau of Census, Current Industrial Reports, M33, 1955-1976.

7 Annual Survey of Manufacturers, 1976. Fuels and Electric Energy.

8 Annual Survey of Manufacturers — General Statistics for Industry Groups and Industries, Bureau of Census, 1976.

9 Foundry File. Penton Publications, 1977.

10 Ferroalloys — U.S. Bureau of Mines Mineral Yearbook, 1976.

11 Minerals Yearbook — Iron and Steel, U.S. Bureau of Mines, 1976

12 World Steel Industry Data Handbook. 33 Metal Producing, 1978.

13 Casting Raw Steel — U.S.A., R.L. Deily, I&SM, December 1977, p. 31-33.

REFERENCES: SECTION 3.3 ALUMINUM

1 Aluminum Prices 1974-75, Staff Report, Council on Wage and Price Stability, Executive Office of the President. September 1976.

2 Census of Manufacturing Industries, 1972. U.S. Bureau of Census.

3 Aluminum Statistical Review 1976. Reported by the Statistical and Marketing Research Committee. Aluminum Association.

4 Recovery and Recycling of Automotive Aluminum, Society for Automotive Engineers, Inc., K.H. Dale, 1978.

5 Economic Analysis of Pretreatment Standards for the Secondary Copper and Aluminum Subcategories of the Nonferrous Metals Manufacturing Paint Source Category, Report to EPA by Arthur D. Little, Inc., October 1976.

6 Value of Product Shipments. Annual Survey of Manufacturers, 1976.

7 Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Vol. VIII, Alumina/Aluminum Industry Report. Report to EPA by Arthur D. Little, Inc., December 1976.

8 The Recovery of Metal and Chemical Values from Aluminum Drosses. Alcan International, Ltd., Hans Spoel, 1975.

9 Furnace Dross — Its Formation and Recovery, Alumax, C.J. Moser.

10 Aluminum Mineral Commodity Profile, Bureau of Mines, May 1978.

11 Aluminum, Preprint from 1976 Minerals Yearbook. U.S. Bureau of Mines.

12 Aluminum Update, Journal of Metals, J.B. Ballance, October 1978, p. 36.

13 Aluminum Monthly, Mineral Industrial Surveys, Bureau of Mines, October 1978.

14 Aluminum, Minerals Yearbook, U.S. Bureau of Mines, 1972-1975.

REFERENCES: SECTION 3.4 COPPER

1 A Study to Identify Opportunities for Increased Solid Waste Utilization, Vol. II to VII, Report to the U.S. EPA by Battelle Columbus Labs, 1972.

REFERENCES: SECTION 3.5 ZINC

1 Energy Use Patterns in Metallurgical and Nonmetallic Processing (Phase 5 — Energy Data and Flowsheets, Intermediate Priority Commodities), U.S. Bureau of Mines, September 16, 1975.

2 Energy Use Patterns for Metal Recycling. Final Report to the U.S. Bureau of Mines by Arthur D. Little, Inc., January 1978.

3 U.S. Bureau of Mines Mineral Commodity Profiles Zinc, May 1978, MCP-12.

REFERENCES: SECTION 3.6 LEAD

1 Calspan, Assessment of Industrial Hazardous Waste Practices in the Metal Smelting and Refining Industry, Volume II, Primary and Secondary Non-Ferrous Smelting and Refining. Report to the EPA.

4.0 EVALUATION OF RECYCLING TARGETS BY INDUSTRY GROUPS IN SIC 33

4.1 INTRODUCTION

This section presents the evaluation of recycling targets for the following five major industry groups:

- Ferrous (includes iron and steel plants, ferrous foundries, and ferroalloy plants)
- Aluminum
- Copper
- Zinc
- Lead

The sixth industry group — Miscellaneous Nonferrous Metals Operations — is excluded from this section because the segments contained in this industry group are either not relevant to the recycling target estimation or their contribution to overall energy savings is insignificant.

Since the purpose of this project is to increase energy savings via the use of recoverable materials, it is important to remember that the ferrous industry (iron and steel, ferrous foundries, and ferroalloys), as defined here accounts for approximately 83% of the energy consumed in SIC 33, aluminum for about 11%, copper for about 3%, lead and zinc each less than 1%, and all others the balance. Therefore, most of the effort in the target evaluation is focused on the ferrous scrap users, followed by aluminum and copper.

The target evaluation procedure is based on a general methodology recommended by the DOE. It is described in detail in Section 2.

In this section, each industry group is discussed under the following general headings:

- Selection of recoverable materials
- Selection of process subdivisions for inclusion in the target
- Technical considerations
- Economic considerations
- Special considerations
- Target estimation
- Sensitivity of target to key factors

4.1.1 Selection of Recoverable Materials

The portions of each industry group to be included in the target estimation analysis are based on:

- Quality of the recoverable material
- Dispersion of the recoverable material

- Quantity of the recoverable material
- Potential new sources, and their quality, dispersion, quantity, etc.
- Changes in existing sources of the recoverable materials

According to the Department of Energy guidelines for this study, recoverable materials include:

- Wastes that contain materials listed in the NECPA
- Wastes from outside the United States
- Any wastes that may provide recoverable materials and replace virgin materials

Sources of recoverable materials do not include:

- Waste materials generated and introduced back into the process within the same plant.
- Waste materials not among those listed in the Energy Act.
- Situations where a clear case can be made that the potential source will not be used as recoverable material by 1987.

The Department of Energy guidelines are followed for all the five major industry segments. Two items for which a discriminatory evaluation procedure is followed are:

- Mine waste is excluded from our analysis, except for the copper industry, even though the Energy Act includes mine waste as a recoverable material. The reason for doing this is that of all the mine wastes generated in the SIC 33 industry groups, only copper mine waste meets the Department of Energy's recoverable material selection criteria. Therefore, mine waste is not included in the analysis, except for copper

- Waste material generated and introduced back in the process within the same plant is not included in the analysis, unless data was available from published sources or the trade associations. Data on dusts and sludges were generally not available and, therefore, these materials are not included in the analysis.

4.1.2. Selection of Process Subdivisions for Inclusion in the Target

For each industry group it is necessary to subdivide the industry on the basis of process or other industry classification. For example, the ferrous industry is subdivided by process because the consumption of recoverable material is process-dependent. The aluminum industry, however, is subdivided into industry groups rather than by process because the consumption of recoverable material is independent of the process (e.g., reverberatory furnace, crucible), but does depend on the industry groups (e.g., primary and secondary).

4.1.3 Technical Considerations

This section deals with three broad technical considerations related to recycling:

- Process Constraints — These relate to process factors that limit recycling. As an example, the scrap/hot metal ratio that can be processed in a copper converter and the basic oxygen furnace is limited because of heat balance considerations. In contrast, the reverberatory furnace and crucible in the aluminum industry can process 100% scrap.

- Product Quality Constraints — The use of recoverable material is also limited by the product specifications. As an example, an antimonial copper scrap with high tin and nickel content cannot be processed in a plant producing wirebars but could be acceptable in a plant making certain specific copper alloys which include antimony, nickel and tin.
- Recoverable Material Quality Constraints — The recoverable material quality constraints are indirectly related to Process and Product Quality constraints. The recoverable material chemical and physical qualities must be compatible with process requirements and product requirements.

4.1.4 Economic Considerations

In most industry groups, economic considerations are the governing factors controlling recycling, rather than technical considerations. These have been discussed in Section 2. The approach used by Arthur D. Little, Inc., for the economic analysis differs somewhat from that in the Department of Energy guidelines. Arthur D. Little uses econometric techniques to estimate the supply of recoverable material in 1987. Most of the effort in econometric modeling is focused on the ferrous industry, followed by aluminum and copper. Details of the approach are discussed in Section 2.2.5. For lead and zinc, targets are developed on the basis of historical data and published forecasts of the future of the industry.

4.1.5 Special Considerations

This section discusses the circumstances and considerations related to recycling but not included in the sections on technological and economic considerations. An example of special consideration is the issue of municipal solid waste recovery of cans for the aluminum industry.

4.1.6 Target Estimation

In this section the method of target estimation and the estimated target are discussed. Because of the wide diversity in the industry segments, the quality of data available, and other factors, the target estimation procedures are not identical for all the five industry segments analyzed. However, every effort has been made to present the targets for individual industry segments in a similar format.

4.1.7 Sensitivity of Target to Key Factors

Because the development of a target depends on the interpretation and projections of the future, and because the projection of future conditions is based on numerous sources of data, many of which are conflicting, it is important to know how inaccuracies in assumptions made of future conditions can affect the target. The section on sensitivity analysis attempts to address this problem.

4.2 FERROUS

The evaluation of the recycling targets for the ferrous industry has been simplified by dividing the industry into the following segments:

- Iron and Steel
- Ferrous Foundries
- Ferroalloys

4.2.1 Selection of Recoverable Materials

4.2.1.1 Iron and Steel

The possible sources of recoverable materials for the iron and steel segment can be grouped into four general categories:

- Ferrous scrap
- Mill scale
- Dust and sludge
- Slag

A brief description of the materials comprising each of these categories has been given in Section 3.2.4 of this report. All the possible sources of recoverable materials for the iron and steel segment are listed in Table 4.2-1. This table indicates which of the materials have been selected for consideration in this study by meeting the criteria for inclusion as defined by the Department of Energy. The selection criteria are outlined in Section 4.1.

Significant quantities of the three types of scrap material (home, obsolete and prompt) composing the ferrous scrap category are presently being utilized as sources of recovered material within the iron and steel segment. This practice is expected to continue into the future, and therefore all three types of ferrous scrap are included in the recycling target evaluation.

In the slag category, blast furnace slag and electric arc furnace slag were not selected for inclusion. Blast furnace slag is usually sold to slag processors who recover the iron from the slag by magnetic separation and sell this material, known as slag scrap, back to the iron and steel industry for reprocessing. Since slag scrap is included in the category of ferrous scrap, blast furnace slag will not be considered separately. Electric furnace slag is recycled to some extent in order to provide a protective slag layer in the furnace. It is not recycled as a source of iron and, therefore, does not meet the inclusion criteria. Basic oxygen and open hearth furnace slags are both processed to some degree to recover contained iron and the processed slag is either sold, dumped or used as a source of flux. These two types of slag provide iron units for recycle which will be included in the evaluation of the recycling target.

Mill scale containing over 50% iron is collected in the water pollution control facilities associated with primary reduction mills, continuous casters, and hot and cold rolling mills. Besides iron, these scales can contain small concentrations of chromium, copper, manganese, nickel, lead, and zinc. Mill scale may also contain over 1.0% oil and grease. These high oil and impurity contents limit their use in the sinter strand. However because of the contained iron units, mill scale is partially recycled to the sinter strand, the blast furnace, and all three types of

TABLE 4.2-1

SELECTION OF RECOVERABLE MATERIALS
IRON AND STEEL SEGMENT

Recoverable Materials	Does the Recoverable Material Meet the Criteria* for Inclusion? Yes	No
Ferrous Scrap		
Home	X	
Prompt Industrial	X	
Obsolete	X	
Mill Scale	X	
Dust and Sludge		
Blast Furnace	X	
Basic Oxygen Furnace	X	
Electric Arc Furnace		X
Open Hearth Furnace	X	
Rolling Operations		X
Slag		
Blast Furnace		X
Basic Oxygen Furnace	X	
Electric Arc Furnace		X
Open Hearth Furnace	X	

* The criteria are outlined in Section 4.1.

steelmaking furnaces, depending on the quality (oil and impurity content) of the scale. This material meets the inclusion criteria and, therefore, will be considered in the analysis.

Electric arc furnace (EAF) dusts and sludges have been excluded from consideration because they are not presently recycled except for isolated cases and are not expected to be recycled to any significant extent in the near future. These dusts and sludges contain measurable amounts of chromium, copper, manganese, nickel, lead and zinc. The "tramp" impurities severely inhibit the industry's ability to process electric furnace dust and sludges for their iron units. In addition, sintering plants, the usual processing route for dusts and sludges, are generally not located in the same plant as the EAF, thus precluding any simple "in-house" recycle scheme.

Primary reduction mills, continuous casting units, hot and cold rolling mills, tin plating mills, and galvanizing mills produce sludges from water pollution control operations at a rate ranging from 0.1 to 10 kg/metric ton of finished steel.[1] In general, these sludges are not recycled because they contain significant amounts of oil and grease. For this reason, as well as the fact that they are generated in relatively small amounts, these sludges will not be considered in the analysis.

Blast furnace, basic oxygen furnace, and open hearth furnace dusts and sludges will be considered in the analysis. These materials are currently being recycled, some to agglomeration plants for the recovery of iron units and some to improve the permeability of the sinter products.

Recent consumption patterns (1970-1976) for the selected recoverable materials within the iron and steel segment are given in Table 4.2-2. Table 4.2-3 contains consumption data for various categories of purchased and home scrap.

4.2.1.2 Ferrous Foundries

Table 4.2-4 lists the potential sources of recoverable material for the ferrous foundry industry and identifies those that meet the criteria necessary for inclusion in this study. The criteria are described in Section 4.1. The recoverable materials are broadly classified into three categories:

- Scrap
- Dust and sludge
- Slag

Though foundry sand is an important material recycled in the ferrous foundry industry, it is excluded from this analysis because it does not contribute ferrous or metallic units and, therefore, does not relate to SIC 33.

Scrap is the most important source of recoverable material in the ferrous foundry industry. The various types of iron and steel scraps that are important recyclable materials are shown in Table 4.2-4. Home scrap consists of the risers and runners, skulls and reject castings generated in the foundries. In most foundries the home scrap is a major component of the charge to the melting furnace, in some instances as high as 50-70% of the metallic charge.

TABLE 4.2-2

CONSUMPTION OF RECOVERABLE MATERIALS (1970-1976)

IRON AND STEEL SEGMENT

Type of Recoverable Material	Quantity Consumed - Million Short Tons 1970	1971	1972	1973	1974	1975	1976
Scrap:							
Home*	46.36	42.61	44.43	50.41	47.42	40.06	43.46
Purchased**	22.96	22.01	28.99	32.06	33.65	22.78	24.97
TOTAL	69.32	63.69	73.42	82.47	81.07	62.84	68.43
Mill Scale	NA	NA	NA	NA	NA	NA	NA
Dust and Sludge	3.23	2.88	2.58	2.29	2.36	2.00	2.45
Slag	NA	NA	NA	NA	NA	6.8-9.6	NA

*Home Scrap Production

**Includes Prompt Industrial and Obsolete scrap

NA: Not Available

Sources: U.S. Bureau of Mines, Minerals Yearbooks, 1970-1976
AISI Annual Statistical Reports, 1970-1976

TABLE 4.2-3

CONSUMPTION OF SCRAP* BY GRADE (1971-1976)

IRON AND STEEL SEGMENT

(Thousand Short Tons)

Type of Scrap	1971	1972	1973	1974	1975	1976
Carbon Steel:						
Low phos. plate & punchings	462	538	532	761	733	987
Cut structural	389	525	782	657	478	393
No. 1 heavy melting	24,178	27,751	30,375	28,274	22,205	23,984
No. 2 heavy melting	3,061	3,362	4,008	4,133	3,064	3,421
No. 1 and EF bundles	5,559	6,746	7,544	9,656	7,597	8,870
No. 2 and other bundles	2,709	2,997	3,549	3,656	2,324	2,584
Turnings and borings	1,632	1,753	1,992	2,185	1,608	1,339
Slag scrap	2,942	3,076	3,658	4,052	4,082	4,180
Shredded or frag.	1,172	1,507	1,778	2,332	2,014	2,064
All other	13,666	15,058	17,491	15,021	11,711	12,933
Stainless Steel	768	930	1,036	1,202	687	1,020
Alloy Steel	2,340	2,450	2,399	2,313	1,869	1,829
Cast Iron**	5,068	5,234	6,364	5,359	3,275	3,770
Other Grades	673	1,481	959	1,473	1,189	1,053
TOTAL	64,619	73,408	82,467	81,074	62,836	68,427

* Includes home scrap.

** Includes ingot mold and stool scrap, machinery and cupola cast iron, cast iron borings and motor blocks and other iron scrap.

Source: U.S. Bureau of Mines, Mineral Yearbook, 1971-1976

TABLE 4.2-4

SELECTION OF RECOVERABLE MATERIALS

FERROUS FOUNDRY SEGMENT

Recoverable Material	Does the Recoverable Material Meet The Criteria* for Inclusion? Yes	No
Scrap		
Carbon Steel	X	
- low phosphorus plate and punchings - cut structural and plate - No. 1 heavy melting steel - No. 2 heavy melting steel - No. 1 and electric furnace bundles - No. 2 and other bundles - turnings and borings - slag scrap (Fe content) - shredded or fragmentized - all other carbon steel scrap		
Stainless Steel	X	
Alloy Steel (except stainless)	X	
Cast Iron (includes borings)	X	
Other Grades of Scrap	X	
Ferrous Fraction of Municipal Solid Waste	X	
Home Scrap	X	
Dust and Sludge		
Cupola Dust		X
Electric Furnace Dust		X
Slag		
Cupola Slag		X
Electric Furnace Slag		X

*The criteria are outlined in section 4.1.

Purchased scrap is most often obtained from scrap dealers, with smaller amounts sold directly by scrap generators. Iron foundries consume most of the iron scrap traded in the market. In addition, they purchase about an equivalent tonnage of steel scrap. Steel foundries buy largely steel scrap.

Of the various dusts and sludges generated in the ferrous foundry industry, the only dusts and sludges that have potential metal values are those that are recovered from the melting operations. Dusts and sludges from molding and coremaking have no ferrous units and, therefore, are not recoverable in the context of this study. The dust from the cupola melting furnace contains iron, but only in small concentrations. Because of its low iron content and because it contains small quantities of zinc, lead, and other undesirable impurities, cupola dust is not expected to be recycled for its ferrous, lead or zinc content by 1987. Therefore it is excluded from the analysis. Electric furnace dust presents the same problems as the cupola dust and, therefore, does not meet the selection criteria outlined by the Department of Energy.

The two principal types of slags generated in the foundry industry are:

- Cupola slag
- Electric furnace slag

Neither of these slag categories is expected to be a potential source of iron units in the near future (1987) because of technical and economic factors. Therefore, both of these slags will be excluded from further analysis. It should be noted, however, that a part of this slag is sold as ballast for road construction.

Recent consumption (1971-1976) of the selected recyclable materials within the ferrous foundry segment are shown in Table 4.2-5.

4.2.1.3 Ferroalloys

Recyclable materials associated with ferroalloy smelting can be grouped into four categories:

- Purchased ferrous scrap
- Ferroalloy home scrap
- Dust and sludge
- Slag

As shown in Table 4.2-6, only purchased ferrous scrap and electric arc furnace slag produced in ferromanganese production meet the selection criteria outlined in Section 4.1. Both of these are consumed in significant amounts and are expected to be in the future. Because the quantity of ferroalloy home scrap is very small, it will be excluded from this analysis. Ferrochromium, silicomanganese and other types of electric arc furnace slag are not presently being recycled and are not expected to be in the near future. These slags will therefore be excluded from the analysis. Slag, dust, and sludge from blast furnaces are not considered because blast furnaces are no longer used for ferroalloy production in the United States. Dust and sludge from electric arc furnaces are not considered for further study because they are not presently being recycled in significant quantities and are not expected to be in the near future.

TABLE 4.2-5

CONSUMPTION OF RECOVERABLE MATERIALS (1971-1976)
FERROUS FOUNDRY SEGMENT

Type of Recoverable Material	Home Scrap Plus Purchased Scrap Consumed in Iron and Steel Foundries (Thousand Short Tons)*					
	1971	1972	1973	1974	1975	1976
Carbon Steel:						
Low Phos. Plate & Punchings	1476	1733	2047	1898	1767	1743
Cut Structural	960	1216	1438	2150	1634	1818
No. 1 Heavy Melting	496	580	711	743	652	623
No. 2 Heavy Melting	218	60	188	122	203	190
No. 1 & EF Bundles	417	475	496	642	460	482
No. 2 & Other Bundles	480	686	625	658	347	441
Turnings and Borings	680	687	802	781	766	831
Slag Scrap	21	23	16	34	38	50
Shredded and Frag.	482	555	639	917	733	935
All Other**	2572	2900	2914	3352	2970	3496
Stainless Steel	197	39	38	83	100	71
Alloy Steel	231	271	254	311	271	246
Cast Iron***	9028	9840	10010	3774	4077	4627
Other Grades****	690	890	943	8838	5477	5929
Total:	17948	19956	21122	24409	19495	21483

* Includes miscellaneous scrap users.
** Includes "all other carbon steel", one foot and under (not bundles), and railroad rails.
*** Includes ingot mold and steel scrap, machinery and cupola cast iron, cast iron borings and motor blocks and other iron scrap.
**** Includes other iron scrap and other mixed scrap.

Source: U.S. Bureau of Mines, Minerals Yearbooks, 1971 - 1976

TABLE 4.2-6

SELECTION OF RECOVERABLE MATERIALS

FERROALLOYS SEGMENT

Recoverable Material	Does the Recoverable Material Meet the Criteria* for Inclusion? Yes	No
Purchased Ferrous Scrap	X	
Ferroalloy Home Scrap		X
Slag		
Blast Furnace		X
Electric Arc Furnace		
Ferrochromium		X
Ferromanganese	X	
Silicomanganese		X
Other		X
Dust and Sludge		
Blast Furnace		X
Electric Arc Furnace		X

* The criteria is outlined in section 4.1.

Recent consumption (1970-1976) for the selected recyclable materials within the ferroalloys segment are given in Table 4.2-7.

4.2.2 Selection of Process Subdivisions for Inclusion in the Target

4.2.2.1 Iron and Steel

The structure of the iron and steel industry is such that, for the purposes of establishing a recycling target, it is most appropriate to subdivide the industry into unit operations. Reasons for this subdivision include:

- The principal industry associations, American Iron and Steel Institute (AISI) and Institute of Scrap Iron and Steel (ISIS) have traditionally followed a breakdown by unit operation in the collection of their data.
- Technological factors affecting recycling can be analyzed on a unit-by-unit basis.
- Relatively few unit operations are capable of processing recoverable materials. Thus, by dividing the industry into unit operations, it is possible to neglect those processes that do not directly affect the recycling target.

Recoverable materials can enter the steelmaking sequence at three points:

- Sinter strand (agglomeration facility)
- Blast furnace
- Steelmaking furnace (open hearth, basic oxygen, or electric arc)

The types of recoverable materials processed by each of these unit operations, are given in Table 4.2-8. As this table shows, sinter strands are capable of processing steelmaking furnace slag, mill scale, and blast furnace and steelmaking furnace dusts and sludges.

Blast furnaces can process ferrous scrap along with relatively small quantities of steelmaking furnace slag. Basic oxygen, electric arc and open hearth furnaces can recycle only ferrous scrap and mill scale. Open hearth furnaces can also process a portion of their own slag, but only for fluxing units and not iron units.

Table 4.2-9 presents quantitative data on the amounts of recoverable materials consumed in each unit operation in 1976. Recent consumption data for recoverable materials (1970-1976) on a unit-by-unit basis are given in Tables 4.2-10A through 4.2-10E.

4.2.2.2 Ferrous Foundries

The ferrous foundry industry can be segregated into two well-defined segments:

- Iron foundry industry
- Steel foundry industry

This breakdown is chosen because the steel foundry industry is essentially 100% scrap-based, whereas the iron foundry industry consumes moderate amounts of pig iron besides scrap. Further, the Bureau of Mines publishes scrap data separately for these two segments.

TABLE 4.2-7

CONSUMPTION OF RECOVERABLE MATERIALS (1970-1976)

FERROALLOYS SEGMENT

Type of Recoverable Material	Quantity Consumed (thousand short tons)						
	1970	1971	1972	1973	1974	1975	1976
Purchased Ferrous Scrap*	573	515	558	557	505	426	422
Electric Arc Furnace Ferromanganese Slag**	301	274	288	246	196	207	174

Sources:

* Ferroalloy production from U.S. Bureau of Mines Minerals Yearbooks, 1970-1976. Ferrous scrap factor from a Predicast computer output, 1978, based on U.S. Census data.

** Ferromanganese production statistics from U.S. Bureau of Mines Minerals Yearbooks, 1970-1976. Recycled slag factor from "Assessment of Industrial Hazardous Waste Practices in the Metal Smelting and Refining Industry", Volume III, 1977.

TABLE 4.2-8

RECOVERABLE MATERIAL SOURCE - INDUSTRY MATRIX

IRON AND STEEL SEGMENT

Subdivision by Process	Types of Recoverable Materials								
	Ferrous Scrap			Mill Scale	Dust & Sludge			Slag	
	Home	Prompt Industrial	Obsolete	Rolling Mills	Blast Furnace	Basic Oxygen	Open Hearth	Basic Oxygen	Open Hearth
Sinter Plant				X	X	X	X	X	X
Blast Furnace	X		X	X				X	X
Basic Oxygen	X	X	X	X					
Electric Arc	X	X	X	X					
Open Hearth	X	X	X	X					

Source: Arthur D. Little, Inc.

TABLE 4.2-9

CONSUMPTION OF RECOVERABLE MATERIALS BY PROCESS IN 1976

IRON AND STEEL SEGMENT

Subdivision by Process	Ferrous Scrap: Home	Ferrous Scrap: Prompt Industrial	Ferrous Scrap: Obsolete	Ferrous Scrap: Total	Mill Scale	Dusts and Sludges	Slag
	Type of Recoverable Material (thousand short tons)						
Sinter Plant	0	0	0	0	3,531	2,452	2,156
Blast Furnace	NA	0	NA	3,692	NA	0	NA
Basic Oxygen	NA	NA	NA	26,204	NA	0	NA
Electric Arc	NA	NA	NA	25,099	NA	0	NA
Open Hearth	NA	NA	NA	12,251	NA	0	NA
Total-Steelmaking	NA	NA	NA	63,554	NA	0	NA
TOTAL	NA	NA	NA	67,245	NA	0	NA

NA: Not available.

Source: AISI Annual Statistical Report, 1977.

TABLE 4.2-10-A

CONSUMPTION OF RECOVERABLE MATERIALS BY THE SINTER PLANT (1970-1976)
IRON AND STEEL SEGMENT

Type of Recoverable Material	Million Net Tons						
	1970	1971	1972	1973	1974	1975	1976
Mill Scale	3.695	3.324	3.464	4.031	3.799	3.211	3.51
Dust & Sludge							
Blast Furnace	NA	NA	NA	NA	NA	NA	NA
Basic Oxygen Furnance	NA	NA	NA	NA	NA	NA	NA
Open Hearth	NA	NA	NA	NA	NA	NA	NA
Total	3.228	2.877	2.575	2.289	2.357	1.999	2.452
Slag							
Basic Oxygen Furnace	NA	NA	NA	NA	NA	NA	NA
Open Hearth Furnace	NA	NA	NA	NA	NA	NA	NA
Total*	0.625	0.934	1.251	1.770	1.699	1.467	2.156

*Cinder and slag.
NA: not available

Source: AISI Annual Statistical Report, 1970-1977.

TABLE 4.2-10-B

CONSUMPTION OF RECOVERABLE MATERIALS BY THE BLAST FURNACE (1970-1976)
IRON AND STEEL SEGMENT

Type of Recoverable Material	Million Net Tons						
	1970	1971	1972	1973	1974	1975	1976
Ferrous Scrap							
Home	NA	NA	NA	NA	NA	NA	NA
Total Scrap*	5.302	3.708	3.565	4.246	4.558	3.931	3.692
Mill Scale	NA	NA	NA	NA	NA	NA	NA
Slag							
Basic Oxygen	NA	NA	NA	NA	NA	NA	NA
Open Hearth	NA	NA	NA	NA	NA	NA	NA

*Includes home and obsolete scrap.

NA: Not Available

Source: AISI Annual Statistical Report, 1970-1977.

TABLE 4.2-10-C

CONSUMPTION OF RECOVERABLE MATERIALS BY THE BASIC OXYGEN FURNACE (1970-1976) IRON AND STEEL SEGMENT

Type of Recoverable Material	Million Net Tons						
	1970	1971	1972	1973	1974	1975	1976
Ferrous Scrap							
Home	NA	NA	NA	NA	NA	NA	NA
Prompt Industrial	NA	NA	NA	NA	NA	NA	NA
Obsolete	NA	NA	NA	NA	NA	NA	NA
Total Scrap*	21.124	20.058	24.194	27.318	26.614	23.392	26.204
Mill Scale	NA	NA	NA	NA	NA	NA	NA

*Includes home, prompt industrial and obsolete.

NA: Not Available

Source: AISI Annual Statistical Reports, 1970-1977.

TABLE 4.2-10-D

CONSUMPTION OF RECOVERABLE MATERIALS BY THE ELECTRIC ARC FURNACE (1970-1976)
IRON AND STEEL SEGMENT

Type of Recoverable Material	Million Net Tons						
	1970	1971	1972	1973	1974	1975	1976
Ferrous Scrap							
Home	NA	NA	NA	NA	NA	NA	NA
Prompt Industrial	NA	NA	NA	NA	NA	NA	NA
Obsolete	NA	NA	NA	NA	NA	NA	NA
Total Scrap*	18.834	20.150	24.886	28.615	29.710	23.010	25.099
Mill Scale	NA	NA	NA	NA	NA	NA	NA

*Includes home, prompt industrial and obsolete scrap.

NA: Not Available

Source: AISI Annual Statistical Reports, 1970-1977.

TABLE 4.2-10-E

CONSUMPTION OF RECOVERABLE MATERIALS BY THE OPEN HEARTH FURNACE (1970-1976)
IRON AND STEEL SEGMENT

Type of Recoverable Material	Million Net Tons						
	1970	1971	1972	1973	1974	1975	1976
Ferrous Scrap							
Home	NA	NA	NA	NA	NA	NA	NA
Prompt Industrial	NA	NA	NA	NA	NA	NA	NA
Obsolete	NA	NA	NA	NA	NA	NA	NA
Total Scrap*	21.935	18.572	18.637	20.419	19.005	11.669	12.251
Mill Scale	NA	NA	NA	NA	NA	NA	NA

*Includes home, prompt industrial and obsolete scrap.

NA: Not Available

Source: AISI Annual Statistical Reports, 1970-1977.

The industry subdivisions and sources of recovered materials are summarized in Table 4.2-11 with the quantities of recoverable materials consumed by the ferrous foundries in 1976. Table 4.2-12 presents the consumption data (1971-1976) of various types of scrap used in the iron and steel foundries.

TABLE 4.2-11

CONSUMPTION OF SCRAP - 1976
FERROUS FOUNDRY SEGMENT*

Industry Subdivision		Scrap Consumed (thousand short tons) Home Scrap	Purchased Scrap**
Gray Iron Ductile Iron Malleable Iron	Iron Foundries	5567*	13,065*
Steel Castings		964	1,887

*Includes miscellaneous scrap users.

**Includes prompt industrial and obsolete scrap.

Source: U.S. Bureau of Mines, Mineral Yearbook, 1976.

4.2.2.3 Ferroalloys

For the purpose of establishing a recycling target, the ferroalloy industry is best divided into sections according to the type of ferroalloy produced. Reasons for this are:

- Available data are broken down by type of ferroalloy.
- Recycle of slag is dependent on type of ferroalloy.

Amounts of recoverable materials consumed in 1976 are shown in Table 4.2-13. Ferrochromium, ferrochromanganese, and ferrosilicon furnaces consume ferrous scrap. A part of ferromanganese slag is recycled to silicomanganese furnaces.

4.2.3 Technical Considerations

Technological considerations governing the recycling of recoverable materials include constraints of process and product quality and limitations of recoverable material. In general, the former establish the limitations of recoverable material quality, which, in turn, determine the amounts of recoverable material that can be recycled. In this section, technological factors affecting recycle within the ferrous industry will be described.

TABLE 4.2-12

CONSUMPTION OF SCRAP*(1971-1976)
FERROUS FOUNDRY SEGMENT

Type of Scrap	Steel Foundries						Iron Foundries**					
	1971	1972	1973	1974	1975	1976	1971	1972	1973	1974	1975	1976
Carbon Steel												
Low Phosphorus Plate and Punchings	643	637	800	840	878	778	833	1046	1247	1058	889	965
Cut Structural	166	178	236	288	248	230	974	1038	1202	1862	1386	1588
No. 1 Heavy Melting	241	203	226	255	244	211	255	377	485	488	408	412
No. 2 Heavy Melting	2	1	13	37	49	56	216	59	175	85	154	134
No. 1 and Electric Furnace Bundles	70	107	73	68	54	58	347	308	423	574	406	424
No. 2 and Other Bundles	19	15	18	15	11	4	461	671	607	643	336	437
Turnings and Borings	66	70	80	74	83	81	614	617	722	707	683	750
Slag Scrap	3	6	3	7	14	11	18	17	13	27	24	39
Shredded or Fragmentized	61	53	77	74	81	96	421	502	562	843	652	839
All Other	830	797	879	907	947	870	1742	2103	2035	2445	2023	2626
Stainless Steel	193	26	25	39	68	51	4	13	13	44	32	20
Alloy Steel (except stainless)	117	127	137	167	181	173	114	144	117	144	90	73
Cast Iron	277	295	285	118	123	119	8751	9545	9725	3656	3954	4508
Other Grades	99	99	97	274	192	113	591	791	846	8564	5285	5816
TOTAL	2787	2664	2949	3269	3173	2851	15161	17292	18173	21140	16322	18632

* Includes home and purchased scrap.

** Includes miscellaneous scrap users.

Source: U.S. Bureau of Mines Minerals Yearbooks, 1971-1976.

TABLE 4.2-13

CONSUMPTION OF RECOVERABLE MATERIALS - 1976
FERROALLOY SEGMENT

Subdivision by Type of Ferroalloy	Scrap (thousand of short tons) Home (Ferroalloy Scrap)	Purchased (Ferrous Scrap)	Total Scrap	Slag FeCr	FeMn
Ferrochromium	NA	0	NA	0	0
Ferromanganese	NA	NA	NA	0	0
Silicomanganese	NA	0	NA	0	174.0**
Ferrosilicon	13.0*	258.0*	271.0*	0	0
TOTAL	NA	NA	422.0*	0	174.0

NA = not available.

* Predicast Data Base, 1978.

** Calspan, Assessment of Industrial Hazardous Waste Practices in the Smelting and Refining Industry, Volume III, 1977.

4.2.3.1 Process Constraints

4.2.3.1.1 Iron and Steel

Operations in the iron and steel segment capable of processing recoverable material include the sinter strand (agglomeration facility), the blast furnace, and the steelmaking furnaces: the open hearth, basic oxygen, and electric arc. The ability of each of these operations to handle recoverable materials depends on such process constraints as energy availability, equipment design, process flexibility, and pollution control. Process constraints for each of these operations are discussed below.

Sinter Strand: In general, sinter strands are incapable of removing impurities; any tramp element entrained in the feed will necessarily report to the discharge. However some elements such as zinc and sulfur and oils can be partially removed. Therefore, the extent to which mill scale, dust and sludge, and slag can be recycled to the sinter plant is determined primarily by the tramp impurities content of these materials. In order for the contaminated material to be recycled, the impurities will have to be removed or diluted in downstream processing. An additional factor is that recycling of in-plant fines (mainly dusts and sludges) to this unit can increase its pollution load in an unacceptable manner.[2]

Blast Furnace: The blast furnace has severe limitations on the chemical specifications of its feedstock; carbon is an asset in any material added to the burden, but zinc and lead must be limited carefully. Physical strength, reducibility, and softening behavior of the iron-bearing constituents of the burden must also meet high standards.

The most troublesome component of residues and scrap recirculated to the blast furnace is zinc. This element is highly detrimental to the furnace and tends to build up in the system. Other undesirable impurities include phosphorus, which will report to the hot metal and, therefore, requires incremental refining operations in subsequent operations; and lead, which is harmful to hearth bottoms.

Open Hearth Furnace: The open hearth furnace is probably the most flexible processing unit within the iron and steel industry for the recycling of recoverable materials. The type and composition of material charged to the open hearth furnace can be varied substantially. However, certain limiting relations among the elements of the charge must be observed. Elements such as copper and nickel, which are not oxidized or eliminated by the reaction in an open hearth process, may be introduced into the furnace only to the extent to which they are permissible in the finished steel. Small amounts of zinc or lead can be included in the charge since they will be readily volatilized at steelmaking temperatures. However, as with blast furnaces, these elements are detrimental to the furnace. A list of elements that report primarily to the slag (oxidation) and the metal in open hearth furnaces is given in Table 4.2-14.

Basic Oxygen Furnace: Because the basic oxygen converter does not rely on external sources of energy, the quantity of ferrous scrap it can process is limited by the amount of energy available for melting. In current practice, BOF's are operated with 20-30% scrap in the charge; 30% is generally recognized as the upper limit for normal operations. The "normal" operation is accomplished without the addition of fuel energy to the BOF or to the scrap.

Unlike the open hearth and the electric furnaces, the BOF utilizes scrap not only as a source of iron, but also as a coolant for controlling temperature. Consequently, the proportion of scrap used cannot be arbitrarily changed without adjusting other variables to maintain the thermal balance. Figure 4.2-1 is a theoretical presentation of how the percentage of scrap in the metallic charge can be increased by increasing the temperature of the hot metal. Alternate means of increasing scrap use include:

- Reducing heat losses of the process
- Adding external fuel to the process
- Raising the temperature of any and all reactants

Of these alternatives, retrofitting for scrap preheating is considered the most practical. However it slows down production and its economics depend on scrap and fuel prices and site specific factors. Although preheating is not common at present, certain BOF shops have shown the ability to operate at almost 45% scrap using this method.[18] The extent to which scrap preheating gains acceptance by the iron and steel industry will depend upon the future availability and prices of ferrous scrap and of energy.

Process constraints for the BOF, other than its thermal requirements, are similar to those for the open hearth furnace.

TABLE 4.2-14

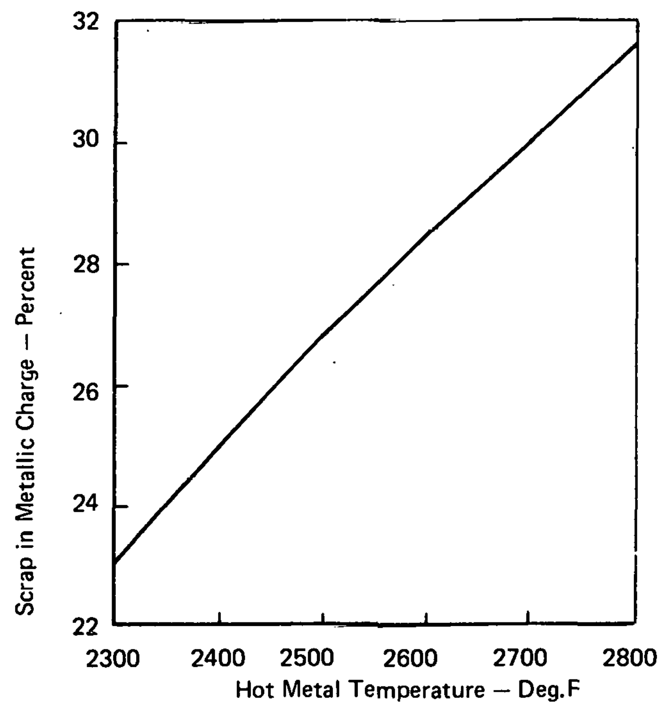
DISTRIBUTION OF ELEMENTS BETWEEN SLAG AND METAL IN AN OPEN HEARTH FURNACE

Elements Primarily Reporting to the Slag	Elements Distributed Between Slag and Metal	Elements Primarily Reporting to Metal	Elements Eliminated From Slag and Metal
Silicon	Manganese	Copper	Zinc
Aluminum	Phosphorus	Nickel	Cadmium
Titanium	Sulfur	Tin	Lead
Zirconium	Chromium	Molybdenum	
Boron		Cobalt	
Vanadium		Tungsten	
		(Arsenic)	
		(Antimony)	

(   ) = Probably

Source: AIME, Basic Open Hearth Steelmaking, 1951.

Basis:
Normal 2400 F Hot Metal Uses 25% Scrap
Steel Tapping Temperature is 2925 F.



Source: Iron & Steel Engineer, June 1963, page 68.

FIGURE 4.2–1 HOT METAL TEMPERATURE VS. % OF FERROUS SCRAP IN METALLIC CHARGE

Electric Furnaces: Most electric furnace installations actually operate on 100% scrap. The extent to which various types of scrap can be utilized is determined primarily by their contained impurities and the compositional requirement of the steel product.

4.2.3.1.2 Ferrous Foundries

The principal melting methods used in the ferrous foundry industry have been discussed in Section 3.2.3.2. The major processes employed are:

Process	Iron Foundries	Steel Foundries
Cupola	X	—
Electric Arc	X	X
Induction	X	X

The cupola furnace usually operates with a scrap charge plus pig iron. The amount of pig iron in the charge is based on the quality of iron required and the quality of the scrap charged to the furnace.

Because steel scrap requires a higher melting temperature than iron scrap, the amount of steel scrap that can be charged to a cupola is restricted. In recent years, introduction of hot blast cupolas and oxygen enrichment with their higher heating capability have made feasible the use of an increased steel scrap content. The cupola cannot handle recyclable materials containing large quantities of non-volatile impurities, e.g., copper, aluminum, and tin. For efficient melting and handling, very large scrap is undesirable for the cupola.

The electric arc and induction melting furnaces are 100% scrap based melting operations. The electric arc furnace can perform some refining operations and, therefore, can handle a wider variety of scrap than the cupola. The induction furnace, on the other hand, can only handle scrap close to the composition of the final metal alloy. Both the electric arc and induction furnaces achieve high melting temperatures and can, therefore, melt 100% steel scrap charges.

4.2.3.1.3 Ferroalloys

The principal process constraint on the type of scrap that can be recycled is the physical form. The amount of scrap consumed is dependent on the ore grade and ferroalloy specification.

Ferromanganese slag can be recycled only if the plant has an integrated silicomanganese operation. The amount of ferromanganese slag that can be recycled to silicomanganese furnaces is limited by the ferromanganese slag composition, the grade of silicomanganese required, plant specific considerations and the prevailing economics of the overall integrated operation.

4.2.3.2 Quality Constraints

4.2.3.2.1 Iron and Steel

In the iron and steel industry only three unit operations are capable of processing recoverable materials: agglomeration, smelting iron ore, and steelmaking. The products (sinter or briquettes, pig iron, and steel, respectively) of these processes must meet independent compositional and physical specifications. The ability of the products to do so is dependent on the raw materials entering each process and on the process itself. In this section, the compositional limits for the three types of products are given.

Agglomerated Products: Among the primary reasons for using sinter or briquettes is an improved burden permeability and improved gas-solid contact in order to lower blast furnace coke rates and increase the rate of reaction. Agglomeration is also used to lessen the amounts of fine materials entering into the furnace and, therefore, enhance their utilization. Furthermore, agglomerated products can be substituted for lump ores in steelmaking furnaces.

A good agglomerate should "contain 60% or more of iron, a minimum of material less than ¼ inch in size and a minimum of material larger than ½ inch."[3] The agglomerate should be strong enough to withstand degradation during handling and shipment so as to arrive at the furnace with at least 85% of the material larger than ¼ inch. Within the furnace, the agglomerate must be able to withstand the high temperature and degradation forces without slumping or decrepitating. The agglomerate must also reduce at a satisfactorily high rate.

Pig Iron (for Steelmaking): Unlike agglomerated products, which are restricted as to physical properties, iron for steelmaking is constrained by chemical composition limits. These limits depend to some extent on the type of steelmaking process for which the iron is destined. The allowable composition ranges for the most important impurities in pig iron for several steelmaking processes are given in Table 4.2-15. Electric furnace steelmaking is not listed because of the relatively minor amounts of pig iron and hot metal charged to such furnaces.

Raw Steel: Each of the many types of raw steel produced by the iron and steel industry has narrow composition limits. Because of the large number of steels produced, these limits are not reproduced here. The interested reader is referred to such sources as AISI's "Steel Products Manual," or "The Making, Shaping and Treating of Steel," by United States Steel Corporation. The relationship between the compositional limits and the impurities contained in recoverable materials charged to the steelmaking furnace is discussed in Section 4.2.3.3.1.

4.2.3.2.2 Ferrous Foundries

Table 4.2-16 shows the compositional constraints for the products produced in the iron and steel foundries. In order to meet the casting grade chemical specifications, the recoverable material (scrap) that can be charged to the melting furnace is somewhat limited. For example, ductile iron castings usually require a good quality control on the metal composition and, therefore, on the scrap that can be consumed. Similarly, alloy castings require good control of impurities that might be introduced via scrap.

Each foundry has its own set of casting quality requirements based on established customer demand and product specifications. Therefore, the mix of scrap used from foundry to foundry can vary significantly.

4.2.3.2.3 Ferroalloys

Specifications on ferroalloy composition are shown in Table 4.2-17. These specifications may control the type of ferrous scrap used in the ferroalloy production.

TABLE 4.2-15

COMPOSITION RANGES OF IRON FOR STEELMAKING

Type	Composition Range (%)				
	Silicon	Sulphur	Phosphorus	Manganese	Total Carbon*
Basic Pig - Northern	1.50	0.05 max	0.400 max	1.01-2.00	3.5-4.40
In steps of	0.25	-	-	0.50	-
Basic Pig - Southern	1.50 max	0.05 max	0.700-0.900	0.40-0.75	3.5-4.40
In steps of	0.25	-	-	-	-
Acid Pig - Bessemer	1.00-2.25	0.045 max	0.04-0.135	0.50-1.00	4.15-4.40
Acid Pig - Open Hearth	0.70-1.50	0.045 max	Under 0.05	0.50-2.50	4.15-4.40
Oxygen Steelmaking Pig	0.20-2.00	0.05 max	0.400 max**	0.40-2.50	3.5-4.40

*Carbon not specified.
**Up to 2.00 percent phosphorus may be used by double slagging in the basic oxygen furnace.

Source: "The Making, Shaping & Treating of Steel," United States Steel Corp., 9th edition.

TABLE 4.2-16

FERROUS FOUNDRY SPECIFICATIONS

Type of Casting	Composition, % Silicon	Carbon	Sulfur	Phosphorus	Manganese
Gray Iron	1.0-3.0	2.5-4.0	0.02-0.25	0.05-1.0	0.25-1.0
White Iron	0.5-1.9	1.8-3.6	0.06-0.20	0.06-0.18	0.25-0.80
Malleable Iron	1.10-1.60	2.00-2.60	0.04-0.18	0.18 max	0.20-1.00
Ductile Iron	1.8-2.8	3.0-4.0	0.03 max	0.10 max	0.10-1.00
Steel	0.2-0.8	0.20-0.50	0.06 max	0.05 max	0.5-1.0

Sources: American Foundrymen's Society, Principles of Metal Casting, 1955,
Gray and Ductile Iron Founders' Society, Iron Castings Handbook, 1971.

TABLE 4.2-17

FERROALLOY SPECIFICATIONS

Ferroalloy		Composition, % Silicon	Carbon	Sulfur	Phosphorus	Manganese	Chromium
Ferrochromium:							
High Carbon	A		6.0-8.0	0.040	0.030	0.75	52.0-58.0
	B	6.0-14.0	4.0-6.0	0.040	0.030	0.75	55.0-64.0
	C	3.0	4.0-9.5	0.060	0.030	0.75	62.0-72.0
Low Carbon	A	1.0-8.0	0.025	0.025	0.030	0.75	60.0-67.0
	B	1.0	0.025	0.025	0.030	0.75	67.0-75.0
	C	1.0	0.050	0.025	0.030	0.75	67.0-75.0
	D	1.0	0.75	0.025	0.030	0.75	67.0-75.0
Vacuum Low Carbon	E	2.0	0.020	0.030	0.030	0.75	67.0-72.0
	F	2.0	0.010	0.030	0.030	0.75	67.0-72.0
	G	2.0	0.050	0.030	0.030	0.75	63.0-68.0
Nitrogen Bearing		1.0	0.10	0.025	0.030	0.75	62.0-70.0
Ferromanganese:							
Standard	A	1.2	7.5	0.050	0.35	78.0-82.0	0.50
	B	1.2	7.5	0.050	0.35	76.0-78.0	0.50
	C	1.2	7.5	0.050	0.35	74.0-76.0	0.50
Medium Carbon	A	1.0	1.5	0.020	0.30	80.0-85.0	0.50
	B	1.5	1.5	0.020	0.30	80.0-85.0	0.50
	C	0.70	1.5	0.020	0.30	80.0-85.0	0.50
	D	0.35	1.5	0.020	0.30	80.0-85.0	0.50
	Nitrided	1.5	1.5	0.020	0.30	75-80	0.50
Low Carbon	A	2.0	.10-.75	0.020	0.20	85.0-90.0	0.50
	B	5.0-7.0	0.75	0.020	0.30	80.0-85.0	0.50
Ferrosilicon:							
Steelmaking	A	92.0-95.0	0.10	0.025	0.025	0.25	0.25
	B	83.0-88.0	0.15	0.025	0.030	0.35	0.25
	C	74.0-79.0	0.10	0.025	0.035	0.40	0.30
	D	65.0-70.0	0.10	0.025	0.035	0.50	0.50
	E	47.0-51.0	0.10	0.025	0.040	0.75	0.50
	F	20.0-24.0	0.50	0.025	0.120	1.00	-
	G	14.0-17.0	0.70	0.025	0.120	1.25	-
Silicomanganese:							
Standard	A	18.5-21.0	1.5	0.04	0.20	65.0-68.0	0.50
	B	16.0-18.5	2.0	0.04	0.20	65.0-68.0	0.50
	C	12.5-16.0	3.0	0.04	0.20	65.0-68.0	0.50

Source: American Society of Testing and Materials, Annual Book of ASTM Standards, 1977

4.2.3.3 Recoverable Materials Constraints

Before a recoverable material can be utilized (recycled) in a given unit operation, its quality with respect to physical characteristics and chemical composition must conform to the specifications required by the processing unit and by the products produced. In this section, the physical and chemical requirements for the recoverable materials within the ferrous industry are described.

4.2.3.3.1 Iron and Steel

Ferrous Scrap: Approximately 30% of the raw steel produced by current industry practices is recycled as home scrap,[4] and about 70% of this is charged to the furnaces with only minimal preparation. In general, the only processing required for the remaining 30% is to cut it into manageable pieces.

Purchased scrap, composed of prompt industrial and obsolete scrap, cannot be recycled as readily as home scrap. Purchased scrap can be both physically and chemically heterogeneous and, therefore, must be segregated and prepared to conform to specification.

The ideal bulk density of scrap for steelmaking depends on the working conditions of each steel mill where scrap must be charged. Charging a mixture of various kinds of scrap, heavy and small size scrap, can be used to fill voids. Melting the scrap will be faster if the pieces present a large surface area. Unfortunately, the loss by oxidation increases with surface area. With turnings or shredder scrap, the upper part of the bath can weld together, and melting the material then becomes more difficult.

For electric furnaces producing unalloyed carbon steel, thickness of individual pieces is not as important as for open hearth furnaces. In the United States a 100% shredder charge is economically possible only with continuous melting. The proportion of turnings containing oil must be limited because of smoking and environmental problems. The optimum scrap sizes depend on furnace size.

Special attention must be paid to the non-iron content of the various kinds of scrap. Impurities reduce the value of the scrap, especially nonmetallic impurities that increase the quantity of slag as well as the consumption of energy and, hence, the melting cost. The proportion of iron oxide, the impurities consisting of zinc, tin, and coatings, and the presence of nonmetallic foreign materials may vary widely within the same category of scrap. This variability imposes restrictions on the use of scrap for certain products or processes. Copper and tin in scrap cannot be eliminated in steelmaking and are usually held within manageable limits by dilution. In a steel production process using scrap intensively, the presence of high concentrations of these elements can preclude the use of such scrap as raw material. This is particularly the case in mills that use scrap without any pig iron.

An example of the effect of No. 2 bundle scrap on residual copper and sulfur in the steel is given in Figures 4.2-2 and 4.2-3. These data show that for the example analyzed, there is a direct proportionality between the amount of scrap charged and the levels of copper and sulfur in the steel.[16] Zinc, lead, arsenic, and alkaloid metals, and PVC are also undesirable in recoverable and scrap materials in order to meet product, process or environmental constraints.

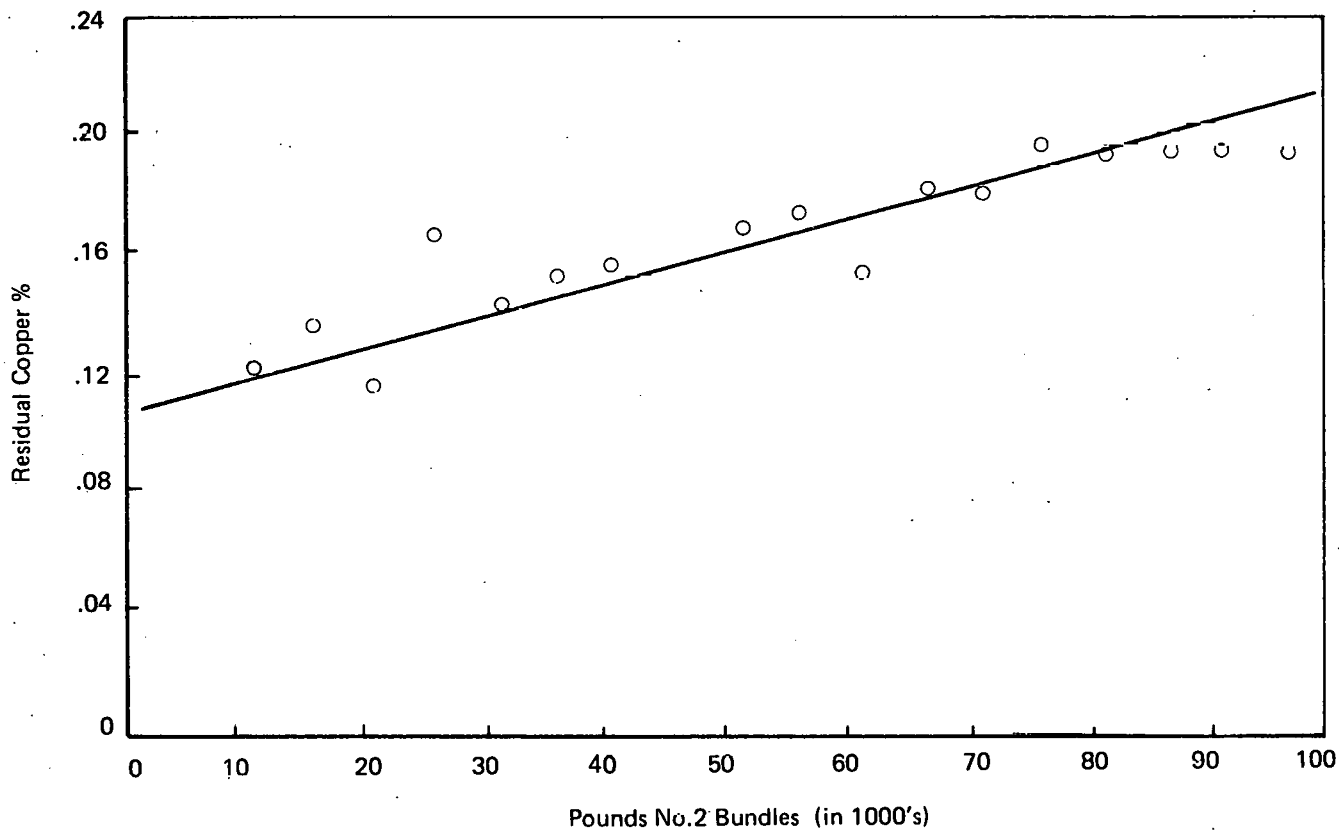


FIGURE 4.2–2 EFFECT OF NO. 2 BUNDLE SCRAP ON RESIDUAL COPPER

Source: Blast Furnace and Steel Plant, "The Operating Economic and Quality Considerations of Scrap Preheating in the Basic Oxygen Process," W.F. Kemner, December 1969.

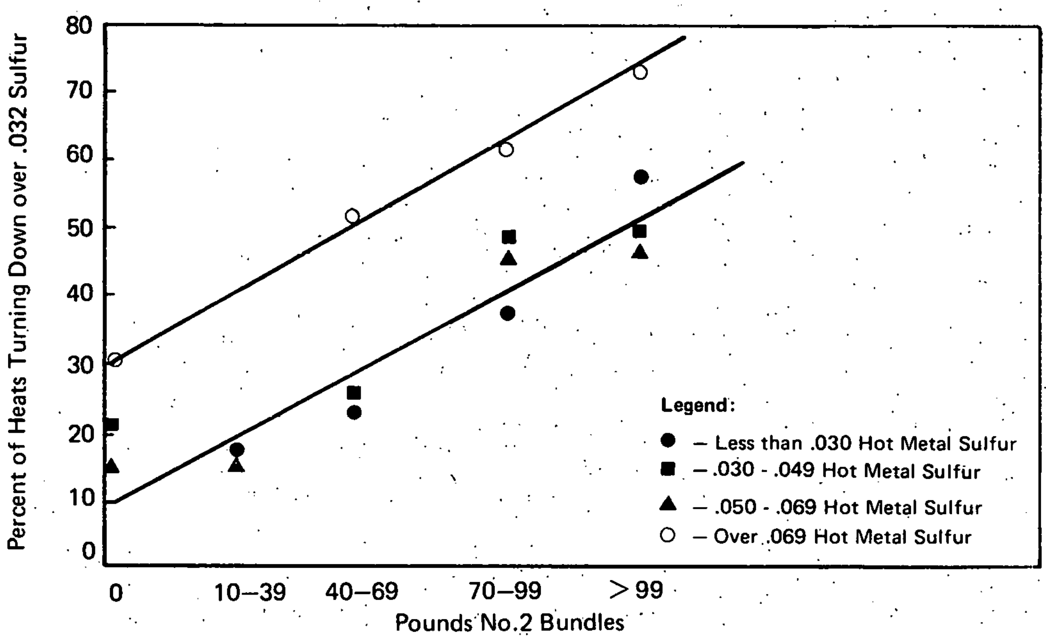


FIGURE 4.2–3 EFFECT OF NO. 2 BUNDLES AND HOT METAL SULFUR ON TURNDOWN SULFUR

Source: Blast Furnace and Steel Plant, "The Operating Economic and Quality Considerations of Scrap Preheating in the Basic Oxygen Process," W.F. Kemner, December 1969.

Slag: From a technical point of view the advantages of steel slag recycle are:

- Steel slag serves as a replacement for flux because the lime it contains is in a calcined form. This means a saving in the heat of calcination and hence leads to a small decrease in coke rate.
- Steel slag is a source of iron, manganese and other metals.

The use of sized slag instead of limestone as flux in the production of sinter of about 1.0 basicity has a beneficial effect both on the cold strength of the sinter and on its resistance to degradation during high temperature reduction.[5] The use of this sinter results in lower coke rates.

Quality constraints for recycling steel slags include tramp element content and size distribution. Tramp elements, such as manganese, alloy metal, and phosphorus are transferred to the hot metal in the blast furnace. The type of steel being made determines the allowable limit of these elements in the hot metal.

A final factor in steel slag quality is that processed slag for recycle to the blast furnace should not be stockpiled for more than 3-4 weeks. Longer stockpiling results in the hydration of free lime and the disintegration and production of fines. Both factors lead to a loss of effectiveness of the slag as a flux.

4.2.3.3.2 Ferrous Foundries

The recoverable material quality constraints are indirectly related to the process and product constraints. For example, the induction furnace is a melting unit and not a refiner; scrap for the induction furnace must be of good quality and very close to the composition of the final product, or suitable for adjustment by alloy addition. In contrast, the electric arc furnace can handle a much more diverse scrap quality because the electric arc furnace is not only a melter, but also a refiner. However, as discussed in the iron and steel section, even with electric arc furnaces, certain elements, like Cu and Sn, are difficult to remove and the scrap charge must be controlled accordingly.

The cupola is a reducing furnace, and scrap should not contain undesirable impurities which will be entrapped in the cupola metal. Though volatile impurities like lead and zinc will leave as dust, they can have deleterious effects on refractory life and are undesirable for environmental reasons. The size of scrap for the cupola is controlled by cupola size.

4.2.3.3.3 Ferroalloys

Ferrous scrap used in electric furnace ferroalloy production must be of suitable composition and physical characteristics. The acceptable level of impurities is governed by the specifications for ferroalloys shown in Table 4.2-17.

4.2.4 Economic Considerations

In 1976 the ratio of ferrous scrap consumption to production of raw steel and castings (hot metal equivalent) came to about 50%. Whether this percentage can be raised by 1987 depends on the demand and supply dynamics of the ferrous scrap market.

On the demand side, the amount of scrap that can be utilized is largely constrained by technical factors. The electric furnace accounted for 19% of 1976 raw steel production with a charge mix consisting almost entirely of scrap. The basic oxygen furnace (BOF) accounted for 62% of 1976 raw steel output; the normal scrap charge mix is 28% with cost penalties associated with deviations from this ratio dependent on plant-specific factors. The open hearth furnace, which accounts for the remaining steel production, is more flexible with regard to the charge mix. The scrap ratio in the charge can be easily changed in response to scrap price. The open hearth furnaces are rapidly being phased out, however, so the proportion of scrap utilized in making raw steel is relatively insensitive to price. In the long run, industry could change capital stock — e.g., opt for electric furnaces — and thereby increase scrap utilization.

Supply consists of "new" scrap generated by current industrial activity and immediately reused, and "old" scrap extracted from discarded steel-containing products. The amount of new scrap generated is a function of technological factors in the steelmaking and steel/consuming industries and is totally price-inelastic in both the short and long run. In principle, scrap price changes will have both a short- and long-run effect on old scrap supply. The amount of old scrap used is a function of price; the short-run effect is that higher scrap prices will make previously uneconomic scrap sources worthwhile. The long-run effect is that higher scrap prices may induce new scrap processors to come on-stream. In practice, the long-run effect is not important. Scrap processing is usually not a three-shift operation; consequently, excess capacity has always been available.

As we have seen, the percentage of steel that can be profitably produced from scrap, rather than from hot metal, is both a technical and an economic question. However, existing models tend to fall into one of two classes, neither of which adequately addresses both issues. The first class of models are those described as engineering-based, containing highly disaggregated specifications of demand and supply, but completely ignoring the role of price in equilibrating demand and supply. The second class of models are microeconomic market models in which recognition is given to the role of price. In this latter class of models the specifications of demand and supply functions do not adequately reflect the technological dynamics of the industry.

Arthur D. Little, Inc., has developed an eclectic model of the ferrous scrap market that incorporates both engineering and economic parameters in an attempt to depict realistically the technological and microeconomic factors that characterize the demand and supply dynamics. The model organizes the extensive technical knowledge concerning this market into a flexible framework that can be used to test the economic viability of a recycling target.

The information incorporated into the model includes details on: the process characteristics of scrap-using and scrap-generating activities; the inventory of obsolete iron and steel scrap; and the price elasticity of obsolete scrap supply.

The purpose of this section is to describe and document the model. The section is organized to cover: the structure of the ferrous scrap material balance, a review of existing scrap models, and an explanation of the Arthur D. Little model.

4.2.4.1 Ferrous Scrap Material Balance

Developing a consistent material balance for ferrous scrap has proved to be a difficult task. We have relied on the *Yearbook* of the Institute of Scrap Iron and Steel, Inc. (ISIS) as the basic data source. It was necessary to disaggregate the ISIS data to provide the detail that is conceptually appropriate. The disaggregation procedures used will be described later.

Table 4.2-18 contains a ferrous scrap material balance for 1976. Supply (or sources) consists of three major categories: home scrap, prompt industrial scrap, and old (obsolete) scrap. Demand (or uses) includes: steel producers, foundries, other domestic uses, and exports.

Home scrap accounted for about half of the 98 million short tons of U.S. scrap supply in 1976. This excellent quality new scrap is generated by the steel producers and foundries as part of their ongoing processing operations. These generators are also scrap consumers, so the scrap never leaves the plant — hence, the name "home." The volume of home scrap generated is directly related to the level of activity at the steelmaking and foundry facilities. Design practices also play a role. For example, rolling of widely diversified products will increase the volume of rejects, and consequently the amount of home scrap.

Prompt industrial scrap accounted for about 21% of supply in 1976. This scrap, also of excellent quality and new, is generated by the manufacturing operations in the metalworking industries. Since these industries have no need for scrap, prompt industrial scrap enters the market quickly, typically moving back to U.S. scrap consumers. The volume of prompt industrial scrap generated is a function of steel consumption. Since steel consumption can diverge from steel production (with the gap largely due to imports) the relative importance of prompt industrial and home scrap can change over time.

In 1976, much of the remaining scrap supply was old scrap. This is a highly heterogeneous category, and unlike the new scrap categories of home and prompt industrial, its composition is not well known. The sources of old scrap are the millions of short tons of steel embodied in obsolescent and discarded products. Some sources, such as railroad equipment, represent an easily accessible and known ferrous scrap source. Reclamation rates are very high for these items. On the other hand, junked consumer appliances, because of their marginal value, have low reclamation rates. Scrapped cars represent a source of intermediate economic value. The number of hulks processed is typically a high portion of the cars scrapped, but the relatively low profit margin on car processing continues to make abandoned vehicles in remote regions an unprofitable source of scrap.

On the demand side of the material balance the steel producers clearly dominate. In 1976, 69% of the U.S. scrap supply was consumed by the steelmaking and pig iron-producing furnaces.

Foundries produce ferrous castings from charges of iron and steel scrap, pig iron, and inoculants. They represent a major source of scrap demand and accounted for 21% of the 1976 supply. Foundries depend on scrap considerably more than steel manufacturers.

The remainder of the U.S. scrap consumption goes to miscellaneous domestic uses (about 2% of supply) and exports (about 8%). U.S. scrap exports have historically been quite large. Major markets are Japan (particularly for West Coast scrap dealers), Canada, and Mexico, as well as Western Europe, especially Italy and Spain. Almost all the scrap exported is old scrap.

TABLE 4.2-18

FERROUS SCRAP MASS BALANCE - 1976
(thousand short ton)

Quantity Demanded	
Basic Oxygen Furnace	26,207
Electric Furnace	25,102
Open Hearth Furnace	12,339
Foundries	20,542
Blast Furnaces	3,692
Other	2,035
Total Domestic Demand	89,916
Net Exports	7,611
Total Quantity Demanded	97,527
Quantity Supplied	
Home Scrap - Steel	41,984
Home Scrap - Foundries	6,561
Home Scrap - Blast Furnaces	1,477
Total Home Scrap	50,022
Prompt Industrial Scrap	20,761
Obsolete Scrap	20,648
Total Purchased Scrap	41,409
Inventory Adjustment	-1,515
Subtotal	89,916
Net Exports	7,611
Total Quantity Supplied	97,527

Source: Arthur D. Little, Inc. estimates.
AISI Statistical Report, 1976.

4.2.4.2 Review of Modeling Literature

Modeling of the ferrous scrap market has been the subject of both doctoral dissertations and consultant reports. Dissertations by Shriner [6] and Plater-Zyberk [7] on the ferrous scrap markets are simple efforts consisting of unconnected regression equations. Because their emphasis tends to be on testing hypotheses rather than on developing a forecasting system, they offer little that is useful in setting ferrous scrap recycling targets.

There are two major consultant reports: a study by the Industrial Economics Research Institute at Fordham University for the American Iron and Steel Institute (AISI) [8]; and a study by Robert Nathan Associates for the Metal Scrap Research and Education Foundation.[9] A third interesting, but less substantive, report is by Professor John Elliot of the Department of Metallurgy and Material Science at M.I.T. for the U.S. Bureau of Mines.[10]

The Fordham and Elliot studies can be characterized as engineering models. They contain a wealth of detail on the technology of scrap utilization and scrap generation. Their parameters are generally not based on published time series but on knowledge of practices in the steelmaking and steel-using industries; this means that these models cannot be used to replicate history.

The Elliot report contains no mention of scrap price, while the Fordham report concludes that the supply/price elasticity of old scrap is 0.07, but does not incorporate this parameter into the model. The Fordham price elasticity is based on a regression of monthly quantities against monthly price for the period 1973-1974. During this period, scrap price more than doubled with little effect on the supply, leading to a low estimated elasticity. The small increase in supply was in part due to special short run factors ignored in the regression; for example, during 1974 a shortage of gondola cars limited the shipment of scrap. Also, the number of automobiles scrapped during that period was low — a factor unrelated to scrap price — thus reducing the available scrap pool.

We are reviewing the Nathan report in some detail because it is the most recent of the three studies.

The Nathan model is based entirely on econometrics and completely ignores the technology behind scrap consumption and scrap supply. For example, in modeling the supply of home scrap, Nathan does not take into account the increasing use of continuous casting, despite the fact that the implementation of this technology will significantly reduce the amount of home scrap generated. This total reliance on econometrics is inappropriate given the overwhelming importance of technological forces in the ferrous scrap market.

Further diminishing the utility of the Nathan model is that it contains fundamental econometric flaws. For example, six of the seven equations in the Nathan model contain at least two variables with t statistics less than one.

Data Evaluation: Nathan carefully documents their data sources and in general we find no fault in their collection of publicly recorded statistics. However, when it comes to variables for which no published statistics are available, Nathan's lack of familiarity with the technology and practices in the ferrous scrap industry cause them to make mistakes. For example, the government does not publish a series on obsolete scrap supply, and Nathan created their own series. In doing so, Nathan excluded exports of scrap from their definition of obsolete scrap. As it turns out, much of the scrap exports is made up of obsolete materials, and since a significant percentage of U.S. scrap supply is exported, Nathan's exclusion causes them to seriously underestimate the quantity of obsolete scrap supplied during the year.

Conceptual Evaluation: 1) The supply of obsolete scrap depends on a) inventory and b) price. (By inventory we mean the reservoir of iron and steel potentially available for scrap recovery.) This is a very large amount and in any one year only a tiny fraction will be recovered. The actual recovery will be dependent in price, in that a higher price will justify the recovery of relatively inaccessible scrap. Nathan does not have a scrap-inventory variable in their equation to explain obsolete scrap supply. Since the effect of inventory (which is continually rising) on supply is positive, this exclusion results in over-estimating the obsolete scrap supply price elasticity, the estimation of which was a major purpose of the Nathan study.

2) The Nathan model is small and so does not contain an adequate level of disaggregation. For example, scrap consumption is not predicted separately for each of the four major user categories (foundries, electric furnaces, basic oxygen furnaces, and open hearth furnaces).

3) The equations contain superfluous variables. For example, the equation to explain the supply of purchased scrap includes the price of scrap. But about half the purchased scrap is prompt industrial, and the supply of prompt industrial scrap is totally insensitive to price.

4) The equations exclude variables. For example, the equation to predict the supply of home scrap does not include a variable to represent the effect of continuous casting on home-scrap generation.

Statistical Evaluation: 1) The relationships in the Nathan model are often statistically insignificant. Six of the seven equations in the Nathan model each contain at least two explanatory variables with t statistics less than one. Five of the seven equations contain two variables with t statistics less than 0.5. One quation contains two variables with t statistics lower than 0.1.

2) The relationships in the ferrous scrap industry are of a straightforward and technical nature. For example, an examination of historical data would show that the amount of scrap purchased for use in basic oxygen furnaces is an almost perfect linear function of the steel produced in these furnaces. Given this, it is surprising to find Nathan Associates adopting a procedure which is an anathema to experienced econometricians. The Nathan equations contain an unusually large number of independent variables. Only one equation of the seven contains less than six explanatory variables.

4.2.4.3 Data Sources for Arthur D. Little Model

In order to develop the Arthur D. Little model for this study, it was necessary to have consistent material balance, such as the one presented in Table 4.2-18. It was also necessary to obtain values for the activity variables — e.g., steel production by electric furnace — to derive the model parameters.

The source of data used for ferrous scrap material balance was the Institute of Scrap Iron and Steel, Inc. (ISIS), but the ISIS data was not in the form required for the model. In particular, the problems were:

- Foundry scrap consumption is not reported as such by ISIS; they report scrap consumption by cupolas and electric furnaces.
- There is no series on prompt industrial scrap and obsolete scrap; instead ISIS reports domestically purchased scrap.
- Home scrap is not disaggregated by generating source.

To obtain a data series on foundry scrap consumption, it was assumed that all cupola scrap was consumed by foundries along with a percentage of the electric furnace scrap. This allocation was determined by subtracting the amount of scrap used in steelmaking electric furnaces, as given by AISI, from the total amount of scrap consumed in electric furnaces, as given by ISIS.

To develop a series on prompt industrial scrap and obsolete scrap, a variant of the procedure adopted by Robert Nathan Associates was used. Nathan develops a prompt industrial scrap series by multiplying steel-using activity by a prompt industrial generation factor. The excess of domestically purchased scrap over prompt industrial scrap (with some allowance for losses) was then treated as old scrap supply. The Nathan procedure seriously underestimated the U.S. supply of old scrap, since it ignored the fact that the United States exports a significant amount of scrap — almost all old.

The Arthur D. Little, Inc., prompt industrial scrap series is in essence the one used by Nathan, except that it is based on more recent revised data. In deriving the Arthur D. Little old scrap series, the excess of purchased over prompt industrial scrap was first calculated. Next, exports were added to the result of the preceding operation to give obsolete scrap supply.

Total home scrap, as reported by ISIS, was disaggregated by Arthur D. Little, Inc., into the amount generated by pig iron production, raw steel production, and foundries. Engineering-based parameters were multiplied by activity levels to develop a home scrap series by source. Not surprisingly, adding up the values for these three sources gave a figure that did not agree with the ISIS home scrap total. Consequently, the numbers were "calibrated" to force consistency with the reported data.

The activity variables required for the Arthur D. Little model consist of data on the production levels in the steel and foundry industry. The source of data for steel variables was the American Iron and Steel Institute (AISI), *Annual Statistical Report.* For the foundry industry, the source was the U.S. Department of Commerce, Bureau of the Census, *Current Industrial Reports: Series M33A.* The Arthur D. Little model also required an inventory of old scrap. This was obtained from the Fordham Study which obtained an inventory analysis originally done by Battelle.[11]

4.2.4.4 Description of Model

The Arthur D. Little model for ferrous scrap is articulated to determine the percentage of scrap that can be economically recycled in a given year. The model forecasts the ferrous scrap material balance for the year and the price of scrap that will bring about such balance. In the model, a given material balance reflects assumed values for demand and supply parameters; changing the demand parameter values will change the scrap consumption levels and, therefore, the percentage of metal that is recycled. Changed scrap consumption will, of course, mean a new material balance and a new equilibrium scrap price. Thus, the Arthur D. Little model can trace out the scrap price corresponding to a given target. Targets are not always economically rational; consequently, the model has built into it logic statements that test the feasibility of a target.

Figure 4.2-4 contains a schematic exposition of the model logic and Tables 4.2-19 to 4.2-21 document the model. As the figure demonstrates, the model contains a Demand Module, a (New) Scrap Supply Module, and an Integration Module. These modules, or blocks, are recursively linked. Specifically, demand for scrap and supply of new scrap (home and prompt) is predicted, using known technological relationships. The excess of demand over new scrap supply constitutes the requirement for old scrap. The Integration Module solves for the scrap price necessary to bring forth the required old supply.

The model's recursive structure may be criticized for ignoring the simultaneity of the market. Open hearth furnaces do change their scrap utilization in response to the ratio of scrap price to pig iron price. Also BOF's faced with an extremely low scrap-to-pig price ratio could, in theory, conceivably opt for preheating and so raise their scrap demand. However, historical data do not indicate any responsiveness of BOF scrap utilization to scrap price. Therefore, from the data, at least, demand appears to be price-inelastic.

4.2.5 Special Considerations

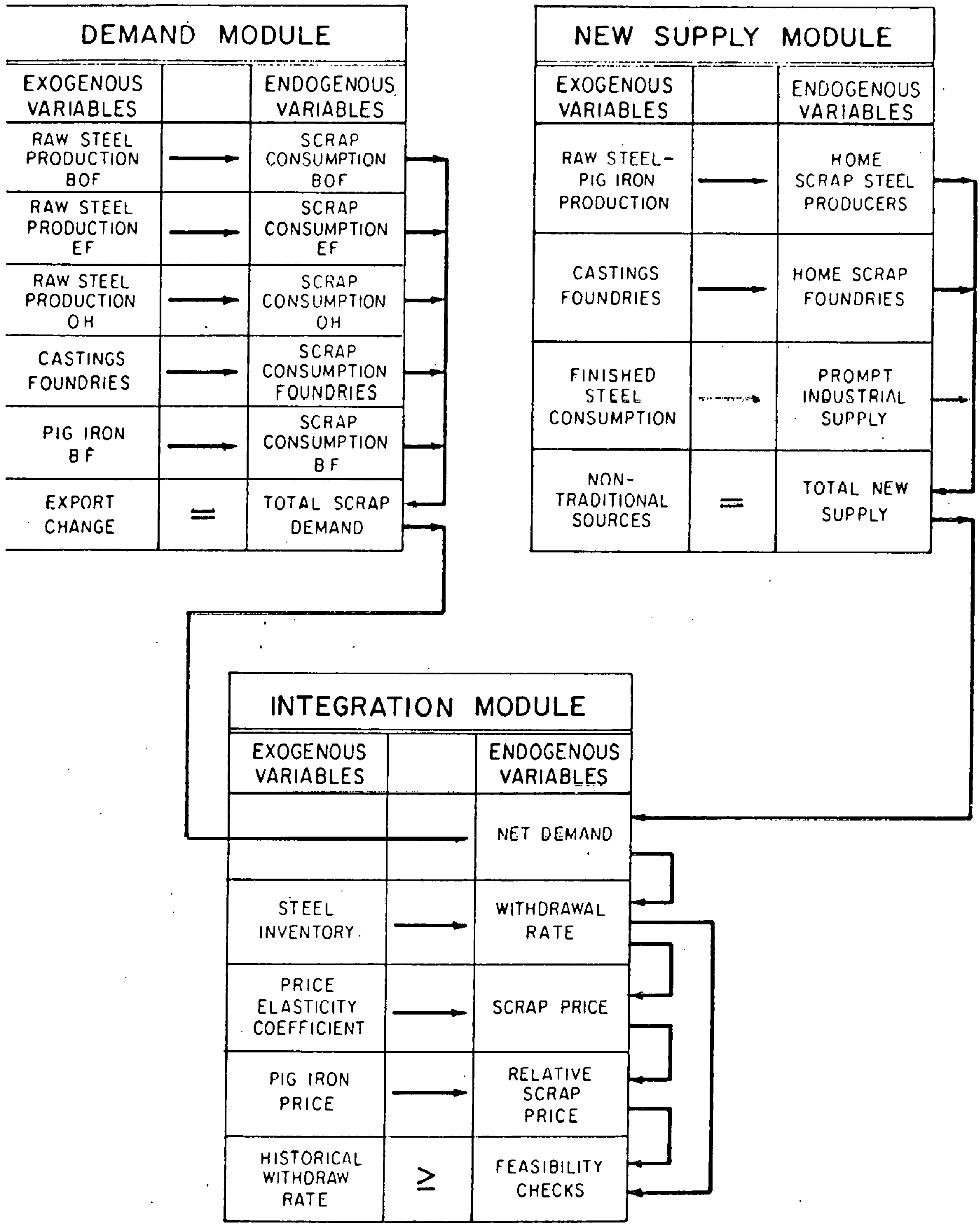
Several factors must be considered in analyzing the consumption of recoverable materials by the ferrous industries. The technical and economic considerations have been discussed in Sections 4.2.3 and 4.2.4. Some of the other considerations not included in those sections are:

- Steelmaking furnace process mix in 1987
- Variable use of scrap by basic oxygen furnaces
- The trend toward continuous casting
- Scrap substitutes

Because these considerations are of special importance in determining future recycling targets for the ferrous industry, they are discussed in this section.

4.2.5.1 Expected Process Mix in 1987

In 1960, the percentages of total raw steel produced by open hearth and basic oxygen furnaces were 87.0% and 3.3%, respectively. By 1976, these percentages had so drastically changed that basic oxygen furnaces accounted for 62.4% and open hearths only 18.4% of raw steel production. In the same period, the percentage of raw steel produced by electric arc furnaces grew from 8.4% to 19.3%.[12]



FERROUS SCRAP MODEL SCHEMATIC

FIGURE 4.2-4

TABLE 4.2-19

EQUATIONS OF THE FERROUS SCRAP MODEL

Equation Number	Module	Endogenous Variable	Explanatory Segment
1	Demand	SCBOF	d1 * BOFS
2	Demand	SCEF	d2 * EFS
3	Demand	SCOH	d3 * OHS
4	Demand	SCBF	d4 * BFP
5	Demand	SCFN	d5 * FNC
6	Demand	SCT	SCBOF + SCEF + SCOH + SCBF + SCEN + SCO
7	Demand	SCD	SCT + XSC ± SA
8	New Supply	HSRS	s1 * RS
9	New Supply	HSBF	s2 * BFP
10	New Supply	HSFN	s3 * FNC
11	New Supply	PIS	s4 * FSC
12	New Supply	TNS	HSRS + HSBF + HSFN + PIS
13	New Supply	TNPES	TNS + NID
14	Integration	NDS	SCD - TNPES
15	Integration	PSC	e1 + e2 (NDS/INV)
16	Integration	PRSCP	PSC/PPIG
17	Integration	(NDS/INV)	If ≥ 0.015 Solution = Nonfeasible
18	Integration	RPSCP	If ≤ 0.40 or ≥ 0.60 Solution = Nonfeasible

TABLE 4.2-20

DEFINITION OF VARIABLES - FERROUS SCRAP MODEL

DEMAND MODULE

Endogenous Variables

1. SCBOF = Consumption of scrap by basic oxygen furnaces (BOF)
2. SCBF = Consumption of scrap by blast furnaces (BF)
3. SCEF = Consumption of scrap by electric furnaces (EF)
4. SCFN = Consumption of scrap by foundries
5. SCO = Other scrap consumption
6. SCOH = Consumption of scrap by open hearth furnaces (OH)
7. SCT = Total domestic scrap consumption

Exogenous Variables

1. BOFS = Raw steel production by BOF
2. BFP = BF pig iron production
3. EFS = Raw steel production by EF
4. SCO = Other scrap consumption
5. XSC = Scrap exports
6. SA = Statistical adjustments
7. SCD = Total scrap demand

NEW SUPPLY MODULE

Endogenous Variables

1. HSRS = Home scrap production by steel producers
2. HSBF = Home scrap production by pig iron producers
3. HSFN = Home scrap production by casting producers

TABLE 4.2-20

(Continued)

4. PIS = Prompt industrial scrap supply

5. TNPES = Total non-price elastic scrap supply

6. TNS = Total new scrap supply

Exogenous Variables

1. FSC = Finished steel consumption

2. RS = Raw steel production

3. NID = Scrap from new technologies, e.g., urban waste

INTEGRATION MODULE

Endogenous Variables

1. NDS = Net requirement for old scrap

2. PSC = Price of scrap

3. RPSCP = Relative scrap to pig price

Exogenous Variables

1. INV = Scrap inventory

2. PPIG = Price of pig

TABLE 4.2-21

DEFINITION OF PARAMETERS - FERROUS SCRAP MODEL

DEMAND MODULE

1. d1 = BOF scrap charge coefficient
2. d2 = EF scrap charge coefficient
3. D3 = OH scrap charge coefficient
4. d4 = BF scrap charge coefficient
5. d5 = Foundry castings production

NEW SUPPLY MODULE

1. s1 = Steel home scrap generation rate
2. s2 = Pig iron home scrap generation rate
3. s3 = Casting home scrap generation rate
4. s4 = Prompt industrial generation rate

INTEGRATION MODULE

1. e1 = Withdrawal constant
2. e2 = Withdrawal price slope

The decline of the open hearth furnace and concurrent increase in basic oxygen and electric arc furnace production can be attributed to several factors. Foremost among these is that the cost of production is higher for open hearths than for competitive processes. In recent years this differential has been exacerbated by the need for pollution control devices. Other factors include the increased productivity of the basic oxygen furnace and the proliferation of small scale "mini mills" that produce raw steel from local sources of ferrous scrap or, in a few cases in the United States, direct reduced iron.

The trend away from open hearth furnaces is expected to continue. Predictions [13,14] of the percentage of total raw steel produced by open hearths for 1987 range from 0% to 10%. Industry observers[14] indicate that by 1987 the primary role for open hearths will be in handling swings in steel demand, with basic oxygen furnaces and electric arc furnaces providing most of the raw steel production.

This prediction of steelmaking process mix is important when estimating recycle targets in that each furnace has distinct scrap utilization requirements. Electric arc furnace installations are generally not located near a ready supply of hot metal and are normally operated with charges consisting primarily of scrap or even 100% scrap. The basic oxygen furnace is constrained by the thermal balance within the furnace to operate with a maximum scrap charge of about 28-30%. In contrast, open hearth shops are extremely flexible with regard to scrap utilization and can operate with virtually any scrap proportion in the metallic charge.

A change in the process mix of the three steelmaking furnaces could therefore significantly affect overall scrap utilization as a fraction of steelmaking furnace charge. This has not been true, however, for the period 1960-1976, during which the overall scrap ratio has been surprisingly constant, averaging 45.2% with a standard deviation of 0.6%, despite dramatic shifts in the process mix (Table 4.2-22).

A number of scenarios are presented in Section 4.2.6 in order to quantify the target under different process mix situations.

4.2.5.2 Scrap Use by Basic Oxygen Furnaces

Basic oxygen furnaces consumed 26.20 million short tons of ferrous scrap and 66.1 million short tons of hot metal in 1976 to produce 79.9 million short tons of raw steel.[12] These statistics indicate that in 1976 ferrous scrap in the basic oxygen furnace metallic charge averaged about 28% scrap. Historically, scrap as a percentage of the charge to the basic oxygen furnace has varied between 26.9 and 30.6%. The iron and steel industry would like to reduce its dependence on purchased scrap since its supply and prices fluctuate widely.

The basic oxygen process utilizes ferrous scrap (and, to a lesser extent, iron oxides), not only as a source of iron units, 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 smooth operation that is characteristic of the process.

Theoretically, raising the hot metal temperature by 100°F would allow an increase of 67 pounds of scrap per ton of hot metal, or about two percentage points of the charge. Other techniques of increasing scrap usage in the BOF include the addition of external energy sources to

TABLE 4.2-22

SCRAP IN FURNACE CHARGE AS A PERCENTAGE OF RAW STEEL PRODUCTION - BY FURNACE TYPE (1960-1976): IRON AND STEEL SEGMENT

	Basic Oxygen		Open Hearth		Electric		All Steelmaking Furnaces
Year	% Steel Production	% Scrap in Charge	% Steel Production	% Scrap in Charge	% Steel Production	% Scrap in Charge	% Scrap in Charge
1976	62.4	28.4	18.4	44.1	19.2	98.4	44.7
1975	61.6	28.3	19.0	44.5	19.4	96.8	44.7
1974	56.0	28.6	24.4	45.8	19.6	97.0	46.2
1973	55.2	28.7	26.4	44.5	18.4	96.9	45.4
1972	56.0	28.7	25.2	45.46	17.8	97.0	45.3
1971	53.1	28.9	29.5	43.6	17.4	97.9	45.2
1970	48.1	30.0	36.5	45.0	15.4	99.0	46.0
1969	42.7	29.9	43.2	45.1	14.1	98.6	46.2
1968	37.1	29.1	50.1	44.1	12.8	97.4	45.4
1967	32.7	29.4	55.7	41.6	11.6	98.0	44.2
1966	25.3	29.0	63.4	41.5	11.0	98.4	44.4
1965	17.4	29.6	71.6	41.6	10.5	99.7	45.5
1964	12.1	30.6	77.2	41.2	9.9	97.9	45.2
1963	7.8	28.0	81.3	41.0	10.0	98.0	45.3
1962	5.6	26.9	84.3	40.3	9.2	97.8	44.5
1961	4.0	27.9	86.2	40.9	8.8	97.3	45.0
1960	3.3	28.1	87.0	41.7	8.4	96.4	45.3

ource: AISI Annual Statistical Reports, 1960-1976.

Average: 45.21

Standard Deviation: 0.59

the charge, such as silicon, minimizing heat losses of the process, or preheating the scrap. There are practical and economic limitations to implementing these concepts, however. On a limited scale, the Alan Wood basic oxygen furnace operation (now closed down)[18,19] demonstrated that scrap charge ratios up to about 45% could be achieved through scrap preheating. Inland Steel also uses scrap preheating to increase the percentage of scrap in a basic oxygen furnace charge.[20] The economics of scrap preheating are primarily influenced by the relative costs of hot metal and scrap. The issue of hot metal capacity is of prime concern. Integrated plants in which the rate of raw steel production is limited by hot metal production find preheating an economically attractive alternative to installing another blast furnace. Conversely, plants that are limited by steelmaking capacity will not, in general, consider preheating. Other economic factors, such as fuel availability and cost, are also important. Given the large variations in scrap price with location, the question of preheating economics is very site-specific. Preheating also involves the broader question of the quality of energy consumed for steel production; i.e., oil or gas in preheating of scrap versus coal for iron production.

On the other hand, the industry is anxious to reduce its dependence on purchased scrap because of the uncertainties of the scrap market. The concern is so strong that future integrated plants are being designed to be completely independent of the purchased scrap market. This could have an effect of reducing the ratio of purchased scrap to furnace charge in the foreseeable future.

The approach taken in this investigation is that, although it is possible to change basic oxygen furnace scrap demand coefficients, it is not likely that the ratio will change significantly by 1987. Thus, scrap coefficients have been estimated for 1987 to be identical to current values.

4.2.5.3 The Trend Towards Continuous Casting

The share of domestic steel output continuously cast equalled 11.8% (14.3 million net short tons) in 1977. This output was an increase of 12% over the 1976 value and almost four times that of 1969.[16]

Since its debut in 1964, continuous casting technology has steadily grown within the U.S. iron and steel industry; 46 companies currently operate approximately 84 casters at 64 different locations. The total number of strands is close to 320 with billet casters representing about 70% of the facilities, followed by slab casters at approximately 27%, and bloom units at 2%.[16]

Energy, yield, and productivity gains and its compatibility with electric arc furnace operations have made continuous casting an attractive alternative to conventional ingot casting within the iron and steel industry. The improvement in yield associated with continuous casting is pertinent to this study. Elliott[10] has estimated the average yield, defined as short tons of finished steel per ton of raw steel, to be 0.79 for continuous casting compared with 0.69 for conventional casting. Hogan and Koelble[8] have estimated these yields to be 0.78 and 0.70, respectively.

The improvement in yield is due primarily to a reduction of ingot cropping and subsequent hot-rolling losses. Several steps in the conventional route are eliminated by continuous casting, namely, teeming the molten steel into ingot molds, stripping the molds from the ingots, placing the ingots in the soaking pits to develop an even temperature, and primary rolling by which the ingots are transformed into intermediate steel shapes. Increased yield necessarily means decreased home scrap generation rates per ton of steel produced.

Predictions of the percentage of total raw steel to be produced by continuous casting in 1987 range from about 20% to 30%. In the target analysis presented in Section 4.2.6, 25% continuous casting is used in all scenarios.

4.2.5.4 Scrap Substitutes

Iron oxides (ore, mill scale, etc.) and directly reduced iron can be partially substituted for ferrous scrap in steelmaking furnaces, although this is presently not common practice in the domestic industry. The potential does exist, however, for substantial quantities of ferrous scrap to be displaced by these substitutes, particularly direct reduced iron, in the future.

It is possible to substitute iron oxides for scrap as a coolant in the basic oxygen furnace. According to published reports, about 0.35 short tons of iron ore can be substituted for each ton of scrap.[10] Although such substitution is not common practice in the United States, it is used extensively elsewhere in the world where hot metal may be plentiful and scrap is limited or scarce and therefore expensive. Unless the ferrous scrap supply in this country should become exceedingly tight, iron oxide substitution will probably not be practiced to any appreciable extent by 1987.

Direct reduced iron offers a much greater potential than oxides as a scrap substitute. New iron oxides (oxide pellets, lump ore, etc.) can be partially reduced in the solid state by reaction with a reductant at a temperature of about 1800°F. These reduced materials, known as direct reduced iron, can contain up to 95% of their iron content in the metallic state. They can partially or completely replace ferrous scrap in the steelmaking electric arc furnace. They can also be charged to the blast furnace to increase its productivity or be used in the steelmaking furnace in lieu of scrap and as a cooling agent.[17]

Despite the fact that many firms will design, engineer, and construct direct reduction plants and that interest in making steel by this route will be maintained, total production of direct reduced iron in the United States is not expected to exceed a few million short tons by 1987.[16] The recycling target analysis in Section 4.2.6 includes the consumption of 2 million short tons prereduced iron in 1987. This figure is based on published literature[16] and Arthur D. Little, Inc. estimates.

4.2.6 Target Estimation

4.2.6.1 Introduction

The objective of this section is to present the 1987 recycling targets for the ferrous industries (iron and steel, ferrous foundries, and others including ferroalloys). Recycling targets have been computed for a number of probable "scenarios." The scenarios were based on analyses of historical data, discussions with various industry contacts, and Arthur D. Little, Inc. estimates. The econometric model discussed in Section 4.2.4 was used to determine whether or not a given scenario resulted in an acceptable target in the context of scrap availability and the economic viability. The nine scenarios presented in this section fulfilled these conditions.

4.2.6.2 Scenarios Analyzed

Supply and demand coefficients and other assumptions for 1987 used in each of the nine scenarios are presented in Table 4.2-23. The supply and demand coefficients for 1975 and 1976 are

TABLE 4.2-23

LIST OF MODEL PARAMETERS AND ASSUMPTIONS
FOR THE NINE SCENARIOS ANALYZED
FERROUS INDUSTRY

Parameter	Units	1975	1976	1987 CASE I (Base Case)	CASE II	CASE III	CASE IV	CASE V	CASE VI	CASE VII	CASE VIII	CASE IX
A. Supply and Demand Coefficients												
Basic Oxygen Furnace scrap charge coefficient	ton/ton raw steel	0.326	0.328	0.326	*	*	*	*	*	*	*	*
Electric Arc Furnace scrap charge coefficient	ton/ton raw steel	1.015	1.020	1.030	*	*	*	*	*	*	*	*
Open Hearth Furnace scrap charge coefficient	ton/ton raw steel	0.532	0.526	0.528	*	*	*	*	*	*	*	*
Blast Furnace scrap charge coefficient	ton/ton hot metal	0.049	0.042	0.040	*	*	*	*	*	*	*	*
Foundry scrap charge coefficient	ton/ton casting shipments	1.230	1.226	1.230	*	*	1.300	*	1.300	*	*	*
Steel home scrap generation rate	ton/ton raw steel	0.332	0.328	0.300	*	*	*	*	*	*	*	*
Pig iron home scrap generation rate	ton/ton hot metal	0.017	0.017	0.022	*	*	*	*	*	*	*	*
Casting home scrap generation rate	ton/ton casting shipments	0.396	0.392	0.370	*	*	*	*	*	*	*	*
Prompt industrial generation rate	ton/ton finished steel consumed	0.203	0.205	0.205	*	*	*	*	*	*	*	*
Price elasticity		0.64	0.64	0.64	*	*	*	*	*	*		
B. Industry Activities												
Total raw steel production	thousand net tons	116,640	128,000	173,820	*	*	*	*	*	166,460	*	*
Basic Oxygen Furnace raw steel production	thousand net tons	71,804	79,923	117,834	111,401	122,804	*	116,373	122,804	114,425	112,983	107,768
Electric Arc Furnace raw steel production	thousand net tons	22,675	24,614	47,296	45,037	42,325	*	40,066	42,325	43,712	52,146	57,361
Open Hearth Furnace raw steel production	thousand net tons	22,162	23,475	8,691	17,328	*	*	17,382	*	8,323	8,691	8,691
Blast Furnace production	thousand net tons	79,923	86,870	104,730	104,670	108,600	*	108,540	108,600	101,710	*	*
Foundry casting shipments	thousand net tons	15,109	16,750	21,980	*	*	*	*	*	*	*	*
Apparent Steel Supply[1]	thousand net tons	89,016	101,078	142,470	*	*	*	*	*	136,440	*	*
Inventory of obsolete scrap	million tons	2,356	2,445	2,826	*	*	*	*	*	*	*	*
Overall yield for iron & steel sector	ton finished steel/ton raw steel	.6955	.6988	.72	*	*	*	*	*	*	*	*
C. Assumptions												
Finished steel production/Growth rate	percent per annum				*	*	*	*	*	1.6	*	*
Finished steel consumption/Growth rate	percent per annum			2.0	*	*	*	*	*	1.6	*	*
Steelmaking furnace mix												
Basic Oxygen	percent	61.56	62.44	67.8	64.1	70.7	*	67.0	70.7	65.8	65.0	62.0
Open Hearth	percent	19.00	18.33	5.0	10.0	*	*	10.0	*	*	5.0	5.0
Electric Arc	percent	19.44	19.23	27.2	25.9	24.3	*	23.0	24.3	25.2	30.0	33.0
Raw steel by continuous casting	percent	8.5	10.5	25.0	*	*	*	*	*	*	*	*

*Same as the Base Case.

[1]Apparent Steel Supply = Total Net Shipment Less Exports Plus Imports.

Sources: AISI Annual Statistical Reports; 33 Metal Producing, World Steel Industry 1978 Data Handbook, Vol. 1; Arthur D. Little, Inc. estimates.

also presented for comparison. Some of the key factors in the ferrous industry, which will affect the 1987 recycling target and which have many uncertainties built into them, are:

- The percentage of continuous cast steel
- Foundry scrap charge coefficient
- Total raw steel production
- Mix of steelmaking furnaces

The variations in the key factors are presented in nine scenarios. Case I, the base case, is considered the most likely. The other cases are considered plausible. Cases II, III, V, VIII and IX are based on variations in the mix of steelmaking furnaces. Cases IV and VI presume a higher foundry scrap charge coefficient. Case VII projects a lower overall annual growth rate for the iron and steel sector. In order to minimize the number of scenarios, the percentage of continuous cast steel has been fixed at 25% of total steel production for all cases.

4.2.6.3 Basis of Coefficients Used in the Analysis

The basis of the coefficients for 1987 are:

Finished Steel Production: The prediction of raw steel production in 1987 was arrived at by dividing the estimated 1987 finished steel production by the estimated overall yield for the iron and steel industry in that year. This procedure was adopted because finished steel production can be predicted with reasonable accuracy from historical trend data whereas overall industry yield, and therefore raw steel production, cannot be.

The prediction of future production levels requires an estimate of *current production* and *rate of growth.* The base year for this study was 1976. During 1976 finished steel production, as measured by total net shipments of finished steel, equalled 89.4 million tons, according to AISI.[12] This production level was much lower than would normally be expected of the overall condition of the U.S. economy in 1976. To account for this, 1976 production levels were normalized so that predictions of 1987 levels (made with 1976 data) would be for "normal" operating conditions.

The procedure used in normalizing 1976 finished steel shipments was as follows. A trend line for finished steel shipments for the recent past (1959-1976) was determined by linear regression. This trend line is compared with actual historical data in Figure 4.2-5. As indicated, "normal" production for 1976 as predicted by the regression equation is 100.65 million net tons. This production is equivalent to 144.03 million net tons of raw steel using an average yield of 0.6988 tons of finished steel per ton of raw steel, which, according to AISI,[12] was the actual overall yield in the iron and steel industry in 1976. Since total raw steel capacity was estimated by AISI to be 158.3 million net tons in 1976,[12] this is equal to a 91% capacity utilization.

The quantity of finished steel production for 1987 was calculated by increasing the normalized 1976 level according to an average annual rate of growth. The equation used in estimating 1987 levels was:

$$P_{1987} = P_{1976}\,(1+i)^n$$

where P_{1987} and P_{1976} denote 1987 and 1976 finished steel production, respectively, i is the average annual rate of growth and n is the number of years between 1976 and 1987 (eleven). An analysis of

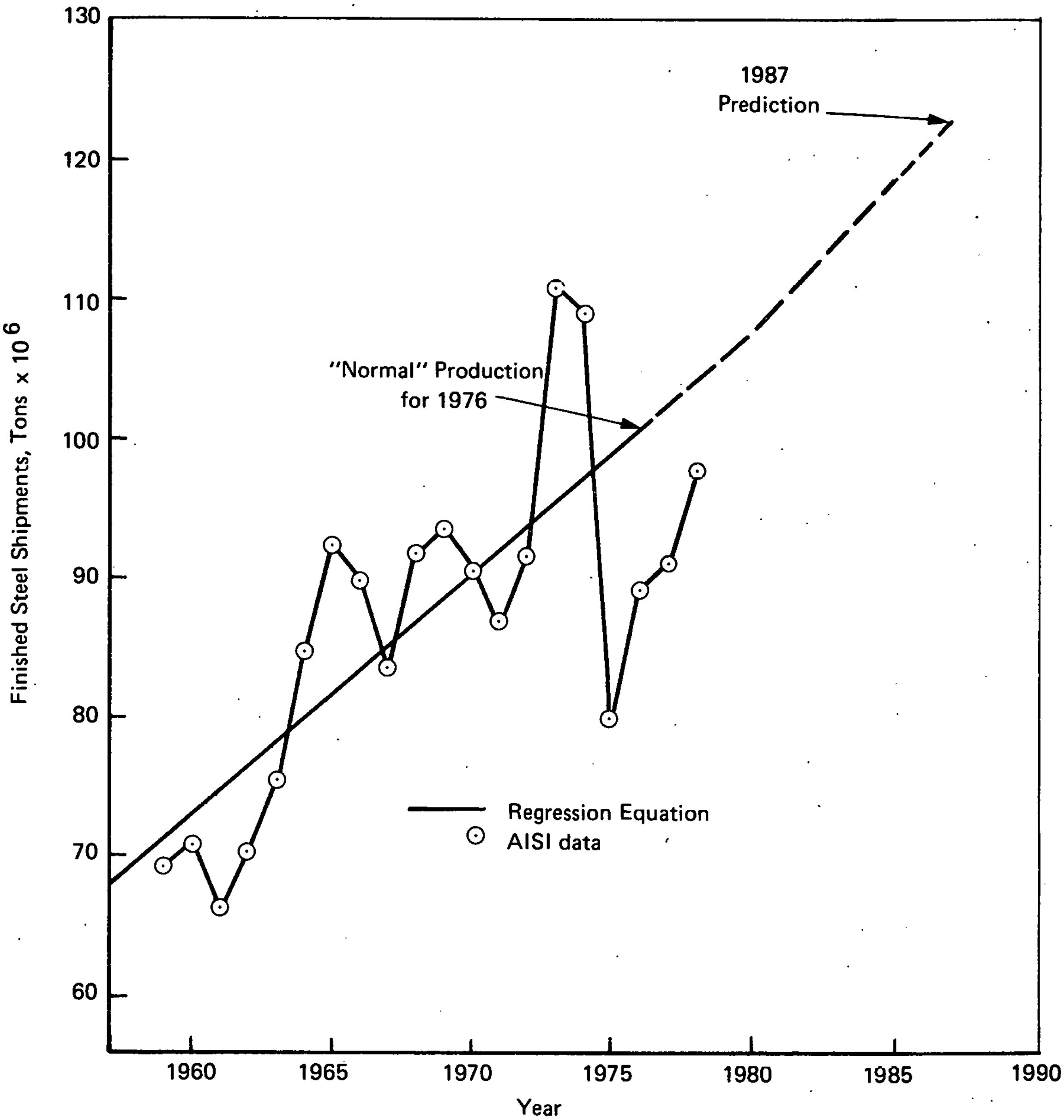


FIGURE 4.2–5 COMPARISON OF FINSISHED STEEL PRODUCTION (AS MEASURED BY SHIPMENTS) WITH PROJECTED TREND LINE

the historical data indicates that the growth rate of finished steel production has been sporadic and has ranged from 1.5 to 2.5 percent. Discussions with individuals in the industry indicated that the expected growth rate is in the 1.5-2.0% range. In all but one of the scenarios analyzed here the growth rate was taken to be 2.0 percent.

Overall Yield for the Iron and Steel Sector: The yearly average yields (tons of finished steel shipped per ton of raw steel produced) for the period 1959-1976 are given in Table 4.2-24. These values were calculated from AISI data.[12] As shown, the average yield for the industry has ranged from a low of 0.6685 in 1964 to a high of 0.7503 in 1951. The spread in these data is due to many factors, including uncertainties in raw steel production and changing operating practices. What is significant about this table is that overall yield cannot be calculated from historical data.

The method used in this study to estimate overall yield was based on the presumption that the overall yield can be partitioned between continuous casting operations and ingot casting operations.[10] Hence, the equation used to estimate overall yield was:

$$Y_{overall} = Y_{concast}\,F_{concast} + Y_{ingot}\,(1\text{-}F)_{concast}$$

where $Y_{overall}$, $Y_{concast}$ and Y_{ingot} are the overall, continuous caster and ingot yields, respectively and $F_{concast}$ is the fraction of raw steel processed through continuous casters. Based on the literature[8,10] and discussions with industry experts, Y_{ingot} and $Y_{concast}$ were estimated to be 0.69 and 0.79, respectively. As has been discussed, the fraction of raw steel produced through strand-casting was estimated to be 25% for 1987. Thus the overall industry yield was calculated to be 0.72 tons of finished steel per ton of raw steel. This compares with 0.6988 tons of finished steel per ton of raw steel in 1976, an increase of 3%. It is important to note that, given the variation in historical yields shown in Table 4.2-24, it would be wrong to assume that the 1987 overall yield could be estimated with any higher degree of accuracy, that is, specifying four or five significant figures.

Finished Steel Consumption: Apparent steel supply is defined by AISI to be total net shipments less exports plus imports. It is therefore a measure of domestic finished steel consumption. The apparent steel supply was used within the Arthur D. Little, Inc., econometric model to calculate the quantities of prompt industrial scrap generated in 1987; that is,

$$PIS = S4 * FSC$$

where PIS denotes prompt industrial scrap supply, S4 the prompt industrial scrap generation factor and FSC the finished steel consumption.

As with the finished steel production level, the apparent finished steel supply had to be estimated for 1987 from 1976 data. This was done in a completely analogous manner as for finished steel production. A regression line was determined for the recent past (1959-1976) using standard techniques, as shown in Figure 4.2-6. From this regression line, the "normalized" 1976 steel consumption was computed to be 114.58 million net tons. This value was then extrapolated into the future using the compound growth equation and an average annual growth rate, which was equal to 2% per year for the base case. Thus, the estimated finished steel consumption for the 1987 base case equalled 142.47 million net tons.

TABLE 4.2-24

AVERAGE ANNUAL YIELDS FOR THE U.S.
IRON AND STEEL INDUSTRY (1951-1976)

YEAR	STEEL SHIPMENTS Net Tons	RAW STEEL PRODUCED Net Tons	AVERAGE YIELD Ton/Ton
1976	89,447	128,000	0.6988
1975	79,957	116,642	0.6855
1974	109,472	145,720	0.7512
1973	111,430	150,799	0.7389
1972	91,805	133,241	0.6890
1971	87,038	120,443	0.7226
1970	90,798	131,514	0.6904
1969	93,877	141,262	0.6646
1968	91,856	131,462	0.6987
1967	83,897	127,213	0.6595
1966	89,995	134,101	0.6711
1965	92,666	131,462	0.7049
1964	84,945	127,076	0.6685
1963	75,555	109,261	0.6915
1962	70,552	98,328	0.7175
1961	66,126	98,014	0.6747
1960	71,149	99,282	0.7166
1959	69,377	93,446	0.7424
1958	59,914	85,255	0.7028
1957	79,895	112,715	0.7088
1956	83,251	115,216	0.7226
1955	84,717	117,036	0.7239
1954	63,153	88,312	0.7151
1953	80,152	111,610	0.7181
1952	68,004	93,168	0.7299
1	78,929	105,200	0.7503

Source: AISI Annual Statistical Reports, 1960-1976.

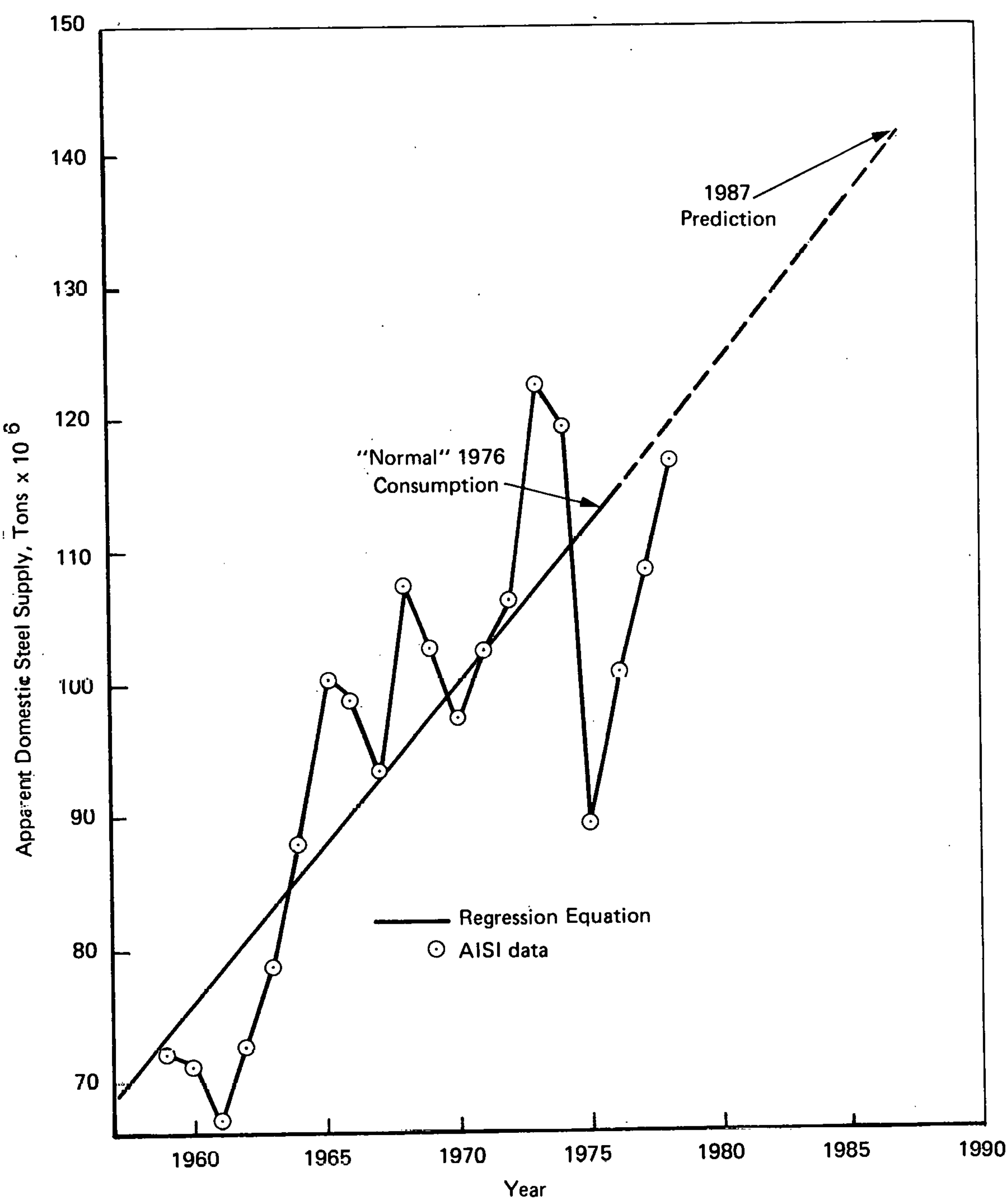


FIGURE 4.2–6 COMPARISON OF APPARENT STEEL SUPPLY (A MEASURE OF FINISHED STEEL CONSUMPTION) WITH PROJECTED TREND LINE

As noted above, consumption of finished steel was assumed to increase at an average annual growth rate of 2% until 1987. This figure is based on Arthur D. Little's input/output model of the U.S. economy. The Department of Commerce projects a growth of about 2.2%. Historically, finished steel consumption has averaged approximately 2.5% annually.

Steelmaking Process Mix: The percentages of raw steel produced by basic oxygen, electric arc, and open hearth furnaces in 1987 were determined as follows:

(1) The growth in raw steel production was split between the basic oxygen furnace and the electric arc furnace, either on a 1:1 basis or a 2:1 basis. An analysis indicated that a 1:2 split would be unlikely because it would impose serious pressures on scrap prices and supply. A 1:1 split was selected for the base case.

(2) Raw steel produced by open hearth furnaces was calculated by assuming that 5% or 10% of total raw steel would be produced by open hearths in 1987. Numerous references cite the proportion of raw steel from open hearths in the mid-eighties to be 5-10%. A 5% figure was assumed for the base case.

(3) The decrease in open hearth production after 1976 was apportioned between basic oxygen and electric arc furnaces on the basis of hot metal displaced The increase in basic oxygen furnace production caused by the open hearth decline was estimated by dividing the displaced hot metal quantity by the 1987 basic oxygen furnace scrap demand coefficient.

(4) Total basic oxygen production in 1987 was determined by adding Step 1 and Step 3 values to the 1976 basic oxygen furnace production figures on the historical trend line.

(5) Total electric arc production in 1987 was found by subtracting basic oxygen and open hearth furnace production from total raw steel production. This result was checked against projections by industry contacts, Arthur D. Little, Inc., estimates and the Bureau of Mines estimates.

(6) The mix of steelmaking processes was determined by dividing the production rates for each of the steelmaking furnaces by total raw steel production.

Foundry Casting Shipments: The quantity of castings shipped in 1987 was based on Arthur D. Little, Inc. estimates.

Blast Furnace Production: The production of pig iron by blast furnaces in 1987 was calculated by multiplying the pig iron demand coefficients for the steelmaking furnaces and ferrous foundries by their respective production rates. The individual process demands for pig iron were summed to give total pig iron production in 1987. Thus, it is implicitly assumed that pig iron inventories in 1987 are constant.

Inventory of Obsolete Scrap: Hogan [8] has presented the inventory data through 1982. These data were extended to 1987 by extrapolation and adjustment to incorporate production/consumption of scrap and steel through 1987.

Steelmaking Scrap Demand Coefficient: An analysis of the historical scrap demand coefficients (1959-1976) for the basic oxygen and electric arc furnaces indicated that these coefficients have remained reasonably constant during recent years. This is expected to remain constant in the near future. Scrap demand coefficients for the years 1972-1976 were averaged to give the 1987 values.

Steelmaking Scrap Demand Coefficient: An analysis of the historical scrap demand coefficients (1959-1976) for the basic oxygen and electric arc furnaces indicated that these coefficients have remained reasonably constant during recent years. This is expected to remain constant in the near future. Scrap demand coefficients for the years 1972-1976 were averaged to give the 1987 values. The scrap demand coefficient for open hearth indicated an increase during the same period. Based on a regression analysis of historical data, this coefficient was predicted to be 0.58 tons scrap/ton raw steel in 1987.

Blast Furnace Scrap Demand Coefficient: Historical blast furnace scrap demand coefficients (1955-1976) were analyzed to develop the trend line forecast to 1987. The 1987 scrap demand coefficient was estimated to be 0.040 short tons scrap/ton pig iron produced based on the trend data.

Foundry Scrap Demand Coefficient: Historical foundry scrap demand coefficients (1956-1976) were analyzed. During this period use of pig iron significantly decreased. Industry sources had conflicting views of whether this trend would continue. In view of this uncertainty, two values for the foundry scrap demand coefficient (short tons scrap/ton casting shipment) were used in the estimation of the recycle target: 1.23 (Case I) and 1.30 (Case IV). Although these figures seem low, they are based on the best available published data.

Steel Plant Home Scrap Generation Factor: The historical data were analyzed and adjusted to incorporate the change expected with the increase in continuous casting to about 25% in 1987. Based on the estimated overall yield of 0.72 for 1987, this factor is estimated to be 0.30.

Foundry Home Scrap Generation Factor: This was based on historical trend data. Although the documented figures seem low, the data were used because they are the best documented. Furthermore, any error in the figure does not affect the purchased scrap and obsolete scrap recycling targets significantly.

Blast Furnace Home Scrap Factor: The 1987 figure was based on the historical trend line. The 1987 value was predicted to be 0.022 short tons scrap/ton pig iron produced.

Prompt Industrial Scrap Generation Factor: This coefficient was assumed to remain unchanged from 1976 to 1987. Because of the nature of the scrap generating operations of the manufacturing industries, this factor is expected to change very little, if at all.

4.2.6.4 Recycling Targets for 1987

The recycling targets for each of the nine scenarios analyzed are presented in various formats. Each format represents the ratio of a specific class of ferrous scrap to a specific charge or product. Numerators in the target ratios are:

- Total scrap consumption — home, prompt industrial, and obsolete scrap consumed in the steel industry, ferrous foundries and ferroalloy plants. Slag scrap is included in total scrap

- Purchased scrap consumption — prompt industrial and obsolete scrap consumed in the steel industry, ferrous foundries, and ferroalloy plants
- Obsolete scrap consumed in the steel industry, ferrous foundries and ferroalloy plants

Denominators in the target ratios are:

- Pig iron and scrap charged to steelmaking furnaces, ferrous foundries and ferroalloy plants
- Raw metal equivalent (raw steel plus hot metal equivalent in ferrous foundries)
- Shipments (finished steel plus ferrous castings shipped)

Target ratios have also been calculated for the years 1975 and 1976 in order to validate the model. The analysis for 1975 and 1976 proved the validity of the model. Table 4.2-25 shows the targets for each of the nine scenarios. This table shows that for the base case, purchased scrap target as a percent of scrap and pig iron charged in the ferrous industry increases from 22.6% in 1976 to 26.4% by 1987. Similarly, purchased scrap target as a percent of finished product increases from 37.6% to 41.3%. The rise in recycling targets is due primarily to an expected increase in demand for ferrous scrap by steelmaking electric arc furnaces.

Table 4.2-26 shows the target in units selected by DOE for recovered materials as a percent of total shipments.

4.2.7 Sensitivity of Targets to Key Factors

The recycling targets presented in the previous section are directly affected by a number of factors. The most significant factors are:

- Predicted annual growth rates for the iron and steel and ferrous foundry sectors
- Steelmaking process mix
- Scrap demand coefficients for the three steelmaking furnaces and ferrous foundries
- Raw steel to finished product yields for the iron and steel and ferrous foundry sectors

The effect of these variables on the recycle targets is shown in Table 4.2-27. The summary of the results is as follows:

- Increasing the growth rate of finished steel production by 20% increases the purchased scrap target by 1.1% on a metallic charge basis and 1.2% on a finished product basis. Decreasing the growth rate by 20% lowers the targets by 1.1% and 0.9%, respectively.
- Increasing the estimate of foundry shipments by 10% increases the purchased scrap target by 1.9% on a metallic charge basis and 1.7% on a finished product basis. Decreasing foundry shipments by 10% lowers the targets by 1.5% and 1.7%, respectively.

TABLE 4.2-25

RECYCLING RATIOS FOR FERROUS INDUSTRY FOR NINE SCENARIOS - 1987

Scenario	Total Scrap Consumed[1] to Pig Iron and Scrap Charged[3]	Purchased Scrap Consumed[2] to Pig Iron and Scrap Charged[3]	Obsolete Scrap Consumed to Pig Iron and Scrap Charged[3]	Total Scrap Consumed[1] to Raw Metal Equivalent[4]	Purchased Scrap Consumed[2] to Raw Metal Equivalent[4]	Obsolete Scrap Consumed to Raw Metal Equivalent[4]	Total Scrap Consumed[1] to Product Shipments[5]	Purchased Scrap Consumed to Product Shipments[5]	Obsolete Scrap Consumed to Product Shipments[5]
1975 =	0.507	0.224	0.115	0.591	0.261	0.134	0.866	.382	0.196
1976 =	0.509	0.226	0.117	0.588	0.261	0.135	0.847	.376	0.194
1987 =									
Case I: Base case	0.536	0.264	0.137	0.597	0.294	0.153	0.839	.413	0.214
Case II: Base case except - Production by open hearth furnaces equals 10% total raw steel production.	0.538	0.266	0.139	0.600	0.297	0.156	0.843	.418	0.219
Case III: Base case except - Growth in raw steel production split 2:1 between basic oxygen and electric arc shops.	0.520	0.249	0.122	0.581	0.278	0.136	0.816	.390	0.191
Case IV: Base case except - Scrap demand coefficient for foundries equals 1.3 ton/ton shipments.	0.539	0.269	0.143	0.605	0.302	0.160	0.849	.424	0.225
Case V: Base case except - Growth in raw steel production split 2:1 between basic oxygen and electric arc shops. - Production by open hearth furnaces equals 10% total raw steel production.	0.522	0.251	0.124	0.584	0.281	0.139	0.820	.394	0.195
Case VI: Base case except - Growth in raw steel production split 2:1 between basic oxygen and electric arc shops. - Scrap demand coefficient for foundries equals 1.3 ton/ton shipments.	0.524	0.254	0.128	0.588	0.285	0.144	0.826	.400	0.202
Case VII: Base case except - Growth rate for finished steel production equals 1.6% per annum.	0.533	0.261	0.135	0.593	0.291	0.150	0.834	.409	0.211
Case VIII: Base case except - 30% raw steel production by electric furnaces.	0.552	0.279	0.152	0.613	0.310	0.169	0.861	.436	0.237
Case IX: Base case except - 33% raw steel production by electric furnaces	0.568	0.296	0.168	0.630	0.328	0.186	0.885	.461	0.262

Target Expressed As Ratio Of: (columns 2–7)

1. Includes home, prompt industrial and obsolete scrap.
2. Includes prompt industrial and obsolete scrap.
3. Charged to steelmaking furnaces, ferrous foundries and ferroalloy plants.
4. Raw steel plus hot metal equivalent in the ferrous foundries.
5. Finished steel plus ferrous casting shipments.

SOURCE: Arthur D. Little, Inc.

TABLE 4.2-26

RECOVERED MATERIAL TARGET FOR FERROUS INDUSTRY
(1987)

$$\frac{\text{Recovered Material*}}{\text{Industry Shipments**}} \times 100 = 41.3\%$$

* Prompt industrial and obsolete scrap.

** Steel and foundry shipments.

TABLE 4.2-27

SENSITIVITY OF TARGETS TO KEY FACTORS

FERROUS INDUSTRY

Factor	Target Expressed as Ratio of Total Purchased Scrap to Metallics Charged	Raw Steel Equivalent	Finished Product
1976	.226	.261	.376
1987			
Base Case	.264	.294	.413
Finished Steel Production Growth Rate			
rises 20%	.267	.298	.418
falls 20%	.261	.291	.409
Foundry Shipments			
rises 10%	.269	.299	.420
falls 10%	.260	.290	.406
Electric Arc: Basic Oxygen Growth Rate			
1:1 (base case)	.264	.294	.413
1:2	.249	.278	.390
Percent of Raw Steel from Open Hearth Furnace			
5% (base case)	.264	.294	.413
10%	.266	.297	.418
Scrap Demand Coefficient: Basic Oxygen Furnace			
rises 10% (.359)	.281	.310	.439
falls 10% (.259)	.248	.276	.307
Scrap Demand Coefficient: Open Hearth Furnace			
rises 10% (.64)	.271	.301	.423
falls 10% (.52)	.258	.287	.404
Scrap Demand Coefficient: Electric Arc Furnace			
rises to maximum (1.05)	.267	.299	.420
falls 10% (.93)	.249	.271	.381
Scrap Demand Coefficient: Ferrous Foundries			
base case (1.23)	.264	.294	.413
rises 6% (1.30)	.269	.302	.424
Yield: Iron and Steel			
rises 10% (.79)	.310	.346	.449
falls 10% (.65)	.219	.243	.373
Yield: Ferrous Foundries			
rises 10% (.74)	.264	.291	.407
falls 10% (.61)	.267	.297	.424

- Increasing the ratio of electric arc to basic oxygen furnace growth rate from 1:1 to 1:2 decreases the purchased scrap target by 5.7% on a metallic charge basis and 5.6% on a finished product basis.
- Increasing the percentage of total raw steel produced by open hearth furnaces from 5% to 10% increases the purchased scrap target by 0.7% on a metallic charge basis and 1.2% on a finished product basis.
- Increasing the basic oxygen furnace scrap demand coefficient by 10% increases the purchased scrap target by 6.4% on a metallic charge basis and 6.3% on a finished product basis. Decreasing this coefficient by 10% lowers the targets by 6.1% and 6.3%, respectively.
- Increasing the open hearth furnace scrap demand coefficient by 10% increases the purchased scrap target by 2.7% on a metallic charge basis and 2.4% on a finished product basis. Decreasing this coefficient by 10% lowers the targets by 2.3% and 2.2%, respectively.
- Increasing the scrap demand coefficient for electric arc furnaces to the maximum possible (1.05) increases the purchased scrap target by 1.1% on a metallic charge basis and 1.7% on a finished product basis. Decreasing this coefficient by 10% lowers the targets by 5.7% and 7.7%, respectively.
- Increasing the scrap demand coefficient for the ferrous foundries by 6% increases the purchased scrap target by 1.9% on a metallic charge basis and 2.7% on a finished product basis.
- Increasing the yield (finished steel/raw steel) for the iron and steel sector by 10% increases the purchased scrap target by 17.4% on a metallic charge basis and 8.7% on a finished product basis. Decreasing the yield by 10% lowers the targets by 17.1% and 9.7%, respectively.
- Increasing the yield (finished casting/raw steel) for the ferrous foundry sector by 10% has little effect ($<$0.5%) on the purchased scrap target on a metallic charge basis and lowers the target by 1.4% on a finished product basis. Decreasing the yield by 10% increases the targets by 1.1% and 2.7%, respectively.

Indirectly, the recycling target is affected by such factors as the availability of scrap substitutes (e.g. prereduced iron), scrap exports, and the inventory of obsolete scrap.

The availability of scrap substitutes from domestic or imported sources could affect the scrap market and, therefore, the target. However, because the tonnage of scrap substitutes involved is expected to be low, the target is not very sensitive to changes in the availability of the scrap substitutes. In the base case scenario (Case I) it is assumed that 2 million short tons of prereduced iron will be available in 1987.

Scrap exports are a major factor in the recycling target. Because scrap exports impact the domestic scrap supply and prices, they can, in the long run, alter the process mix in the iron and steel industry and the scrap demand coefficients for the steelmaking processes and ferrous foundries. These factors, in turn, can affect the targets. Scrap exports are a major factor in the recycling target. Because scrap exports impact the domestic scrap supply and prices, they can, in the long run, alter the process mix in the iron and steel industry and the scrap demand

coefficients for the steelmaking processes and ferrous foundries. These factors, in turn, can affect the targets. Sensitivity analysis of scrap exports indicated that if exports in 1987 exceed 15 million or decrease below 5 million tons, they will alter scrap prices significantly. However, the impact of scrap exports on such factors as the process mix, industry structure, etc., is outside the scope of this study.

Changes in the size of obsolete scrap inventory affect scrap supply, and therefore scrap prices. In turn these affect the long-term trends in process mix, furnace scrap demand coefficients, etc. — thereby affecting the recycling targets. Detailed study of the impact of obsolete scrap inventory changes on the recycling targets is outside the scope of this study.

The objective of the ADL Model is to determine the scrap price necessary to bring forth the obsolete supply that is demanded. This price is determined as a function of a so-called withdrawal rate. This is defined as obsolete-scrap supply divided by inventory. If we were to double the historical inventory number, this would cause the historical withdrawal rate to be half its original value. Because the forecasted withdrawal rate and inventory values are based on their historical values, the absolute size of the inventory is consequently not important.

The issue arises, however, as to whether in fact (as opposed to theory) the price solution of the ADL Model is sensitive to choice of inventory data.

For the recycling target analysis, a scrap inventory time series from a report prepared by Father Hogan for the American Iron and Steel Institute entitled "Purchases Ferrous Scrap: United States Demand and Supply Outlook" was used. An alternative inventory series has been derived by Robert R. Nathan Associates entitled "Iron and Steel Scrap — Its Accumulation and Availability Updated to December 31, 1977."

Substitution of the Nathan series for the Hogan series changed the model results only by about two percent.

4.3 ALUMINUM

4.3.1 Selection of Recoverable Materials

The recoverable materials considered for inclusion in the aluminum industry can be grouped into three broad categories:

- Purchased New Scrap
- Purchased Old Scrap
- Non-Bauxite Sources of Alumina

The various materials considered for inclusion under these three categories are presented in Table 4.3-1. Each "recoverable material" was assessed using the selection criteria discussed in Section 4.1, to determine whether it would be considered in this analysis.

New scrap includes material generated in the production of primary aluminum, the fabrication of aluminum mill products, or the manufacture of finished aluminum products. It includes aluminum in the form of solids such as new casting scrap; clippings or cuttings of new sheet, rod, wire, and cable; borings and turnings from the machining of aluminum parts; residues, drosses, sweepings, etc.; and aluminum foil. New scrap in any of the above forms can be further categorized as being purchased or runaround scrap. Purchased new scrap (or prompt industrial scrap) is scrap purchased, imported, or treated on toll by primary or secondary smelters; all purchased new scrap is considered in this analysis. Runaround (or home scrap), is new scrap recovered or recycled within the facility generating the scrap. Such scrap, by definition, never leaves the company generating it and therefore is never marketed as scrap. Home scrap complies with the criterion for the selection of recoverable materials, but no data on home scrap are available, and hence it has not been included in the estimation of targets.

Old scrap, all of which is purchased, comes from discarded, used and worn out products. It includes aluminum pistons or body parts from junked cars, used aluminum cans and utensils, siding, awnings and other building products and old wire and cable. Sweated pig, which is scrap that has been sweated or melted into pig or ingot form, and obsolete scrap, consisting of technologically obsolete aluminum parts, outdated inventory materials, production overruns and spare parts for machines and equipment no longer being used, are included as old scrap. Aluminum from the non-ferrous fraction of shredded automobiles and the aluminum fraction from municipal solid waste (MSW) are listed as separate categories; it is likely that these sources will be more important in the future than at present.

Alumina from non-bauxite sources of recovered materials is the only type of potential recovered material that does not comply with the criterion for inclusion as a source. This category has been excluded because technology for recovering alumina from these sources is not likely to be commercial by 1987.

4.3.2 Selection of Process Subdivisions for Inclusion in the Target

The industry subdivisions are based on the historical and current use of recovered materials in the industry, the potential for their use between now and 1987, and the energy consumption levels in the industry.

TABLE 4.3-1

SELECTION OF RECOVERABLE MATERIALS
ALUMINUM INUDSTRY

Recovered Material	Does the Recoverable Material Meet Criteria* for Inclusion? Yes	No
NEW SCRAP		
Purchased New Scrap		
Solids and Clippings	X	
Borings and Turnings	X	
Residue (Drosses and Skimmings)	X	
Foil and Others	X	
Runaround or Home Scrap	X	
OLD SCRAP		
Purchased Old Scrap		
Castings, Sheet, and Clippings	X	
Aluminum Cans	X	
Sweated Pig	X	
Copper-Aluminum Radiators and Others	X	
Aluminum Fraction of Municipal Solid Wastes (MSW)	X	
Aluminum Fraction of Shredded Automobiles	X	
ALUMINA FROM NON-BAUXITE SOURCES		
Coal Mining Wastes		X
Residue from Oil Shale Operations		X
Fly-Ash		X

*Criteria for Inclusion outlined in Section 4.1.

Table 4.3-2 presents historical data on the consumption of purchased scrap by industry subdivision:

Primary Producers,
Secondary Smelters,
Independent Fabricators,
Aluminum Foundries, and
Chemical Producers.

The consumption figures are in thousands of short tons of scrap type for the period 1970-1976. The industry subdivisions and sources of recovered materials have been summarized in Table 4.3-3 in a matrix form. A checked cell indicates that a defined source is presently providing recoverable material for a defined industry subdivision, or could realistically be expected to do so in the future. As mentioned earlier, the aluminum fraction of municipal solid waste and from shredded automobiles have been identified as separate categories because they are likely to become more important sources in the future.

4.3.3 Technical Considerations

4.3.3.1 Process Constraints

Aluminum-based scrap is usually recycled by melting in gas or oil-fired reverberatory furnaces (10-100 short tons heat size), crucible furnaces (less than 5 short tons per hour), and induction furnaces (1-10 short ton heat size). There are no process technology constraints concerning the amount of scrap (percentage scrap in charge) that can be melted in each of these furnaces, although the different types of furnaces do provide different melting capacities.

The principal refining step in the recycling of aluminum-based scrap is the removal of magnesium by treating the molten metal with chlorine or aluminum fluoride. Any other impurities in the metal are usually controlled by dilution of the charge with pure metal. This need for dilution can, in many instances, limit the amount of impure scrap recycle.

The recycling furnaces are best suited for melting (as distinct from refining) and adequate scrap preparation is required to minimize contamination of the melt with impurities from the scrap.

Suitable technology is needed to separate aluminum from the non-magnetic fraction of shredded automobiles and from the non-ferrous fraction obtained in the treatment of municipal refuse. Techniques in various stages of development include water elutriation, heavy media separation, eddy current, etc.

4.3.3.2 Product Quality Constraints

Product quality constraints arise from having to meet specifications for composition. The composition limits and uses of the principal aluminum wrought and casting alloys are shown in Table 4.3-4.

4.3.3.3 Recoverable Materials Quality Constraints

Raw material constraints arise from the fact that the metal produced from the scrap has to meet a product specification; with the exception of magnesium removal, impurity levels are reduced by dilution with primary aluminum, and other alloying elements are added to attain the

TABLE 4.3-2

CONSUMPTION OF RECOVERABLE MATERIALS BY INDUSTRY SUBDIVISION* (1970-1976)
ALUMINUM INDUSTRY
(thousands of short tons)

	Secondary Smelters							Primary Producers Fabricators, Foundries, Chemical Producers							Total						
	1970	1971	1972	1973	1974	1975	1976	1970	1971	1972	1973	1974	1975	1976	1970	1971	1972	1973	1974	1975	1976
PURCHASED NEW SCRAP																					
Solids & Clippings	247	261	303	346	262	189	231	229	245	311	345	356	334	350	476	506	614	691	618	523	581
Borings & Turnings	119	107	99	115	97	124	136	22	26	1	1	1	3	16	141	133	100	116	98	127	152
Drosses and Skimmings	111	95	116	108	84	94	126	49	47	72	86	124	92	104	160	142	188	194	208	186	230
Foil and Others						15	25						44	67						59	92
SUBTOTAL	477	463	518	569	443	422	518	300	318	384	432	481	473	537	777	781	702	1001	924	895	1055
PURCHASED OLD SCRAP																					
Castings, Sheet & Clippings	126	118	118	112	125	86	121	10	20	34	65	71	28	35	136	138	152	177	196	114	156
Aluminum Cans	-	-	-	-	-	7	8	-	-	-	-	-	77	01	-	-	-	-	-	84	109
Sweated Pig	47	58	71	56	63	65	82	11	27	29	30	24	25	17	58	85	100	86	87	90	99
Cu-Al Radiators and Others	-	-	-	-	-	32	30	-	-	-	-	-	18	17	-	-	-	-	-	50	47
SUBTOTAL	173	176	189	168	188	190	241	21	47	63	95	95	148	170	194	223	252	263	283	338	411
TOTAL	650	639	707	737	631	612	759	321	365	447	527	576	621	707	971	1004	1154	1264	1207	1233	1466
Home Scrap	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

* Source: 1970-1975: U.S. Bureau of Mines Minerals Yearbooks.
1976: U.S. Bureau of Mines Minerals Yearbook Aluminum Preprint.

TABLE 4.3-3

RECOVERABLE MATERIAL SOURCE - INDUSTRY MATRIX

ALUMINUM INDUSTRY

SIC Code	Industry Subdivision	Purchased New Scrap: Solids & Clippings	Purchased New Scrap: Borings & Turnings	Purchased New Scrap: Drosses & Residues	Purchased New Scrap: Foil, Other	Purchased New Scrap: Home Scrap	Purchased Old Scrap: Castings, Sheet & Clippings	Purchased Old Scrap: Cans	Purchased Old Scrap: Sweated Pig	Purchased Old Scrap: Al-Cu Radiators, Others	Purchased Old Scrap: Al Fraction of MSW	Purchased Old Scrap: Al Fraction of Shredded Auto
3334, 3353, 3354, 3355, 3357	Primary Producers	X	X	X	X	X	X	X	X	X	X	X
3341	Secondary Smelters	X	X	X		X	X	X	X	X	X	X
3353, 3354, 3355, 3357	Independent Fabricators	X	X		X	X	X			X		
3361	Aluminum Foundries	X	X		X	X	X		X	X		X
	Chemical Producers	X	X		X					X		

Source: Arthur D. Little, Inc.

TABLE 4.3-4

ALUMINUM

Composition limits and uses of some aluminum wrought and casting alloys[1]

(Weight—percent)

Aluminum Association designations	Aluminum	Copper	Manganese	Magnesium	Silicon	Other constituents	Applications
Wrought alloy series:							
1000	99.00–99.75	0.2	0.05	0.05	1.0 including iron	0.1 zinc, 0.05 titanium	Electrical conductors, chemical equipment, cooking utensils.
2000	Balance[2]	19–68	12	18	01–25	13 iron, 0.15 ttanium, 2.3 nickel.	Screw machine products, forgings, aircraft, rocket fuel tanks, pistons.
3000	do[2]	.3	0.3–1.5	1.3	.6	0.4 zinc, 0.1 titanium	Ductwork, can bodies, architecture, hydraulic tubing, roofing.
4000	do[2]	.25–1.3	.1	1.3	4.5–13.5	1.3 nickel	Welding and brazing wire, pistons, architectural fittings.
5000	do[2]	.2	1.0	0.5–5.6	0.5 including iron	0.35 chromium, 0.2 titanium.	Bus and truck bodies, screens, pressure vessels, aircraft tubing, automotive trim, can lids.
6000[3]	do[2]	1.2	1.1	1.5	1.8	2.4 zinc, 1.0 iron	Heavy-duty structures, pipe, railing, busbars.
7000	do[2]	2.6	.7	3.7	0.7 including iron	0.3 chromium, 3.0 zinc	Aircraft structurals and skins.
Diecasting ingot:[4]							
A380.1	do[2]	3.0–4.0	.5	.1	7.5–9.5	0.5 nickel, 0.1 zinc, 1.1 iron	General purposes castings, large instrument cases, street lamp housings.
413.2	do[2]	.1	.1	.07	11.0–13.0		
Sand and permanent mold casting ingot:[4]							
201.2	do[2]	4.0–5.2	.2– .5	.2– .55	.1	0.1 iron, 0.35 titanium	Aircraft and electrical transmission components.
242.2	do[2]	3.5–4.5	.1	1.3–1.8	.6	0.6 iron, 2.3 nickel, 0.1 zinc, 0.2 titanium.	Cylinder heads, diesel engine pistons.
295.2	do[2]	4.0–5.0	.3	.03	.7–1.2	0.8 iron, 0.3 zinc, 0.20 titanium.	Crankcases, wheels, fittings.
356.2	do[2]	.1	.05	.3– .4	6.5–7.5	0.25 iron, 0.05 zinc, 0.2 titanium.	Automatic-transmission cases, aircraft and marine fittings, truck axle housings.
A390.1	do[2]	4.0–5.0	.1	.5– .65	16.0–18.0	0.4 iron, 0.1 zinc, 0.2 titanium.	Automobile engine blocks, pumps, pulleys, brake shoes.

[1] Maximum weight-percent of the casting ingot or of at least one of the wrought alloys in the series unless a range is given, in which case the upper and lower limits do not necessarily apply to the same alloy in the series.
[2] Balance after deducting percent composition of specified alloying constituents plus other normal impurities. Minimum impurities for casting alloys are normally specified but are not shown in this table.
[3] Alloy 6262 may contain 0.4 to 0.7 percent each of lead and bismuth.
[4] [illegible]position of castings may differ from that of the ingot.

Source: U.S. Bureau of Mines Mineral Commodity Profiles - Aluminum, May 1978, p. 7.

desired composition. Even well-segregated aluminum scrap is often contaminated with other metals, many of which can be considered impurities. Stainless steel is particularly troublesome because, unlike common steel, it cannot be separated from scrap magnetically, it is difficult to detect visually, and it dissolves in aluminum more readily than common steel. Free zinc is present in some borings, in jar covers, and as die castings. Magnesium, whether free or alloyed, is usually disadvantageous, since the principal alloys produced from scrap are permanent mold and die casting alloys which contain little magnesium (usually less than 0.1%). Since about 85% of the recoverable material available to a smelter consists of mill products (high in magnesium content) the molten metal contains 0.5-0.8% magnesium, and has to be brought back into specification by demagging. Conversely, in the production of extrusion billets, magnesium and primary aluminum generally have to be added. Demagging is also not required for deoxidizer material (used in the steel industry) since magnesium is not critical.

Non-metallic contaminants in aluminum scrap such as paint, oil, plastic, insulation, and rubber are a major source of air pollution.

4.3.4 Economic Considerations

In setting a target for scrap recovery the analysis must take into account supply and demand, in both physical and economic terms.

The physical aspect of scrap demand concerns the process limitations on the amount of scrap that can be utilized. In the aluminum industry, unlike steel, there are no relevant physical demand constraints imposed by technology. The economic aspects of scrap demand relate to the price of scrap. The price of scrap is driven to a large extent by demand rather than by supply (i.e., inelastic to supply).

4.3.4.1 Data Sources for Arthur D. Little Model

The Arthur D. Little scrap model is designed to predict the volume of scrap that will be generated under a variety of scenarios. These volumes of scrap estimates are then used to calculate targets.

For data on scrap, we have relied on the U.S. Bureau of Mines *Minerals Yearbook* and *Mineral Industry Surveys.* Their detailed data on scrap consumption does not represent a full industry coverage. The Bureau reports that, in 1976, for example, full industry coverage would raise their aggregate figures by 18%.[1] Using this figure, we multiplied new scrap and old scrap domestically consumed to a full industry equivalent. Aluminum can scrap and exports were assumed to be complete as reported, i.e., not requiring expansion to full coverage.

Data on aluminum ingot production and consumption were obtained from the *Aluminum Statistical Review* published by the Aluminum Association. Data on aluminum scrap and product prices were obtained from *Metal Statistics.*

The U.S. Bureau of Mines, *Minerals Yearbook,* reports the consumption of new purchased aluminum scrap, aluminum can scrap, and other old aluminum scrap, as well as on U.S. exports of aluminum scrap — which is chiefly old obsolete scrap. Ignoring year-to-year inventory changes, the sum of consumption and exports gives us available U.S. scrap supply.

The U.S. Bureau of Mines also reports aluminum scrap consumption by primary producers, secondary producers, foundries, fabricators, and chemical producers. The Bureau also presents calculated metal recovery from scrap.

4.3.4.2 Aluminum Scrap Material Balance

Table 4.3-5 shows the balance of sources and uses for aluminum scrap for 1976. This table is based on reported purchased scrap consumption expanded to full industry coverage for all categories except aluminum cans which was taken as reported. Aluminum scrap export data is as published by the Aluminum Statistical Review, and estimates for home or runaround scrap were provided by the Aluminum Association.[13] We have assumed in this analysis that aluminum scrap that is exported is principally old scrap.

In 1976 purchased new scrap accounted for 68% of the supply of purchased scrap or 24% of the total scrap supply, i.e., purchased plus home scrap. In the category of old scrap, cans accounted for 6% of the purchased scrap supply or 2.1% of the total scrap supply. Other old scrap such as obtained from junked car and appliances accounts for the remaining 26% of the purchased scrap supply or 9% of the total scrap supply. The domestic consumption accounted for slightly over 95% of the U.S. purchased scrap supply. It is to be noted that home scrap represents 64.6% of the total scrap supply.

4.3.4.3 Potential for Increased Use of Recovered Material

An examination of the statistics on scrap consumption trends (Table 4.3-2), analysis to identify opportunities for increased solid waste utilization[2], and a paper examining recycling opportunities[3] indicate that the potential for increased scrap utilization is in the area of old scrap. Battelle stated "according to industry sources well over 90% of the new scrap is recycled," and their analysis assumed that all new scrap is being recycled. [2] Battelle also estimated that in 1969, only 13% of the scrap available for recycling was actually being recycled. The amount of scrap available for recycle was calculated by Battelle on the basis of estimated life cycles of various aluminum-containing products. This approach yields estimates of tonnages of aluminum products becoming obsolete. The drawbacks of the life cycle approach are: (a) items such as aircraft may be exported and hence not scrapped within the United States; (b) it may be difficult to collect certain packaging items that are widely dispersed; (c) some obsolete items may not be scrapped; and (d) yield losses in recycling. Their approach, however, points out that old scrap is potentially attractive for augmenting scrap supplies. The main problem, however, lies in the collection of old scrap. The most promising sectors for improved recycling of old scrap are:

- *Consumer recycling programs aimed at source segregation:* Table 4.3-6 shows data on aluminum can reclamation for the period 1972-1976. Reclaimed cans represent approximately 25% of the cans being produced. We anticipate that this source will have significant potential for increased recycling. Most of the cans and other packaging items not collected go to the municipal solid waste stream.

TABLE 4.3-5

1976 MATERIAL BALANCE FOR ALUMINUM SCRAP
(Millions of Pounds)

Sources		Uses	
Purchased Scrap		U.S. Consumption of Purchased Scrap[1]	3,482
New Scrap[1]	2,490	U.S. Consumption of Home Scrap[3]	6,675
Old Scrap		Exports[2]	171
Aluminum Cans[1]	217		
Other Old Scrap[1,2]	946		
Purchased Scrap	3,653		
Home Scrap[3]	6,675		
Total	10,328	Total	10,328

Source: Arthur D. Little, Inc. estimates derived from:

[1] Aluminum, Preprint 1976 Minerals Yearbook.
[2] Aluminum Statistical Review, 1976.
[3] Communication, The Aluminum Association, May 8, 1979.

TABLE 4.3-6

ALUMINUM CAN RECLAMATION DATA
(1972-1976)

Year	Million Pounds of Aluminum Reclaimed	Billions of Aluminum Cans Reclaimed
1972	53[1]	1.2
1973	68[1]	1.6
1974	103[1]	2.3
1975	180	4.0
1976	212*	4.8

*Represents incomplete industry coverage.

[1] Represents total industry; includes an additional 1, 5, and 18 million pounds in the years 1972, 1973, and 1974, respectively. This accounts for all aluminum cans collected by non-members of the Aluminum Association.

Source: Aluminum Statistical Review, 1976

- *Recovery of aluminum from municipal solid waste:* The potential for aluminum from MSW has been reviewed by Testin.[4] The amount of solid waste generated annually in the United States is estimated by the EPA at 136 million short tons.[4] The aluminum content of this material is approximately 0.7%, or about 2 billion pounds of aluminum. Present systems, which generally include some type of front-end processing followed by dense media or eddy current separation, will collect about half of the aluminum contained in the municipal solid waste stream. With present technology, lighter gauge aluminum, such as paper-backed foils as well as aluminum ends on steel beverage containers, are lost. Hence, the maximum amount of aluminum that could be recovered from this source if all the municipal solid waste were processed and the aluminum recovered is about a billion pounds. However, of nineteen U.S. locations with resource recovery systems (either on stream or under shakedown), only six have opted for aluminum recovery. These are expected to yield about 6 million pounds of aluminum annually from 10,000 short tons per day of refuse processed.[4] Nine other locations are under construction, with three providing for aluminum recovery and four in which aluminum recovery can be incorporated. These plants can process an additional 1.6% of the national refuse and recover an estimated 16 million pounds annually. In addition, 34 communities have systems under design or study or have requested construction funds, and another 75 are undergoing feasibility studies. If every system now being considered were implemented and all had aluminum recovery, an absolute maximum is 250 million pounds. A realistic maximum might be half as much or about 125 million pounds. Although these figures[4] are a year old and the technology can be classified as emerging the analysis provides a perspective on the aluminum that can be recovered from this source.

The aluminum recovered is in the form of contaminated wrought product alloys comprising cans, rigid foil containers, extrusions, and lawn furniture with very few casting alloys. It should be emphasized that the technology for municipal waste treatment and aluminum recovery falls in the category of emerging technology. There is considerable uncertainty about the ability of many of the processes to operate on a sustained basis and about the amount of aluminum that will be available by 1987. It is expected to be a relatively small portion of the scrap supply in 1987.

- *Automotive scrap:* The use of aluminum in cars has been steadily increasing, from about 50 lbs per car ten years ago to about 114 lbs per car in 1978. [5] This trend is likely to continue in order to meet the 1985 goal of 27.5 miles per gallon required by the Energy Policy and Conservation Act of 1975. The use of aluminum in passenger cars in 1985 is estimated to range from 225-425 pounds per car.[6] Therefore, shredded automobile scrap should represent a substantial opportunity to recover aluminum. There are now about 180 shredders in the United States, shredding 9 million short tons, or approximately 5-7 million cars per year. [5]

4.3.4.4 Description of Model

The aluminum scrap model is, as stated before, designed to predict the volume of scrap that will be generated under a variety of scenarios. This volume is then used to calculate the target.

Table 4.3-7 lists the equations of the model, Table 4.3-8 defines the symbols used in the equations, and Table 4.3-9 gives the values of parameters in the equations. Equations (1) through (5) are used to predict the supply of scrap from different sources. Equations (6) through (9) forecast scrap consumption expressed in a variety of forms, e.g., gross weight as opposed to metallic. Equations (10) through (13) calculate the targets as the ratio of scrap consumption, variously expressed, to domestic aluminum production.

Equation 1: The amount of new scrap that will be generated is calculated by multiplying aluminum consumption by a prompt scrap generation rate. The historical generation rate is calculated by dividing new scrap consumption by aluminum consumption.

Equation 2: The amount of scrap that will be recovered from cans is calculated by multiplying the number of cans produced by a can reclamation rate and by the aluminum recovered per can. The can reclamation rate is the percentage of cans produced that are turned in at reclamation centers.

Equations 3 and 4: The amount of 'other old scrap' (all old scrap except cans) is estimated by multiplying the withdrawal rate by the aluminum inventory.

The aluminum inventory variable is a measure of the amount of aluminum existing within the domestic economy. The aluminum inventory is defined as the cumulative total of aluminum

TABLE 4.3-7

EQUATIONS OF THE ALUMINUM SCRAP MODEL

Equation Number	Endogenous Variable	Explanatory Segment
1	NEWSP	b_1 x ALCON
2	CANSP	b_2 x b_3 x NOCAN
3	WD	b_4 + (b_5 x PSCP)
4	OLDSP	WD x INV
5	DCRSP	b_6 x CARSC
6	SCON1	CANSP + OLDSP + DCRSP + WST - EXP
7	SCON2	SCON1 + NEWSP
8	SCON3	b_7 x SCON1
9	SCON4	b_7 x SCON3
10	TRGT1	SCON1/DOMPRD
11	TRGT2	SCON2/DOMPRD
12	TRGT3	SCON3/DOMPRD
13	TRGT4	SCON4/DOMPRD

TABLE 4.3-8

DEFINITION OF VARIABLES AND PARAMETERS

ALUMINUM SCRAP MODEL

Endogenous Variables

1	NEWSP	New Scrap
2	CANSP	Scrap from cans
3	WD	Scrap withdrawal rate
4	OLDSP	Other old scrap supply
5	DCRSP	Scrap created by increased aluminum in vehicles
6	SCON1	U.S. old scrap consumption (gross weight)
7	SCON2	U.S. total scrap consumption (gross weight)
8	SCON3	U.S. old scrap consumption (metallic recovery)
9	SCON4	U.S. total scrap consumption (metallic recovery)
10	TRGT1	Target 1 - Old scrap gross weight
11	TRGT2	Target 2 - Total scrap gross weight
12	TRGT3	Target 3 - Old scrap metallic recovery
13	TRGT4	Target 4 - Total scrap metallic recovery

Exogenous Variables

1	ALCON	Aluminum consumption
2	NOCAN	Number of aluminum cans produced
3	PSCP	Price of aluminum scrap
4	INV	Aluminum scrap inventory
5	CARSC	Number of cars and Class 1 trucks scrapped
6	WST	Scrap recovered from municipal solid waste
7	EXP	Scrap exports
8	DOMPRD	Domestic aluminum production from all sources

Parameters

1	b_1	Prompt scrap generation rate
2	b_2	Aluminum recovered per can
3	b_3	Can reclamation rate
4	b_4	Withdrawal rate constant
5	b_5	Withdrawal rate slope
6	b_6	Additional aluminum scrap recovered from vehicle scrapped in 1987 over vehicle scrapped in 1976
7	b_7	Metallic recovery factor

TABLE 4.3-9

VALUES OF PARAMETERS USED IN TARGET EVALUATION

ALUMINUM INDUSTRY

Item	1976	1987
Prompt scrap generation rate, b_1	0.203	0.203
Aluminum recovered in U.S. per can, b_2	0.0453	0.0330
Can reclamation rate, b_3	23%	40%
Withdrawal rate constant, b_4	0.001755	0.001755
Withdrawal rate slope, b_5	0.000218	0.000218
Additional aluminum scrap in U.S. recovered from vehicle scrapped in 1987 over vehicle scrapped in 1976, b_6	---	38
Metallic recovery factor, b_7	0.845	0.845

consumed to date less the scrap recycled. Thus the inventory at the beginning of a year is estimated by adding to the inventory at the beginning of the previous year, the amount of aluminum consumed less the scrap recycled during the previous year. Values for the inventory series were obtained for the period 1965-1974 from Synergy, Inc.[7] The values for 1975 and 1976 were calculated by Arthur D. Little, Inc., using the procedure described in the Synergy report. The forecast of the aluminum inventory variable was based on a linear extrapolation of the series to 1987. The fit is represented by the following equation:

$$\underset{}{\mathrm{INV}} = -\underset{(39.4)}{876189.4} + \underset{(47.4)}{15029\,(t)} \qquad \underset{.996}{R^2}$$

The withdrawal rate variable is calculated by dividing old scrap consumption by the aluminum inventory variable for each year from 1961 to 1976. We have hypothesized that the withdrawal rate is a function of price of scrap. We feel that the withdrawal rate is a more appropriate dependent variable than old scrap consumption. The major problem with trying to estimate the supply of old scrap as a function of price is that the supply curve shifts down and out with time as the amount of aluminum in the economy increases. However, by normalizing according to this, inventory variable, it is hoped that the supply dynamics can be captured by econometric estimation.

$$W_D = \underset{(3.259)}{0.001755} + \underset{(3.378)}{0.000218}\ \mathrm{PSCP} \qquad \underset{0.533}{R^2}$$

From the above equation, the supply price elasticity (Es) (calculated at the mean value of dependent and independent values) can be calculated as follows:

$$Es = (dWD)(PSCP)/(dPSP)(WD) = (0.000218)(8.0344)(0.0035) = 0.50$$

Equation 5: The supply of other old scrap in equation (4) does not include the increasing contribution due to the increasing aluminum content of cars and Class 1 trucks. The number of vehicles scrapped (in 1987) is multiplied by the incremental aluminum content, (incremental aluminum is defined as the difference in aluminum recovered from a vehicle scrapped in 1987 over a vehicle scrapped in 1976) in order to capture the contribution to aluminum scrap supply due to the increased use of aluminum in cars and Class 1 trucks.

Equation 6: Old U.S. scrap consumption is calculated. First, the aluminum can scrap prediction from equation (2), the other old scrap prediction from equation (4), and the incremental vehicle scrap from equation (6) are summed to give U.S. old scrap supply. Next, an exogenous scrap export is deducted from scrap supply to give U.S. old scrap consumption.

Equation 7: Total U.S. scrap consumption is computed by summing old scrap consumption as predicted by equation (6) and new scrap as predicted by equation (1).

Equations 8 and 9: U.S. scrap consumption is put on a metallic recovery basis. In equation (8), old scrap consumption on a gross weight basis from equation (6) is multiplied by a recovery factor to give metal recovered from old scrap. Equation (9) performs an analogous operation to give metal recovered from total scrap.

Equations 10 to 13: The four targets are calculated. The numerator of the first and second targets are on a gross weight basis and the numerators of the third and fourth are on a metallic recovery basis. In all cases, the denominator is domestic secondary metallic recovery plus domestic primary production.

The numerator of the first target is from equation (6) and is old scrap gross weight; the numerator of the second is total scrap gross weight and is predicted from equation (7); the numerator of the third is old scrap metallic recovery and is from equation (8); and the numerator of the fourth is total scrap metallic recovery.

4.3.5 Special Considerations

The targets in Section 4.3.6 do not consider the effect of nationwide legislation such as "bottle" bills that now apply in several states (Connecticut, Iowa, Maine, Vermont, Michigan and Delaware*) i.e., requiring deposits on beverage containers. This legislation can be either single tier ('uniform') or 'two tier' (discriminatory). In the two tier law, a lower deposit is required on refillable containers i.e., glass than on non-refillable containers. Although, in general, such legislation is likely to increase the reclamation ratio as it promotes increased source segregation, concerns have been expressed that a two tier legislation may promote a shift toward refillable beverage containers. In Oregon, for instance, it is claimed that the reclamation ratio has in-

* The law has been passed, but will take effect only when neighboring states Pennsylvania and Maryland adopt a 'bottle' bill.

creased to 80%. Any federal legislation requiring mandatory segregation of recyclable materials might have a similar effect. Also, action taken to reduce solid waste in dumps might also result in increased aluminum supply.

Another important consideration is that in the past the primary and secondary aluminum industries have generally catered to different markets. Traditionally, the primary industry bought little scrap and supplied the wrought products market, while the secondary industry was scrap-based and supplied the cast product market. Recently, the secondary aluminum industry has supplied almost 75-80% of the ingot metal for the foundry and die casting trades and has depended on the casting industry to consume almost 90% of its production. In the period 1965-1976, the amount of scrap consumed by secondary smelters has increased by about 19%, whereas that consumed by primary producers has almost doubled. Part of this increased scrap supply has been the result of consumer recycling programs for can reclamation. Since not much additional primary capacity is planned, it is likely that the competition for scrap between secondary and primary producers will increase. The primary industry now ships hot metal to automotive foundries. These shipments represent about 5-6% of the secondary aluminum capacity of about 2.45 billion pounds. There is also the possibility of primary producers increasing their market share in shipments to foundries. Recycling targets may well accelerate those structural changes that are already taking place.

4.3.6 Target Estimation

Recycling targets for 1987 have been developed for the aluminum industry utilizing the economic model developed in Section 4.3.4. The model is designed to predict the volume of scrap that will be available for recycling from different sources based on forecasts for exogenous variables used in the model. These volumes are then used to calculate targets. Because the projected targets are based on forecasts for exogenous variables, various possible scenarios have been considered.

Case I — Most Probable Exogenous Variables

(a) *Projected aluminum consumption in 1987.* The Economic Advisory Service at Arthur D. Little, Inc. assumes a 5% growth rate which has been selected for this case. The U.S. Bureau of Mines, on the other hand, projects a probable annual growth rate of 7.1% for the period 1976-1985, slowing to 4.3% between 1985-2000.[8] This averages 5.3% from 1976-2000.

(b) *Price of scrap.* The price of scrap is assumed to remain constant in real terms (1967 $).

(c) *Scrap from cans.* We project that this source of scrap will provide 505 million pounds by 1987, and that the aluminum reclaimed per can will decrease by 27% between 1976 and 1987. The can reclamation rate is expected to increase to 40% of cans made in 1987 and aluminum can production will increase from 20.1 billion in 1976 to 38.5 billion in 1987.

(d) *Aluminum imports.* During the 1968-1977 period, the U.S. produced 94% of the primary aluminum it consumed.[8] However, industry plans to increase its primary metal production capacity by less than 10% in the next five years. In 1985, domestic production of primary aluminum metal will comprise about 85% of the U.S. primary metal demand and 80% of the demand in 2000.[8] We have assumed that in 1987, the United States will produce about 85% of its primary metal demand. In the model, the estimated scrap supply is based on aluminum consumption and the price of scrap from which secondary recovery is estimated. When the ratio of pr.imary production to primary plus imports is known, primary production can be determined.

(e) *Scrap recovered from municipal solid waste.* We have assumed a reasonably optimistic view of aluminum recovery from solid waste streams of 100 million pounds in 1987. There is considerable uncertainty, however, about the ability of resource recovery plants equipped for aluminum recovery to operate on a sustained basis and about the amount of aluminum scrap available from this source. We have, therefore, examined the effects of + 50% variation in supply from this source in the section on sensitivity analysis.

(f) *Aluminum scrap inventory.* The time series of inventory (defined as the cumulative total of domestic aluminum consumption, less the cumulative scrap reclamation to date) for the period 1965-1976, described in Section 4.3.4, was extrapolated to 1987 to yield an estimate of 43.1 billion pounds.

(g) *Number of vehicles scrapped in 1987.* The number of vehicles scrapped in a given year has been around 70% of the number of cars sold in that year. On the basis of an estimated 15.8 million cars and Class I trucks projected to be produced in 1987, and using the 70% factor for scrappage, we estimate that 11 million cars will be scrapped and 80% of these, or 8.8 million vehicles, will be processed. If each of these vehicles yields about 38 pounds more of aluminum than cars processed in 1976, 334 million pounds of aluminum will be added to the scrap supply. If current trends continue, more scrap will be available from this source after 1987. We expect this trend to continue up to the early 1990's, after which the scrap from this source is likely to level off, as cars scarpped will be post 1985 cars.

(h) *Scrap export.* Exports of aluminum scrap are expected to increase slightly but decrease as a percentage of scrap consumption. For 1987, scrap exports are estimated at 200 million pounds.

Case II — Identical to the base case except that the real price of scrap rises to 13.1 cents per pound (1975).

Although the ratio of the price of secondary ingot to the price of old scrap is about 3.5 in 1976 (base case scrap price of 7.55¢/lb), it has been as low as 2 historically.

We have assumed that this ratio represents the minimum feasible margin under which secondary smelters may operate. A price of 13.1¢/lb (1975) for scrap with the price of secondary ingot held constant in real terms simulates this minimum ratio. This results in an increase in withdrawal rate for old scrap of 0.00461 compared to the base case withdrawal rate of 0.0034.

Case III —Identical to the base case, except exports in in 1987 drop to zero, to simulate a policy of restricting scrap exports.

Case IV —Identical to the base case, except that the new scrap generation coefficient is 0.19 compared to the base case coefficient of 0.206. This represents about a 1% improvement in fabrication yields, which Battelle believes to be technically feasible and economically practicable.[11, 12]

Recycling targets are presented in Table 4.3-10 for the 1987 scenarios. These targets represent ratios of:

(a) gross weight of old scrap

(b) gross weight of total scrap

(c) metallic recovery from old scrap, and

(d) total scrap metallic recovery to domestic primary production plus domestic secondary metallic production.

Table 4.3-10 shows that the recycle targets for total purchased scrap consumed increases 8.8% on a gross weight basis and 8.9% on a metallic recovery basis between 1976 and 1987 (base case). The target for old scrap consumed increases 18.0% on a gross weight basis and 18.3% on a metallic recovery basis between 1976 and 1987 (base case).

A comparison of the targets for the various cases indicates:

- Increasing the price of scrap by 73.5% over the base price of scrap increases old scrap target by about 23.7% on a gross weight basis and on a metallic recovery basis by 23%. The total scrap target increases approximately 7.5%, both on a total scrap and metallic recovery basis.
- Reducing exports to zero increases old scrap target by about 9.3% on a gross weight basis and 9.0% on a metallic recovery basis. The total scrap targets increase 2.9% on a gross weight basis and 3.1% on a metallic recovery basis.
- Increasing the new scrap generation coefficient to 0.19 from 0.203 does not affect old scrap recovery targets. Total scrap recovery on a gross weight basis and recovered metal basis decreases by about 4% from the base case target.

4.3.7 Sensitivity of Target to Key Factors

Table 4.3-11 shows the target in units selected by DOE for the target, i.e., the ratio of purchase scrap (prompt industrial and old, to total shipments or production of the primary and secondary industries.

The recycling targets presented in the previous section are directly affected by:

- Maximum withdrawal rate for old scrap, which is one of the most important determinants of old scrap supply. It has been as high as 0.53%, though it was only 0.34% in 1976. We have examined the effect of the two-year maximum withdrawal rate of 0.48%.
- Variation of new scrap generation coefficient.
- Scrap reclaimed from cans.
- Scrap recovered from municipal solid waste.
- Growth rate in consumption (a) 7% (b) 3%.
- Level of imports.

TABLE 4.3-10

RECYCLING RATIOS FOR ALUMINUM INDUSTRY
FOR FOUR SCENARIOS - 1987

Scenario	Old Scrap Consumption	Old Scrap Metallic Recovery	Total Purchased Scrap Consumption	Total Scrap Metallic Recovery
	Target Expressed as Ratio of ... to Domestic Primary Production Plus Secondary Metallic Production			
1976 =	0.100	0.0845	0.319	0.269
1987 =				
Case I Base Case	0.118	0.100	0.347	0.293
Case II Base Case except Price of scrap=13.1¢/lb WD = 0.00461	0.146	0.123	0.373	0.315
Case III Base Case except Exports = 0	0.129	0.109	0.357	0.302
Case IV Base Case except New Scrap Generation Coefficient = 0.19	0.118	0.100	0.333	0.281

TABLE 4.3-11

RECOVERED MATERIAL TARGET FOR ALUMINUM INDUSTRY - 1987

$$\frac{\text{Recovered Material*}}{\text{Domestic Primary \& Secondary Production}} \times 100 = 34.7\%$$

*Total Purchased Scrap Consumption (prompt industrial and obsolete).

The effect of these variables on the recycle targets is shown in Table 4.3-12.

- Increasing the withdrawal rate to the historic two-year high of 0.0477 increases old scrap consumption targets by 26.3% on a gross weight basis and 26% on a metallic recovery basis and total scrap consumption by 8.6% on a gross weight basis and 8.5% on a metallic recovery basis.
- Increasing new scrap generation rate by 10% increases total scrap consumption by about 6% on a gross weight basis and on a metallic recovery basis.
- Increasing scrap from cans by 10%, or increasing the aluminum scrap recovered from MSW by 50% increases old scrap consumption target by 2.5% on a gross weight basis and 2.0% on a metallic recovery basis and the total scrap consumption by 0.6% on a gross weight basis and 0.7% on a metallic recovery basis.
- If imports increase to 20% of domestic primary metal demand (domestic primary plus imports), the old scrap target increases by 4.2% on a gross weight basis and 4.0% on a metallic recovery basis. The total scrap consumption target increases by 4.3% on a gross weight basis and 4.4% on a metallic recovery basis.
- For a 7% growth rate in consumption for the period, the old scrap consumption target decreases 18.6% on a gross weight basis and by 19% on a metallic recovery basis. The total scrap target decreases by 3.7% on a gross weight basis and 3.75% on a metallic recovery basis.
- For a 3% increase in consumption of aluminum, the old scrap target increases by 30% on a gross weight basis and 29% on a metallic recovery basis. The total scrap consumption target increases by 13% on a gross weight basis and 13.3% on a metallic recovery basis.

4.4 COPPER

4.4.1 Selection of Recoverable Materials

Recoverable materials in the copper industry may come from a variety of solid wastes. In order to determine which of these should be included in the 1987 Recovered Materials Target, the criteria described in 4.1 Introduction have been used.

Table 4.4-1 lists all solid wastes containing copper, and notes which of them meet the criteria for inclusion in the 1987 Recovered Materials Target.

Materials meeting the criteria can be placed in the following categories:

- *No. 1 wire and heavy copper scrap* includes clean, uncoated, and unalloyed copper scrap containing more than 99% copper. This type of scrap normally does not require refining but is remelted and cast into shapes. Because of its high quality, this type of scrap is used by brass and bronze ingot makers, brass mills and secondary producers of unalloyed copper.
- *No. 2 wire, mixed light and heavy scrap* includes unalloyed copper relatively free of contaminants. The copper content normally is 92-96%. This type of scrap is mainly consumed by brass and bronze ingot makers and secondary producers of unalloyed copper.

TABLE 4.3-12

SENSITIVITY OF TARGETS TO KEY FACTORS

ALUMINUM INDUSTRY

Factor	Target Expressed as Ratio of			
	Old Scrap Consumption	Old Scrap Metallic Recovery	Total Scrap Consumption	Total Scrap Metallic Recovery
	to Domestic Primary Production plus Secondary Metallic Production			
1976:	0.100	0.0845	0.319	0.269
1987:				
Base Case	0.118	0.100	0.347	0.293
Withdrawal rate is average of historical two-year high WD = 0.00477	0.149	0.126	0.377	0.318
New scrap generation coefficient				
rises 10% (.223)	0.118	0.100	0.368	0.311
falls 10% (.183)	0.118	0.100	0.325	0.279
Scrap from cans				
rises 10%	0.121	0.102	0.349	0.295
falls 10%	0.116	0.098	0.349	0.291
Scrap from MSW				
rises 50%	0.121	0.102	0.349	0.295
falls 50%	0.116	0.098	0.349	0.295
Imports as a ratio of primary production plus imports				
ratio 20%	0.123	0.104	0.362	0.306
ratio 10%	0.114	0.096	0.333	0.281
Growth rate for aluminum consumption				
growth rate 7%	0.096	0.081	0.334	0.282
growth rate 3%	0.153	0.129	0.392	0.332

TABLE 4.4-1

SELECTION OF RECOVERABLE MATERIALS
COPPER INDUSTRY

Materials Possible to Recover	Does the Recoverable Material Meet Criteria for Inclusion? Yes	No
No. 1 Wire & heavy copper	X	
No. 2 Wire, mix heavy and light	X	
Composition of Red Brass	X	
Railroad Car Boxes	X	
Yellow Brass	X	
Cartridge Cases & Brass	X	
Auto Radiators	X	
Bronze	X	
Nickel Silver & Cupronickel	X	
Aluminum Bronze	X	
Low Brass	X	
Refinery Brass	X	
Low-Grade Scrap & Residues	X	
Aluminum Base Scrap		X
Nickel Base Scrap		X
Tin Base Scrap		X
Zinc Base Scrap		X
Home Scrap	X	
Smelter Waste Slag or Slag Tailings		X
Sludge		X
Skimming		X
Fume		X
Solution		X
Mine Waste	X	

*Criteria for inclusion outlined in Section 4.1.

- *Brass and bronze scrap* includes various types of alloyed copper such as composition or red brass containing 82.5% copper; yellow brass containing 65%; low brass scrap with 80%; and bronze with 57.5% copper. These types of scrap are mainly consumed by brass and bronze ingot makers and brass mills.
- *Other alloyed copper scrap* such as railroad car boxes with 73% copper, consumed mainly by foundries; cartridge cases, 70%, consumed almost entirely by brass mills; auto radiators, 70%, consumed by brass and bronze ingot makers; nickel-silver and aluminum-bronze, consumed mainly by brass mills; refinery brass with 65% copper, consumed by primary refiners.
- *Low-grade scrap and residues:* this form of copper scrap, which is difficult to define, is estimated to contain an average of 34% copper and is consumed entirely by primary and secondary smelters making unalloyed copper. Although the copper content in this scrap category is low the copper is relatively free of unwanted contaminants, such as bismuth. A major part of low-grade scrap consists of armatures from electrical motors and consequently contains major amounts of iron besides the copper.
- *Home scrap:* the industry generates home scrap in various forms and, if it is not contaminated during processing and handling, it is generally recycled to 100% within the industry segments. Included in homescrap are the dusts generated in various air pollution control devices.
- *Mine waste:* this recoverable material is derived from leaching of mine waste dumps, that is, dumps containing mined material not classified as ore because the low grade of copper precludes economic processing in the beneficiation plant. Copper is recovered in the form of cement copper and is consumed entirely by primary smelters. The mine waste category does not include copper recovered from the leaching of copper concentrate.

Excluded as not meeting the criteria are the following materials:

- Sludge: The amount of copper contained in majority is not sufficient to make recovery economically viable by 1987 and is therefore excluded from the analysis.
- Skimming: Small amounts of skimmings are presently recycled. The amount is insignificant today, however, and no increase is foreseen before 1987.
- Slag: Waste smelter slags are usually low in copper (less than 1 percent). Recovery of copper from waste slag is unlikely in the foreseeable future and is excluded from the analysis.
- Fume: The amount of copper contained in fumes is insignificant and is excluded from the analysis.
- Solution: The amount of copper contained in solutions is insignificant and is excluded from the analysis.
- Aluminum-, Nickel-, Tin-, and Zinc-based scrap: These materials are recycled and the contained copper recovered. However, the recycling is not normally done within the copper industry. Therefore these materials are excluded from the 1987 Recoverable Materials Target for copper.

4.4.2 Selection of Process Subdivision for Inclusion in the Target

Table 4.4-2 shows the consumption pattern of recoverable materials in the copper industry for the following four industry subdivisions:

- Primary Producers, including primary smelters and refiners producing refined copper,
- Secondary Smelters, producing refined copper, and brass and bronze ingot makers.
- Brass Mills
- Foundries, chemical plants and other manufacturers.

Table 4.4-3 shows that brass mills were the largest consumer of purchased copper scrap (i.e., all recoverable materials excluding home scrap and mine waste) consuming 662,454 short tons, which represents 44% of the total scrap consumption of 1,513,972 short tons in 1976. Of this scrap, 95% was new and 5% was old scrap.

Primary producers used 425,790 short tons or 28% of total scrap consumed in 1976. Of this, 44% was new and 56% old scrap. Secondary smelters consumed 356,786 short tons or 24% of total scrap consumption, of which 29% was new and 71% was old.

The remainder, 68,912 short tons or 5% of the purchased scrap consumed in 1976 went to foundries, chemical plants, and other manufacturers; 29% of this was new scrap and 71% old. A summary of the flow of purchased copper scrap in 1976, divided between new and old scrap is shown in Figure 4.4-1.

The historical (1970-1976) consumption of the recoverable materials meeting the criteria for inclusion in the 1987 copper recycling are shown in Table 4.4-4. This table also shows the average dealers' buying prices for various types of purchased copper scrap in this period.

Table 4.4-5 shows the historical consumption of recoverable materials from 1970 to 1976 with consumption split among the four industry subdivisions.

4.4.3 Technical Considerations

4.4.3.1 Process Constraints

4.4.3.1.1 Secondary Smelters

Secondary smelters can be subdivided into two categories —those which can smelt and refine and those which are essentially remelters and refiners and have no smelting capability. Secondary smelters having smelting and refining capability can process a wide variety of scrap, low or high grade, old or new, to produce "black copper" which contains over 80% copper. The black copper is then fire or electrolytically-refined to produce secondary refined copper, or it is used to produce alloy ingot. These types of secondary smelters are 100% scrap based and have practically no process constraints in processing copper scrap.

A class of secondary smelters, mostly ingot makers, can process only those types of scrap which require no smelting or converting operations. They can only melt and fire refine high grade

TABLE 4.4-2

RECOVERABLE MATERIAL - SOURCE - INDUSTRY MATRIX - COPPER INDUSTRY

Industry Subdivision	No. 1 Wire	No. 2 Wire	Composition	Railroad Car Box	Yellow Brass	Cartridge Cases	Auto Radiators	Bronze	Nickel Silver	Aluminum Bronze	Low Brass	Refinery Brass	Low-grade Scrap	Homescrap	Mine Waste
Secondary Smelters	x	x	x	x	x	x	x	x	x	x	x			x	
Primary Producers	x	x										x	x	x	x
Brass Mills	x	x			x	x		x	x	x	x			x	
Foundries Chemical Plants Other Manuf.	x	x	x	x	x	x	x	x	x	x	x		x	x	

Source: Arthur D. Little, Inc.

TABLE 4.4-3

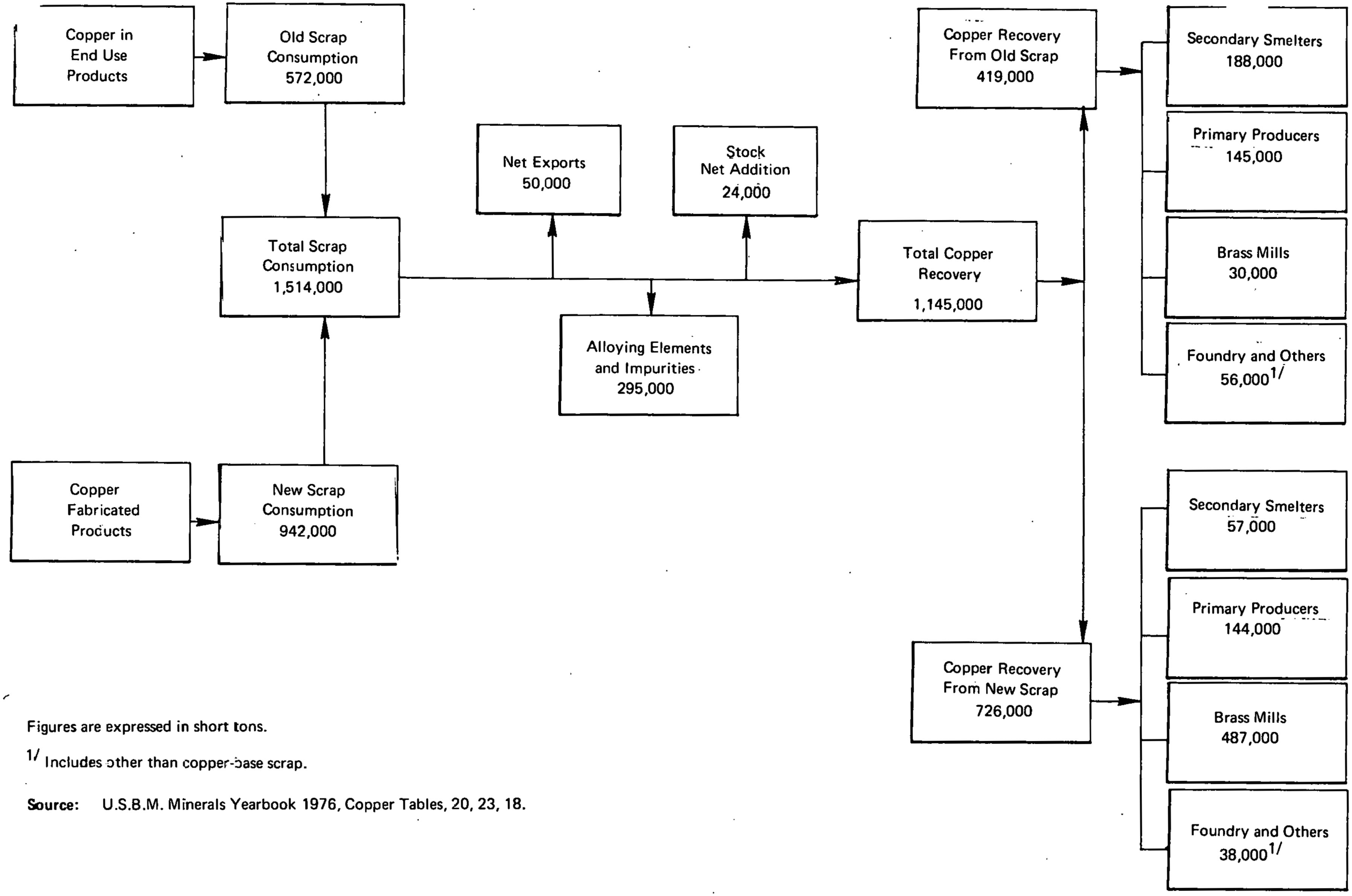
CONSUMPTION OF RECOVERABLE MATERIALS 1976 - COPPER INDUSTRY[1]

(Gross Weight in Tons)

Industry Subdivision	No. 1 Wire	No. 2 Wire	Compo- sition	Railroad Car Box	Yellow Brass	Cartridge Cases	Auto Radiators	Bronze	Nickel Silver	Alum. Bronze	Low Brass	Refin. Brass	Low Grade Scrap	Home Scrap	Mine Waste[2]
Secondary Smelters	27,028	59,900	58,605	1,852	46,217	195	57,823	19,920	3,085	567	2,882	-	78,712	0	-
Primary Producers	117,669	128,340	-	-	-	-	-	-	-	-	-	4,230	175,551	0	126,144
Brass Mills	159,250	71,778	-	-	269,074	78,028	-	4,219	33,791	355	45,959	-	-	0	-
Foundries, Chemical Plants and Other Manufacturers	29,187	9,328	4,518	4,325	8,048	-	10,258	598	82	449	1,455	-	64	0	-

[1] U.S. Bureau of Mines Minerals Yearbook 1976, Copper - Table 23

[2] Net Weight of Copper, U.S. Bureau of Mines, Minerals Yearbook 1976, Copper - Table 7.



Figures are expressed in short tons.

1/ Includes other than copper-base scrap.

Source: U.S.B.M. Minerals Yearbook 1976, Copper Tables, 20, 23, 18.

FIGURE 4.4–1 FLOW OF PURCHASED COPPER SCRAP IN 1976

TABLE 4.4-4

PRICE/QUANTITY DATA FOR RECOVERABLE MATERIALS (1970-1976)
COPPER INDUSTRY

Recoverable Material	Consumption[1] Gross Weight (short tons)							Price ($/ton)[4]						
	1970	1971	1972	1973	1974	1975	1976	1970	1971	1972	1973	1974	1975	1976
No. 1 Wire	304821	297752	331470	421570	411343	285947	333134	921	(730)[5]	(880)	(1140)	1300	(810)	(980)
No. 2 Wire	346300	299872	332476	346366	345083	242514	269946	789[2]	551	780	1004	1098	679	814
Composition	84263	83716	87508	84692	81796	53968	63123	725[3]	598	591	817	875	649	681
Railroad Car	28073	10495	8994	9427	8107	5668	6177	530	(440)	(520)	(740)	750	(480)	(580)
Yellow Brass	321131	307258	404423	405375	358291	254769	323339	480	(370)	(460)	(680)	716	(420)	(510)
Cartridge Case	116801	143946	112684	89053	77450	56062	78223	(520)	(400)	(500)	(710)	(760)	(460)	(540)
Auto Radiators	56713	64935	73540	68744	69215	53321	68081	520	(400)	(500)	(710)	800	(460)	(540)
Bronze	34522	31306	32152	34575	32153	24114	24737	(430)	(310)	(390)	(630)	(660)	(380)	(470)
Nickel Silver	22949	28161	32601	32835	40140	42028	36958	(480)	(370)	(460)	(680)	(720)	(420)	(510)
Aluminum Bronze	1483	1177	1381	1953	1497	1002	1371							
Low Brass	49398	54291	42481	29419	31362	31317	50296	(625)	(600)	(590)	(810)	(860)	(560)	(650)
Refinery Brass	6540	6195	6127	5112	9953	3229	4230	(480)	(370)	(460)	(680)	(720)	(420)	(510)
Lowgrade Scrap	381862	330495	315437	333938	311139	198629	254327	290	(180)	(240)	(470)	540	(210)	(320)
Home Scrap	NA	NA	NA	NA	NA	NA	NA							
Mine Waste[6]	171968	154515	170993	159023	146108	144294	126144							

[1]USBM Minerals Yearbook 1970-1975, Copper - Table 23 (24).
[2]Metal Statistics 1977, p. 101, Dealers Buying Price.
[3]Metal Statistics 1977, p. 127, Dealers Buying Price.
[4]American Metal Market 1970,1974.
[5]( ) Arthur D. Little Estimate.
[6]Net weight (short tons) copper content.

TABLE 4.4-5

CONSUMPTION OF RECOVERABLE MATERIAL 1970-1976
COPPER INDUSTRY
Gross Weight (Short Tons)

Recovered Material	Secondary Smelters 1970	1971	1972	1973	1974	1975	1976
No. 1 Wire, Heavy	22489	30774	32432	28058	31439	25278	27028
No. 2 Wire, Mixed Light and Heavy	76202	64321	64887	77369	71417	60177	59900
Composition	78474	78419	82597	79169	74917	49276	58605
Railroad Car Boxes	2107	1584	2712	2395	1366	1083	1852
Yellow Brass	58730	64235	65482	60491	51993	38668	46217
Cartridge Cases	358	146	204	144	00	75	195
Auto Radiators	49359	55902	63281	58220	60426	45659	57823
Bronze	27688	25630	27653	28144	26112	19642	19920
Nickel Silver	4034	4386	3578	4681	4203	2785	3085
Aluminum Bronze	478	284	423	917	583	339	567
Low Brass	4535	4201	3713	3359	2544	2329	2882
Refinery Brass							
Lowgrade Scrap	45125	93606	82120	59176	59127	56290	78712
Home Scrap[2]	NA	NA	NA	NA	NA	NA	NA
Mine Waste[3]							

Recovered Material	Primary Producers 1970	1971	1972	1973	1974	1975	1976
No. 1 Wire, Heavy	144177	90423	95143	128931	138098	97787	117669
No. 2 Wire, Mixed Light and Heavy	225288	183102	199315	195812	203415	129201	128340
Composition							
Railroad Car Boxes							
Yellow Brass							
Cartridge Cases							
Auto Radiators							
Bronze							
Nickel Silver							
Aluminum Bronze							
Low Brass							
Refinery Brass	6540	6195	6127	5112	9953	3229	4230
Lowgrade Scrap	329468	236349	232344	273975	251369	142288	175551
Home Scrap[2]	NA	NA	NA	NA	NA	NA	NA
Mine Waste[3]	171968	154513	170993	159023	146108	144294	126144

Recovered Material	Brass Mills 1970	1971	1972	1973	1974	1975	1976
No. 1 Wire, Heavy	117567	155023	172640	228083	205240	137580	159250
No. 2 Wire, Mixed Light and Heavy	35234	39666	56882	60275	59672	43061	71778
Composition							
Railroad Car Boxes							
Yellow Brass	256618	236967	333348	340110	299061	209959	269074
Cartridge Cases	116443	143800	112480	88909	77350	55987	78028
Auto Radiators							
Bronze	5937	4870	3859	5492	5319	3803	4219
Nickel Silver	18884	23750	28998	28208	35930	39233	33791
Aluminum Bronze	600	436	458	322	398	394	355
Low Brass	44440	49628	38099	25315	27369	28347	45959
Refinery Brass							
Lowgrade Scrap							
Home Scrap[2]	NA	NA	NA	NA	NA	NA	NA
Mine Waste[3]							

Recovered Material	Foundries, Chemical Plants and Other Manufacturers 1970	1971	1972	1973	1974	1975	1976
No. 1 Wire, Heavy	20588	21532	30455	36498	36519	25302	29187
No. 2 Wire, Mixed Light and Heavy	9567	12783	11392	12910	10579	10075	9928
Composition	5789	5297	4911	5523	6879	4692	4518
Railroad Car Boxes	25966	8911	6282	7032	6741	4585	4325
Yellow Brass	5783	6056	5593	4774	7237	6142	8048
Cartridge Cases							
Auto Radiators	7354	9083	10259	10524	8789	7662	10258
Bronze	897	806	640	939	722	669	598
Nickel Silver	31	25	25	6	7	10	82
Aluminum Bronze	405	457	500	724	516	269	449
Low Brass	423	462	669	745	849	641	1455
Refinery Brass							
Lowgrade Scrap	729	540	973	787	643	51	64
Home Scrap[2]	NA	NA	NA	NA	NA	NA	NA
Mine Waste[3]							

Recovered Material	Total 1970	1971	1972	1973	1974	1975	1976
No. 1 Wire, Heavy	304821	297752	331470	421510	411343	285947	333134
No. 2 Wire, Mixed Light and Heavy	346300	299872	332476	346366	345083	242514	269946
Composition	84263	83716	87508	84692	81796	53968	63123
Railroad Car Boxes	28073	10495	8994	9427	8107	5668	6177
Yellow Brass	321131	307258	404423	405375	358291	254769	323339
Cartridge Cases	116801	143946	112684	89053	77450	56062	78223
Auto Radiators	56713	64985	73540	68744	69215	53321	68081
Bronze	34522	31306	32152	34575	32153	24114	24737
Nickel Silver	22949	28161	32601	32895	40140	42028	36958
Aluminum Bronze	1483	1177	1381	1963	1497	1002	1371
Low Brass	49398	54291	42481	29419	31362	31317	50296
Refinery Brass	6540	6195	6127	5112	9953	3229	4230
Lowgrade Scrap	381862	330495	315437	333938	311139	198629	254327
Home Scrap[2]	NA	NA	NA	NA	NA	NA	NA
Mine Waste[3]	97824	73711	88501	76129	69952	56828	0

[1]U.S. Bureau of Mines Minerals Yearbook 1970-1976, Copper Table 23 (24).

[2]Includes slag and flue dust.

[3]U.S. Bureau of Mines Minerals Yearbook 1970-1976, Copper Table 7.
Net weight copper content, short tons.

scraps because of process equipment limitations. Most low grade scraps require some form of melting and converting, or converting and complex fire refining; whereas high grade scrap can be just smelted and fire refined in a conventional manner.

In general, secondary smelters are 100% scrap based and can process a wide range of copper scrap. The process limitations depend on the type of equipment installed in the smelter.

4.4.3.1.2 Primary Producers

Primary refiners can produce anodes by melting high-grade scrap. The anodes are in turn used to produce electrolytically-refined copper. Although there are no process restraints on refining of high-grade scrap, there are definite limits to scrap utilization in the smelting process. Primary smelters, like secondary, purchase large amounts of low-grade scrap and residues for upgrading to blister. The scrap is normally added in the converter step. Smelting furnaces can, in principle, melt scrap, but they are designed for handling finely-powdered concentrates and not heavy, bulky scrap. It is not likely that the furnaces will be altered for the feeding of substantial quantities of heavy scrap in the near term.

Since there are no external heat inputs, the scrap handling ability of a converter is determined by its ability to absorb heat losses incurred from addition of scrap into the molten matte this in turn is determined by the matte grade. Assuming the average matte grade in the U.S. industry to be 35%, the maximum consumption of recoverable materials in the converter step would be approximately 35% of blister output.

4.4.3.1.3 Brass Mills

Brass mills melt copper, copper scrap, a small amount of recycled alloy ingot, and alloying material into billets, slabs, or cakes. From these they then fabricate tubes, sheets, rods, and mechanical wire. Because brass mills usually have only melting facilities, they purchase clean and well-sorted scrap and do not recycle any low-grade scrap or residues; the amount of old scrap consumed is very small. Brass produced from scrap is, however, interchangeable with brass produced from refined metal if alloying constituents are comparable.

4.4.3.1.4 Foundries, Chemical Plants and Other Manufacturers

Foundries, like brass mills, are basically remelters and as such have very limited ability to consume low-grade scrap and residues. Scrap consumption in foundries is based on high grade unalloyed copper scrap used as a substitute for refined copper. For such high-grade scrap there are no process restraints. Consumption of lower grade scrap is limited to scrap with a desired and well-known composition.

Consumption of copper scrap by powder manufacturers, chemical plants, and other manufacturers, such as the steel and aluminum industries, is limited and will have no impact on the target setting for recoverable materials.

4.4.3.2 Product Quality Constraints

As secondary refined copper is a perfect substitute for primary refined copper and as brass and foundry products produced from scrap are interchangeable with brass produced from refined metal if alloying constituents are comparable, there are no product quality constraints that will have any impact on the 1987 recycling target. In specific plants, however, the requirement for impurity dilution will constrain the type and amount of recovered material that can be used.

4.4.3.3 Recoverable Materials Quality Constraints

Purchased Scrap: Almost any type of copper-containing material can be reclaimed and used in the production of secondary copper, regardless of age, condition, or degree of contamination. Quality constraints must, however, be recognized when discussing the various consumers.

High-grade copper scrap can theoretically be used in all segments of the industry, although most of it is consumed by brass mills, ingot makers, and foundries, all remelters with process constraints on using low-grade scrap.

Low-grade scrap and residues can only be used by primary, and to a much lesser degree, secondary smelters because upgrading is required. Brass and bronze scrap cannot be used to produce refined copper. This type of scrap is consequently limited to brass mills, ingot makers, and foundries.

Home Scrap: There are no quality constraints to the recovery of copper in home scrap as long as the quality of the home scrap is well-defined. Included under the term home scrap are such recoverable materials generated within the consuming plant such as cuttings, grindings, trimmings, flue dust, spills, and sweeps.

Mine Wastes: Copper in mine wastes is recovered by leaching of mine waste dumps and precipitation on iron to form cement copper. Because of the iron and other impurities in the cement copper, and because the primary producers all of the cement copper, consumption is constrained to primary smelters.

4.4.4 Economic Considerations in Recycling

As with other metals, copper can be recovered from old and new scrap sources. New scrap is generated automatically from fabricating activities in copper processing and fabricating industries. Thus, the supply fluctuates with the level of copper-based production and is relatively independent of price considerations. Old scrap, on the other hand, represents recovery of the copper embodied in discarded materials, and some degree of price responsiveness in its availability is to be expected.

As Table 4.4-6 indicates, old scrap has played a significent, but not dominant role as a balancing agent in U.S. refined copper production. Since the production of copper ore is relatively inflexible in the short run, and new scrap production is largely determined by activity levels in the copper fabricating industry, old scrap plays an important role in meeting fluctuating levels of excess demand in the system. Because scrap copper can be recovered with varying degrees of difficulty from different materials, it is natural to expect some degree of price responsiveness from old scrap suppliers.

The major sources of secondary scrap copper are No. 1 and No. 2 wire, yellow brass, and low-grade scrap, with cartridge cases and composition/red brass playing a significant but secondary role. Since the high-exploitation sources (No. 1 and No. 2 wire) are usable at low cost, most expansion in periods of heightened demand will come from the marginal sources at intermediate and low levels of exploitability (yellow brass/ cartridge cases and low-grade scrap/composition, respectively). The resulting relationship between scrap price and supply levels is likely to be

TABLE 4.4-6

COPPER PRODUCTION BY REFINERIES (BY INPUT SOURCE), 1974-1976

	1974	1975	1976
Total Production ('000 short tons),	2,068	1,714	1,826
Primary Refined (%)	80.0	84.2	84.2
Secondary Refined (%)	20.0	15.8	15.8
New Scrap (%)	11.1	8.1	7.9
Old Scrap (%)	8.9	7.7	7.9

Source: U.S. Bureau of Mines, Mineral Industry Surveys, "Copper in 1976", April 15, 1977, p. 4.

discontinuous. Nevertheless, it is useful for long-range policy planning to have some estimate of the average price elasticity of the secondary scrap supply. The best available numbers are provided by three econometric models of the copper industry that use recent time series data.

The three models are Forecasts and Analysis of the Copper Market, prepared for the General Services Administration by Charles River Associates, Inc., in May 1973 (henceforth referred to as CRA); An Economic Analysis of the Secondary Copper Industry in the United States, a Ph. D. dissertation submitted to the College of Earth and Mineral Sciences, Pennsylvania State University, in August 1976 by Elizabeth S. Bonczar (henceforth PS); and An Econometric Model of the World Copper Industry by F.M. Fisher, O.H. Cootner, and M.N. Bailey (originally published in The Bell Journal of Economics and Management (1971)) (henceforth FCB). The evidence provided by each of these models is regarded as relevant, because all use acceptable corrections for the simultaneity problem and all make use of the Fair technique.*

The general approach to estimation in the three models is similar, but differences in estimates of short- and long-run price elasticities of copper scrap supply in the United States result from differences in the design of the estimating equations, the periods over which the estimates are taken, and the unit of time used for the econometric exercises. Although no final judgment on the relative quality of the three models can be made, it appears that the model of the market incorporated in the CRA and FCB approaches is superior to that in the PS effort.

The short-run estimates for the scrap supply elasticities do not differ widely for the three models: CRA (0.49), FCB (0.42), PS (0.24). Using the reported standard errors for the CRA and FCB results, it is also possible to estimate the interval of values within which it is 95% probable that the true short-run elasticity (SRE) lies by the standard statistical criteria: CRA (0.30 ≤SRE

* See Section 2.1.6 on econometric estimation procedures for a discussion of these points.

0.68), FCB (0.20 ≤SRE ≤0.65). If both results are considered as equal in value, any estimate of the SRE between 0.20 and 0.68 cannot be rejected as implausible.

The long-range estimates are quite different. The best estimates of long-run elasticities (LRE's) are quite different: CRA (0.66), FCB (0.31), PS (0.24). The CRA specification seems somewhat superior to the others, but the difference does not seem sufficient to generate such divergent long-run estimates. In any case, the existing estimates serve to define the range within which an appropriate estimate of the LRE's may be supposed to lie.

4.4.5 Special Considerations

One of the special considerations in recycling of copper is the proposed governmental pollution control regulations and their impact on the industry structure and the ability of the industry to process scrap and low quality materials in compliance with these regulations.

4.4.6 Target Estimation

Shown in Table 4.4-7 is the historical consumption of the various forms of recoverable material being considered for the 1987 target. The quantities are given in short tons of contained copper and are derived from Table 4.4-4 by applying the average figures for contained metal in the various forms of recoverable materials discussed in Section 4.4.1.1. Table 4.4-7 also gives the historical recycling ratio, which is defined as the ratio of recovered copper to (recovered copper plus primary production) expressed as a percentage for the period 1970-1976. The recycling ratio over this period has a mean value of 47.0%, a maximum value of 49.4%, and a minimum value of 44.8%. Consequently, the recycling ratio has been relatively stable between 1970 and 1976.

The econometric results discussed in Section 4.4.4 are useful for projecting copper recovery given projections of scrap price and the size of the recoverable copper reservoir can be provided. Calculation of the recycling ratio (recovered copper/(recovered copper plus primary production)) also requires a projection of primary refined copper production. This report employs the projected increase rates for scrap price and primary production which are found in the Arthur D. Little, Inc., report "Economic Impact of Environmental Regulations on the United States Copper Industry," submitted to the U.S. Environmental Protection Agency in January 1978. The Arthur D. Little projections also incorporate the anticipated impact of pollution abatement legislation during the coming decade. The increase in the recoverable copper reservoir has been calculated using an observable average lag of approximately 20 years between the use of copper in capital equipment and its release through scrapping. The estimated rate of increase from 1974 to 1987 has been extrapolated from data on copper consumption during the period 1954-1967.[1] The estimated short-run scrap price elasticities for the CRA/FCB models are similar, while the long-run elasticities diverge considerably: 0.45 is adopted here as a reasonable intermediate figure. The CRA estimate of the elasticity of recovery from the available reservoir (0.55) is also employed. With these price, production, and reservoir growth rate projections (summarized in Table 4.4-8), and the CRA/FCB estimates of response elasticities for scrap price and reservoir recovery, the copper recovery level is projected to increase 26.3% through 1987. Table 4.4-9 shows the target in units selected by DOE for the target, i.e., recovered material as a percentage of total shipments or production of the primary and secondary industries. As Table 4.4-10 reveals, the target does differ significantly from the typical ratio that has prevailed during the 1970's.

TABLE 4.4-7

HISTORICAL RECYCLING DATA - 1970-1976
COPPER INDUSTRY
(Short Tons Contained Copper)

Recovered Material	1970	1971	1972	1973	1974	1975	1976
No. 1 Wire	304,516	297,454	331,139	421,148	410,932	285,661	332,801
No. 2 Wire	231,522	231,880	312,527	325,584	324,378	227,963	253,749
Composition	63,517	59,066	72,194	69,871	67,482	44,524	52,076
Railroad Car Boxes	20,493	7,661	6,566	6,882	5,918	4,138	4,509
Yellow Brass	203,735	199,718	262,875	263,494	232,889	165,600	210,170
Cartridge Cases	81,761	100,762	78,879	62,337	54,215	39,243	54,756
Auto Radiators	39,699	45,490	51,473	48,121	48,451	37,325	47,657
Bronze	19,850	18,001	18,487	19,881	18,488	13,866	14,224
Nickel-Silver	14,917	18,305	21,191	21,382	26,091	27,318	24,023
Aluminum-Bronze	964	765	898	1,276	973	651	891
Low Brass	39,518	43,433	33,985	23,535	25,090	25,054	40,237
Refinery Brass	4,251	4,027	3,983	3,323	6,469	2,099	2,750
Low-Grade Scrap	129,833	112,368	107,249	113,539	105,787	67,534	86,471
Mine Waste	17[illegible],968	154,515	170,993	159,023	146,108	144,294	126,144
TOTAL COPPER RECOVERED	1,337,544	1,353,445	1,472,444	1,539,396	1,473,271	1,055,270	1,250,458
TOTAL PRIMARY* PRODUCTION	1,593,126	1,437,267	1,702,240	1,709,465	1,508,550	1,229,084	1,413,164
RECOVERED COPPER / RECOVERED COPPER AND PRIMARY PRODUCTION	.456	.435	.464	.474	.494	.448	.469

*Excluding mine waste - defined as secondary.

Source: U.S. Bureau of Mines Minerals Yearbook 1970-1976, Copper.
Arthur D. Little, Inc. estimates.

TABLE 4.4-8

COPPER INDUSTRY ESTIMATED INCREASE (1974-1987)

Primary Refined Output	21.5%*
Scrap Price	17.0%**
Recoverable Reservoir	34.0%***

* Economic Impact of Environmental Regulations on the United States Copper Industry, Report to the U.S. EPA by Arthur D. Little, Inc., January, 1978, Table XII-7, p. XII-9.

** Op. Cit., Table XII-9, p.XII-25.

*** Metal Statistics, (1955, 1962, 1971, 1976)

TABLE 4.4-9

RECOVERED MATERIAL TARGET FOR COPPER INDUSTRY (1987)

$$\frac{\text{Recovered Material*}}{\text{Domestic Primary \& Secondary Production}} \times 100 = 50.4\%$$

*Prompt industrial and obsolete scrap, plus precipitate copper from mine waste.

TABLE 4.4-10

COPPER RECYCLING RATIOS, 1970-1976*

Year	Ratio
1970	45.6%
1971	48.5%
1972	46.4%
1973	47.4%
1974	49.4%
1975	44.8%
1976	46.9%
Mean Ratio:	47.0%

* Ratios derived from Table 4.4-7.

4.4.7 Sensitivity of Target to Key Factors

Key factors that could have a positive effect on the 1987 target are:

- Rising energy costs will probably be the most important commercial incentive for recycling of more copper in the near future. Industry sources estimate that energy consumed per pound of refined metal recovered from low-grade obsolete scrap is approximately one-third that needed to produce refined copper from virgin material.

- The high level of industrial activity during the 1960's will result in a surge of copper scrap entering the market in the 1980's. Regulatory and public pressure could influence increased recycling.

- Further regulations governing the mining industry which would drastically increase the cost of primary production.

- Changes in freight rates might favor scrap transportation.

Key factors that could have a negative effect on the 1987 target are:

- Legislative action that would reduce the amount of recycling, such as sale of emergency copper stockpiles.

- A decrease in the amount of less desirable scrap recycled. All industrial, or new scrap is already recycled to almost 100% which means that any change in the recycling ratio would have to be from obsolete or old scrap. A Battelle study[2] shows that the approximate composition of old scrap that is not recycled is:

  16% — End uses in which copper is widely dispersed, as in consumer durables.

  15% — Magnet wire used primarily in small electric motors.

  10% — A copper used as sacrificial additives that disappear during processing.

  8% — Unrecovered cartridge brass, often spread out over large areas.

  51% — "Other brass" including thousands of relatively minor end uses.

Because the collection, sorting, and preparation of the above categories of copper scrap are extremely labor-intensive and costs for transportation are high, recycling of these categories is very dependent on scrap prices, particularly on a short-term basis. The only situation that could have an important positive influence on the recycling of this scrap would probably be a significant increase of scrap prices over the long term, and no such long-term stability is evident in the scrap price historical data. Labor and transportation costs are likely to increase further, and reduction in recycling of the above described scrap categories could be the result by 1987.

4.5 ZINC

4.5.1 Selection of Recoverable Materials

Recovered material for the zinc industry means zinc recovered from any waste. This includes both materials generated in the manufacture of zinc products (new scrap) and post consumer materials (old scrap) that have been collected or recovered from discarded products. The criteria that have been used to determine if a particular source of material should be considered in the context of this study include:

- The quality, dispersion, and quantity of existing sources;
- Any changes in existing sources for the period to 1987;
- Any potential new sources;
- Any wastes listed in the National Energy Conservation Act, such as mine wastes;
- Any source that may provide recovered material to replace any virgin materials in any zinc industry subdivision.

Materials specifically excluded are:

- Any wastes not among those listed in the National Energy Conservation Act;
- Any wastes that are not expected to be used as a recovered material by 1987 for whatever reason — technical, economic, or institutional.

The sources screened for inclusion as recoverable material are listed in Table 4.5-1. Each type of scrap is checked against the criteria for inclusion to see if it should be included as a recoverable material in the target. Many of the new zinc scraps, both purchased and home scrap, are included in the target setting; these are most often recycled at present. For example, the zinc supplier to a galvanizer generally contracts to buy back all zinc-containing residues. The galvanizer residues repurchased under these agreements includes drosses, skimming, ashes, and sal skimmings. Zinc die casters generally do not enter into such contracts, but their scrap is generally recycled as home scrap or sold to dealers for recycle. Some chemical residues and flue dusts are also recycled as sources of recoverable materials. The main new stream source is electroplating liquors, which will not be reprocessed for their zinc content by any zinc industry subsector before 1987. Other industry sectors might reprocess these electroplating solutions for their more valuable metal content.

The zinc contained in brass scrap is not included in the zinc target, primarily because it would result in double counting. Brass has its own targets (see discussion of the copper industry, Section 4.4) and zinc is included there. The concern about double counting zinc should not allow any recycle zinc to go unreported since the zinc in brass always remains in recovered brass alloys.

The old purchased scrap category shown in Table 4.5-1 includes several materials that will be included in the target and several that are not. The old die cast scrap, mainly recovered from automobiles and home appliances is included and is an area for increased recovery. The general zinc scrap includes old engravers plates and old zinc metal. The zinc-containing fractions from municipal incinerators are a category which might make a small contribution before 1987. The

TABLE 4.5-1

SELECTION OF RECOVERABLE MATERIALS

ZINC INDUSTRY

Recovered Material	Does the Recoverable Material Meet the Criteria* for Inclusion? Yes	No
New Scrap		
Purchased New Scrap		
• Galvanizers' Residues	X	
• Prompt Die-Cast Scrap	X	
• Chemical Residue and Flue Dust	X	
• Electroplating Liquors		X
Home Scrap	X	
Old Purchased Scrap		
• Old Die-Cast Scrap	X	
• General Zinc Scrap	X	
• Municipal Incinerator Wastes	X	
Miscellaneous Wastes Containing Zinc		
• Rubber Products and Tires		X
• Paint Pigments		X
• Building Demolition Wastes		X
• Municipal Landfills		X
• Old Mine Wastes		X

*Criteria is outlined in Section 4.1.

other miscellaneous wastes that contain zinc are not included in the target because they are either dissipative uses of zinc or they are not expected to be recovered before 1987. For example, the zinc oxide will not be recovered from rubber products until a process is developed to recover the energy or chemicals from the rubber. Paint pigments are a dissipative use of zinc, and building demolition wastes will not be sorted for metals because of labor costs. The zinc content of old municipal landfills or old mine wastes is not high enough to warrant its processing before 1987.

4.5.2 Selection of Process Subdivision for Inclusion in the Target

The historical consumption pattern for waste materials in each of the major industry processes is given in Table 4.5-2. The different recoverable materials have historically gone to different types of processing depending upon the process and recoverable material constraints. One of the striking features of this table is that electrolytic reduction plants do not generally process any scrap except their home scrap. The major factor restricting the use of recovered materials in these plants is the necessity of avoiding contaminating metal ions in the electrolytic bath solutions. Another feature of Table 4.5-2 is that secondary distillers process all types of scrap, both metallic and oxidized.

4.5.3 Technical Considerations

The technological factors controlling recycling can be discussed in terms of process constraints, product quality constraints, and recovered material quality constraints. The recoverable materials that pass all these constraints are the basis of the technological targets.

4.5.3.1 Process Constraints

Looking at the process contraints by class of recoverable material, the following statements can be made:

- The only processes that generally recover zinc products from oxidized zinc materials are the vertical distillation retorts and the chemical and pigment plants. The types of scrap that are generally highly oxidized include the galvanizers' scrap, the chemical residues, and the flue dusts.

- The foundries recover zinc from scrap that has a high metallic zinc content and controlled metallic impurities. They usually process their own home scrap and other new zinc die-cast scrap.

- The secondary distillers process all zinc scrap, but can recover only the metallic zinc content of the scrap. They must sell the residues to other plants for recovery of the zinc values from the oxidized zinc content.

Table 4.5-3 shows the amounts of scrap utilized by each zinc producing process. The secondary distillers, vertical distillers, and chemical plants are the largest processors of scrap in that order.

If all smelter capacity capable of processing scrap processed scrap rather than virgin ore, an additional 350,000 short tons of zinc scrap could be processed per year. Most of this additional capacity is in the primary vertical retorts, which could accept more scrap in their charge. The large excess smelting capacity indicates that processing is not a major restriction to increased zinc recycling.

TABLE 4.5-2

RECOVERABLE MATERIAL - SOURCE - INDUSTRY MATRIX - ZINC INDUSTRY

	Types of Recoverable Materials					
Process	Galvanizers' Residues	New Die Cast Scrap	Chemical Residues	Home Scrap	Old Die Cast Scrap	General Zinc Scrap
Electrolytic Reduction				X		
Vertical Distillation Retorts	X		X	X		
Secondary Distillers	X	X	X	X	X	X
Foundries		X		X	X	
Chemical and Pigment Plants	X		X	X	X	

Source: 1970-1976 Mineral Yearbooks, Volume I, Metals, Minerals and Fuels, U.S. Department of the Interior, Bureau of Mines. Tables 13, 14, 15 for Zinc.

TABLE 4.5-3

CONSUMPTION OF RECOVERABLE MATERIALS - 1976

ZINC INDUSTRY

	Types of Recovered Materials in Tons of Zinc Contained						
Process	Galvanizers' Residues	New Die Cast Scrap	Chemical Residues	Home Scrap	Old Die Cast Scrap	General Scrap	Total
Electrolytic Reduction				NA			NA
Vertical Distillation Reports	31,500		10,500	NA			43,000
Secondary Distillers	55,800	7,900	1,500	NA	53,300	10,800	129,300
Foundries				NA	2,200		2,200
Chemical and Pigment Plants	8,300		22,700	NA	0		31,000

NA: Data not available.

Source: Estimates based on unpublished Tables 13, 14, 15 for Zinc to be in the 1976 Mineral Yearbook, Volume I, Metals, Minerals and Fuels, U.S. Department of the Interior, Bureau of Mines.

4.5.3.2 Product Quality Constraints

Very little recycle zinc is used by the die-cast industry except for home scrap because of the tight standards required for the main raw material, specification 49 zinc. This zinc can contain less than 0.001% of lead, tin, or cadmium, a degree of purity that is difficult to obtain from recycle zinc. The other applications, such as galvanizing and zinc oxide products, do not have the same stringent requirements. For example, prime western grade zinc with 98.5% zinc, the standard grade of zinc needed for galvanizing, can be produced from recovered materials. The presence of zinc oxides in the recoverable material is also not a major problem, since the vertical distillation retorts can reduce the oxides to metallic zinc.

4.5.3.3 Recoverable Materials Quality Constraints

The recoverable materials quality constraints are not very severe as long as there is some type of reducing distillation system available. All types of recoverable materials projected to be significant before 1987 could be processed.

4.5.4 Economic Considerations in Recycling

Economic considerations were not directly evaluated in this industry analysis. However, they are incorporated in assumptions used in the analysis and in the projection of historic trends.

The recovery of new materials, including galvanizers' residues and prompt die-cast scrap, has very favorable economics and is widely practiced. All galvanizers' residues are generally repurchased under contract by the zinc smelter or distiller supplying the zinc metal. Die-cast scrap also has a high value and is either reprocessed as home scrap or sold to dealers for subsequent use. With a stable consumption of zinc, the recovery of these new scraps should remain approximately at present levels. The recovery of chemical residue and flue dust is also fairly steady over the long term, although it is very sensitive to short-term swings in the zinc prices.

The great majority of old zinc scrap comes from the shredding of old automobiles and appliances. The resulting shredded materials are sorted into a ferrous fraction, a nonferrous fraction, and fluff by magnetic and air classifiers. The copper and brass are hand picked from the nonferrous fraction, leaving a mixture of aluminum, zinc, and solder. The zinc that is sweated from the remaining mixture and sold as ingot makes up the bulk of the old general zinc scrap. If the aluminum is separated from the zinc and solder by heavy media separation, the zinc and solder go into the old die-cast scrap category.

Automobiles scrapped in 1978 contain about 250,000 short tons of zinc die castings. Because new cars contain less zinc, those scrapped in 1987 will have only 125,000 short tons of zinc. More efficient recovery, however, could still meet a 1987 target of 70,000 short tons per year. This target is a growth rate of 3% annual increase of zinc from die-cast scrap. However, the level of 70,000 short tons per year of required old die castings predicted for 1987 should start dropping by 1990 as automobiles built in the very late 1970's reach the shredders in significant numbers.

The other uses of zinc, such as galvanizing, rubber products, and paints are largely dissipative uses where the zinc is not generally recovered. The only exception is some zinc from galvanized steel recovered from electric arc furnace dusts.

4.5.5 Special Considerations

Zinc is a metal with very mature types of demand patterns. It is unlikely that any large new uses or new regulatory pressures will shake the zinc industry before 1987. All zinc markets face competition from other metals such as aluminum and from plastics, which should severely limit any significant growth for zinc. However, zinc has sufficient advantage in price and properties to ensure its continued use in most existing applications. The consumer's perception of a metal product as being more durable than plastic and the acceptance of new thin-wall die-cast technology should help stabilize the important die-cast market.

The output of zinc products should not change dramatically from present levels before 1987. By 1976 all of the older, marginal, and more polluting horizontal retort plants had been shut down. Some form of both electrolytic and pyrometallurgical reduction should survive to 1987.

4.5.6 Target Estimation

As discussed in Section 4.5.5, increased recovery of zinc will center on old die castings. The recovery rate for old die casting should increase from a 1973-1976 average of 49,600 short tons per year to 70,000 short tons per year by 1987. This increase in recovery coupled with a decrease in zinc content of automobiles would raise the proportion of old automobile die castings recovered from 20% in 1976 to 64% in 1987. The other categories of recoverable materials should remain fairly constant if zinc consumption remains fairly level until 1987. The recovery target would then increase from 33% of production in 1976 to 36% of production in 1987.

4.5.7 Sensitivity of Target to Key Factors

Table 4.5-4 shows the target in units selected by DOE for the target, i.e., the ratio of purchased scrap (prompt industrial and old) to total shipments or production of the primary and secondary industries. The target of 36% recovery of the domestic zinc smelted by 1987 will depend on galvanizer zinc consumption, the rate of increase of automobile shredder sources with the ability to separate out the nonferrous fractions, any increase in the recovery of flue dust and chemical residues, and domestic production rates. Since new galvanizers' scrap accounts for 49% of the 1987 target, any major change in galvanized steel production would directly affect the overall zinc target. Several conflicting forces tend to obscure the actual level of recovery of new galvanizing residues by 1987. Positive factors include predicted increased use of galvanized sheet in automobiles, galvanized rebar steel, and post-fabrication galvanized steel. Negative factors on zinc consumption include the penetration into the galvanizing market of steel sheet galvanized only on one side and the use of aluminum/zinc alloy (Galvalume) for galvanizing. The projected 29% of target represented by old die casting could change, depending on the technology for the separation of the nonferrous fraction from automobile shredders. Increased adoption of new methods for separating nonferrous at the shredder could produce a purer zinc fraction that would be a more desirable recovered material. Based on historical patterns, the recovery of zinc from flue dust could fluctuate by about 30,000 short tons per year, depending on the price of zinc. The higher prices for zinc relative to the general price index would tend to lead to higher recovery rates. The final important assumption is that the domestic smelting of zinc in both primary and secondary smelters will remain constant for the next ten years. It is expected that any smelter capacity retired will be replaced, but that the economics in the industry may not justify much expansion of capacity.

TABLE 4.5-4

RECOVERED MATERIAL TARGET FOR ZINC INDUSTRY
(1987)

$$\frac{\text{Recovered Material*}}{\text{Domestic Primary \& Secondary Production}} \times 100 = 36\%$$

* Purchased scrap, i.e., prompt industrial and obsolete scrap.

4.6 LEAD

4.6.1 Selection of Recoverable Materials

The scrap materials considered for inclusion in target selection are presented in Table 4.6-1. They are broadly grouped as new scrap, old scrap, slags, and dusts. Each category of scrap was assessed using the selection criteria (see Section 4.1) to determine whether it would contribute significantly to recycling in the lead industry by 1987.

New scrap is composed of purchased drosses and residues that result from melting, smelting, refining, and manufacturing of lead and lead products (principally batteries and TEL). Drosses and residues normally contain various impurities and must be refined for reuse; they normally are sold to a reprocessor. Home scrap (or runaround scrap) also results from manufacturing operations and is generally in the form of lead metal. It requires only remelting for reuse and is normally recycled within the plant and is not sold. Home scrap is not included in target selection due to lack of data.

Old scrap, or post-consumer scrap, is broken down into the major categories by which scrap is normally sold or traded; battery plates, cable lead, soft lead, hard lead, type metal, babbit, and solders. All of the old scrap categories are in target selection.

Slags include secondary reverberatory slag, secondary blast furnace slag, and primary blast furnace slag. Secondary reverberatory slag contains significant quantities of lead and antimony and is normally recycled to a blast furnace; however due to lack of data it is not included in the target. Because of the low lead content of secondary blast furnace slag, it is normally dumped. A small quantity of secondary blast furnace slag is recycled to the blast furnace. It is used as a slagging agent however, not for its lead content. Because secondary blast furnace slag contains little recoverable lead and is not substitutable for virgin ore, it is excluded from this analysis. Primary blast furnace slag is normally dumped. Because of its low lead content, this slag will probably not be recycled by 1987 and, therefore, is not included in the target. The high sulfur matte from secondary blast furnace smelting of battery plates is normally dumped. Because it is produced in very small quantities and it is unlikely that it would be reprocessed for its lead content by 1987, it is also excluded from this analysis.

Dusts are mainly from air pollution control equipment and are generally recycled because of their lead content. However, due to lack of data, neither primary nor secondary dusts are included in the target.

TABLE 4.6-1

SELECTION OF RECOVERABLE MATERIALS - LEAD INDUSTRY

Material	Does the Recoverable Material meet the Criteria* for Inclusion? Yes	No
New Scrap:		
Drosses and Residues	X	
Home Scrap	X	
Old Scrap:		
Battery Plates	X	
Cable Lead	X	
Soft Lead	X	
Hard Lead	X	
Type Metal	X	
Mixed Common Babbit	X	
Solders and Tinny Lead	X	
Primary Blast Furnace Slag		X
Primary Blast Furnace Dust		X
Secondary Reverberatory Slag		X
Secondary Reverberatory Dust		X
Secondary Blast Furnace Slag		X
Secondary Blast Furnace Dust		X
Matte from direct Secondary Blast Furnace Melting		X

*Criteria is outlined in Section 4.1.

4.6.2 Selection of Process Subdivisions for Inclusion in the Target

The historical consumption pattern for waste materials consumed by the primary and secondary lead industries is given in Table 4.6-2. The different recoverable materials (RM) have historically gone to different types of processing, depending upon the process and RM constraints. Primary blast furnaces use very little, if any, recoverable materials other than the small quantities of dusts, drosses, and skimmings generated in the plant. Secondary blast furnaces or reverberatory/blast furnace combinations can treat most wastes including oxides. Kettles can treat a variety of metallic lead materials but cannot handle wastes which require refining.

4.6.3 Technical Considerations

4.6.3.1 Process Constraints

The blast furnace is the principal process in the primary lead industry that can handle recoverable materials. The blast furnace is an efficient reducer (metallic oxides to metal) and could, therefore, process a wide range of recoverable materials including oxidized materials, dust, drosses, skimmings, etc. It could also be used to melt metallic scrap, although it is not designed for this use. The blast furnace reduces to metal most of the impurities found in the recoverable materials charge. Since the primary industry, for the most part, produces pure lead, these impurities will have to be removed from the lead by refining before use.

The blast furnace used by the secondary lead industry has process characteristics similar to those of the blast furnaces used in the primary industry. Reduction of impurities to metal is an advantage in this case, because of the difference in product and product specifications, i.e., alloys instead of pure lead. Unlike the primary blast furnace, the secondary blast furnace is used almost entirely to process recoverable material. Its ability to reduce to metal other elements in the recoverable materials (notably antimony), along with the lead, is a desirable feature for the secondary industry, which produces, for example, antimonial lead from high-antimony recoverable materials. A possible constraint on blast furnaces (both primary and secondary) is that very fine recoverable materials (e.g., dusts) must be agglomerated before use to avoid being blown out of the furnace.

The reverberatory furnace is employed only in the secondary lead industry. The furnace, even with furnace atmosphere control, is essentially a non-reducing process. In the secondary lead industry, reverbs are often used in conjunction with a blast furnace to process recoverable materials that contain both metallic lead and oxides. The recoverable material charge is melted in the reverberatory furnace, producing metallic lead and a slag layer containing any oxidized material (e.g., lead, antimony). The slag layer is reduced in the blast furnace, producing metallic lead (or alloy). Without the blast furnace, the reverb is extremely limited and can only process recoverable materials that contain metallic lead.

The kettle is essentially a melter and can handle only scrap materials requiring melting only. The kettle is also used for refining operations. Because of heat transfer considerations and because kettle melting/refining is a batch operation, kettle melting is used only on small batches of scrap.

TABLE 4.6-2

SCRAP CONSUMPTION IN THE LEAD INDUSTRY (1970-1976)
(Gross Tons)

	1970	1971	1972	1973	1974	1975	1976
New Scrap:							
Drosses & Residues	121,766	143,382	158,881	154,682	129,400	136,066	141,923
Home Scrap	NA	NA	NA	NA	NA	NA	NA
Old Scrap:							
Battery Plates	512,030	486,792	509,858	544,438	614,364	623,448	589,797
Cable Lead	26,544	29,455	26,775	26,397	45,507	50,569	47,738
Soft Lead	52,426	48,925	46,668	36,279	33,641	32,642	29,172
Hard Lead	19,015	27,254	27,641	51,992	54,778	26,912	30,395
Type Metal	32,001	25,813	23,690	27,950	25,745	19,820	14,292
Mixed Common Babbitt*	11,799	11,665	11,049	13,534	12,025	8,552	7,839
Solders & Tinny Lead	10,640	11,464	9,815	11,991	13,663	11,250	3,517
Slag :							
Secondary Reverberatory	----------			NA			----------
Dust :							
Primary Blast Furnace	----------			NA			----------
Secondary Blast Furnace	----------			NA			----------
Secondary Reverberatory	----------			NA			----------

*includes consumption at foundries

NA: Not available.
Source: U.S. Bureau of Mines Minerals Yearbook, 1976.
Arthur D. Little, Inc.

4.6.3.2 Product Constraints

Product constraints are set by the compositional limits imposed on the product by the applicable specification. Table 4.6-3 presents the specifications for pig lead; Table 4.6-4 presents the normal compositions for alloyed products.

4.6.3.3 Recoverable Material Quality Constraints

Constraints on the recoverable material are set by the product specifications, the technical limitations of the available equipment, and the chemistry of the process.

The recoverable material can be altered in the following ways:

- It can be melted.
- If oxides (PbO) are present, they can be reduced to metallic lead in a blast furnace.
- If impurities cannot be removed, they can be diluted to acceptable limits by the addition of pure (or purer) metal.
- If higher levels of certain constituents are desired, the melt can be alloyed.

Normally, it is advantageous to match the feed material as closely as possible to the final product specifications. Thus, battery plates are normally recycled as antimonial lead, type metal is recycled to type, cable to soft lead, etc.

Theoretically, there is no technical limit to the amount of recoverable material a secondary plant can recycle, provided the product constraints are overcome.

However, on an industry level, the amount of recoverable material that can be recycled is limited by the availability of scrap materials. Based on historical recovery rates and the type of material under consideration, it is possible to estimate the maximum amount of material that can be recycled under foreseeable economic conditions. This information, along with projected growth rates for the various end uses, and knowledge of the lifetime (i.e., years from production to availability for recycle) allows the calculation of a theoretical maximum of production which is sustainable in the long run by the secondary producers, based on scrap availability.

For 1987, we estimate that the maximum secondary production based on scrap availability constraints is about 61% of total (primary plus secondary) production. The following assumptions were used in this calculation.

- Primary production will remain relatively constant at 700,000 short tons of lead annually.
- Demand for lead in batteries will grow at 4% annually.
- Demand for lead in metal products (except batteries and ammunition) will grow at 1% annually.
- Demand for lead in all other products together will grow little, if at all.
- In the long run, 75% of the lead used in batteries is recycled as scrap three years later.

TABLE 4.6-3

STANDARD SPECIFICATIONS FOR PIG LEAD

	Corroding Lead*	Chemical Lead*	Acid Copper Lead*	Common Desilverized Lead*
Silver, max, percent	0.0015	0.020	0.002	0.002
Silver, min, percent	-	0.002	-	-
Copper, max, percent	0.0015	0.080	0.080	0.0025
Copper, min, percent	-	0.040	0.040	-
Silver and copper together, max, percent	0.0025	-	-	-
Arsenic, antimony and tin together, max, percent	0.002	0.002	0.002	0.005
Zinc, max, percent	0.001	0.001	0.001	0.002
Iron, max, percent	0.002	0.002	0.002	0.002
Bismuth, max, percent	0.050	0.005	0.025	0.150
Lead (by difference), min, percent	99.94	99.90	99.90	99.85

*NOTE: Corroding lead is a designation that has been used in the trade for many years to describe lead refined to a high degree of purity. Chemical lead has been used in the trade to describe the undesilverized lead produced from Southeastern Missouri ores. Acid-copper lead is made by adding copper to fully refined lead. Common desilverized lead is a designation used to describe fully refined desilverized lead. Chemical analyses to be made in accordance with methods prescribed in A.S.T.M. Designation E37.

Source: Metal Statistics, 1977.

TABLE 4.6-4

COMPOSITION OF LEAD ALLOYS

Name	Pb	Sb	Sn	Cu	Ca	Bi	Cd	As
	Percent							
Babbitt, lead-antimony, No. 6	63.5	15	20	1.5	-	-	-	0.15
Babbitt, lead-antimony, No. 12	89.3	10	-	0.5	-	-	-	0.20
Cable sheathing, lead-antimony	90.0	1.0	-	-	-	-	-	-
Cable sheathing, lead-calcium	99.9	-	-	-	0.1	-	-	-
Fusible plug alloy, m.p., 68°C	25.0	-	12.5	-	-	50.0	12.5	-
Fusible plug alloy, m.p., 100°C	20.0	-	40.0	-	-	40.0	-	-
Hard lead, 6% antimony	94	6	-	-	-	-	-	-
Hard lead, 12% antimony	88	12	-	-	-	-	-	-
Pewter	10	10	79.8	0.2	-	-	-	-
Shot	94	6	-	-	-	-	-	-
Solder, common	50	-	50	-	-	-	-	-
Solder, plumber's	60	2.5	37.5	-	-	-	-	-
Terne, low tin	75	-	25	-	-	-	-	-
Terne, high tin	50	-	50	-	-	-	-	-
Type metal, foundry	62	24	14	-	-	-	-	-
electroytype	94	3	3	-	-	-	-	-
stereotype	81	14	5	-	-	-	-	-

Source: Bray, J. L., Non-Ferrous Production Metallurgy. John Wiley & Sons, Inc. New York, New York, 1947.

- In the long run, 40% of the lead used in metal products is recycled ten years later.
- On the average, drosses amount to about 15% of the lead consumed in batteries in the same year.
- Net scrap exports will be zero.

4.6.4 Economic Considerations

Econometric modeling was not used to explicitly evaluate the economics of using recovered metals in this industry analysis. However, economic considerations are incorporated in assumptions used in the analysis and in the projection of historic trends.

Figure 4.6-1 presents data for the ratio of secondary to total production for the period 1970-1976 and a least-squares fit to that data. As can be seen, if historic trends continue, secondary production may reach 63% of total production by 1987.

The changeover to maintenance-free batteries may affect the profitability of the secondary lead industry. Traditionally, antimonial-lead battery plates (about 7% antimony) have been produced by the secondary producers who purchase antimonial lead scrap at the cost of the lead and sell the antimony at a profit. With the introduction of maintenance-free batteries, the plates are being produced with low-antimony or calcium-lead alloys. With these alloys, the secondary producers lose the antimony credit (calcium is not recoverable with current technology) and also must produce costlier pure lead for the battery plates. The speed at which maintenance-free batteries penetrate the market and the type of alloy ultimately used for the plates may affect the profitability of the secondary industry as well as the supply structure of the lead industry (i.e., the cost to secondaries may be increased vis-à-vis the primaries).

4.6.5 Special Considerations

Significant baseline structural changes in the U.S. lead industry may result from decreased demand for lead because of EPA regulations, the changeover from antimonial-lead to calcium-lead maintenance-free batteries (discussed in Section 4.6.4), and the economic impact of proposed EPA and OSHA regulations which could potentially result in many plant closings and a lower rate of utilization of recovered materials.

Two end-use markets, pigments and chemicals, will probably experience significant demand reductions over the next 5-10 years. Chemicals demand will decrease as a result of EPA regulations limiting the amount of TEL (about 99% of chemicals) in gasoline. Similarly, the demand for lead oxides in pigments will decrease as a result of various regulations concerning the lead content of paint. Demand reduction in these two end-use sectors will decrease lead demand proportionately. Most of the lead consumed in pigments and chemicals is refined soft lead and has historically come primarily from the primary industry (about two-thirds). Since primary and secondary lead are technical substitutes in most cases, this decrease in demand for soft lead may cause some market reorganization.

Finally, the outcome of proposed EPA air and OSHA air regulations may adversely affect both primary and secondary producers in the lead industry. The final economic outcome of these regulations is unknown at this time.

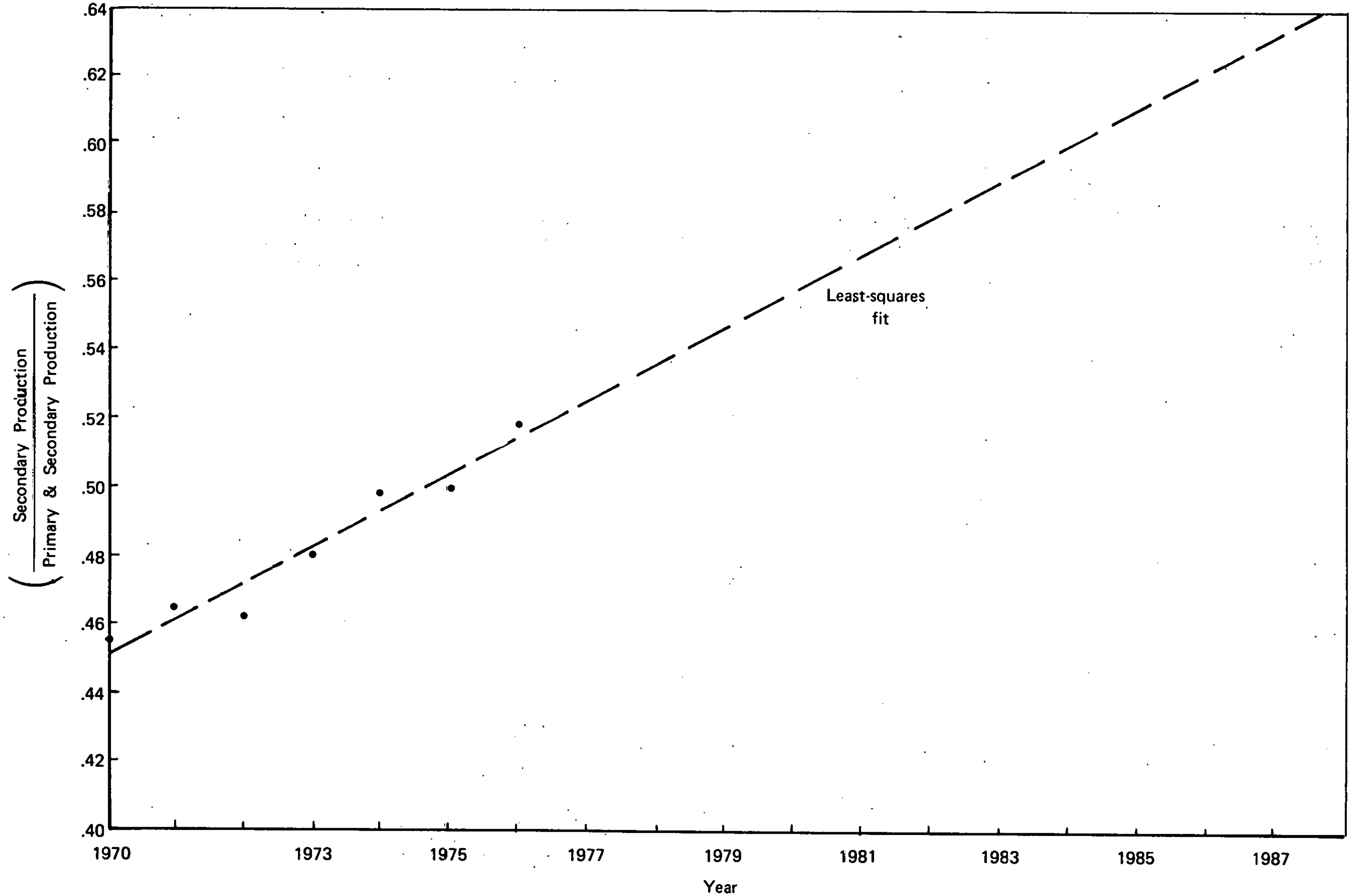


FIGURE 4.6.1 SECONDARY PRODUCTION RATIO – 1970-1976

4.6.6 Target Estimation

The recycling target for the lead industry has been estimated based upon the following information and assumptions:

- There will be no significant use of recoverable material in the primary industry by 1987.
- The secondary industry uses recoverable material as 100% of its raw material.
- Based on DOE guidelines, the recycling target has been defined as the percentage of recovered material to primary plus secondary production (in net short tons).
- The capacity of the primary industry will remain at its 1976 level. Because of the lead-time requirements for mine/mill/smelter/refinery, no new capacity will come onstream by 1987. The net effect of any additions to capacity at existing smelters will be offset by capacity decreases caused by regulations.
- In the long term, maximum capacity utilization by the primary industry is about 86% or 700,000 short tons of lead annually.
- Secondary capacity can be increased in a relatively short (several years) period of time.
- The changeover to maintenance-free batteries will not adversely affect the secondary industry.
- The demand reduction in chemicals and pigments will not adversely affect the primary industry.
- Based on scrap availability, the maximum secondary production of lead is 61% of total production.
- Based on historic projections, secondary production might increase to 63% of total production, without technical constraints.
- Total demand for lead will increase by 1987; demand in batteries will increase at 4% annually, and in metal products at 1% annually.
- Net scrap exports in 1987 will be zero.

Based on this information, Table 4.6-5 shows the target in units selected by DOE, i.e., recovered material as a percent of primary and secondary production.

4.6.7 Sensitivity of Target to Key Factor

In developing the recycling target for the primary and secondary lead industry, it was necessary to make a variety of plausible assumptions concerning the evolution of the industry between 1976 and 1987. It was beyond the scope of this analysis to evaluate the effects of alternative assumptions.

The extent to which these assumptions hold true over the next eight years will affect the validity of the target; to the extent that these assumptions do not hold true, the target should be modified.

TABLE 4.6-5

RECOVERED MATERIAL TARGET FOR LEAD INDUSTRY
(1987)

$$\frac{\text{Recovered Material*}}{\text{Domestic Primary \& Secondary Production}} \times 100 = 60\%$$

* Purchased scrap, i.e., prompt industrial and obsolete scrap.

The assumptions used in target estimation fall into two broad categories and were evaluated somewhat differently. The assumptions concerning the environment (scenario) within which the industry will evolve (e.g., effect of the introduction of maintenance-free batteries) could only be judged qualitatively based upon our knowledge of the industry. Numerical assumptions concerning the growth of the industry within this scenario (e.g., growth rate of demand for lead in batteries) were evaluated analytically using the economic concept of elasticity (i.e., the percentage change in the value of interest divided by percentage change of the variable in question). For example, an elasticity of 1.0 for the growth rate of battery lead demand implies that a 1% change in growth will change the target by 1%; an elasticity of 0.5 implies a 1% change will cause a 0.5% change in the target, etc. In other words, the lower (relative to 0) the elasticity, the less sensitive the result to the variable in question.

There are four critical assumptions vis-à-vis scenario development: long run demand growth is 1.8% annually, net scrap exports are zero, maintenance-free batteries will not adversely affect the secondary industry, and the decrease in lead demand for TEL and pigments will not adversely affect the primary industry. The last two assumptions have been discussed in Section 4.6.5 - Special Considerations.

Because of the large amount of lead that is potentially recoverable after consumption, if demand for lead products does not continue increasing, scrap will be added to the scrap pool, increasing its size. This, in turn, would tend to decrease the price of scrap and give secondary producers a cost advantage vis-à-vis the primaries. The minimum growth rate (based on 1976 consumption and the scrap availability equation) required to avoid this problem is 1.5% annually to 1987. This assumes that domestic producers can undersell imported metal. If imported metal remains at 1976 levels, the required growth is 2.2%. If this overall level of growth is not obtained by 1987, the target will be inaccurate, with the direction of the error depending upon where demand constraints occur. This analysis assumed an annual growth rate of 1.8% (as indicated by the Bureau of Mines) and some displacement of imports.

Scrap exporters compete directly with secondary producers for lead scrap from the scrap pool. Therefore, scrap exports represent lost production to the secondaries (if the scrap is exported it cannot be used domestically) and their output in the long run will be reduced accordingly. This analysis assumed that by 1987, net scrap exports of lead will be zero. If they are not, the target will be increased if there are net imports, or decreased if there are net exports.

The marginal sensitivity of the target to the individual growth rates used in the scrap availability equation was evaluated relative to the projected 1987 data; the resultant elasticities are presented below, and expressed as:

$$\left(\frac{\%\ \text{Change in Target}}{\%\ \text{Change in Variable}} \right)$$

Variable	Elasticity
P_1	0.39
K_B	0.31
i_B	0.12
K_D	0.07
K_M	0.02
i_M	0.00

where:

$$\text{Target} = \frac{P_2}{P_1 + P_2}$$

P_1 = Domestic primary lead production.

P_2 = Domestic secondary production.

C_B = Consumption of lead in batteries.

K_B = Fraction of C_B which is ultimately recycled.

i_B = Annual growth rate of C_B.

K_D = Fraction of C_M which is recycled as dross or residue.

C_M = Consumption of lead in metal products, but not batteries, ammunition, or brass or bronze.

K_M = Fraction of C_M which is ultimately recycled (old scrap).

i_M = Annual growth rate of C_M.

As can be seen, the most critical assumption is that primary production will remain at 700,000 short tons annually. For each 7,000 short ton difference (1%), the target (0.60) would change by 0.00234 (0.39%). The second critical assumption is that K_B the ultimate recovery rate for batteries, is 0.75. For each 0.0075 difference in K_B (1%), the target would change by 0.0019 (0.31%). The other variables have relatively little effect on the target, given their precision.

REFERENCES

REFERENCES: SECTION 4.2 FERROUS

1 Assessment of Industrial Hazardous Waste Practices in the Metal Smelting and Refining Industry, Volume III, Calspan, April 1977.

2 An Overview of Steel Mill Dust Recycling Activity, Internal Memorandum Report by Arthur D. Little, Inc.

3 United States Steel Corporation, The Making, Shaping and Treating of Steel, H.E. McGannon, 1971.

4 U.S. Bureau of Mines Information Circular 8771, Energy Use Patterns for Metal Recycling, C.L. Kusik and C.B. Kenahan, 1978.

5 The Use of Steelmaking Slag as a Sinter Flux, M.R. Faigen, Applied Research Laboratories, U.S. Steel Corporation.

6 An Econometric Analysis of the Demand and Supply for Scrap Iron and Steel, (Unpublished Ph.D. Dissertation by R. Shriner, Indiana University, 1974).

7 The Economics of Ferrous Scrap Recycling, (Unpublished Ph.D. Dissertation by J. Plater-Zyberk, Drexel University, 1972).

8 Purchased Ferrous Scrap: United States Demand and Supply Outlook, Fordham University Report to AISI, 1976.

9 Price-Volume Relationships for the Supply of Scrap Iron and Steel: A Study of the Price Elasticity of Supply, Report to Metal Scrap Research and Education Foundation by R. Nathan Associates, January 1978.

10 Mathematical Modeling of Raw Materials and Energy Needs of the Iron and Steel Industry in the U.S.A. Phase II. Report to the U.S. Bureau of Mines by J.F. Elliott, April 1975.

11 The Processing Capacity of the Ferrous Scrap Industry, Report to Metal Scrap Research and Education Foundation by Battelle Columbus Labs., August 10, 1976.

12 AISI Annual Statistical Reports, 1960-1977.

13 Predicasts, 1978.

14 Private communications with Dr. B. Bovarnick, independent consultant.

15 Iron and Steel Engineer, Increasing Scrap Usage by the L-D Process — Theory, Practice and Prospects, J.K. Stone, June 1965.

16 World Steel Industry Data Handbook, 33 Metal Producing, 1978.

17 Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Vol. III, Iron and Steel Industry Report, Report to the U.S. EPA by Arthur D. Little, Inc., December 1978.

18 The Operating, Economic and Quality Considerations of Scrap Preheating in the Basic Oxygen Process, Blast Furnace & Steel Plant, W.F. Kemner, December 1969.

19 Basic Oxygen Steelmaking — Alan Wood's Method, Iron and Steel Engineer, A.J. Moresco, June 1969.

20 In-Furnace Scrap Preheating on BOF Performance, Iron and Steelmaker, J.G. Dalal and E.H. Wozniak, August 1976.

REFERENCES: SECTION 4.3 ALUMINUM

1 Aluminum, Preprint from 1976 Minerals Yearbook. U.S. Bureau of Mines.

2 A Study to Identify Opportunities for Increased Solid Waste Utilization, Vol. II to VII, Report to EPA by Battelle Columbus Labs., 1972.

3 Recycling Opportunities and Challenges for the Aluminum Industry, Reynolds Metals Co., R.F. Testin, 1975.

4 Municipal Resource Recovery — What Impact Will It Have on Markets for Aluminum Scrap?, Reynolds Metals Co., Presented by R.F. Testin to NARI on March 10, 1978.

5 Recovery and Recycling of Automotive Aluminum, Society for Automotive Engineers, Inc., K.H. Dale, 1978.

6 Use of Aluminum in Automobiles — Effect on Energy Dilemma, Aluminum Association, April 1977.

7 Joint Aluminum/Copper Forecasting and Simulation Model, Prepared for U.S. Bureau of Mines by Synergy, Inc., June 1977.

8 Aluminum, Mineral Commodity Profile, U.S. Bureau of Mines, MCP-14, May 1978.

9 The Recovery of Metal and Chemical Values from Aluminum Drosses, Alcan, International, Ltd., Han Spoel, 1975.

10 Furnace Dross — Its Formation and Recovery, Alumax, C.J. Moser.

11 Energy Efficiency Improvement Targets for Primary Metal Industries, SIC 33, Volume I. Draft Target Support Document, Battelle Columbus Labs., August 1976.

12 Energy Efficiency Improvement Targets for Primary Metal Industries. SIC 33. Volume II, Draft Target System Document. Appendices, Battelle Columbus Labs., August 1976.

13 Communication from W. Pritsky, The Aluminum Association, May 8, 1979.

REFERENCES: SECTION 4.4. COPPER

1 Economic Impact of Environmental Regulations on the U.S. Copper Industry, Report to the U.S. Bureau of Mines by Arthur D. Little, Inc., 1978.

2 A Study to Identify Opportunities for Increased Solid Waste Utilization, Vol. II to VII, Report to the U.S. EPA by Battelle Columbus Labs, 1972.

REFERENCES: SECTION 4.6 LEAD

1 U.S. Bureau of Mines, Mineral Commodity Profiles, Lead — 1977.

2 Preliminary Technological Feasibility, Cost of Compliance and Economic Impact Analysis of the Proposed OSHA Standard for Lead. Report to OSHA by John Short and Associates, January 4, 1977.

BIBLIOGRAPHY

Albrecht, O.W. and R.G. McDermott. Economic and Technological Impediments to Recycling Obsolete Ferrous Solid Waste. EPA, October 1973.

Alter, H. Processes for the Recovery of Aluminum from Municipal Solid Waste. International Waste Equipment & Technology Exposition, 1975.

Aluminum Association, Aluminum Statistical Review, 1976.

Aluminum Recycling Association. Use of Aluminum in Automobiles — Effect on Energy Dilemma. April 1977.

Amelung, E. Physical and Chemical Requirements for Scrap Deliveries to Steel Mills. Recycling Today, July 1976.

American Bureau of Metal Statistics, Inc. Nonferrous Metal Data, 1974, 1975, 1976.

American Institute of Mining, Metallurgical and Petroleum Engineers (AIME). Energy Use and Conservation in the Metals Industry. 104th AIME Annual Meeting, New York, February 16-20, 1975.

American Iron & Steel Institute (AISI). Annual Statistical Report, 1976.

American Iron & Steel Institute (AISI). Annual Statistical Report, 1977.

American Iron & Steel Institute (AISI). Directory of Iron & Steel Works of the U.S. and Canada, 1977.

American Iron & Steel Institute (AISI). Directory of Iron & Steel Plants, 1977.

Anderson, R.C. Economic Incentives for the Recovery of Secondary Lead. Resource Recovery & Conservation, 1977.

Anderson, R.C. and R.D. Spiegelman. Impact of the Federal Tax Code on Resource Recovery. EPA, December 1976.

Annual Survey of Manufactures. Fuel and Electric Energy Consumed, 1976.

Annual Survey of Manufactures. General Statistics for Industry Groups and Industries (Including Supplemental Labor Costs), 1976.

Annual Survey of Manufactures. Value of Manufacturers' Inventories, 1976.

Annual Survey of Manufactures. Value of Product Shipments, 1976.

Annual Survey of Manufactures. Origin of Exports of Manufacturing Establishments, 1976.

Ballance, J.B. Aluminum Update. Journal of Metals, October, 1978.

Baptizmanskii, V.I., et al. Fundamental Mechanisms Associated with the Melting of Steel Scrap in the Basic Oxygen Furnace. Steel in the USSR, February 1975.

Battelle, Columbus Laboratories. Energy Efficiency Improvement Targets for Primary Metal Industries. SIC 33. Vol. I. Draft Target Support Document. DOE. August 1976.

Battelle, Columbus Laboratories. Energy Efficiency Improvement Targets for Primary Metal Industries. SIC 33. Vol. II. Draft Target System Document. Appendices. DOE. August 1976.

Battelle, Columbus Laboratories. Energy Efficiency Improvement Target for SIC 34. Fabricated Metal Products. Vol. I. Draft Target Support Document. DOE. June 28, 1976.

Battelle, Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4 - Energy Data and Flowsheets High-Priority Commodities). Bureau of Mines, June 27, 1975.

Battelle, Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 5 - Energy Data and Flowsheets, Intermediate — Priority Commodities). Bureau of Mines, September 16, 1975.

Battelle, Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 7 - Summary of the Results of Phases 4,5 & 6). Bureau of Mines, September 21, 1976.

Battelle, Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 8 - Opportunities to Improve Energy Efficiency in Production of High-Priority Commodities Without Major Process Changes). Bureau of Mines, September 17, 1975.

Battelle, Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 9 - Areas Where Alternative Technologies Should be Developed to Lower Energy Use in Production of High-Priority Commodities). Bureau of Mines, August 25, 1976.

Battelle, Columbus Laboratories. The Processing Capacity of the Ferrous Scrap Industry. Metal Scrap Research and Education Foundation, August 10, 1976.

Battelle Memorial Insitute. A Study to Identify Opportunities for Increased Solid Waste Utilization, Vol. I - VII. EPA, 1972.

Bever, M.B. Recycling in the Materials System. Technology Review, February 1977.

Bonczar, E.S. An Economic Analysis of the Determinants of Metal Recycling in the United States: A Case Study of Secondary Copper. Bureau of Mines, May 1975.

Booz-Allen. An Analysis of the Abandoned Automobile Problem. Prepared for EPA, July 1973.

Brinn, D.G. A Survey of the Published Literature Dealing with Steel Industry In-Plant Fines and Their Recycling. British Steel Corporation, August 1974.

Brooks, C. L. New Technology in Recovery and Reuse of Aluminum Scrap.

Brown, C. K. et al. Energy Analysis of Resource Recovery Options. Prepared for the Ministry of the Environment and the Ministry of Energy. Ontario Research Foundation, April 30, 1976.

Calspan. Assessment of Industrial Hazardous Waste Practices in the Metal Smelting and Refining Industry. April 1977.

Carney, D. J. Electric Furnace Steelmaking in the Next Decade. Journal of Metals, March 1974.

Carrillo, F. V. et al. Recovery of Secondary Copper and Zinc in the United States. Bureau of Mines, May 1974.

Coleman, R. T. et al. Final Report Pollution Control and Heat Recovery from Nonferrous Smelters Vol. I: Executive Summary. Radian Corp., February 28, 1977.

Commins, J. A. and V. Hathaway. Barriers to the Use of Secondary Metals. JACA Corp., August 1977.

Cooperman, R. M. Secondary Aluminum Shipment in First Quarter. Aluminum Recycling Association, July 31, 1978.

Cooperman, R. M. Shipments of Recycled Aluminum Update. Aluminum Recycling Association, November 8, 1978.

Copper Development Assoc. Annual Data 1975: Copper, Brass, Bronze.

Copper Development Assoc. Copper Supply & Consumption, 1955-1974. 1975.

Coyle, B. H. and J. A. Koperski. Hydrometallurgical Separation of the Zinc-Base Fraction of Shredded Automobiles. Conservation & Recycling, Vol. 1, 1977.

Cutler, H. Snail Paced Progress Frustrates Year for Scrap Metal Industry. Institute of Scrap Iron & Steel, (ISIS)January 1977.

Cutler, H. and G.S. Goldman. Transportation: Bugaboo of Scrap Iron Recycling. Vol. 7, No. 5. Environmental Science & Technology, May 1977.

Dalal, J. G. and E. H. Wozniak. In-Furnace Scrap Preheating on BOF Performance. Iron and Steelmaker, August 1976.

Dale, K.H. Recovery and Recycling of Automotive Aluminum. Society for Automotive Engineers, Inc., 1978.

Deily, R. L. Casting Raw Steel - U.S.A. Iron and Steel Maker, December 1977.

Dean, K. C. and J. W. Sterner. Metal Recovery by Dismantling of Scrapped Starter Motors, Auto Generators, and Alternators. Bureau of Mines, 1976.

DeHuff, G. L. and T. S. Jones. Manganese, Mineral Commodity Profiles, MCP-7. U.S. Bureau of Mines, October 1977.

Dower, R. C. and R. C. Anderson. Futures Markets: An Alternative for Stabilizing Secondary Materials Markets? Resources Policy, December 1977.

Elliot, J. F. Mathematical Modeling of Raw Materials and Energy Needs of the Iron and Steel Industry in the U.S.A. - Phase I - A Model of the Raw Materials Requirements of the U.S. Steel Industry. Bureau of Mines, April 24, 1973.

Elliott, J.F. Phase II - Metallic Supply for Steelmaking - A Dynamic System. Bureau of Mines, April 2, 1975.

Elliott, J.F. Future Raw Materials Needs of the American Steel Industry. Iron & Steel Maker, April 1975.

Elliott, J.F. Recycling and Energy Use in the Production of Metals, Abstract No. 297. The Electrochemical Society, May 16, 1975.

Faigen, M.R. The Use of Steelmaking Slag as a Sinter Flux, Applied Research Laboratories, U.S. Steel Corporation.

Federal Register. Proposed Criteria for Classification of Solid Waste Disposal Facilities, Vol. 43, No. 79. April 24, 1978.

Federal Register. Standards Applicable to Transporters of Hazardous Wastes, Part IV, Vol. 43, No. 83. April 28, 1978.

Federal Register. Preliminary Notification of Hazardous Waste Activities, Vol. 43, No. 133. July 11, 1978.

Federal Register. Resource Recovery Project Development Grants Under the President's Urban Policy, Part VII, Vol. 43, No. 147. July 31, 1978.

Federal Register. Public Participation in Programs Under the Resource Conservation and Recovery Act, the Safe Drinking Water Act, and the Clean Water Act. Vol. 43, No. 152. August 7, 1978.

Federal Register. PSD Permit Denial, Resource Conservation and Recovery Act of 1976, Public Meeting, Vol. 43, No. 159. August 16, 1978.

Federal Register. State Solid Waste Management Plans, Guidelines for Development and Implementation, Part IV, EPA. August 28, 1978.

Federal Register. Vol. 44, No. 5. January 8, 1979.

Fernandes, J.H. Processing and Recycling: Producing End Products and Energy. Combustion, February 1977.

Fink, D.A. Market Structure and Recycling in the Nonferrous Metals Industries. Resource Conservation, D.W. Pearce and I. Walter, eds., New York: New York University Press, 1977.

Fletcher, A.W. Review Lecture: Metal Recycling from Scrap and Waste Materials, A. 351. Proc. Royal Society, London, October 22, 1976.

Fordham University. Purchased Ferrous Scrap: United States Demand and Supply Outlook. Report to American Iron and Steel Institute, June 1977.

Gill, D. R. Exports of Ferrous Scrap. Iron and Steel Maker, March 1979.

Gordon, R. L. et al. Effective Systems of Scrap Utilization: Copper, Aluminum, and Nickel. Pennsylvania State University, July 1972.

Graham, W. O. Marketing and Equipment Design—Municipal Solid Waste-Ferrous Metal Recovery. Scrap Age, June 1976.

Great Lakes Research Institute. Evaluation, Extraction, and Recycling of Certain Solid Waste Components. Report for EPA, 1971.

Gross. Energy Saving Recovered Materials Targets Guidance to Methodology. Internal Memorandum, U.S. Department of Energy. January 10, 1979.

Harwood, J. J. Recycling the Junk Car. Technology Review, February 1977.

Henn, J. J. Updated Cost Evaluation of a Metal and Mineral Recovery Process for Treating Municipal Incinerator Residues. Bureau of Mines, December 1975.

Hickman, H. L. Review of EPA's OSWMP Activities for Fiscal Year 1977. Waste Age, November 1976.

Higley, L. W. and M. M. Fine. Electric Furnace Steelmaking Dusts—A Zinc Raw Material. Bureau of Mines, 1977.

Hogan, W. T. Steel Demand, Capital Costs, and Imports: Impact on the Steel Industry's Capital Needs. Fordham University, October 1975.

Hogan, W. T. and F. T. Koelble. Purchased Ferrous Scrap— United States Demand and Supply Outlook. Fordham University Study for American Iron & Steel Institute, June 1977.

Hogan, W. T. and F. T. Koelble. Ibid. Appendix I-1— Forecast of U.S. Steel Demand in 1982.

Institute of Scrap Iron and Steel. Identification of Opportunities for Increased Recycling of Ferrous Solid Waste. 1972.

Institute of Scrap Iron and Steel. FACTS: 32nd Edition, 1974 Yearbook. 1975.

Institute of Scrap Iron and Steel. Ibid. 33rd Edition, 1975 Yearbook. 1976.

Institute of Scrap Iron and Steel. Ibid. 34th Edition, 1976 Yearbook. 1977.

Institute of Scrap Iron and Steel. Ibid. 35th Edition, 1977 Yearbook. 1978.

Iron Age. Classification by Firm, 1977 Steel Industry Financial Analysis. April 24, 1977.

Iron & Steel Engineer. Statistical Highlights—1967-1976, U.S. Iron and Steel Industry. July 1977.

Jackson, D. V. The Recovery of Metals—General Considerations. Chemistry & Industry, December 6, 1975.

Jacobi, J. S. Recovery and Reuse of Metals. Iron & Steel International, June 1976.

Jones, T. S. Silicon, Preprint from the 1975 Bureau of Mines Minerals Yearbook.

Jones, T. S. Ferroalloys. Bureau of Mines Yearbook, 1976.

Kearney, A. T. Inc. Economic Analysis of Effluent Guidelines: Ferroalloys Industry. Report to EPA, June 1974.

Kearney, A. T. Inc. Ferrous Scrap Geographical Distributions Demand vs. Newly Available Supply 1975-1985. Report to Bureau of Mines, July 1976.

Kellogg, H. H. The Role of Recycling in Conservation of Metals and Energy. Journal of Metals, December 1976.

Kemner, W. F. The Operating, Economic and Quality Considerations of Scrap Preheating in the Basic Oxygen Process. Blast Furnace & Steel Plant, December 1969.

Kotsch, J. A. et al. Developments in the Iron and Steel Industry, U.S. and Canada—1976. Iron & Steel Engineer, February 1977.

Little, Arthur D., Inc. Steel and the Environment—A Cost Impact Analysis. Study for the AISI, 1975.

Little, Arthur D., Inc. Economic Analysis of Pretreatment Standards for the Secondary Copper and Aluminum Subcategories of the Nonferrous Metals Manufacturing Paint Source Category. Report to EPA, October 1976.

Little, Arthur D., Inc. Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Vol. VIII, Alumina/Aluminum Industry. Report to EPA, December 1976.

Little, Arthur D., Inc. Preliminary Assessment of Woolworth Scrap Preheater. Report to ERDA, September 6, 1977.

Little, Arthur D., Inc. Economic Impact of Environmental Regulations on the United States Copper Industry. Report to EPA, January 1978.

Little, Arthur D., Inc. Energy Use Patterns for Metal Recycling. Final Report to U.S. Bureau of Mines, January 1978.

Little, Arthur D. Inc. Computer Search of Chemical Abstracts, Engineering Index and Metals Abstract (4,000 References). December 1978.

Little, Arthur D., Inc. Computer Search of NTIS Publications on Metal Recycling (700 References). December 1978.

MacKallor, J. A. and G. H. K. Schenck. Future U.S. Supplies and Demands for Lead. American Institute of Mining, Metallurgical and Petroleum Engineers (AIME).

Mahoney, L. R. and J. J. Harwood. The Automobile as a Renewable Resource. Resources Policy, September 1975.

Makar, H. V. and P. J. Gallagher. Deoxidation of Steel Using Waste Aluminizing Dross (A Feasibility Study). Bureau of Mines, July 1972.

Mantle, E. C. Advances in the Recovery of Waste Non-Ferrous Metals. Chemistry & Industry, September 1976.

Manzone, M. G. Recycling Copper Scrap at United States Metals Refining Company. CIM Bulletin, August 1977.

Marketing Economics. Employment of SIC 33 Companies Arranged by 4 Digit SIC Classifications. 1977-1978.

Matyas, A. G. Utilization of Steelmaking Slag. Iron & Steel Engineer, August 1978.

Mautz, E. W. The Ferrous and Common Nonferrous Metals Industries and Associated Scrap Metals—A Review. National Lead Co. of Ohio, November 1975.

McGannon, Harold, ed. United States Steel Corporation. The Making, Shaping and Treating of Steel. 9th Ed., 1971.

McManus, G. The View from '77: How Steel's Future Stacks Up. Iron Age, May 23, 1977.

Meier, P. M. et al. An Assessment of Wet Systems for Residential Refuse Collection: Summary Report. Curran Associates, August 1974.

Metal Progress. Steel Availability...Short and Long Term Aspects. September 1974.

Metals & Materials. The Recovery of Secondary Copper— Its Technology & Economics. September 1977.

Midwest Research Institute. Base Line Forecasts of Resource Recovery, 1972 to 1990. Prepared for EPA, March 1975.

Modern Casting. Iron-Steel Distribution in U.S.A., October 1977.

Moresco, A. J. Basic Oxygen Steelmaking — Alan Wood's Method. Iron and Steel Engineer, June 1969.

Morgan, J. D. World Distribution and Flow of Major Mineral Commodities. Bureau of Mines, April 28, 1976.

Morning, J. L. Chromium, Mineral Commodity Profiles. U.S. Bureau of Mines, MCP-1, May 1977.

Moser, C. J. Furnace Dross—Its Formation and Recovery. Alumax, San Mateo, CA.

Nathan, Robert R. Associates, Inc. Iron and Steel Scrap: Its Accumulation and Availability as of December 31, 1975. Report to Metal Scrap Research & Education Foundation, August 22, 1977.

Nathan, Robert R. Associates, Inc. Ibid. Updated to December 31, 1977. August 25, 1978.

Nathan, Robert R. Associates, Inc. Price-Volume Relationships for the Supply of Scrap Iron and Steel: A Study of the Price Elasticity of Supply. Report to Metal Scrap Research & Education Foundation, January 8, 1979.

National Association of Recycling Industries. Membership Directory, 1976-1977. July 1976.

National Center for Resource Recovery, Inc. Magnetic Separation: Recovery of Saleable Iron and Steel from Municipal Waste. March 1977.

Nicola, A. G. Blast Furnaces—U.S. & Canada. Iron & Steel Engineer, September 1978.

Nicola, A. G. Open Hearth Facilities in the U.S. Op. cit., October 1978.

Nicola, A. G. Electric Arc Furnace Shops in the U.S. and Canada. Op. cit., November 1978.

Nussbaum, A. I. Remelt Shop Systems for Aluminum Mill Scrap Recycling. Light Metal Age, April 1975.

Opie, W. R. Problems in Smelting Copper. Scrap Journal, pp. 52-54.

Organization for European Economic Co-Operation (OEEC). Zinc and Lead Smelting and Refining in the U.S.A. Technical Assistance Mission No. 85, Vol. II, January 1955.

Organization for European Economic Co-Operation (OEEC). Industrial Adaptation in the Primary Aluminum Industry, 1976.

Ostrowski, E. J. Recycling of Solid Waste Ferrous Scrap in the Blast Furnace. Minnesota AIME.

Ottmar, H. et al. Technical and Economic Effects of the Substitution of Scrap by Sponge Iron in the Arc Furnace. Stahl u. Eisen 97, July 28, 1977.

Page, T. Conservation and Economic Efficiency, Resources for the Future. Baltimore, John Hopkins University Press, 1977.

Parfet, H. B. Manganese for Steelmaking: A Crisis of the Future? Iron & Steel Maker, January 1975.

Penton Publications. Foundry File. 1977.

Phillips, T. A. An Economic Evaluation of a Process to Separate Raw Urban Refuse into its Metal, Mineral, and Energy Components. Bureau of Mines, 1977.

Pietrucha, W. E. and R. L. Deily. Steel Industry in Brief: Databook, U.S.A. 1977. Institute for Iron & Steel, 1977.

Plater-Zyberk, J. The Economics of Ferrous Scrap Recycling. Unpublished Ph.D. Dissertation: Drexel University, 1972.

Powell, H. E. et al. Converting Stainless Steel Furnace Flue Dusts and Wastes to Recyclable Alloy. Bureau of Mines, June 1975.

Predicasts Basebook. Predicasts Annual Cumulative Edition. Issue No. 72, 1978.

Predicasts Basebook—Iron & Steel. 1978.

Predicasts Basebook—Slag: Iron & Steel. 1978.

Predicasts Basebook. Computer Printout of Scrap Consumption in Ferroalloys Industry. 1978.

Reade, K.H. Recovery and Recycling of Automotive Aluminum, Society for Automotive Engineers, Inc., 1978.

Regan, W. J. et al. Identification of Opportunities for Increased Recycling of Ferrous Solid Waste. Institute of Scrap Iron and Steel, 1972.

Reuter, F. H. et al. A Cost-Effectiveness Analysis of Junk Vehicle Abatement Programs. CONSAD Research Corp. for Motor Vehicle Mfgrs. October 31, 1975.

Roscrow, W. J. Furnaces and Processes for Non-Ferrous Metal Recovery. Metallurgia and Metal Forming, August 1975.

Schloemann, E. Recovering Metal from Trash. Iron & Steel International, June 1976.

Schottman, F. J. Silicon: Preprint from the Bureau of Mines Minerals Yearbook, 1976.

Short, John, and Assoc. Preliminary Technological Feasibility, Cost of Compliance and Economic Impact Analysis of the Proposed OSHA Standard for Lead. OSHA, January 4, 1977.

Shriner, R. An Econometric Analysis of the Demand and Supply for Scrap Iron and Steel. Unpublished Ph.D. Dissertation: Indiana University, 1974.

Silk, L. Lighter Cars Add Problems. Economic Scene. New York Times, January 17, 1979.

Sizemore, R. C. Lead Recyclers Face Market Shift. AMN—Batteries Section, April 1977.

Smith, M. F. Lead Batteries (Citations from the Engineering Index Data Base), August 1978.

Solow, R.M. The Economics of Resources or the Resources of Economics. The American Economic Review, Vol. 67, No. 1, February 1977.

Spendlove, M. J. Methods for Producing Secondary Copper. Bureau of Mines, 1961.

Spendlove, M. J. Recycling Trends in the United States: A Review. Bureau of Mines, May 1976.

Spoel, Hans. The Recovery of Metal and Chemical Values from Aluminum Drosses. Alcan Inter., Ltd., 1975.

Staker, W. L. and R. D. Groves. Use of Shredded Automobile Scrap for Copper Cementation. Bureau of Mines, 1976.

Stevens, B. J. Impact of the Federal Tax Code on Resource Recovery: A Condensation. Report by Columbia University for EPA, August 1977.

Stone, J. K. Joint Venture Iron and Steel Plants. Iron & Steel Maker, June 1977.

Stone, J. K. Worldwide Roundup of Basic Oxygen Steelmaking. Iron & Steel Maker, September 1977.

Strauss, S.D. Competition in the Non-Ferrous Metal Markets. Presentation before the Annual Meeting of the American Insitute of Mining, Metallurgical and Petroleum Engineers, Atlanta, GA, March 9, 1977.

Synergy, Inc. Joint Aluminum/Copper Forecasting and Simulation Model, Prepared for U.S. Bureau of Mines, June 1977.

Testin, R.F. Municipal Resource Recovery - What Impact Will it Have on Markets for Aluminum Scrap? Reynolds Metals Co., Presented to NARI on March 10, 1978.

Testin, R.F. Recycling Opportunities and Challenges for the Aluminum Industry. Reynolds Metals Company, American Chemical Society Symposium, June 11, 1975.

Townsend, N.A. A Review of Recent Developments in Scrap Preparation. British Steel Corp., April 1972.

Tress, J.E. and W.L. Hunter. Secondary Pig Iron from Shredded Auto Scrap. Bureau of Mines, November 1973.

United Nations. The Steel Market in 1977, U.N. ECE/ STEEL/23, 1978.

U.S. Bureau of Census. Annual Survey of Manufactures — General Statistics for Industry Groups & Industries, 1976.

U.S. Bureau of Mines. Minerals Yearbooks, 1974, 1975, 1976 (preprints).

U.S. Bureau of Mines. Energy Use Patterns in Metallurgical and Nonmetallic Processing (Phase 5 - Energy Data and Flowsheets, Intermediate Priority Commodities.) September 1975.

U.S. Bureau of Mines. Mineral Commodity Profiles, 1976 and 1977.

U.S. Bureau of Mines. Mineral Industry Surveys, 1976.

U.S. Bureau of Mines. Recycling Trends in the United States: A Review. May 1976.

U.S. Bureau of Mines. Commodity Data Summaries, 1977.

U.S. Bureau of Mines. Mineral Industry Surveys, 1970 through 1977.

U.S. Code Annotated, June 1978. Public Health and Welfare, 1977-1978. p. 845-858. No. 1.

U.S. Code Annotated, October 20, 1978. Title II Solid Waste Disposal Act. P.L. 89-272.

U.S. Code Congressional & Administration News. President's Messages: National Urban Policy. No. 3. April 1978.

U.S. Department of Commerce. Annual Statistical Review, Metal Prices and Production as of December 31, 1977, Steel Production. Iron Age, January 1, 1978.

U.S. Department of Commerce. Annual Statistical Review. Metal Prices and Production as of December 31, 1978. Iron Age, January 1, 1979.

U.S. Department of Commerce. Legislative History of Solid Waste: 1976-1978, Resource Conservation and Recovery Act of 1976. P.L. 94-580, October 11, 1976.

U.S. Department of Commerce. Legislative History: Resource Conservation and Recovery Act of 1976, P.L. 94-576, October 11, 1976.

U.S. Department of Commerce. The Foundry Industry: A Current Overview of Factors Affecting the Availability of Castings for Project Independence and Suggested Actions to Alleviate Problems. March 1975.

U.S. Department of Energy. Industrial Energy Efficiency Improvement Program, Annual Report Support Document. Vol. II. June 1978.

U.S. Department of Energy. Solid Waste Reclamation and Recycling Part 3. Metals - A Bibliography with Abstracts. 1978.

U.S. Executive Office of the President, Council on Wage and Price Stability. Aluminum Prices 1974-1975. Staff Report, September 1976.

U.S. Executive Office of the President, Office of Management and Budget. Statistical Policy Division. Standard Industrial Classification Manual, 1972.

U.S. Federal Energy Administration, Industrial Energy Conservation Program. Final Industrial Energy Efficiency Improvement Targets, Part II. June 9, 1977.

Wallace, John F. Foundries: A New Market for Reclaimed Ferrous Scrap. Recycling Today, March 1977.

Watson, G.A. The Ferroalloy Industry. Speech given at Ferroalloy Association 32nd Electric Furnace Conference, December 11, 1974. 22 pp.

Watson, G.A. The Future of the Ferroalloy Industry. Iron & Steel Maker, May 1977.

Weismantel, G.E. Needs and Knowhow Boost Aluminum Recycle. Chemical Engineering, May 9, 1977.

Wentz, C.N. Trends in Recycling Scrap-Sources of Secondary Metals. Colorado Mining Association. 1976 Mining Yearbook.

West, N.G. Recycling Ferruginous Wastes: Practice and Trends. Iron & Steel International, June 1976.

Westinform Service. Iron and Steel Scrap on the Ocean Routes up to 1980. January 1974.

Whalley, L. and V.F. Broadie. U.K. Metal Reclamation: Prospects for Improvement. Resources Policy, December 1977.

Whitten, H.O. & Associates. Recyclamation: Rail Transport Economics of Substitutability of Recycled Scrap or Waste for Basic Raw Materials. DOT, December 1971.

Ziegler, R.C. et al. Environmental Impacts of Virgin and Recycled Steel and Aluminum. EPA, February 1974.

33 Magazine. World Steel Industry Data Handbook. 1978.